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**EXPOSURE SCENARIOS & UNIT FACTORS FOR THE HANFORD
TANK WASTE PERFORMANCE ASSESSMENT [SEC 2 OF 3]
[APPENDIX B PAGE B-1 THRU APPENDIX C PAGE C-74]**

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as a single document. It has
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SECTION 2

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APPENDIX B
DECAY PROGENY INGROWTH

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DECAY PROGENY INGROWTH

B1.0 INTRODUCTION

The mathematical models incorporating radioactive decay are described in this section. The various pathway parameters discussed in Appendix A are put to use in the formulas. The presence of radioactive decay chains complicates this discussion, and the subsequent calculations. But the use of decay chains is necessary because some progeny nuclides are more significant than the parent nuclide.

To facilitate calculations with the large number of nuclides that may be found at the Hanford Site, the hand calculations were automated using commercial spreadsheet software. Spreadsheet calculations have been verified by hand calculations presented in the attachments to this appendix.

Doses to humans exposed to exhumed contamination or irrigation water include both internal and external radiation exposures. The internal dose comes from the inhalation of resuspended dust and the ingestion of contaminated water, soil, and foodstuffs. The external dose comes primarily from being near the contaminated soil. The sections below describe how the human dose is computed from the parameters of Appendix A together with standard models for estimating this dose. First, the time dependence of soil concentrations are presented. Second, the external and inhalation doses received from contaminated soil are described. Third, the concentrations and doses for various plant types are described. Finally, the concentrations and doses for animal products are described. The role of radioactive decay and daughter in-growth is discussed in each section.

B2.0 TIME DEPENDENCE OF SOIL CONCENTRATIONS

The soil concentrations are of two types. The first type of soil contamination results from drilling a hole through the waste site and spreading the contamination in a garden. In this case *there is some initial concentration of a nuclide in the surface layer that decreases with time due to radioactive decay and leaching from the surface layer.* The second type of soil concentration results from irrigating with contaminated water. In this case the contamination increases with time due to the added radioactivity. However, this increase is offset by radioactive decay and leaching from the surface layer.

In the description of progeny in-growth, it will be assumed that only the parent nuclide along with any of its short-lived progeny shown in Table A1 is present initially. Each nuclide in the decay chains listed in Table A2 must be treated independently. This enables the calculation of unit dose factors for each of the principal nuclides in a decay chain. In the case of irrigation water, it is also assumed that the decay chain progeny are not accumulating in the water prior to irrigation. Only the parent nuclide is coming from the well and being deposited on the soil. In addition, it is assumed that the water concentration is constant during the year of irrigation. As

before, this enables the calculation of unit dose factors for each of the principal nuclides in a decay chain.

The discussion below is divided into three parts. The first describes the decay of a nuclide and progeny in-growth with time due to nuclear decay alone, i.e., without leaching or additions from contaminated irrigation water. The second part adds decay in the presence of leaching from the surface layer. The third includes irrigation with contaminated water. In all cases, the decay chains shown in Table A2 are used. The longest decay chain has just four members because decay times less than 1000 years are assumed for generation of the unit dose factors. Additional discussion is provided to show how decay chains are incorporated into the calculations.

B2.1 DECAY WITHOUT LEACHING OR IRRIGATION DEPOSITION

The radioactive decay constants will be represented as λ_{1r} , λ_{2r} , λ_{3r} , λ_{4r} , and so forth until λ_{nr} , which is the last member of the chain. The leaching coefficients describing removal from the surface layer by water infiltration will be represented as λ_{1s} , λ_{2s} , λ_{3s} , λ_{4s} , and so forth. The sum of these the radioactive and leaching constants for a given nuclide will be represented as λ_1 , λ_2 , λ_3 , λ_4 , and so forth. In other words, λ_2 is defined by the equation $\lambda_2 = \lambda_{2r} + \lambda_{2s}$. Radioactive decay constants are computed by dividing the half life of the nuclide (Table A1) into the logarithm of 2 ($\text{Ln } 2 = 0.69314718$). Leaching coefficients for radionuclides are listed in Table A40.

The following demonstrates the general form of the customary decay chain formula to describe the in-growth of the "nth" progeny from the first member of the chain. In other words, the only member of the chain with any activity to begin with is the first nuclide. The equations below describe the in-growth of a specific progeny nuclide, the "nth" member of the chain in the absence of leaching and irrigation with contaminated water. These equations also describe the activity in contaminated vegetables or animal products after they are harvested.

$$C_{sn} = C_{s1}^0 \left(\prod_{k=1}^{n-1} B_{k,k+1} \right) \left(\prod_{k=2}^n \lambda_{kr} \right) DR_{1n} \quad (1)$$

$$DR_{1n} = \sum_{k=1}^n \frac{e^{-\lambda_{kr} t}}{PD_{1,kr,n}} \quad (2)$$

$$PD_{1,kr,n} = \prod_{\substack{i=1 \\ i \neq k}}^n (\lambda_{ir} - \lambda_{kr}) \quad (3)$$

C_{s1}^0 is the initial soil concentration of the first member of the chain. C_{sn} is the concentration of the "nth" member of the chain after the time "t" has elapsed. C_{sn} is assumed to be zero initially, and to increase with time. Both concentrations have units of Ci/kg.

The term $B_{k,k+1}$ is the fraction of decays of nuclide number "k" which produce nuclide number "k+1". $B_{k,k+1}$ is also known as the branching ratio for nuclear transition from k to k+1. Most branching ratios are simply 1.0. Non-unit branching ratios are given in Table A2.

The term DR_{1n} contains the time dependent functions for each nuclide in the chain from nuclide "1" down to nuclide "n". For convenience in writing the denominator, the product of decay constant differences is defined as shown in Equation (3). Note that when $n=1$, $PD_{1,1}=1$.

The decay equations are presented as Equation (4) for the first four nuclides. In a four-step decay chain, nuclide 1 (the parent) decays to nuclide 2, which then decays to nuclide 3, which then decays to nuclide 4.

$$\begin{aligned}
 C_{s1} &= C_{s1}^0 \text{Exp}(-\lambda_{1r}T) & (4) \\
 C_{s2} &= C_{s1}^0 B_{12} \lambda_{2r} \gamma \text{Exp}(-\lambda_{1r}T)/(\lambda_{2r}-\lambda_{1r}) + \text{Exp}(-\lambda_{2r}T)/(\lambda_{1r}-\lambda_{2r})? \\
 C_{s3} &= C_{s1}^0 B_{12} B_{23} \lambda_{2r} \lambda_{3r} \gamma \text{Exp}(-\lambda_{1r}T)/[(\lambda_{2r}-\lambda_{1r})(\lambda_{3r}-\lambda_{1r})] \\
 &\quad + \text{Exp}(-\lambda_{2r}T)/[(\lambda_{1r}-\lambda_{2r})(\lambda_{3r}-\lambda_{2r})] + \text{Exp}(-\lambda_{3r}T)/[(\lambda_{1r}-\lambda_{3r})(\lambda_{2r}-\lambda_{3r})] ? \\
 C_{s4} &= C_{s1}^0 B_{12} B_{23} B_{34} \lambda_{2r} \lambda_{3r} \lambda_{4r} \gamma \text{Exp}(-\lambda_{1r}T)/[(\lambda_{2r}-\lambda_{1r})(\lambda_{3r}-\lambda_{1r})(\lambda_{4r}-\lambda_{1r})] \\
 &\quad + \text{Exp}(-\lambda_{2r}T)/[(\lambda_{1r}-\lambda_{2r})(\lambda_{3r}-\lambda_{2r})(\lambda_{4r}-\lambda_{2r})] \\
 &\quad + \text{Exp}(-\lambda_{3r}T)/[(\lambda_{1r}-\lambda_{3r})(\lambda_{2r}-\lambda_{3r})(\lambda_{4r}-\lambda_{3r})] \\
 &\quad + \text{Exp}(-\lambda_{4r}T)/[(\lambda_{1r}-\lambda_{4r})(\lambda_{2r}-\lambda_{4r})(\lambda_{3r}-\lambda_{4r})] ?
 \end{aligned}$$

where,

C_{s1}^0 = initial concentration of nuclide 1 (i.e. at $T=0$), in Ci/kg. The initial concentrations of all other members of the chain are assumed to be zero.

$C_{s1}, C_{s2}, C_{s3}, C_{s4}$ = concentration of nuclides 1, 2, 3, and 4 at time T , in Ci/kg.

B_{12}, B_{23}, B_{34} = branching ratios for nuclides 1, 2, and 3.

$\lambda_{1r}, \lambda_{2r}, \lambda_{3r}, \lambda_{4r}$ = radioactive decay constants for nuclides 1, 2, 3, and 4. Note that the decay constant is the natural logarithm of 2 divided by the half-life of the nuclide. Note also that the decay constants in a decay chain are all different so the differences will never be zero.

B2.2 DECAY WITH LEACHING BUT WITHOUT IRRIGATION DEPOSITION

The situation with an initial soil contamination that decreases due to irrigation and radioactive decay is described next. When leaching from the surface layer takes place, there is an additional removal mechanism that increases the size of the removal terms. Leaching coefficients were discussed in Section A6.0 and are listed in Tables A38 and A40. Multiple years of leaching and decay will be described using a two-part irrigation model. The first half of the year has significant leaching due to the irrigation. The second half of the year has no leaching.

B2.2.1. Initial Soil Concentration During the Irrigation Season

The addition of leaching only changes Equations (2) and (3) by replacing the radioactive decay constants (λ_{kr}) with the combined leaching and decay coefficients ($\lambda_k = \lambda_{ks} + \lambda_{kr}$). In effect, the radioactive decay constant increases. The new equations for decay with leaching are shown below as Equations (5), (6), and (7). Note that the product of radioactive decay constants in Equation (5) is unchanged from Equation (1).

$$C_{sn} = C_{s1}^0 \left(\prod_{k=1}^{n-1} B_{k,k+1} \right) \left(\prod_{k=2}^n \lambda_{kr} \right) DS_{1n} \quad (5)$$

$$DS_{1n} = \sum_{k=1}^n \frac{e^{-\lambda_k t}}{PD_{1,k,n}} \quad (6)$$

$$PD_{1,k,n} = \prod_{\substack{i=1 \\ i \neq k}}^n (\lambda_i - \lambda_k) \quad (7)$$

The term C_{s1}^0 is the same as in Equation (1). It is the initial soil concentration of the parent nuclide in the chain. The $B_{k,k+1}$ terms are also the same as in Equation (1). The change in the definition of the time-dependent function DS_{1n} increases the exponents, so the decline in soil concentration is faster. Note that when $n=1$, $PD_{1,1,1}=1$. Note also that the subtractions in the $PD_{1,k,n}$ term do not eliminate the leaching factor unless they are all the same for that decay chain. Therefore Equations (3) and (7) are normally not the same.

B2.2.2. Initial Soil Concentration at the End of the First Year

To describe the concentration of a nuclide in the soil at the end of the first year, one must combine the equations of the previous section into the physically allowable sequences. During the first 6 months of the year irrigation takes place. During the second 6 months of the year irrigation ceases and the precipitation rate is assumed to match the evapo-transpiration rate, so that the leaching factors are all zero. The second half of the year has only radioactive decay.

In the post-intrusion garden scenario, for the first member of a decay chain, the soil concentration at the end of the year is the initial concentration multiplied by factors for decay and leaching during the irrigation season followed by simple decay during the remainder of the year. This is shown in Equation (8) below. The W_{11} term is introduced to simplify later equations.

$$\begin{aligned} C_{s1}(1) &= C_{s1}^0 DS_{11} DR_{11} = C_{s1}^0 W_{11} \\ W_{11} &= \text{Exp}(-\lambda_1 T_{irr}) \text{Exp}(-\lambda_{1r} T_{no}) \\ \text{and } \lambda_1 &= \lambda_{1s} + \lambda_{1r} \quad \text{and} \quad T_{irr} + T_{no} = 1 \text{ y} \end{aligned} \quad (8)$$

where,

$$C_{s1}(1) = \text{soil concentration of the first member of the decay chain at the end of the first year, in Ci/kg}$$

- C_{S1}^0 = initial soil concentration of the first member of the decay chain, in Ci/kg
 T_{irr} = irrigation period, 0.5 y
 T_{no} = no irrigation period, $T_{no} = 1 \text{ y} - T_{irr} = 0.5 \text{ y}$
 W_{11} = fraction of the initial soil concentration of the first member of the decay chain that is left at the end of 1 year when the irrigation water adds no contaminants
 λ_1 = total removal constant for the first member of the chain, per year
 λ_{1r} = radioactive decay constant for the first member of the chain, per year
 λ_{1s} = average soil leaching coefficient for the first member of the chain, per year

The first daughter of nuclide "1" is produced during the irrigation period and then decays during the rest of the year. It also is produced from the decay of the parent nuclide that is present at the end of the irrigation season. This is shown in Equation (9). The term B_{12} contains the branching ratio and product of decay constants found in Equations (1) and (5). It is not the branching ratio shown in Equation (4). The W_{12} term is introduced to simplify later equations.

$$C_{32}(1) = C_{S1}^0 B_{12} \equiv (DS_{12} DR_{22} + DS_{11} DR_{12}) = C_{S1}^0 B_{12} W_{12} \quad (9)$$

The concentration of the third and fourth nuclides in the chain at the end of the first year is calculated using Equations (10). Longer chains are computed in a similar fashion. Note that all possible decay paths must be considered. This leads to as many terms as there are members in the decay chain.

$$\begin{aligned}
 C_{33}(1) &= C_{S1}^0 B_{13} (DS_{13} DR_{33} + DS_{12} DR_{23} + DS_{11} DR_{13}) \\
 &= C_{S1}^0 B_{13} W_{13} \\
 C_{34}(1) &= C_{S1}^0 B_{14} (DS_{14} DR_{44} + DS_{13} DR_{34} + DS_{12} DR_{24} + DS_{11} DR_{14}) \\
 &= C_{S1}^0 B_{14} W_{14}
 \end{aligned} \quad (10)$$

B2.2.3. Initial Soil Concentration after Several Years

To describe the concentration of a nuclide in the soil after several years, the decay factors are multiplied by the soil concentration at the start of each year. This is demonstrated for the first member of the decay chain in Equation (11). The concentration is at the end of N years when the amount at the start of the first year was C_{s1}^0 . Each year the concentration decreases by the factor W_{11} .

$$C_{s1}(N) = C_{s1}(N-1)W_{11} = C_{s1}^0 W_{11}^N \quad (11)$$

For the 2nd member of the decay chain, there are two sources. The first source is the 1st member of the decay chain. The 1st member's activity is multiplied by $B_{12}W_{12}$. The second source is the presence of the 2nd member in the soil after the first year. The activity of the 2nd member is multiplied by W_{22} , which is similar to W_{11} except that the decay factors use the decay and leaching parameters for the 2nd nuclide. The X-notation is introduced in Equation (12) to simplify the calculation. The exponent (N-1) does not refer to the exponentiation process, but rather is another index. When N=1 the X_{12} term is 1.

$$C_{s2}(N) = C_{s2}(N-1)W_{22} + C_{s1}(N-1)B_{12}W_{12} = C_{s1}^0 B_{12} X_{12}^{N-1} \quad (12)$$

$$X_{12}^{N-1} = \frac{W_{11}^N - W_{22}^N}{W_{11} - W_{22}} = \sum_{K=0}^{N-1} W_{11}^K W_{22}^{N-1-K}$$

For the 3rd member of the decay chain, there are three sources. The first source is the 1st member of the decay chain. The 1st member's activity is multiplied by $B_{13}W_{13}$. The second source is the presence of the 2nd member in the soil after the first year. The activity of the 2nd member is multiplied by $B_{23}W_{23}$. The third source is the presence of the 3rd member in the soil after the first year. The activity of the 3rd member is multiplied by W_{33} . The X-notation is used in Equation (13) to simplify the calculation. The exponents of X are indices rather than exponentiation. When N=1 the X_{13} term is 1 but the X_{123} term is 0.

$$C_{s3}(N) = C_{s3}(N-1)W_{33} + C_{s2}(N-1)B_{23}W_{23} + C_{s1}(N-1)B_{13}W_{13} \quad (13)$$

$$C_{s3}(N) = C_{s1}^0 B_{13} (W_{13} X_{13}^{N-1} + W_{12} W_{23} X_{123}^{N-2})$$

$$X_{13}^{N-1} = \frac{W_{11}^N - W_{33}^N}{W_{11} - W_{33}}$$

$$X_{123}^{N-2} = \frac{W_{11}^N}{(W_{11} - W_{22})(W_{11} - W_{33})} + \frac{W_{22}^N}{(W_{22} - W_{11})(W_{22} - W_{33})} + \frac{W_{33}^N}{(W_{33} - W_{11})(W_{33} - W_{22})}$$

For the 4th member of the decay chain, there are four sources corresponding to the four members of the decay chain. The X-notation is used in Equation (14) to simplify the calculation. This notation also indicates the technique for modeling longer decay chains. When N=1 the X_{14}

term is 1 but the X_{134} , X_{124} , and X_{1234} terms are all 0. When $N=2$ the X_{134} and X_{124} terms are 1 but the X_{1234} term is 0.

$$C_{s4}(N) = C_{s4}(N-1)W_{44} + C_{s3}(N-1)B_{34}W_{34} + C_{s2}(N-1)B_{24}W_{24} + C_{s1}(N-1)B_{14}W_{14} \quad (14)$$

$$C_{s4}(N) = C_{s1}^0 B_{14} \left(W_{14} X_{14}^{N-1} + W_{13} W_{34} X_{134}^{N-2} + W_{12} W_{24} X_{124}^{N-2} + W_{12} W_{23} W_{34} X_{1234}^{N-3} \right)$$

$$X_{1234}^{N-3} = \frac{W_{11}^N}{(W_{11} - W_{22})(W_{11} - W_{33})(W_{11} - W_{44})} + \frac{W_{22}^N}{(W_{22} - W_{11})(W_{22} - W_{33})(W_{22} - W_{44})}$$

$$+ \frac{W_{33}^N}{(W_{33} - W_{11})(W_{33} - W_{22})(W_{33} - W_{44})} + \frac{W_{44}^N}{(W_{44} - W_{11})(W_{44} - W_{22})(W_{44} - W_{33})}$$

B2.2.4. Initial Soil Concentration Cumulative Dose

The doses that result from continuous intakes, or exposures, during the years of interest can be calculated from the above equations for soil concentration assuming the instantaneous dose rate (i.e. dose per day) is proportional to the soil concentration. The dose during one year is the time-integral of the soil concentration times a conversion factor. This time integral of the soil concentration during the irrigation period is shown in Equations (15) and (16). Note that Equation (7), which defines $PD_{1,k,n}$, is not changed by the integration. Also note that the integrated soil concentration term (IDS) is unitless.

$$\int C_{sn} dt = t C_{s1}^0 \left(\prod_{k=1}^{n-1} B_{k,k+1} \right) \left(\prod_{k=2}^n \lambda_{kr} \right) IDS_{1n} \quad (15)$$

$$IDS_{1n} = \sum_{k=1}^n \frac{1 - e^{-\lambda_k t}}{\lambda_k t} PD_{1,k,n} \quad (16)$$

A similar function results from the time integral of DR over the latter half of the year. The total dose that accumulates during the first year is shown in the equations below (17). The year must be divided into the irrigation and non-irrigation parts to complete the integration.

$$H_{s1}(1) = CF_1 C_{s1}^0 (IDS_{11} T_{irr} + DS_{11} IDR_{11} T_{no}) = CF_1 C_{s1}^0 T_{11}$$

$$= CF_1 C_{s1}^0 \left[\left(\frac{1 - \text{Exp}(-\lambda_1 T_{irr})}{\lambda_1 T_{irr}} \right) T_{irr} + \text{Exp}(-\lambda_1 T_{irr}) \left(\frac{1 - \text{Exp}(-\lambda_{1r} T_{no})}{\lambda_{1r} T_{no}} \right) T_{no} \right] \quad (17)$$

$$\begin{aligned}
H_{s2}(l) &= CF_2 C_{s1}^0 B_{12} (IDS_{12} T_{irr} + (DS_{12} IDR_{22} + DS_{11} IDR_{12}) T_{no}) = CF_2 C_{s1}^0 B_{12} T_{12} \\
H_{s3}(l) &= CF_3 C_{s1}^0 B_{13} (IDS_{13} T_{irr} + (DS_{13} IDR_{33} + DS_{12} IDR_{23} + DS_{11} IDR_{13}) T_{no}) \\
H_{s3}(l) &= CF_3 C_{s1}^0 B_{13} T_{13} \\
H_{s4}(l) &= CF_4 C_{s1}^0 B_{14} (IDS_{14} T_{irr} + (DS_{14} IDR_{44} + DS_{13} IDR_{34} + DS_{12} IDR_{24} + DS_{11} IDR_{14}) T_{no}) \\
H_{s4}(l) &= CF_4 C_{s1}^0 B_{14} T_{14}
\end{aligned}$$

The cumulative dose after N years is the sum of the doses received in the previous (N-1) years plus the dose that accumulates during the Nth year. For the 1st isotope in the decay chain, it is the sum of N terms, as shown in Equation (18). The Y term is introduced to simplify later equations. Note that the upper index of the Y term is not an exponent, unlike the upper index of the W₁₁ term.

$$H_{s1}(N) = \sum_{K=1}^N H_{s1}(K) = \sum_{K=1}^N H_{s1}(l) W_{11}^{K-1} = H_{s1}(l) \frac{1 - W_{11}^N}{1 - W_{11}} = H_{s1}(l) Y_1^{N-1} \quad (18)$$

For decay fractions that are close to 1, a small decay approximation has been derived to improve numeric accuracy. This approximation is shown below.

For $W = e^{-\epsilon}$ and $\epsilon < 0.001$

$$\begin{aligned}
\frac{W^{N_1} - W^{N_2}}{1 - W} &\cong 1 - \frac{\epsilon}{2}(N-1) + \frac{\epsilon^2}{12}(2N^2 - 3N + 1) \\
&\quad - \frac{\epsilon^3}{24}(N^3 - 2N^2 + N) + \frac{\epsilon^4}{720}(6N^4 - 15N^3 + 10N^2 - 1)
\end{aligned}$$

where $N = N_1 + N_2$ and $N^2 = N_1^2 + N_1 N_2 + N_2^2$

$$\text{in general, } N^K = \frac{N_1^{K+1} - N_2^{K+1}}{N_1 - N_2}$$

For the 2nd member of the decay chain the cumulative dose has two components. The first is the contribution from the 1st member of the decay chain each year. The second comes from the 2nd member of the decay chain as it accumulates after the first year. These are shown in Equation (19). The Y term simplifies later equations. It also illustrates the technique for modeling longer decay chains. Equation (19) is largely the same as Equation (12) except that W^N has been replaced with $(1 - W^N)/(1 - W)$. Note that when $N=1$, the Y_1 term is 1 while the Y_{12} term is zero. This indicates that all the dose calculated from the 2nd member during the first year comes directly from the 1st member of the decay chain. Not until the second year does the 2nd member become a separate source of dose.

$$\begin{aligned}
 H_{s2}(N) &= \sum_{K=1}^N H_{s2}(1) W_{11}^{K-1} + \sum_{K=2}^N CF_2 C_{s1}^0 B_{12} X_{12}^{K-2} T_{22} \\
 H_{s2}(N) &= CF_2 C_{s1}^0 B_{12} (Y_1^{N-1} T_{12} + W_{12} Y_{12}^{N-2} T_{22}) \\
 Y_{12}^{N-2} &= \frac{\left(\frac{1-W_{11}^N}{1-W_{11}}\right) - \left(\frac{1-W_{22}^N}{1-W_{22}}\right)}{W_{11} - W_{22}} = \frac{Y_1^{N-1} - Y_2^{N-1}}{W_{11} - W_{22}}
 \end{aligned} \tag{19}$$

For the 3rd member of the decay chain the cumulative dose has three components. The first is the contribution from the 1st member of the decay chain each year. The second and third come from the 2nd and 3rd members of the decay chain as they accumulate after the first year. These are shown in Equation (20). The Y term illustrates the technique for modeling longer decay chains. Equation (20) is largely the same as Equation (13) except that W^N has been replaced with $(1-W^N)/(1-W)$. Note that the Y_{123} term is zero until $N=3$.

$$\begin{aligned}
 H_{s3}(N) &= \sum_{K=1}^N H_{s3}(1) W_{11}^{K-1} + \sum_{K=2}^N CF_3 C_{s1}^0 B_{13} [W_{12} X_{12}^{K-2} T_{23} + (W_{13} X_{13}^{K-2} + W_{12} W_{23} X_{123}^{K-3}) T_{33}] \\
 H_{s3}(N) &= CF_3 C_{s1}^0 B_{13} [Y_1^{N-1} T_{13} + W_{12} Y_{12}^{N-2} T_{23} + (W_{13} Y_{13}^{N-2} + W_{12} W_{23} Y_{123}^{N-3}) T_{33}] \\
 Y_{13}^{N-2} &= \frac{\left(\frac{1-W_{11}^N}{1-W_{11}}\right) - \left(\frac{1-W_{33}^N}{1-W_{33}}\right)}{W_{11} - W_{33}} = \frac{Y_1^{N-1} - Y_3^{N-1}}{W_{11} - W_{33}} \\
 Y_{123}^{N-3} &= \frac{Y_1^{N-1}}{(W_{11} - W_{22})(W_{11} - W_{33})} + \frac{Y_2^{N-1}}{(W_{22} - W_{11})(W_{22} - W_{33})} + \frac{Y_3^{N-1}}{(W_{33} - W_{11})(W_{33} - W_{22})}
 \end{aligned} \tag{20}$$

For the 4th member of the decay chain the cumulative dose has four components. The first is the contribution from the 1st member of the decay chain each year. The others are from the 2nd, 3rd, and 4th members of the decay chain as they accumulate after the first year. These are shown in Equation (21). The Y term illustrates the technique for modeling longer decay chains. Equation (21) is largely the same as Equation (14) except that W^N has been replaced with $(1-W^N)/(1-W)$. Note that the Y_{1234} term is zero until $N=4$.

$$\begin{aligned}
 H_{s4}(N) &= \sum_{K=1}^N H_{s4}(1) W_{11}^{K-1} + \sum_{K=2}^N C F_4 C_{s1}^0 B_{14} \left[W_{12} X_{12}^{K-1} T_{24} + (W_{13} X_{13}^{K-1} + W_{12} W_{23} X_{123}^{K-2}) \Gamma_{34} \right. \\
 &\quad \left. + (W_{14} X_{14}^{K-1} + W_{13} W_{34} X_{134}^{K-2} + W_{12} W_{24} X_{124}^{K-2} + W_{12} W_{23} W_{34} X_{1234}^{K-3}) \Gamma_{44} \right] \\
 H_{s4}(N) &= C F_4 C_{s1}^0 B_{14} \left[Y_1^{N-1} T_{14} + W_{12} Y_{12}^{N-2} T_{24} + (W_{13} Y_{13}^{N-2} + W_{12} W_{23} Y_{123}^{N-3}) \Gamma_{34} \right. \\
 &\quad \left. + (W_{14} Y_{14}^{N-2} + W_{13} W_{34} Y_{134}^{N-3} + W_{12} W_{24} Y_{124}^{N-3} + W_{12} W_{23} W_{34} Y_{1234}^{N-4}) \Gamma_{44} \right] \\
 Y_{1234}^{N-4} &= \frac{Y_1^{N-1}}{(W_{11} - W_{22})(W_{11} - W_{33})(W_{11} - W_{44})} + \frac{Y_2^{N-1}}{(W_{22} - W_{11})(W_{22} - W_{33})(W_{22} - W_{44})} \\
 &\quad + \frac{Y_3^{N-1}}{(W_{33} - W_{11})(W_{33} - W_{22})(W_{33} - W_{44})} + \frac{Y_4^{N-1}}{(W_{44} - W_{11})(W_{44} - W_{22})(W_{44} - W_{33})}
 \end{aligned} \tag{21}$$

B2.3 DECAY WITH LEACHING AND IRRIGATION DEPOSITION

The sources of contaminated irrigation water are either groundwater or Columbia River water. The instantaneous rate of addition of contamination to the soil is given by the equation below. The conversion factor shown in the equations changes centimeters of water applied to the soil to liters applied per square meter.

$$ID_p = C_w I (10 \text{ L m}^{-2} \text{ cm}^{-1}) / T_{\text{irr}}$$

Where

ID_p = instantaneous activity deposition rate during the irrigation of areas growing plant type p, in curies per square meter per year ($\text{Ci y}^{-1} \text{m}^{-2}$).

C_w = irrigation water concentration, in curies per liter (Ci/L). This concentration is assumed to be constant (no decay) during the 6 month application period.

I = irrigation water applied to plants during the irrigation period. For the maximum individual cases, this value is 82.3 cm. For the population dose, this value was lowered to 63.5 cm due to less irrigation in areas farther down the Columbia River (WHC-SD-WM-EE-004).

T_{irr} = irrigation period in years. The value 0.5 yr is used since the irrigation is assumed to take place 6 months per year (April through September).

The instantaneous rate of increase in the soil concentration is computed from Equation (22).

$$ID_{s1}^0 = ID_p / (\rho d) \tag{22}$$

Where

ID_{s1}^0 = instantaneous rate of increase in the soil concentration during the irrigation season, in curies per kilogram per year.

ID_p = instantaneous activity deposition rate during the irrigation of soils growing plant type p, in curies per square meter per year ($Ci\ y^{-1}\ m^{-2}$).

ρ = bulk density of the surface soil, in grams per cubic centimeter. The value normally used in Hanford Site PA work is 1.5 g/cc.

d = thickness of soil from which nuclides migrate, in centimeters. This is assumed to be 15 cm (5.9 inches).

The instantaneous deposition rate is twice the average deposition rate for the year because the deposition only occurs during the irrigation season. Additional formulas for soil concentration are presented in the sections that follow.

B2.3.1. Irrigated Soil Concentration During the Irrigation Season

Using contaminated irrigation water, the concentration of radioactivity in the surface layer of soil increases with time. The equations to represent this turn out to be the time integral of Equations (5), (6), and (7). This activity accumulation is shown in Equations (23) and (24), below. Equation (7), which defines $PD_{1,k,n}$, is not affected by the integration. The term ID_{s1}^0 is the rate at which the concentration of the parent nuclide increases due to irrigation deposition. Note the addition of the irrigation time (t) to the equation to make the DI decay term a unitless fraction representing accumulation in the soil of contaminants that decay or are leached from the surface layer. At the end of the irrigation period, $t=T_{irr}$. The DI term is mathematically identical to the IDS term shown in Equation (16).

$$C_{sn} = t \left(ID_{s1}^0 \right) \left(\prod_{k=1}^{n-1} B_{k,k+1} \right) \left(\prod_{k=2}^n \lambda_{kr} \right) DI_{1n} \tag{23}$$

$$DI_{1n} = \sum_{k=1}^n \frac{1 - e^{-\lambda_k t}}{\lambda_k t} PD_{1,k,n} \tag{24}$$

Equations (1), (2), and (3) apply to soil with no leaching at all. Whatever water falls on the soil evaporates without forcing contamination through the surface layer into deeper layers. The key to represent this ordinary decay is the term DR_{1n} . Equations (5), (6), and (7) apply to soil with some leaching taking place. This might be due to excess natural precipitation or irrigation with uncontaminated water. The key to represent this decay with leaching is the term DS_{1n} . Equations (23) and (24) apply to soil being irrigated with contaminated water. Leaching from the surface layer is also occurring. The key to represent this combination of decay, leaching, and accumulation is the term DI_{1n} . These key terms will be used in the next section to describe the soil concentration after many years of irrigation with contaminated water.

One exception to the above is for tritium in the irrigation water applied to the soil. An equilibrium approach is used. The tritium concentration in the soil moisture is assumed to equal the tritium concentration in the applied irrigation water, adjusted for natural precipitation. This is calculated using the formula below. Note the absence of time dependence. The tritium concentration is constant during the irrigation season.

$$C_{s,H3} = 8.94 F_{H3} C_{w,H3} I/(I+P)$$

Where

- $C_{s,H3}$ = concentration of tritium in the surface soil during the irrigation season, in curies per kilogram.
- 8.94 = factor to convert the hydrogen weight fraction into a water fraction. It comes from the ratio of molecular weights for hydrogen (2.0159 g/gmole) and water (18.0153 g/gmole).
- F_{H3} = fraction of hydrogen in garden soil, 0.0149 g hydrogen per gram of soil (from Table A34).
- $C_{w,H3}$ = concentration of tritium in the irrigation water, in pCi/L.
- I = total irrigation water applied to the soil during the irrigation season, 82.3 cm/y (63.5 cm/y for the population).
- P = total natural precipitation water reaching the soil during the irrigation period, 5.77 cm/y (PNNL-13859).

The ratio $I/(I+P)$ incorporates the dilution of contaminated irrigation water with natural precipitation. This soil concentration is constant during the irrigation season, but decreases exponentially during the non-irrigation season due to continuing precipitation and evaporation.

B2.3.2. Irrigated Soil Concentration at the End of the First Year

In the irrigation scenarios, for the first member of the chain, the concentration at the end of the year is the product of the accumulated activity at the end of the irrigation season and the decay factor resulting from decay without irrigation or leaching for the remainder of the year. This is shown in Equation (25). Note the similarity between Equations (12) and (25). This will be seen again in the next few equations.

$$C_{s1}(1) = T_{irr} ID_{s1}^0 DI_{11} DR_{11} \left(\frac{1 - \text{Exp}(-\lambda_1 T_{irr})}{\lambda_1 T_{irr}} \right) \text{Exp}(-\lambda_1 T_{no}) \quad (25)$$

where,

- $C_{s1}(1)$ = soil concentration of the first member of the decay chain at the end of the first year, in Ci/kg
- ID_{s1}^0 = instantaneous soil deposition rate from irrigation for the first member of the decay chain, in Ci/kg per year
- T_{irr} = irrigation period, 0.5 y
- T_{no} = no irrigation period, $T_{no} = 1 \text{ y} - T_{irr} = 0.5 \text{ y}$
- W_{11} = fraction of the initial soil concentration of the first member of the decay chain that is left at the end of 1 year when the irrigation water adds no contaminants

- λ_1 = total removal constant for the first member of the chain, per year
 λ_{1r} = radioactive decay constant for the first member of the chain, per year
 λ_{1s} = average soil leaching coefficient for the first member of the chain, per year

The first daughter of nuclide "1" is produced during the irrigation period and then decays during the rest of the year. It also is produced from the decay of the parent nuclide that is present at the end of the irrigation season. This is shown in Equation (26). Note that the assumed amount of the daughter in the irrigation water is always zero. The term B_{12} contains the branching ratio and product of decay constants found in Equations (1) and (23).

$$C_{s2}(1) = T_{irr} ID_{S1}^0 B_{12} (DI_{12} DR_{22} + DI_{11} DR_{12}) \quad (26)$$

The concentration of the third and fourth nuclides in the chain at the end of the first year is calculated using Equation (27). Longer chains are computed in a similar fashion. Note that all possible decay paths must be considered. This leads to as many terms as there are members in the decay chain, as shown below.

$$C_{s3}(1) = T_{irr} ID_{S1}^0 B_{13} \cong (DI_{13} DR_{33} + DI_{12} DR_{23} + DI_{11} DR_{13}) \quad (27)$$

$$C_{s4}(1) = T_{irr} ID_{S1}^0 B_{14} (DI_{14} DR_{44} + DI_{13} DR_{34} + DI_{12} DR_{24} + DI_{11} DR_{14})$$

In practice, it is better to calculate the decay factors for each nuclide, since these are unitless fractions whose value is near 1.0 for nuclides with long half lives. The calculation of media concentrations and dose can be carried out ignoring decay. A decay factor can then be added.

B2.3.3. Irrigated Soil Concentration after Several Years

After the first year of irrigation, there is residual contamination, which must be taken into account when computing the total activity at the end of the year under consideration. The activity after N years is the sum of the activity after $(N-1)$ years decaying for 1 year, plus the activity that normally accumulates during the year. The added activity is independent of the amount of residual contamination. The residual contamination from prior years irrigation is modeled as an initial soil concentration, described in Section B2.2.

For the 1st member of the decay chain (the parent nuclide) after several years of irrigation, the total soil concentration is the sum of N years of deposition each adjusted for decay. This is demonstrated in Equation (28). The concentration is at the end of N years when the amount added every year is C_{s1} . Each year the concentration added in any year decreases by the factor W_{11} . The Y -notation is used in Equation (28) to simplify the calculation. These are the same W 's and Y 's that were used in Equation (18). The exponent $(N-1)$ does not refer to the exponentiation process, but rather is another index. When $N=1$ the Y_1 term is 1.

$$C_{s1}(N) = \sum_{K=1}^N C_{s1}(1) W_{11}^{K-1} = C_{s1}(1) \frac{1 - W_{11}^N}{1 - W_{11}} = C_{s1}(1) Y_1^{N-1} \quad (28)$$

For the 2nd member of the decay chain, there are two sources for the residual contamination. The first source is the activity of the 1st member of the decay chain at the end of (N-1) years. The 1st member's activity is multiplied by $B_{12}W_{12}$. The second source is the presence of the 2nd member in the soil after the first year. The activity of the 2nd member of the decay chain after (N-1) years is multiplied by W_{22} . The W's and Y's are the same as used in Equation (19).

$$\begin{aligned} C_{s2}(N) &= C_{s2}(1) + C_{s2}(N-1)W_{22} + C_{s1}(N-1)B_{12}W_{12} \\ C_{s2}(N) &= \sum_{K=1}^N C_{s2}(1)W_{22}^{K-1} + \sum_{K=2}^N C_{s1}(1)B_{12}W_{12}X_{12}^{K-2} \\ C_{s2}(N) &= C_{s2}(1)Y_2^{N-1} + C_{s1}(1)B_{12}W_{12}Y_{12}^{N-2} \\ Y_2^{N-1} &= \frac{1 - W_{22}^N}{1 - W_{22}} \quad \text{and} \quad Y_{12}^{N-2} = \frac{Y_1^{N-1} - Y_2^{N-1}}{W_{11} - W_{22}} \end{aligned} \quad (29)$$

For the 3rd member of the decay chain, there are three sources of residual contamination. The first source is the activity of the 1st member of the decay chain at the end of (N-1) years of irrigation. The 1st member's activity is multiplied by $B_{13}W_{13}$ and $B_{13}W_{12}W_{23}$. The second source is the presence of the 2nd and 3rd members of the decay chain at the end of (N-1) years. The activity of the 2nd member is multiplied by $B_{23}W_{23}$. The activity of the 3rd member is multiplied by W_{33} . The Y-notation used in Equation (30) is the same as used in Equation (20). The exponents of Y are indices rather than exponentiation. When N=1 the Y_{13} term is 1 but the Y_{123} term is 0. This indicates that during the first year, all the activity of the 3rd member comes directly from the 1st member of the chain.

$$\begin{aligned} C_{s3}(N) &= \sum_{K=1}^N C_{s3}(1)W_{33}^{K-1} + \sum_{K=2}^N C_{s2}(1)B_{23}W_{23}X_{23}^{K-2} + \sum_{K=2}^N C_{s1}(1)B_{13}(W_{13}X_{13}^{K-2} + W_{12}W_{23}X_{123}^{K-3}) \\ C_{s3}(N) &= C_{s3}(1)Y_3^{N-1} + C_{s2}(1)B_{23}W_{23}Y_{23}^{N-2} + C_{s1}(1)B_{13}(W_{13}Y_{13}^{N-2} + W_{12}W_{23}Y_{123}^{N-3}) \\ Y_3^{N-1} &= \frac{1 - W_{33}^N}{1 - W_{33}} \quad \text{and} \quad Y_{13}^{N-2} = \frac{Y_1^{N-1} - Y_3^{N-1}}{W_{11} - W_{33}} \\ Y_{123}^{N-3} &= \frac{Y_1^{N-1}}{(W_{11} - W_{22})(W_{11} - W_{33})} + \frac{Y_2^{N-1}}{(W_{22} - W_{11})(W_{22} - W_{33})} + \frac{Y_3^{N-1}}{(W_{33} - W_{11})(W_{33} - W_{22})} \end{aligned} \quad (30)$$

For the 4th member of the decay chain, there are four sources of residual activity corresponding to the four members of the decay chain. These are shown in Equation (31). The Y term illustrates the technique for modeling longer decay chains. It is the same Y shown in Equation (21).

$$C_{s4}(N) = \sum_{K=1}^N C_{s4}(1)W_{44}^{K-1} + \sum_{K=2}^N C_{s3}(1)B_{34}W_{34}X_{34}^{K-2} + \sum_{K=2}^N C_{s2}(1)B_{24}(W_{24}X_{24}^{K-2} + W_{23}W_{34}X_{234}^{K-3}) \\ + \sum_{K=2}^N C_{s1}(1)B_{14}(W_{14}X_{14}^{K-2} + W_{13}W_{34}X_{134}^{K-3} + W_{12}W_{24}X_{124}^{K-3} + W_{12}W_{23}W_{34}X_{1234}^{K-4}) \quad (31)$$

$$C_{s4}(N) = C_{s4}(1)Y_4^{N-1} + C_{s3}(1)B_{34}W_{34}Y_{34}^{N-2} + C_{s2}(1)B_{24}(W_{24}Y_{24}^{N-2} + W_{23}W_{34}Y_{234}^{N-3}) \\ + B_{14}(W_{14}Y_{14}^{N-2} + W_{13}W_{34}Y_{134}^{N-3} + W_{12}W_{24}Y_{124}^{N-3} + W_{12}W_{23}W_{34}Y_{1234}^{N-4})$$

$$Y_{1234}^{N-4} = \frac{Y_1^{N-1}}{(W_{11} - W_{22})(W_{11} - W_{33})(W_{11} - W_{44})} + \frac{Y_2^{N-1}}{(W_{22} - W_{11})(W_{22} - W_{33})(W_{22} - W_{44})} \\ + \frac{Y_3^{N-1}}{(W_{33} - W_{11})(W_{33} - W_{22})(W_{33} - W_{44})} + \frac{Y_4^{N-1}}{(W_{44} - W_{11})(W_{44} - W_{22})(W_{44} - W_{33})}$$

B2.3.4. Irrigated Soil Concentration Cumulative Dose

Dose calculations involving several years irrigation with contaminated water are calculated as the sum of an initial soil concentration case and an irrigation case. The dose from irrigation water used during the year of interest is the same every year. This dose has a component that depends on the soil concentration. The other components are direct intakes of irrigation water and shoreline sediment exposures.

The dose from the irrigated soil can be calculated from the above equations for irrigated soil concentration assuming the instantaneous dose rate (i.e. dose per day) is proportional to the soil concentration. The dose during one year is the time-integral of the soil concentration times a conversion factor. This time integral of the soil concentration during the irrigation period is shown in the equations below. Note that Equation (7), which defines $PD_{1,k,n}$, is not changed by the integration. Also note that the integrated soil concentration term (IDI) is unitless.

$$\int C_{sn} dt = t^2 ID_{s1}^0 \left(\prod_{k=1}^{n-1} B_{k,k+1} \right) \left(\prod_{k=2}^n \lambda_{kr} \right) IDI_{1n} \quad (32)$$

$$IDI_{1n} = \sum_{k=1}^n \frac{\lambda_k t - 1 + e^{-\lambda_k t}}{(\lambda_k t)^2} PD_{1,k,n} \quad (33)$$

The total dose that accumulates during the first year is shown in the equations (34). The year must be divided into the irrigation and non-irrigation portions to complete the integration.

$$H_{s1}(t) = CF_1 T_{irr} DI_{s1}^0 (IDI_{11} T_{irr} + DI_{11} IDR_{11} T_{no}) \quad (34) \\ = CF_1 T_{irr} DI_{s1}^0 \left[\left(\frac{\lambda_1 T_{irr} - 1 + \text{Exp}(-\lambda_1 T_{irr})}{(\lambda_1 T_{irr})^2} \right) T_{irr} + \left(\frac{1 - \text{Exp}(-\lambda_1 T_{irr})}{\lambda_1 T_{irr}} \right) \left(\frac{1 - \text{Exp}(-\lambda_{1r} T_{no})}{\lambda_{1r} T_{no}} \right) T_{no} \right]$$

$$H_{s2}(1) = CF_2 T_{irr} ID_{s1}^0 B_{12} (IDI_{12} T_{irr} + (DI_{12} IDR_{22} + DI_{11} IDR_{12}) T_{no})$$

$$H_{s3}(1) = CF_3 T_{irr} ID_{s1}^0 B_{13} (IDI_{13} T_{irr} + (DI_{13} IDR_{33} + DI_{12} IDR_{23} + DI_{11} IDR_{13}) T_{no})$$

$$H_{s4}(1) = CF_4 T_{irr} ID_{s1}^0 B_{14} (IDI_{14} T_{irr} + (DI_{14} IDR_{44} + DI_{13} IDR_{34} + DI_{12} IDR_{24} + DI_{11} IDR_{14}) T_{no})$$

The cumulative dose after N years is the sum of the doses received in the previous (N-1) years plus the dose that accumulates during the Nth year. The dose in the Nth year is the dose from irrigation (the same every year) plus the dose from the soil contamination that is present after (N-a) years of irrigation. For the first member of the decay chain, the cumulative total dose at the end of N years is shown in Equation (35). $C_{s1}(1)$ is the soil concentration at the end of the first year of irrigation as defined in Equation (25). T_{11} is the same as defined in Equation (17). The Z term is introduced to simplify later equations. The Z terms are sums of the Y terms.

$$H_{s1}(N) = \sum_{k=1}^N \left(H_{s1}(1) + \sum_{j=2}^k CF_1 C_{s1}(1) W_{11}^{j-2} T_{11} \right) = N H_{s1}(1) + \sum_{k=1}^N CF_1 C_{s1}(1) \left(\frac{1 - W_{11}^{k+1}}{1 - W_{11}} \right) T_{11}$$

$$H_{s1}(N) = N H_{s1}(1) + \left(\frac{CF_1 C_{s1}(1)}{1 - W_{11}} \right) \left(N - \frac{1 - W_{11}^N}{1 - W_{11}} \right) T_{11} = N H_{s1}(1) + CF_1 C_{s1}(1) Z_1^{N-2} T_{11} \quad (35)$$

For decay fractions that are close to 1, a small decay approximation has been derived to improve numeric accuracy. This approximation is shown below.

For $W = e^{-\epsilon}$ and $\epsilon < 0.001$

$$\frac{1 - \frac{W^{N_1} - W^{N_2}}{(N_2 - N_1)(1 - W)}}{1 - W} \cong \frac{(N - 1)}{2} + \frac{\epsilon}{6} (N^2 - 3N + 2)$$

$$- \frac{\epsilon^2}{24} (N^3 - 4N^2 + 5N - 2) + \frac{\epsilon^3}{360} (3N^4 - 15N^3 + 25N^2 - 15N + 2)$$

where $N = N_1 + N_2$ and $N^2 = N_1^2 + N_1 N_2 + N_2^2$

$$\text{in general, } N^k = \frac{N_1^{k+1} - N_2^{k+1}}{N_1 - N_2}$$

For the second member of the decay chain, the cumulative total dose at the end of N years is shown in Equation (36). $C_{s2}(1)$ is the soil concentration of the 2nd member at the end of the first year of irrigation as defined in Equation (26). T_{12} is the same as defined in Equation (17). T_{22} is similar to T_{11} except that the decay and leaching parameters belong to the 2nd member of the chain.

$$\begin{aligned}
H_{s2}(N) &= \sum_{k=1}^N \left[H_{s2}(1) + CF_2 C_{s1}(1) Y_1^{k-2} B_{12} T_{12} + CF_2 \left(C_{s2}(1) Y_2^{k-2} + C_{s1}(1) B_{12} W_{12} Y_{12}^{k-3} \right) T_{22} \right] \\
H_{s2}(N) &= N H_{s2}(1) + CF_2 \left[C_{s1}(1) Z_1^{N-2} B_{12} T_{12} + \left(C_{s2}(1) Z_2^{N-2} + C_{s1}(1) B_{12} W_{12} Z_{12}^{N-3} \right) T_{22} \right] \quad (36) \\
Z_{12}^{N-3} &= \frac{\left(\frac{1}{1-W_{11}} \right) \left(N - \frac{1-W_{11}^N}{1-W_{11}} \right) - \left(\frac{1}{1-W_{22}} \right) \left(N - \frac{1-W_{22}^N}{1-W_{22}} \right)}{W_{11} - W_{22}} = \frac{Z_1^{N-2} - Z_2^{N-2}}{W_{11} - W_{22}}
\end{aligned}$$

For the third member of the decay chain, the cumulative total dose at the end of N years is shown in Equation (37). $C_{s3}(1)$ is the soil concentration of the 3rd member at the end of the first year of irrigation as defined in Equation (27). T_{13} is the same as defined in Equation (17).

$$\begin{aligned}
H_{s3}(N) &= \sum_{k=1}^N \left\{ H_{s3}(1) + CF_3 C_{s1}(1) Y_1^{k-2} B_{13} T_{13} \right. \\
&\quad + CF_3 \left(C_{s2}(1) Y_2^{k-2} + C_{s1}(1) B_{12} W_{12} Y_{12}^{k-3} \right) B_{23} T_{23} \\
&\quad \left. + CF_3 \left[C_{s3}(1) Y_3^{k-2} + C_{s2}(1) B_{23} W_{23} Y_{23}^{k-3} + C_{s1}(1) B_{13} \left(W_{13} Y_{13}^{k-3} + W_{12} W_{23} Y_{123}^{k-4} \right) \right] T_{33} \right\} \quad (37) \\
H_{s3}(N) &= N H_{s3}(1) + CF_3 \left\{ C_{s1}(1) Z_1^{N-2} B_{13} T_{13} + \left(C_{s2}(1) Z_2^{N-2} + C_{s1}(1) B_{12} W_{12} Z_{12}^{N-3} \right) B_{23} T_{23} \right. \\
&\quad \left. + \left[C_{s3}(1) Z_3^{N-2} + C_{s2}(1) B_{23} W_{23} Z_{23}^{N-3} + C_{s1}(1) B_{13} \left(W_{13} Z_{13}^{N-3} + W_{12} W_{23} Z_{123}^{N-4} \right) \right] T_{33} \right\} \\
Z_{123}^{N-4} &= \frac{Z_1^{N-2}}{(W_{11} - W_{22})(W_{11} - W_{33})} + \frac{Z_2^{N-2}}{(W_{22} - W_{11})(W_{22} - W_{33})} + \frac{Z_3^{N-2}}{(W_{33} - W_{11})(W_{33} - W_{22})}
\end{aligned}$$

For the fourth member of the decay chain, the cumulative total dose at the end of N years is shown in Equation (38). $C_{s4}(1)$ is the soil concentration of the 4th member at the end of the first year of irrigation as defined in Equation (27). T_{14} is the same as defined in Equation (17).

$$\begin{aligned}
H_{s4}(N) = \sum_{K=1}^N \{ & H_{s4}(1) + CF_4 C_{s1}(1) Y_1^{K-2} B_{14} T_{14} \\
& + CF_4 (C_{s2}(1) Y_2^{K-2} + C_{s1}(1) B_{12} W_{12} Y_{12}^{K-3}) B_{24} T_{24} \\
& + CF_4 [C_{s3}(1) Y_3^{K-2} + C_{s2}(1) B_{23} W_{23} Y_{23}^{K-3} + C_{s1}(1) B_{13} (W_{13} Y_{13}^{K-3} + W_{12} W_{23} Y_{123}^{K-4})] B_{34} T_{34} \\
& + CF_4 [C_{s4}(1) Y_4^{K-2} + C_{s3}(1) B_{34} W_{34} Y_{34}^{K-3} + C_{s2}(1) B_{24} (W_{24} Y_{24}^{K-3} + W_{23} W_{34} Y_{234}^{K-4}) + \\
& + C_{s1}(1) B_{14} (W_{14} Y_{14}^{K-3} + W_{13} W_{34} Y_{134}^{K-4} + W_{12} W_{24} Y_{124}^{K-4} + W_{12} W_{23} W_{34} Y_{1234}^{K-5})] T_{44} \} \quad (38)
\end{aligned}$$

$$\begin{aligned}
H_{s4}(N) = N H_{s4}(1) + CF_4 \{ & C_{s1}(1) Z_1^{N-2} B_{14} T_{14} + (C_{s2}(1) Z_2^{N-2} + C_{s1}(1) B_{12} W_{12} Z_{12}^{N-3}) B_{24} T_{24} \\
& + [C_{s3}(1) Z_3^{N-2} + C_{s2}(1) B_{23} W_{23} Z_{23}^{N-3} + C_{s1}(1) B_{13} (W_{13} Z_{13}^{N-3} + W_{12} W_{23} Z_{123}^{N-4})] B_{34} T_{34} \\
& + [C_{s4}(1) Z_4^{N-2} + C_{s3}(1) B_{34} W_{34} Z_{34}^{N-3} + C_{s2}(1) B_{24} (W_{24} Z_{24}^{N-3} + W_{23} W_{34} Z_{234}^{N-4}) + \\
& + C_{s1}(1) B_{14} (W_{14} Z_{14}^{N-3} + W_{13} W_{34} Z_{134}^{N-4} + W_{12} W_{24} Z_{124}^{N-4} + W_{12} W_{23} W_{34} Z_{1234}^{N-5})] T_{44} \} \\
Y_{1234}^{N-5} = & \frac{Z_1^{N-2}}{(W_{11} - W_{22})(W_{11} - W_{33})(W_{11} - W_{44})} + \frac{Z_2^{N-2}}{(W_{22} - W_{11})(W_{22} - W_{33})(W_{22} - W_{44})} \\
& + \frac{Z_3^{N-2}}{(W_{33} - W_{11})(W_{33} - W_{22})(W_{33} - W_{44})} + \frac{Z_4^{N-2}}{(W_{44} - W_{11})(W_{44} - W_{22})(W_{44} - W_{33})}
\end{aligned}$$

B3.0 EXTERNAL AND INHALATION DOSE

The inhalation dose that is received by exposure to airborne water during showering or a sauna or under ambient conditions is simply the product of the volume of water inhaled during the year, the water concentration, and the inhalation dose factor as shown in Equation (42). No consideration of radioactive decay or progeny in-growth is needed, because the water concentration is assumed to be constant during the year, and no progeny are allowed to accumulate in the water.

$$H_{bw} = Q_{wb} C_w D_{inh} T_{inh} \quad (42)$$

Where

- H_{bw} = inhalation dose from airborne moisture during one year, in mrem.
- Q_{wb} = quantity of contaminated water inhaled by the person while in the shower or sauna, in L/y. Values are given in Table A28.
- C_w = concentration of a nuclide in the contaminated water, in pCi/L.
- D_{inh} = inhalation dose factor for a nuclide, in mrem per pCi inhaled. Values are given in Table A22.
- T_{inh} = inhalation exposure time of the individual, 1 y.

The external and inhalation dose due to exposure to contaminated soil are accumulated over the course of a year for all exposure scenarios except the waste intruder (driller). The amount accumulated per day depends on the soil concentration on that day. The external dose rate and the inhalation dose rate are proportional to the soil concentration. The total accumulated over the year is proportional to the time integral of the soil concentration. The external dose and inhalation doses are shown in equation (43). To obtain the total dose from the parent nuclide it is necessary to include the contributions from each progeny nuclide. Hence the sum over nuclides in a decay chain. Note that radioactive decay is not considered for the well drilling scenario because the exposure time is so brief (5 days) compared to the half lives of the nuclides selected for analysis.

$$H_{xs} = \sum_{i=1}^n \int_0^{1y} \rho d C_{s,i} D_{ext,i} dT \quad (43)$$

$$H_{bs} = \sum_{i=1}^n \int_0^{1y} M_{sb} C_{s,i} D_{inh,i} dT$$

Where

- H_{xs} = external dose accumulated during the year from one radionuclide and its progeny due to radioactivity in the soil, mrem

- H_{bs} = inhalation dose accumulated during the year from one radionuclide and its progeny due to radioactivity in the soil, mrem
- I = index over the decay chain. $I=1$ refers to the first member, or parent nuclide; $I=2$ refers to the second member of the decay chain; $I=3$ refers to the third member; $I=4$ refers to the fourth member.
- ρ = bulk density of the surface soil, in grams per cubic centimeter. The value normally used in Hanford Site PA work is 1.5 g/cc.
- d = thickness of soil from which nuclides migrate, in centimeters. This is assumed to be 15 cm (5.9 inches).
- C_{si} = time-dependent soil concentration of the i th nuclide during the year, in Ci/kg. It is affected by radioactive decay and leaching from the surface layer of soil.
- $D_{ext,i}$ = external dose rate factor for exposure to radiation from nuclide "I" in contaminated soil, in mrem/h per Ci/m². Values are given in Table A25.
- M_{sb} = mass of soil inhaled annually by the individual, in mg/y. Values are discussed in Section A3.2.1.
- $D_{inh,i}$ = inhalation dose factor for nuclide "I", in mrem per pCi inhaled. Values are given in Table A22.

The only term in the integrals with any time dependence is the soil concentration. Thus the accumulated dose at time T is the time integral of the activity equations. These integrations are simply the integral of each exponential. Each of the exponential terms in the decay Equations (2) and (6), namely, $\text{Exp}(-\lambda T)$, are replaced with the time integral shown in Equation (44). Note that the integral of the DS term in Equation (16) is the same as the DI term in Equation (24).

$$\text{Time Integral} = \int_0^T \text{Exp}(-\lambda t) dt = \frac{1}{\lambda} [1 - \text{Exp}(-\lambda T)] \quad (44)$$

If the product λT is less than 0.0002, a loss of numeric accuracy is experienced. To overcome this, the integral in Equation (31) is replaced with the equivalent polynomial to improve the numeric precision of the calculation. The polynomial used is shown in Equation (32).

$$[1 - \text{Exp}(-\lambda T)]/\lambda = T \cong [1 - \lambda T/2 + (\lambda T)^2/6 - (\lambda T)^3/24] \quad (45)$$

Notice that if the product λT is very small, the time integral approaches the decay period. For this reason, the time integral of the decay equation is sometimes referred to as an effective time period. In effect, it is a particular time period adjusted for radioactive decay. To consistently work with unitless decay periods, all time integrals are divided by the integration period. Thus the integration period must be made a factor in the calculation. A thorough discussion of small time approximations in radioactive decay is found in WHC-SA-1282-FP.

For the irrigated farm scenario, the concentration of nuclides in the soil increases with time due to the activity accumulating in the soil as shown in Equations (23) and (24). The soil concentration follows the time integral formula of Equations (44) and (45). The accumulated intake or dose at time T is the time integral of the Equation (24). In other words, each exponential term in the decay Equation (6), namely, $\text{Exp}(-\lambda T)$ is replaced with its second integral, shown in Equation (46).

$$\text{Second Integral} = [\lambda T - 1 + \text{Exp}(-\lambda T)]/\lambda^2 \quad (46)$$

If the product λT is less than 0.001, a loss of numeric accuracy is experienced. To overcome this, the integral in Equation (46) is replaced with the equivalent polynomial to improve the numeric precision of the calculation. The polynomial used is shown in Equation (47).

$$[\lambda T - 1 + \text{Exp}(-\lambda T)]/\lambda^2 = T^2 \cong [1 - \lambda T/3 + (\lambda T)^2/12 - (\lambda T)^3/60]/2 \quad (47)$$

Notice that if the product λT is very small, the time integral in Equations (46) and (47) approaches the decay period squared. Again, to only work with unitless decay factors, the second integral is divided by the integration period squared. This time must then be made a factor in the dose equation.

Using the two-part irrigation model, the dose accumulated during the first 6 months depends only on the DS or DI integration. The dose during the second 6 months (without irrigation) depends only on the DR integration. This idea is summarized in the equations below. Equation (48) shows the time integral of Equations (8), (9), and (10) for an initial soil contamination (e.g. the post-intrusion garden), while Equation (49) shows the time integral of Equations (25), (26), and (27) for irrigation with contaminated water. Constant factors have been omitted to simplify the equations. In both equations the first integral represents the dose from the nth member of the decay chain during the first 6 months. During the first 6 months the only source of this nuclide is the decay of the parent nuclide. After 6 months of decay and in-growth, each member of the decay chain will be present in the soil. Thus the second time integral on the right has contributions from decay of the parent as well as decay of the other members of the chain.

Initial Soil Contamination: (from Equation 8)

$$\int_0^{1y} Y_{1n}(T) dT = \int_0^{T_{ir}} DS_{1n}(T) dT + \sum_{k=1}^n DS_{1k}(T_{ir}) \int_0^{T_{no}} DR_{kn}(T) dT \quad (48)$$

$$\int_0^{1y} Y_{1n}(T) dT = T_{ir} IDS_{1n}(T_{ir}) + T_{no} \sum_{k=1}^n DS_{1k}(T_{ir}) IDR_{kn}(T_{no})$$

Irrigation with Contaminated Water: (from Equation 25)

$$\int_0^{1y} C_{j1} dT = \int_0^{T_{irr}} DI_{1n}(T) dT + \sum_{k=1}^n DI_{1k}(T_{irr}) \int_0^{T_{irr}} DR_{kn}(T) dT$$

$$\int_0^{1y} C_{j1} dT = T_{irr} IDI_{1n}(T_{irr}) + T_{no} \sum_{k=1}^n DI_{1k}(T_{irr}) IDR_{kn}(T_{no})$$

(49)

The above equations show the decay factors that represent each integral. Additional terms needed in later calculations are defined below. Note that the integration period becomes a factor in the equation because the decay factors are designed to be unitless quantities between 0 and 1.

$$\int_0^{T_{irr}} DS(T) dT = T_{irr} IDS(T_{irr}) \quad \int_0^{T_{no}} DR(T) dT = T_{no} IDR(T_{no})$$

$$\int_0^{T_{irr}} DI(T) dT = T_{irr} IDI(T_{irr}) \quad T_{no} = 1y - T_{irr}$$

$$\int_0^{T_{veg}} DR(T) dT = T_{veg} IDR(T_{veg}) \quad \int_0^{T_{beef}} DR(T) dT = T_{beef} IDR(T_{beef})$$

(50)

note that

T_{irr} = irrigation period in years. The value of 0.5 yr is assumed based on current practices near the Hanford Site.

T_{no} = interval during which no irrigation takes place, $T_{no} = 1y - T_{irr}$

T_{veg} = consumption period for garden produce, assumed to be 90 days

T_{beef} = consumption period for beef after slaughter, assumed to be 120 days.

B4.0 INGESTION DOSE

Human ingestion dose comes from the pathways discussed earlier, such as contaminated drinking water, trace intakes of soil, vegetables grown on contaminated soil, and animal products. Each of these is discussed below. The basic dose calculation is the product of three factors, (1) the quantity consumed, (2) the radionuclide concentration in what is consumed, and (3) the ingestion dose factor. The addition of radioactive decay and progeny in-growth is discussed with each pathway.

B4.1 SOIL AND WATER INGESTION

The ingestion dose from drinking water is shown in Equation (51). The drinking water has no progeny. The concentration of each nuclide in a chain is treated separately.

$$H_{ew} = Q_{we} C_w D_{ing} T_{ing} \quad (51)$$

where

H_{ew} = ingestion dose from drinking water, in mrem.

Q_{we} = quantity of contaminated drinking water ingested by the person, in L/y. See Table A5 for values.

C_w = concentration of a nuclide in the contaminated water, in pCi/L.

D_{ing} = ingestion dose factor for a nuclide, in mrem per pCi ingested. Values are given in Table A21.

T_{ing} = ingestion exposure time of the individual, 1 y.

The ingestion dose from the intake of trace amounts of soil is shown in Equation (52). The soil concentration does include leaching, decay and progeny in-growth. Because the soil is consumed in small amounts during the year, the total dose is represented as the time integral of the daily intake. As before, the time integral must accommodate the change in infiltration rates during the year, just as was done for the inhalation and external doses using Equations (48) and (49).

$$H_{es} = \sum_{i=1}^n \int_0^{1y} M_{se} C_{si} D_{ing,i} dT \quad (52)$$

where

H_{es} = ingestion dose accumulated during the year from one radionuclide and its progeny due to radioactivity in the soil, mrem

I = index over the decay chain. $I=1$ refers to the first member, or parent nuclide; $I=2$ refers to the second member of the decay chain; $I=3$ refers to the third member; $I=4$ refers to the fourth member.

M_{se} = mass of soil ingested annually by the individual, in mg/y.

C_{si} = time-dependent soil concentration of the i th nuclide during the year, in Ci/kg. It is affected by radioactive decay and leaching from the surface layer of soil.

$D_{ing,i}$ = ingestion dose factor for nuclide "I", in mrem per pCi ingested. Values are given in Table A21.

B4.2 GARDEN PRODUCE

The ingestion dose from garden produce grown in contaminated soil is the product of the quantity of vegetables eaten, the concentration of radioactivity in the vegetables, and the ingestion dose factor. The ingestion dose factors are given in Table A21. Quantities eaten are given in Table A5. The calculation of radionuclide concentrations in living plants uses three main routes, (1) root uptake, (2) resuspension to leaves (also called "rain splash"), and (3) direct deposition of irrigation water on foliage. Each of these will be considered separately below. The three uptake routes are then combined to obtain the total ingestion dose from the garden produce.

The equations presented below apply to both garden produce and cattle feed in the sense that the quantity eaten and the ingestion dose factor can be removed to give the nuclide concentration in the cattle feed. These concentrations are needed to calculate dose from ingestion of contaminated animal products.

The garden produce intakes are based on the two situations. The first applies to leafy vegetables. It is assumed that leafy vegetables are produced more-or-less continuously during the growing season. They are consumed shortly after being collected. Thus the continuous model uses a time integral to represent the accumulated dose from leafy vegetables during the growing season. It is further assumed that leafy vegetables are not raised after the growing season has ended. Any leafy vegetables consumed after the growing seasons ends are assumed to have been imported from uncontaminated areas. The 25% of a person's diet that comes from contaminated sources is then assumed to be 50% during the irrigation period and 0% during the remainder of the year.

The second garden produce model applies to the other types of garden produce. These foods are assumed to be grown and harvested twice during the growing season. The plant concentration depends on the soil concentration at the time of harvest. For an initial soil contamination (e.g. post-intrusion garden or prior irrigation) this time is taken to be midway through the irrigation season. For the irrigation scenarios harvest is assumed to occur at the end of the irrigation season. Because these foods may be stored and eaten over a period of time, radioactive decay during the storage and consumption periods needs to be taken into account. The amount of radioactive contamination eaten during the consumption period is the time integral of the ordinary decay Equations (1), (2), and (3). The average consumption period for non-leafy vegetables is taken to be 90 days. Some products do not keep well, and have shorter consumption periods. Others keep very well and have longer consumption periods. The value selected for the tank waste PA (90 days) simplifies the calculations in that all non-leafy

vegetables have the same period. Note that for long half life nuclides the actual value has no effect on the final doses.

Root uptake is calculated using concentration ratios. These ratios are listed in Table A37. The ingestion dose from garden produce due to root uptake into the various types of vegetation is described with Equation (53). The first equation shows the continuous model for leafy vegetables. Note that the integral is over half the year so the assumed annual intake from garden must be adjusted upward to compensate. Hence the ratio $(1 y)/(T_{irr})$. The second equation shows the harvest model for the other vegetables. In both equations the sum over radionuclides in a decay chain is needed to obtain the total dose from the parent nuclide.

$$H_{epr}(\text{leafy}) = \sum_{i=1}^n \frac{1y}{T_{irr}} \int_0^{T_{ir}} R_p B_{pi} Q_{vp} C_{si} D_{ing,i} dT \quad (53)$$

$$H_{epr}(\text{others}) = \sum_{i=1}^n R_p B_{pi} Q_{vp} C_{si} IDR_i(T_{veg}) D_{ing,i} T_{ing}$$

Where

H_{epr} = ingestion dose from plant type p due to root uptake, in mrem.

p = type of plant. There are 4 types of garden produce. The first equation covers leafy vegetables (p=1). The second equation covers other vegetables, fruit, and grain (p=2,3,4).

R_p = dry to wet ratio for plant type p. See Table A36 for values.

B_{pi} = soil to plant concentration ratio, as Ci/kg dry weight of vegetables to Ci/kg of soil. See Table A37 for values.

Q_{vp} = quantity of plant type p eaten by the person, in kg/y. See Table A5 for values.

C_{si} = soil concentration of the ith nuclide, in Ci/kg. It is affected by radioactive decay and leaching from the surface layer of soil during the irrigation season. In the second equation it is the soil concentration at the time of harvest.

T_{irr} = irrigation period in years. The value of 0.5 yr is assumed based on current practices near the Hanford Site.

IDR_i = decay factor that accounts for radioactive decay of the ith nuclide during the consumption of garden produce

T_{veg} = consumption period for garden produce, assumed to be 90 days

T_{ing} = ingestion exposure time of the individual, 1 y.

$D_{ing,i}$ = ingestion dose factor for nuclide "I", in mrem per pCi ingested. Values are given in Table A21.

The resuspension of dust by wind, or water drops splashing soil onto the foliage leads to some contamination of the edible portion of the plant. The ingestion dose from this source of

contamination is calculated using Equation (54). The first equation shows the continuous model for leafy vegetables. Note that the integral is over half the year so the assumed annual intake from garden must be adjusted upward to compensate. Hence the ratio $(1 \text{ y})/(T_{\text{irr}})$. The second equation shows the harvest model for the other vegetables. Note the sum over radionuclides in a decay chain to obtain the total dose from the parent nuclide.

$$H_{\text{epf}}(\text{leafy}) = \sum_{i=1}^n \frac{1 \text{ y}}{T_{\text{irr}}} \int_0^{T_{\text{irr}}} J_d \frac{F_{\text{fp}} F_{\text{tp}} T_w}{Y_p} Q_{\text{vp}} C_{\text{si}} D_{\text{ing},i} dT \quad (54)$$

$$H_{\text{epf}}(\text{others}) = \sum_{i=1}^n R^i V_d \frac{F_{\text{fp}} F_{\text{tp}} T_w}{Y_p} Q_{\text{vp}} C_{\text{si}} \text{IDR}_i(T_{\text{veg}}) D_{\text{ing},i} T_{\text{veg}}$$

Where

H_{epf} = ingestion dose from plant type p due to resuspension of contaminated soil onto plant surfaces (rain splash), in mrem.

p = type of plant. There are 4 types of garden produce. The first equation covers leafy vegetables (p=1). The second equation covers other vegetables, fruit, and grain (p=2,3,4).

J_d = average soil deposition rate on plant surfaces due to rain splash, 2.7×10^{-4} kg/m² per day. See Section A5.2 for further discussion.

F_{fp} = interception fraction for plant type p. The fraction of what falls to the earth that lands on the plant. Computed as shown in Section A5.2. Values are listed in Table A39.

F_{tp} = translocation factor, i.e. the fraction of what deposits on the foliage that ends up in the edible portions of the plant. Values are listed in Table A39.

T_w = effective exposure period for foliar deposition, in days. The values are computed using a foliage weathering time of 14 days. Values are shown in Table B1.

Y_p = harvest yield of crop type p, in kg/m² (wet weight). Also called the standing biomass. Values are listed in Table A39.

Q_{vp} = quantity of plant type p eaten by the person during the year, in kg/y. See Table A5 for values.

C_{si} = time-dependent soil concentration of the ith nuclide, in Ci/kg. It is affected by radioactive decay and leaching from the surface layer of soil during the irrigation season. In the second equation it is the soil concentration at the time of harvest.

T_{irr} = irrigation period in years. The value of 0.5 yr is assumed based on current practices near the Hanford Site.

IDR_i = decay factor that accounts for radioactive decay of the ith nuclide during the consumption of garden produce

T_{veg} = consumption period for garden produce, assumed to be 90 days

T_{ing} = ingestion exposure time of the individual, 1 y.

$D_{ing,I}$ = ingestion dose factor for nuclide "I", in mrem per pCi ingested. Values are given in Table A21.

One effect of wind, rain, and irrigation is to remove deposited contamination from plant surfaces. This effect is included using a weathering term shown in Equation (55). Values for the effective growing period are only slightly affected by the radioactive half life of the isotope for the long half lives shown in Table A1. Therefore, the decay effects were not considered ($\lambda_w=0$). Values for T_w are given in Table B1 for the growing periods shown in Table A39.

$$T_w = \{ 1 - \text{Exp}[-(\lambda_w + \lambda_r)T_p^f] \} / (\lambda_w + \lambda_r) \quad (55)$$

Where

T_w = effective exposure period for foliar deposition, in days. Values are shown in Table B1.

λ_w = weathering removal coefficient, 0.0495105 per day, or 18.0713 per year, which corresponds to a 14 day half time.

λ_r = radioactive decay constant, namely, the natural logarithm of 2 divided by the radioactive decay half life in days. Values are listed in Table A1.

T_p^f = exposure time of the plant type p to the airborne contamination depositing on the foliage, in days (also called growing period). Values are shown in Table A39.

Table B1. Effective Exposure Times for Foliar Deposition

Growing Period	T_w
30 days	15.6 days
45 days	18.0 days
90 days	20.0 days

The effective exposure times are computed assuming radioactive decay is negligible for the nuclides of Table A1.

The previous two avenues by which contamination reaches the edible portions of the plants apply only to activity, which is present in the soil. This section discusses direct deposition of contaminants in irrigation water onto the foliage. The ingestion dose due to radioactivity in the edible portion of the plants due to direct deposition on foliage is given in equation (56).

$$H_{epd}(\text{leafy}) = ID_p \frac{0.25 F_p T_w}{Y_p} Q_{vp} D_{ing} T_{ing}$$

(56)

$$H_{epd}(\text{others}) = \sum_{i=1}^n ID_p \frac{0.25 F_{tp} T_w}{Y_p} Q_{vp} IDR_i(T_{veg}) D_{ing,i} T_{ing}$$

Where

H_{epd} = ingestion dose from plant type p due to deposition of a nuclide in contaminated irrigation water onto plant surfaces, in mrem.

p = type of plant. There are 4 types of garden produce. The first equation covers leafy vegetables (p=1). The second equation covers other vegetables, fruit, and grain (p=2,3,4).

ID_p = instantaneous activity deposition rate due to irrigation of soils growing plant type p, in Ci/yr/m². Only the parent nuclide is present. Any progeny nuclides are assumed to be absent.

0.25 = interception fraction for contaminants in irrigation water. The fraction of what falls to the earth that lands on the plant.

F_{tp} = translocation factor, i.e. the fraction of what deposits on the foliage that ends up in the edible portions of the plant. Values are listed in Table A39.

T_w = effective exposure period for foliar deposition, in days. The values are computed using a foliage weathering time of 14 days. Values are shown in Table B1.

Y_p = harvest yield of crop type p, in kg/m² (wet weight). Also called the standing biomass. Values are listed in Table A39.

Q_{vp} = quantity of plant type p eaten by the person during the year, in kg/y. See Table A5 for values.

IDR_i = decay factor that accounts for radioactive decay during the consumption of garden produce

T_{veg} = consumption period for garden produce, assumed to be 90 days

T_{ing} = ingestion exposure time of the individual, 1 y.

$D_{ing,i}$ = ingestion dose factor for the ith nuclide, in mrem per pCi ingested. Values are given in Table A21.

The ingestion dose from garden produce due to direct deposition depends on the rate at which water is applied. In the previous two pathways, root uptake and rain splash, the determining factor is the total amount of water (and thus activity) applied to the soil. A summary of the essential calculation and the decay corrections is presented in Table B2.

Table B2. Summary of Ingestion Dose from Garden Produce

Essential Dose Calculation for an Initial Soil Contamination	
Root Uptake:	$R_p B_p C_s Q_{vp} D_{ing} T_{ing}$
Rain Splash:	$J_d F_{fp} (F_{tp} T_w / Y_p) C_s Q_{vp} D_{ing} T_{ing}$
Correction for Radioactive Decay and Progeny In-growth	
Leafy Vegetables:	$IDS(T_{irr})$
Other Vegetables, Fruit, and Grain:	$DS(T_h) \cong IDR(T_{veg})$
Essential Dose Calculation for Irrigation with Contaminated Water	
Root Uptake:	$R_p B_p C_s Q_{vp} D_{ing} T_{ing}$
Rain Splash:	$J_d F_{fp} (F_{tp} T_w / Y_p) C_s Q_{vp} D_{ing} T_{ing}$
Direct Deposition:	$ID_p (0.25) (F_{tp} T_w / Y_p) Q_{vp} D_{ing} T_{ing}$
Correction for Radioactive Decay and Progeny In-growth	
Leafy Vegetables:	Root Uptake & Splash: $IDI(T_{irr})$ Direct Deposition: no decay
Other Vegetables, Fruit, and Grain:	Root Uptake & Splash: $DI(T_{irr}) \cong IDR(T_{veg})$ Direct Deposition: $IDR(T_{veg})$

Notes: Leafy vegetables are consumed continuously during growing season (T_{ir}) only. Other produce is harvested and consumed over a period of time (T_{wp}). The decay factors are unitless fractions shown in Equation (50). Progeny in-growth is computed using the method shown in Section B2.

Explanation of Symbols Used in Table B2.

- B_p = soil to plant concentration ratio, as Ci/kg dry weight of vegetables to Ci/kg of soil. See Table A37 for values.
- C_s = soil concentration of a nuclide, in Ci/kg. It is affected by radioactive decay and leaching from the surface layer of soil during the irrigation season.
- D_{ing} = ingestion dose factor for a nuclide, in mrem per pCi ingested. Values are given in Table A21.
- F_{fp} = interception fraction for plant type p. The fraction of what falls to the earth that lands on the plant. Computed as shown in Section A5.2. Values are listed in Table A39.

- F_{tp} = translocation factor, i.e. the fraction of what deposits on the foliage that ends up in the edible portions of the plant. Values are listed in Table A39.
- ID_p = instantaneous activity deposition rate due to irrigation of soils growing plant type p, in Ci/yr/m².
- J_d = average soil deposition rate on plant surfaces due to rain splash, 2.7×10^{-4} kg/m² per day. See Section A5.2 for further discussion.
- p = type of plant. There are 4 types of garden produce. The first equation covers leafy vegetables ($p=1$). The second equation covers other vegetables, fruit, and grain ($p=2,3,4$).
- Q_{vp} = quantity of plant type p eaten by the person during the year, in kg/y. See Table A5 for values.
- R_p = dry to wet ratio for plant type p. See Table A36 for values.
- T_h = time at which harvest occurs. For initial soil contaminations, harvest is assumed to occur halfway through the growing season, $T_h = T_{irr}/2$. For irrigation with contaminated water, the harvest occurs at the end of the irrigation season to maximize the soil contamination.
- T_{ing} = ingestion exposure time of the individual, 1 y.
- T_{irr} = irrigation period in years. The value of 0.5 yr is assumed based on current practices near the Hanford Site.
- T_{veg} = consumption period for garden produce, assumed to be 90 days
- T_w = effective exposure period for foliar deposition, in days. The values are computed using a foliage weathering time of 14 days. Values are shown in Table B1.
- Y_p = harvest yield of crop type p, in kg/m² (wet weight). Also called the standing biomass. Values are listed in Table A39.

The equilibrium model used for tritium in the post-intrusion residential garden is summarized in Section 3.2. The radioactive decay and leaching terms are shown in Table B2. Tritium in irrigation water leads to an equilibrium situation in which the concentration of tritium in the water is reproduced throughout the plant. Since the equilibrium is established rather quickly, the decay corrections are simpler than for other nuclides. The calculation of dose from tritium in irrigation water is shown in Equation (57) below.

$$H_{epH}(\text{leafy}) = \frac{I C_{w,H3}}{I+P} (8.94 F_{tp}) Q_{vp} D_{ing,H3} T_{ing} \quad (57)$$

$$H_{epH}(\text{others}) = \frac{I C_{w,H3}}{I+P} (8.94 F_{tp}) Q_{vp} IDR(T_{veg}) D_{ing,H3} T_{ing}$$

Where

H_{epH} = ingestion dose from plant type p due to tritium (H-3) in the irrigation water, in

mrem.

- p = type of plant. There are 4 types of garden produce. The first equation covers leafy vegetables ($p=1$). The second equation covers other vegetables, fruit, and grain ($p=2,3,4$).
- I = total irrigation water applied to the soil during the irrigation season, 82.3 cm/y (63.5 cm/y for populations).
- $C_{w,H3}$ = concentration of tritium in the irrigation water, in pCi/L.
- P = total natural precipitation water applied to the soil during the irrigation period, 5.77 cm/y (PNNL-13859).
- F_{Hp} = fraction of hydrogen in plant type p . Values are listed in Table A34. The factor of 8.94 converts the hydrogen fraction to an effective water fraction that includes organically bound hydrogen.
- Q_{vp} = quantity of plant type p eaten by the person during the year, in kg/y. See Table A5 for values.
- IDR = decay factor that accounts for radioactive decay during the consumption of garden produce
- T_{veg} = consumption period for garden produce, assumed to be 90 days
- T_{ing} = ingestion exposure time of the individual, 1 y.
- $D_{ing,H3}$ = ingestion dose factor for tritium, in mrem per pCi ingested. Value is given in Table A21.

B4.3 ANIMAL PRODUCTS EATEN

The simplest animal product to evaluate is fish. The dose from fish consumption is shown in Equation (58). It is the product of the quantity of fish consumed during the year, the concentration in the fish, and the ingestion dose factor. The fish harvested is consumed over the next few days, so there is no need to correct for radioactive decay and progeny in-growth.

$$H_{cf} = Q_{fc} C_w B_f D_{ing} T_{ing} \quad (58)$$

where

- H_{cf} = ingestion dose from contaminated fish, in mrem.
- Q_{fc} = quantity of contaminated fish consumed by the person during the year, in kg/y. See Table A5 for values.
- C_w = concentration of a nuclide in the contaminated water, in pCi/L.
- B_f = bioaccumulation factor in fish from Table A33, in L/kg. It is the ratio of the contamination in the edible parts of the fish to the concentration in the water.
- T_{ing} = ingestion exposure time of the individual, 1 y
- D_{ing} = ingestion dose factor for a nuclide, in mrem per pCi ingested. Values are given in Table A21.

The ingestion dose from foods obtained from land animals is computed using equilibrium transfer factors shown in Table A33. These relate the total radioactive material ingested by the animal each day to the concentration in the animal product consumed by a person. The total diet of the animal must be taken into account. The animal may drink contaminated water, ingest contaminated soil, graze on contaminated grass and be fed stored material that is also contaminated. Each of these will be presented in turn. The total ingestion dose from animal products is the sum of these.

Just as with garden produce there is a continuous production model and a harvest model in which the animal is slaughtered for later consumption. The beef cattle model illustrates the latter, while the milk cow illustrates the former. The chicken (meat) and egg are treated as continuous because these are produced at regular intervals during the year and then consumed shortly thereafter.

The ingestion dose from contaminated water consumed by the animal is shown in Equation (59). Because the progeny nuclides are not allowed to form in the water supply, the dose from each nuclide in a chain will be calculated separately. When the beef cattle is slaughtered (i.e. harvested), there is a large quantity of beef available. This food is then consumed over a period of time during which radioactive decay and progeny in-growth occurs. The quantity of contaminated beef consumed during the year is from Table A5. These values have already been adjusted for the fraction of the year that contaminated beef is consumed. Hence, the factor (T_{ing}/T_{beef}) is included.

$$H_{eqw}(beef) = \sum_{i=1}^n \int_0^{T_{beef}} Q_{wq} C_w F_{qi} Q_{aq} \left(\frac{T_{ing}}{T_{beef}} \right) D_{ing,i} DR_i dT$$

$$H_{eqw}(\text{others}) = Q_{wq} C_w F_q Q_{aq} D_{ing} T_{ing} \quad (59)$$

where

- H_{eqw} = ingestion dose from animal product q due to contaminated drinking water, in mrem.
- q = index for animal products. There are 4 types of animal products, beef, milk, poultry, and eggs.
- Q_{wq} = quantity of contaminated drinking water ingested by the animal associated with animal product q each day, in L/d. See Table A32 for values.
- C_w = concentration of the parent nuclide in a decay chain in the contaminated water, in pCi/L. The progeny nuclide concentrations are assumed to be zero in the water.
- F_{qi} = equilibrium transfer factor for animal product q for the ith nuclide in a decay chain, in d/kg (or d/L for milk). Values are given in Table A33. F_q is the transfer factor of the first nuclide.
- Q_{aq} = quantity of animal product q consumed by the person during the year, in kg/y (or L/y for milk). See Table A5 for values.

- T_{beef} = consumption period for beef cattle, assumed to be 120 days
- T_{ing} = ingestion exposure time of the individual, 1 y
- $D_{ing,i}$ = ingestion dose factor for the *i*th nuclide in a decay chain, in mrem per pCi ingested. Values are given in Table A21. D_{ing} is the ingestion dose factor of the first nuclide in the chain.

The other contributors to the overall contamination of an animal product are summarized in Table B3. For the case of an initial soil contamination, the two components are vegetable foods consumed by the animal and the soil ingestion shown in Table A32. The animal foods are contaminated by root uptake and rain splash. There are three main kinds of food: fresh fodder (grass), stored hay (grass that is harvested and stored), and stored feed (grain that is harvested and stored). For the case of irrigation with contaminated water, additional components are direct deposition on the animal foods, and direct ingestion of the irrigation water.

Table B3. Summary of Ingestion Dose from Animal Products

Essential Dose Calculation for an Initial Soil Contamination. The activity intake rates are computed using the formulas below. These are converted to annual dose equivalent by means of the factor, $F_q Q_{aq} D_{ing} T_{ing}$.	
Trace Soil Ingestion:	$C_s Q_{sq}$
Fodder -- Root Uptake:	$R_p B_p C_s Q_{pq}$
Fodder -- Rain Splash:	$J_d F_{fp} (F_{fp} T_w / Y_p) C_s Q_{pq}$
Correction for Radioactive Decay and Progeny In-growth -- Beef	
Soil Ingestion and Fresh Grass:	$DS(T_h) \cong IDR(T_{beef})$
Stored Hay (grass) and Stored Grain:	$DS(T_h) \cong DR(T_s) \cong IDR(T_{beef})$
Correction for Radioactive Decay and Progeny In-growth -- Milk, Poultry, Eggs	
Soil Ingestion and Fresh Grass:	$[T_{irr} \cong IDS(T_{irr}) + T_{no} \cong DS(T_{irr}) \cong IDR(T_{no})] / T_{ing}$
Stored Hay (grass) and Stored Grain:	$DS(T_h) \cong DR(T_s) \cong IDR(T_{an})$

<p>Essential Dose Calculation for Irrigation with Contaminated Water. The activity intake rates are computed using the formulas below. These are converted to annual dose equivalent by means of the factor, $F_q Q_{aq} D_{ing} T_{ing}$.</p>	
Trace Soil Ingestion:	$C_s Q_{sq}$
Fodder -- Root Uptake:	$R_p B_p C_s Q_{pq}$
Fodder -- Rain Splash:	$R^a V_d F_{fp} (F_{tp} T_w / Y_p) C_s Q_{pq}$
Fodder -- Direct Deposition:	$ID_p (0.25) (F_{tp} T_w / Y_p) Q_{pq}$
Drinking Water Ingestion:	$C_w Q_{wq}$
Correction for Radioactive Decay and Progeny In-growth -- Beef	
Trace Soil Ingestion:	$DI(T_{irr}) \cong IDR(T_{beef})$
Fresh Grass:	Root & Splash: $DI(T_{irr}) \cong IDR(T_{beef})$ Direct Deposition: $IDR(T_{beef})$
Stored Hay and Grain:	Root & Splash: $DI(T_{irr}) \cong DR(T_s) \cong IDR(T_{beef})$ Direct Deposition: $DR(T_s) \cong IDR(T_{beef})$
Drinking Water:	$IDR(T_{beef})$
Correction for Radioactive Decay and Progeny In-growth -- Milk, Poultry, Eggs	
Trace Soil Ingestion:	$[T_{irr} \cong IDI(T_{irr}) + T_{no} \cong DI(T_{irr}) \cong IDR(T_{no})] / T_{ing}$
Fresh Grass:	Root Uptake & Rain Splash: $[T_{irr} \cong IDI(T_{irr}) + T_{no} \cong DI(T_{irr}) \cong IDR(T_{no})] / T_{ing}$ Direct Deposition: no decay
Stored Hay and Grain:	Root & Splash: $DI(T_{irr}) \cong DR(T_s) \cong IDR(T_{an})$ Direct Deposition: $DR(T_s) \cong IDR(T_{an})$
Drinking Water:	no decay

Notes: Beef is harvested and consumed over a period of time. Milk, poultry, and eggs are consumed continuously during the year. The decay factors are unitless fractions shown in Equation (50). Progeny in-growth is computed using the method shown in Section B2.

Explanation of Symbols Used in Table B3.

- B_p = soil to plant concentration ratio, as Ci/kg dry weight of vegetables to Ci/kg of soil. See Table A37 for values.
- C_s = soil concentration of a nuclide, in Ci/kg. It is affected by radioactive decay and leaching from the surface layer of soil during the irrigation season.
- C_w = concentration of a nuclide in the contaminated water, in pCi/L. Any progeny nuclide concentrations are assumed to be zero.
- D_{ing} = ingestion dose factor for a nuclide, in mrem per pCi ingested. Values are given in Table A21.

- F_q = equilibrium transfer factor for animal product q for a nuclide, in d/kg (or d/L for milk). Values are given in Table A33.
- F_{fp} = interception fraction for plant type p. The fraction of what falls to the earth that lands on the plant. Computed as shown in Section A5.2. Values are listed in Table A39.
- F_{tp} = translocation factor, i.e. the fraction of what deposits on the foliage that ends up in the edible portions of the plant. Values are listed in Table A39.
- ID_p = instantaneous activity deposition rate due to irrigation of soils growing plant type p, in Ci/yr/m².
- J_d = average soil deposition rate on plant surfaces due to rain splash, 2.7×10^{-4} kg/m² per day. See Section A5.2 for further discussion.
- p = index for animal fodder. There are 3 types of animal fodder, fresh grass, stored hay, and stored grain.
- q = index for animal products. There are 4 types of animal products, beef, milk, poultry, and eggs.
- Q_{aq} = quantity of animal product q eaten by the person during the year, in kg/y (or L/y for milk). See Table A5 for values.
- Q_{pq} = quantity of fodder type p eaten by the animal during the year, in kg/y. See Table A32 for values.
- Q_{sq} = quantity of contaminated soil ingested by the animal associated with animal product q each day, in kg/d. See Table A32 for values.
- Q_{wq} = quantity of contaminated drinking water ingested by the animal associated with animal product q each day, in L/d. See Table A32 for values.
- R_p = dry to wet ratio for plant type p. See Table A36 for values.
- T_{an} = time period over which stored hay and grain are consumed by the milk cow and chickens. Assumed to be the same as T_{veg} , 90 d.
- T_{beef} = consumption period for beef cattle, assumed to be 120 days.
- T_h = time at which harvest occurs. For initial soil contaminations, harvest is assumed to occur halfway through the growing season, $T_h = T_{irr}/2$. For irrigation with contaminated water, the harvest occurs at the end of the irrigation season to maximize the soil contamination.
- T_{ing} = ingestion exposure time of the individual, 1 y.
- T_{irr} = irrigation period in years. The value of 0.5 yr is assumed based on current practices near the Hanford Site. $T_{no} = 1y - T_{irr}$
- T_s = storage time for the stored feed (hay and grain), 90 d.
- T_w = effective exposure period for foliar deposition, in days. The values are computed using a foliage weathering time of 14 days. Values are shown in Table B1.

Y_p = harvest yield of crop type p, in kg/m² (wet weight). Also called the standing biomass. Values are listed in Table A39.

The one special case nuclide is tritium in contaminated irrigation water. Tritium present in an initial soil contamination is handled using the same method as any other nuclide. The equilibrium transfer factors shown in Table A33 are used. Tritium in irrigation water leads to an equilibrium situation in which the concentration of tritium in the water is reproduced throughout the animal product. Since the equilibrium is established rather quickly, the decay corrections are simpler than for other nuclides. The calculation of dose from tritium in irrigation water is shown in Table B4 below. Note that the tritium model assumes that loss of tritium by evaporation of water from soil or plants is not important.

Table B4. Ingestion Dose from Animal Products from Tritium

Essential Dose Calculation for Irrigation with Contaminated Water.	
The activity intake rates are computed using the formulas below.	
These are converted to annual dose equivalent by means of the factor,	
$C_{w,H3} F_q Q_{sq} D_{ing,H3} T_{ing}$.	
Trace Soil Ingestion:	$8.94 F_{H3} I/(I+P) Q_{sq}$
Fodder -- Root Uptake:	$8.94 F_{Hp} I/(I+P) Q_{pq}$
Drinking Water Ingestion:	Q_{wq}
Correction for Radioactive Decay and Progeny In-growth -- Beef	
Trace Soil Ingestion:	IDR(T_{beef})
Fresh Grass:	IDR(T_{beef})
Stored Hay and Grain:	DR(T_s) \cong IDR(T_{beef})
Drinking Water:	IDR(T_{beef})
Correction for Radioactive Decay and Progeny In-growth -- Milk, Poultry, Eggs	
Trace Soil Ingestion:	$[T_{irr} + T_{no}\cong IDR(T_{no})]/T_{ing}$
Fresh Grass:	$[T_{irr} + T_{no}\cong IDR(T_{no})]/T_{ing}$
Stored Hay and Grain:	DR(T_s) \cong IDR(T_{an})
Drinking Water:	no decay

Notes: Beef is harvested and consumed over a period of time. Milk, poultry, and eggs are consumed continuously during the year. The decay factors are unitless fractions shown in Equation (50). Progeny in-growth is computed using the method shown in Section B2.

Explanation of Symbols Used in Table B4.

$C_{w,H3}$ = concentration of tritium (H-3) in the irrigation water, in pCi/L.

$D_{ing,H3}$ = ingestion dose factor for tritium, in mrem per pCi ingested. Value is given in Table A3.

F_q = equilibrium transfer factor for animal product q for tritium, in d/kg (or d/L for milk). Value is given in Table A33.

- F_{Hs} = fraction of hydrogen in garden soil. The value used is listed in Table A34. The factor of 8.94 converts the hydrogen fraction to an effective water fraction that includes organically bound hydrogen.
- F_{Hp} = fraction of hydrogen in plant type p. Values are listed in Table A34. The factor of 8.94 converts the hydrogen fraction to an effective water fraction that includes organically bound hydrogen.
- I = total irrigation water applied to the soil during the irrigation season, 82.3 cm/y (63.5 for populations).
- p = index for animal fodder. There are 3 types of animal fodder, fresh grass, stored hay, and stored grain.
- P = total natural precipitation water reaching the surface soil during the irrigation period, 5.77 cm/y (PNNL-13859).
- q = index for animal products. There are 4 types of animal products, beef, milk, poultry, and eggs.
- Q_{aq} = quantity of animal product q eaten by the person during the year, in kg/y (or L/y for milk). See Table A5 for values.
- Q_{pq} = quantity of fodder type p eaten by the animal during the year, in kg/y. See Table A32 for values.
- Q_{sq} = quantity of contaminated soil ingested by the animal associated with animal product q each day, in kg/d. See Table A32 for values.
- Q_{wq} = quantity of contaminated drinking water ingested by the animal associated with animal product q each day, in L/d. See Table A32 for values.
- T_{an} = time period over which stored hay and grain are consumed by the milk cow and chickens. Assumed to be the same as T_{veg} , 90 d.
- T_{beef} = consumption period for beef cattle, assumed to be 120 days.
- T_{ing} = ingestion exposure time of the individual, 1 y.
- T_{irr} = irrigation period in years. The value of 0.5 yr is assumed based on current practices near the Hanford Site. $T_{no} = 1y - T_{irr}$
- T_s = storage time for the stored feed (hay and grain), 90 d.

B5.0 REFERENCES

- PNNL-13859, Hoitink, D. J., K. W. Burk, J. V. Ramsdell, and W. J. Shaw, 2002, *Hanford Site Climatological Data Summary 2001 with Historical Data*, Pacific Northwest National Laboratory, Richland, WA.
- WHC-SA-1282-FP, Rittmann, P. D., 1991, *Improvements for Computing Radioactive Decay*, Westinghouse Hanford Company, Richland, WA.
- WHC-SD-WM-EE-004, Revision 1, Kincaid, C. T., et al., 1995, *Performance Assessment of Grouted Double-Shell Tank Waste Disposal at Hanford*, Pacific Northwest National Laboratory and Westinghouse Hanford Company, Richland, WA.

**ATTACHMENT B1.
HAND CALCULATIONS FOR TRITIUM**

BA.1 NO WATER INFILTRATION EXPOSURE SCENARIOS

Each of the exposure scenarios listed in Table 2 (of the main text) will be evaluated. Absorption of airborne tritium through the skin is included in the inhalation dose factor for tritium. The doses calculated are the total accumulated during the first year of exposure.

Normally, three significant digits are kept during calculations. Because the spreadsheet software keeps several digits, agreement with the spreadsheet can only be obtained if 4 or 5 significant digits are retained. This is particularly true in the calculation of decay factors.

For tritium, the inhalation dose factor is $9.60\text{E-}08$ mrem/pCi or 96,000 mrem/Ci inhaled. The ingestion dose factor is $6.40\text{E-}08$ mrem/pCi or 64,000 mrem/Ci ingested. The external dose rate factor is 0.

BA.1.1 Offsite Farmer

Assume 1 curie H-3 is released into the air during the year. The bounding annual average air transport factor is $1.0\text{E-}04$ s/m³.

Inhalation Dose: From Table E1, 0.0237 mrem

BA.1.2 Onsite Resident

Assume the H-3 emanation rate is 1 pCi/m²/s. The average air concentration in a dwelling with an air exchange to floor area ratio of $5.0\text{E-}04$ m/s is computed as shown below.

$$C_{eq} = (1 \text{ pCi/m}^2/\text{s}) / (5.0\text{E-}04 \text{ m/s}) = 2,000 \text{ pCi/m}^3$$

The individual is present in his dwelling about 8,040 h/y from Table A9 (rural pasture scenario). The total volume of air inhaled during this period is computed as shown below.

$$V_{air} = (3,102 \text{ h/y})(0.45 \text{ m}^3/\text{h}) + (4,908 \text{ h/y})(1.18 \text{ m}^3/\text{h}) = 7,187 \text{ m}^3/\text{y}$$

Inhalation Dose:

$$(2,000 \text{ pCi/m}^3)(7,187 \text{ m}^3)(9.60\text{E-}08 \text{ mrem/pCi}) = \underline{1.38 \text{ mrem}}$$

BA.1.3 Intruder (Well Driller)

The unit dose factors for the Well Driller assume an average soil concentration of 1 Ci/kg. The actual concentration is calculated as the activity removed from the borehole divided by the

mass of soil and waste removed. A mass loading approach is used, so that the driller inhales a total of 4.84 mg (4.84E-06 kg) of soil (Table A10). He ingests a total of 500 mg (5.0E-4 kg) soil (Table A8). His external exposure time is 40 hours (Table A15). The inhalation, ingestion, and external dose calculations are shown below.

Inhalation Dose:

$$(4.84\text{E-}06 \text{ kg inhaled})(1 \text{ Ci/kg})(96,000 \text{ mrem/Ci}) = 0.465 \text{ mrem}$$

Ingestion Dose:

$$(5.0\text{E-}04 \text{ kg ingested})(1 \text{ Ci/kg})(64,000 \text{ mrem/Ci}) = 32.0 \text{ mrem}$$

External Dose:

Note that the well tailings have a density of 1,500 kg/m³ and are spread to an average thickness of 5 cm. The worker spends 40 hours in the middle of this radiation source.

$$(40 \text{ h})(1 \text{ Ci/kg})(1,500 \text{ kg/m}^3)(0.05 \text{ m})(0 \text{ mrem/h per Ci/m}^3) = 0 \text{ mrem}$$

Total Dose to Driller:

$$0.465 \text{ mrem} + 32.0 \text{ mrem} + 0 \text{ mrem} = 32.5 \text{ mrem per Ci/kg}$$

Note that the well driller dose factor from Table 7 is 32.5 mrem per Ci/kg.

BA.1.4 Post-Intrusion Suburban Gardener

The unit dose factors for the suburban gardener assume 1 curie H-3 is exhumed from the well and spread over an area of 100 m². The initial average soil concentration is computed as shown below.

$$C_s = (1 \text{ Ci})/(100 \text{ m}^2)/(225 \text{ kg/m}^2) = 4.444\text{E-}5 \text{ Ci/kg}$$

This concentration decreases rapidly with time due to leaching from the surface layer (during the irrigation season), evaporation, and radioactive decay. For all practical purposes, none of the initial tritiated water deposited in the garden is present at the end of the irrigation season. Decay factors used in the dose calculations are computed below using equations from Table B2.

$$\lambda_r = (0.69315)/(12.33 \text{ y}) = 0.056216 \text{ y}^{-1}$$

During the irrigation season :

$$\lambda_s = (5.766 + 82.3 \text{ cm})/(0.2)/(15 \text{ cm})/(0.5 \text{ y}) = 58.710667 \text{ y}^{-1} \text{ (Section A6.0)}$$

$$\lambda_t = \lambda_r + \lambda_s = 58.76688 \text{ y}^{-1}$$

During the non-irrigation season :

$$\lambda_1 = (11.963 \text{ cm})/(0.2)/(15 \text{ cm})/(0.5 \text{ y}) = 7.975333 \text{ y}^{-1} \text{ (Section A6.0)}$$

$$\lambda_t = \lambda_r + \lambda_s = 8.03155 \text{ y}^{-1}$$

$$\lambda_t T_{irr} = (58.76688 \text{ y}^{-1})(0.5 \text{ y}) = 29.38344$$

$$DS(T_{irr}) = \text{Exp}(-29.38344) = 0$$

$$IDS(T_{irr}) = [1 - \text{Exp}(-29.38344)]/(29.38344) = 0.034033$$

$$\lambda_t T_{no} = (8.03155 \text{ y}^{-1})(0.5 \text{ y}) = 4.01578$$

$$\text{IDR}(T_{\text{no}}) = [1 - \text{Exp}(-4.01578)]/(4.01578) = 0.244528$$

$$T_{\text{irr}} \cong \text{IDS}(T_{\text{irr}}) + T_{\text{no}} \cong \text{DS}(T_{\text{irr}}) \cong \text{IDR}(T_{\text{no}}) = \\ (0.5\text{y})(0.034033) + (0.5\text{y})(0)(0.244528) = 0.017017 \text{ y}$$

$$\text{DS}(T_{\text{h}}) = \text{Exp}[-(58.76688 \text{ y}^{-1})(0.25 \text{ y})] = 4.164\text{E-}7$$

$$\lambda_r T_{\text{veg}} = (0.056216 \text{ y}^{-1})(90 \text{ d})/(365 \text{ d/y}) = 0.0138615 \\ \text{IDR}(T_{\text{veg}}) = [1 - \text{Exp}(-0.0138616)]/(0.0138615) = 0.99310 \\ \text{DS}(T_{\text{h}}) \cong \text{IDR}(T_{\text{veg}}) = (4.164\text{E-}7)(0.99310) = 4.135\text{E-}7$$

A special model described in Section A3.2.1 is used for inhalation dose, so that the resident inhales a total of 1.585E-06 Ci tritium per Ci exhumed over the course of a year. He also ingests a total of 0.018 kg soil during the year (Table A8). The effective external exposure time is 180 h (Table A15). The inhalation, ingestion, and external doses from these sources are shown below. These also match the numbers for tritium shown in Table D1.

Inhalation Dose: (resuspended soil)

$$(1.585\text{E-}6 \text{ Ci inhaled/Ci exhumed})(1 \text{ Ci exhumed})(96,000 \text{ mrem/Ci}) = 0.1522 \text{ mrem}$$

Ingestion Dose: (soil only)

Note that the decay factor considers that all of the exposure occurs during the first half of the year.

$$(0.018 \text{ kg})(4.444\text{E-}5 \text{ Ci/kg})(64,000 \text{ mrem/Ci})(0.034033 \text{ y}) = 1.742\text{E-}3 \text{ mrem}$$

External Dose:

Note that the 1 Ci tritium in the well tailings has been mixed into a garden with an area of 100 m².

$$(180 \text{ h/y})(1 \text{ Ci}/100 \text{ m}^2)(0 \text{ mrem/h per Ci/m}^2)(0.034033 \text{ y}) = 0 \text{ mrem}$$

The concentration in vegetable produce from the garden is calculated using the special model for tritium. The concentration in vegetation and the doses from each type are shown below. Grains are not grown in the garden, and all of the other plants have the same hydrogen fraction (0.1). The contaminated food consumption rate is combined with the ingestion period (1 year) so that the column of consumption rates has units of kg rather than kg/y.

$$C_{\text{V,H-3}} = (4.444\text{E-}5 \text{ Ci/kg})(8.94)(0.1)(1.5 \text{ kg/L})/(0.2) = 2.980\text{E-}4 \text{ Ci/kg}$$

Ingestion Dose: (garden produce)

$$\text{leafy: } (0.25)(17.8 \text{ kg})(2.980\text{E-}4 \text{ Ci/kg})(0.034033)(64,000 \text{ mrem/Ci}) = 2.8882 \text{ mrem} \\ \text{other: } (0.25)(86.5 \text{ kg})(2.980\text{E-}4 \text{ Ci/kg})(4.135\text{E-}7)(64,000 \text{ mrem/Ci}) = 1.70\text{E-}4 \text{ mrem} \\ \text{fruit: } (0.25)(85.8 \text{ kg})(2.980\text{E-}4 \text{ Ci/kg})(4.135\text{E-}7)(64,000 \text{ mrem/Ci}) = 1.69\text{E-}4 \text{ mrem} \\ \text{Total from root uptake: } 2.8885 \text{ mrem}$$

Total Dose: Suburban Garden Scenario:

$$0.1522 + 0.001742 + 2.8885 \text{ mrem} = 3.04 \text{ mrem per Ci exhumed}$$

Note that the suburban gardener's dose factor from Table 8 is 3.04 mrem/y per Ci exhumed.

BA.1.5 Post-Intrusion Urban Pasture Scenario

The unit dose factors for the urban pasture scenario assume 1 curie H-3 is exhumed from the well and spread over an area of 5,000 m². The initial average soil concentration is computed as shown below.

$$C_s = (1 \text{ Ci}) / (5,000 \text{ m}^2) / (225 \text{ kg/m}^2) = 8.889\text{E-}7 \text{ Ci/kg}$$

This concentration decreases rapidly with time due to leaching from the surface layer (during the irrigation season), evaporation, and radioactive decay. For all practical purposes, none of the initial tritiated water deposited in the garden is present at the end of the irrigation season. Decay factors used in the dose calculations are the same as shown for the suburban garden scenario.

A special model described in Section A3.2.1 is used for inhalation dose, so that the resident inhales a total of 2.241E-07 Ci tritium per Ci exhumed. He also ingests a total of 0.018 kg soil during the year (Table A8). The effective external exposure time is 360 h (Table A15). The inhalation, ingestion, and external doses from these sources are shown below. These also match the numbers for tritium shown in Table D2.

Inhalation Dose: (resuspended soil)

$$(2.241\text{E-}7 \text{ Ci inhaled/Ci exhumed})(1 \text{ Ci exhumed})(96,000 \text{ mrem/Ci}) = 0.02151 \text{ mrem}$$

Ingestion Dose: (soil only)

Note that the decay factor considers that all of the exposure occurs during the first half of the year.

$$(0.018 \text{ kg})(8.889\text{E-}7 \text{ Ci/kg})(64,000 \text{ mrem/Ci})(0.034033 \text{ y}) = 3.485\text{E-}5 \text{ mrem}$$

External Dose:

Note that the 1 Ci tritium in the well tailings has been mixed into a garden with an area of 100 m².

$$(360 \text{ h/y})(1 \text{ Ci}/5,000 \text{ m}^2)(0 \text{ mrem/h per Ci/m}^2)(0.034033 \text{ y}) = 0 \text{ mrem}$$

Ingestion Dose: (milk)

$$\text{Contaminated water fraction for the milk cow: } 0.54951 / 119.433 = 0.004601$$

source	animal intake kg/d	water fraction	total water intake, L/d	decay	contaminated water intake
forage	36	0.894	32.184	0.017017	0.54768
hay	29	0.894	25.926	4.135E-07	1.072E-05
grain	2	0.6079	1.216	4.135E-07	5.028E-07
soil	0.8	0.1333	0.107	0.017017	1.821E-03
water	60	1	60	1	0
total			119.433		0.54951

$$\text{tritium conc in milk} = (8.889\text{E-}7 \text{ Ci/kg}) / (0.1333 \text{ L/kg}) (0.9834 \text{ L/kg}) (0.85827) = 3.017\text{E-}8 \text{ Ci/kg}$$

$$\text{Total dose from milk: } (3.017\text{E-}8 \text{ Ci/kg})(58 \text{ kg})(64,000 \text{ mrem/Ci}) = 0.1120 \text{ mrem}$$

Total Dose: Rural Pasture Scenario:

$$0.02151 + 3.485E-5 + 0.1120 \text{ mrem} = \underline{0.1335 \text{ mrem per Ci exhumed}}$$

Note that the tritium dose factor from Table 10 is 0.133 mrem/y per Ci exhumed.

BA.1.6 Post-Intrusion Commercial Farm Scenario

The unit dose factors for the urban pasture scenario assume 1 curie H-3 is exhumed from the well and spread over an area of 647,000 m². The initial average soil concentration is computed as shown below.

$$C_s = (1 \text{ Ci}) / (647,000 \text{ m}^2) / (225 \text{ kg/m}^2) = 6.869E-9 \text{ Ci/kg}$$

This concentration decreases rapidly with time due to leaching from the surface layer (during the irrigation season), evaporation, and radioactive decay. For all practical purposes, none of the initial tritiated water deposited in the garden is present at the end of the irrigation season. Decay factors used in the dose calculations are the same as shown for the suburban garden scenario.

A special model described in Section A3.2.1 is used for inhalation dose, so that the resident inhales a total of 1.970E-08 Ci tritium per Ci exhumed. He also ingests a total of 0.018 kg soil during the year (Table A8). The effective external exposure time is 720 h (Table A15). The inhalation, ingestion, and external doses from these sources are shown below.

Inhalation Dose: (resuspended soil)

$$(1.970E-8 \text{ Ci inhaled/Ci exhumed})(1 \text{ Ci exhumed})(96,000 \text{ mrem/Ci}) = 0.001891 \text{ mrem}$$

Ingestion Dose: (soil only)

Note that the decay factor considers that all of the exposure occurs during the first half of the year.

$$(0.018 \text{ kg})(6.869E-9 \text{ Ci/kg})(64,000 \text{ mrem/Ci})(0.034033 \text{ y}) = 2.693E-7 \text{ mrem}$$

External Dose:

Note that the 1 Ci tritium in the well tailings has been mixed into a garden with an area of 100 m².

$$(720 \text{ h/y})(1 \text{ Ci}/647,000 \text{ m}^2)(0 \text{ mrem/h per Ci/m}^2)(0.034033 \text{ y}) = 0 \text{ mrem}$$

Total Dose: Commercial Farm Scenario:

$$0.001891 + 2.693E-7 + 0 \text{ mrem} = \underline{0.001891 \text{ mrem per Ci exhumed}}$$

Note that the tritium dose factor from Table 11 is 0.00189 mrem/y per Ci exhumed.

BA.2 LOW WATER INFILTRATION EXPOSURE SCENARIOS

Each of the exposure scenarios using irrigation water with tritium will be evaluated in this section. The tritium concentration in the irrigation water is assumed constant during the irrigation season. As a result, the tritium concentration in the surface soil is also constant during the irrigation season, but decreases rapidly during the non-irrigation period due to evaporation

and radioactive decay. In each exposure scenario the water concentration is 1 pCi/L. Thus the doses computed are per pCi/L. The soil concentration during the irrigation season is calculated as shown below.

$$C_s = (1.0E-12 \text{ Ci/L})(0.2)/(1.5 \text{ kg/L})(0.9345) = 1.246E-13 \text{ Ci/kg}$$

The external exposures are not computed for tritium because the external dose rate factor for tritium is zero. Absorption through the skin is included in the inhalation dose factor for tritium. The main dose pathway in every case is the drinking water pathway.

Normally, three significant digits are kept during calculations. Because the spreadsheet software keeps several digits, agreement with the spreadsheet can only be obtained if 4 or 5 significant digits are retained. This is particularly true in the calculation of decay factors.

BA.2.1 All Pathways

The soil concentration decreases with time due to leaching from the surface layer during the irrigation season, evaporation, and radioactive decay. Additional decay factors used in the dose calculations for tritium are computed below from the equations in the discussion following Table B2.

$$\lambda_r T_{no} = (8.03155 \text{ y}^{-1})(0.5 \text{ y}) = 4.01578$$

$$IDR(T_{no}) = [1 - \text{Exp}(-4.01578)]/(4.01578) = 0.244528$$

$$T_{irr} + T_{no} \cong IDR(T_{no}) = (0.5 \text{ y}) + (0.5 \text{ y})(0.244528) = 0.62226 \text{ y}$$

$$\lambda_r T_{veg} = (0.056216 \text{ y}^{-1})(90 \text{ d})/(365 \text{ d/y}) = 0.0138615$$

$$DR(T_{veg}) = \text{Exp}(-0.0138615) = 0.98623$$

$$IDR(T_{veg}) = [1 - \text{Exp}(-0.0138615)]/(0.0138615) = 0.99310$$

$$\lambda_r T_{beef} = (0.056216 \text{ y}^{-1})(120 \text{ d})/(365 \text{ d/y}) = 0.018482$$

$$IDR(T_{beef}) = [1 - \text{Exp}(-0.018482)]/(0.018482) = 0.99082$$

Because tritium is bound to water, the inhalation dose from suspended soil is part of the inhalation dose from water, described in Section A3.2.2 Table A13. The farmer also ingests a total of 0.0365 kg soil during the year (Table A8). The inhalation and ingestion doses from these sources are shown below. They match the doses shown in Table D3.

Inhalation Dose: (showering and ambient humidity)

$$(48 \text{ L/y})(1.0E-12 \text{ Ci/L})(96,000 \text{ mrem/Ci})(1 \text{ y}) = 4.608E-6 \text{ mrem}$$

Ingestion Dose: (drinking)

$$(545 \text{ L/y})(1.0E-12 \text{ Ci/L})(64,000 \text{ mrem/Ci})(1 \text{ y}) = 3.488E-5 \text{ mrem}$$

Note that the all pathways farmer's drinking water dose factor from Table 12 is 3.49E-5 mrem/y per pCi/L.

Ingestion Dose: (soil only)

$$(0.0365 \text{ kg/y})(1.246\text{E-}13 \text{ Ci/kg})(64,000 \text{ mrem/Ci})(0.62226 \text{ y}) = 1.811\text{E-}10 \text{ mrem}$$

The vegetable produce contamination is based on the plant moisture having the same tritium concentration as the irrigation water (adjusted for natural precipitation by the factor 0.9345). The contaminated food consumption rate is combined with the ingestion period (1 year) so that the column of consumption rates has units of kg rather than kg/y. The product of plant water concentration and ingestion dose factor is combined into a single quantity to simplify the calculation.

$$(0.9345)(1.0\text{E-}12 \text{ Ci/L})(64,000 \text{ mrem/Ci})=5.981\text{E-}8 \text{ mrem/L}$$

The factors 0.894 L/kg and 0.6079 L/kg in the calculations below are the equivalent volume of water per kilogram of plant. They are calculated from the hydrogen fractions shown in Table A34 multiplied by 8.94 kg water per kg hydrogen, and divided by the density of water, 1.0 kg/L. Grains are not irrigated, and are not shown.

Ingestion Dose: (garden produce)

$$(5.981\text{E-}8 \text{ mrem/L})(0.894 \text{ L/kg}) (4.45 \text{ kg}) (1.00000) = 2.379\text{E-}7 \text{ mrem}$$

$$(5.981\text{E-}8 \text{ mrem/L})(0.894 \text{ L/kg})(21.625 \text{ kg})(0.99310) = 1.148\text{E-}7 \text{ mrem}$$

$$(5.981\text{E-}8 \text{ mrem/L})(0.894 \text{ L/kg})(25.45 \text{ kg}) (0.99310) = 1.139\text{E-}7 \text{ mrem}$$

$$\text{Total from garden produce: } 2.525\text{E-}6 \text{ mrem}$$

The dose for each pathway is the sum of contributions to the animal's diet. In particular, there is fresh feed, stored hay, stored grain, soil, and drinking water. Each of these has a common factor made of the water concentration, the effective water fraction in the animal product, the annual amount consumed by the individual, the ingestion dose factor, and the ingestion period. The fraction of water intake that is contaminated is multiplied by this common factor to obtain the ingestion dose from consumption of the animal product.

Ingestion Dose: (beef)

$$\text{Contaminated water fraction for the beef cow: } 84.176 / 88.558 = 0.95042$$

source	animal intake kg/d	water fraction	total water intake, L/d	rain dilution	decay	contaminated water intake
forage	27	0.894	24.138	0.9345	1	22.557
hay	14	0.894	12.516	0.9345	0.98623	11.535
grain	3	0.6079	1.824	0	0.98623	0
soil	0.6	0.1333	0.080	0.9345	1	0.075
water	50	1	50	1	1	50
total			88.558			84.167

$$\text{tritium concentration in beef} = (1.0\text{E-}12 \text{ Ci/L})(0.894 \text{ L/kg})(0.95042) = 8.497\text{E-}13 \text{ Ci/kg}$$

$$\text{Total dose from beef: } (8.497\text{E-}13 \text{ Ci/kg})(25.15 \text{ kg})(64,000 \text{ mrem/Ci})(0.99082) = 1.355\text{E-}6 \text{ mrem}$$

Ingestion Dose: (milk)Contaminated water fraction for the milk cow: $102.506 / 119.433 = 0.85827$

source	animal intake kg/d	water fraction	total water intake, L/d	rain dilution	decay	contaminated water intake
forage	36	0.894	32.184	0.9345	0.62226	18.715
hay	29	0.894	25.926	0.9345	0.97943	23.729
grain	2	0.6079	1.216	0	0.97943	0
soil	0.8	0.1333	0.107	0.9345	0.62226	0.062
water	60	1	60	1	1	60
total			119.433			102.506

tritium concentration in milk = $(1.0E-12 \text{ Ci/L})(0.9834 \text{ L/kg})(0.85827) = 8.440E-13 \text{ Ci/kg}$ Total dose from milk: $(8.440E-13 \text{ Ci/kg})(58 \text{ kg})(64,000 \text{ mrem/Ci}) = 3.133E-6 \text{ mrem}$ Ingestion Dose: (poultry)Contaminated water fraction for the chicken: $0.36843 / 0.47240 = 0.77991$

source	animal intake kg/d	water fraction	total water intake, L/d	rain dilution	decay	contaminated water intake
forage	0.13	0.894	0.11622	0.9345	0.62226	0.06758
hay	0	0.894	0	0.9345	0.97943	0
grain	0.09	0.6079	0.05471	0	0.97943	0
soil	0.011	0.1333	0.00147	0.9345	0.62226	0.00085
water	0.3	1	0.3	1	1	0.3
total			0.47240			0.36843

tritium concentration in poultry = $(1.0E-12 \text{ Ci/L})(0.894 \text{ L/kg})(0.77991) = 6.972E-13 \text{ Ci/kg}$ Total dose from poultry: $(6.972E-13 \text{ Ci/kg})(14.7 \text{ kg})(64,000 \text{ mrem/Ci}) = 6.560E-7 \text{ mrem}$ tritium concentration in eggs = $(1.0E-12 \text{ Ci/L})(0.9834 \text{ L/kg})(0.77991) = 7.670E-13 \text{ Ci/kg}$ Total dose from eggs: $(7.670E-13 \text{ Ci/kg})(6.8 \text{ kg})(64,000 \text{ mrem/Ci}) = 3.338E-7 \text{ mrem}$ Total dose for all animal pathways = $5.478E-6 \text{ mrem}$ Total Dose for the All Pathways Farmer (irrigation from a well): $4.608E-6 + 3.488E-5 + 1.811E-10 + 2.525E-6 + 5.478E-6 = 4.749E-5 \text{ mrem per pCi/L}$ Note that the all pathways farmer's total dose factor from Table 12 is $4.75E-5 \text{ mrem/y per pCi/L}$.

The above total applies to the inland well situation in which does not include a dose from fish. When the Columbia River is the source of tritium, the fish dose is calculated as shown below and added to the above total.

Ingestion Dose: (fish) $(1.0E-12 \text{ Ci/L})(1 \text{ L/kg})(0.50)(6.58 \text{ kg})(64,000 \text{ mrem/Ci})(1 \text{ y}) = 2.106E-7 \text{ mrem}$ Note that the all pathways farmer's fish dose factor from Table 13 is $2.11E-7 \text{ mrem/y per pCi/L}$.Ingestion Dose: (shoreline sediment) $(1.0E-12 \text{ Ci/L})(0.1333 \text{ L/kg})(0.0007 \text{ kg})(64,000 \text{ mrem/Ci})(1 \text{ y}) = 5.973E-12 \text{ mrem}$

Total Dose for the All Pathways Farmer (irrigation from the Columbia River):

$$4.696E-5 + 2.106E-7 + 5.973E-12 = 4.770E-5 \text{ mrem per pCi/L}$$

Note that the all pathways farmer's total dose factor from Table 13 is 4.77E-5 mrem/y per pCi/L.

BA.2.2 Native American Subsistence Resident

The doses for each pathway are calculated in the same manner as the all pathways farmer except that the exposure parameters are larger. The Native American doses are listed below. They match the doses shown in Table D4.

Inhalation Dose: (sweat lodge and ambient humidity)

$$(105 \text{ L/y})(1.0E-12 \text{ Ci/L})(96,000 \text{ mrem/Ci})(1 \text{ y}) = 1.008E-5 \text{ mrem}$$

Ingestion Dose: (drinking)

$$(1,095 \text{ L/y})(1.0E-12 \text{ Ci/L})(64,000 \text{ mrem/Ci})(1 \text{ y}) = 7.008E-5 \text{ mrem}$$

Ingestion Dose: (soil)

$$(0.073 \text{ kg/y})(1.246E-13 \text{ Ci/kg})(64,000 \text{ mrem/Ci})(0.62226 \text{ y}) = 3.622E-10 \text{ mrem}$$

Ingestion Dose: (garden produce)

$$(5.981E-8 \text{ mrem/L})(0.894 \text{ L/kg})(16 \text{ kg})(1.00000) = 8.555E-7 \text{ mrem}$$

$$(5.981E-8 \text{ mrem/L})(0.894 \text{ L/kg})(77 \text{ kg})(0.99310) = 4.089E-6 \text{ mrem}$$

$$(5.981E-8 \text{ mrem/L})(0.894 \text{ L/kg})(76 \text{ kg})(0.99310) = 4.036E-6 \text{ mrem}$$

$$\text{Total from garden produce: } 8.980E-6 \text{ mrem}$$

Ingestion Dose: (beef)

$$\text{Total dose from beef: } (8.497E-13 \text{ Ci/kg})(28 \text{ kg})(64,000 \text{ mrem/Ci})(0.99082) = 1.509E-6 \text{ mrem}$$

Ingestion Dose: (milk)

$$\text{Total dose from milk: } (8.440E-13 \text{ Ci/kg})(226 \text{ kg})(64,000 \text{ mrem/Ci}) = 1.221E-5 \text{ mrem}$$

Ingestion Dose: (poultry)

$$\text{Total dose from poultry: } (6.972E-13 \text{ Ci/kg})(16 \text{ kg})(64,000 \text{ mrem/Ci}) = 7.140E-7 \text{ mrem}$$

Ingestion Dose: (eggs)

$$\text{Total dose from eggs: } (7.670E-13 \text{ Ci/kg})(7.7 \text{ kg})(64,000 \text{ mrem/Ci}) = 3.780E-7 \text{ mrem}$$

$$\text{Total dose for all animal pathways} = 1.481E-5 \text{ mrem}$$

Total Dose for the Native American (irrigation from a well):

$$1.008E-5 + 7.008E-5 + 3.622E-10 + 8.980E-6 + 1.481E-5 = 1.039E-4 \text{ mrem per pCi/L}$$

Note that the Native American's total dose factor from Table 16 is 1.04E-4 mrem/y per pCi/L.

The above total applies to the inland well situation in which does not include a dose from fish. When the Columbia River is the source of tritium, the game and fish doses are calculated as shown below and added to the above total.

The game is largely deer that obtain drinking water from the Columbia River, but graze on uncontaminated vegetation. The intake model is that of the milk cow, except the wet masses of stored hay and grain are added to the fresh forage category for a total of $(36+29+2)=67$ kg/d. The deer consumption rate is assumed to be 25% of the milk cow, but the actual percentage does not matter for the tritium calculation. When the contaminated water fraction is calculated, the fraction is present in both numerator and denominator. The contaminated water fraction says that the deer gets about half of its water from the Columbia River, and the other half from forage.

Ingestion Dose: (game)

Contaminated water fraction for the game: $15 / 30.002 = 0.49997$

source	animal intake kg/d	water fraction	total water intake, L/d	rain dilution	decay	contaminated water intake
forage	16.75	0.894	14.975	0	1	0
hay	0	0.894	0	0	0.98623	0
grain	0	0.6079	0	0	0.98623	0
soil	0.2	0.13333	0.027	0	1	0
water	15	1	15	1	1	15
total			30.002			15

tritium concentration in game = $(1.0E-12 \text{ Ci/L})(0.9834 \text{ L/kg})(0.49997) = 4.470E-13 \text{ Ci/kg}$

Total dose from game: $(4.470E-13 \text{ Ci/kg})(22 \text{ kg})(64,000 \text{ mrem/Ci}) = 6.236E-7 \text{ mrem}$

Like the deer, the waterfowl drink from the river, but have uncontaminated feed. The intakes used for the chicken are assumed for the waterfowl.

Ingestion Dose: (waterfowl and waterfowl eggs)

Contaminated water fraction for the waterfowl: $0.3 / 0.49815 = 0.60223$

source	animal intake kg/d	water fraction	total water intake, L/d	rain dilution	decay	contaminated water intake
forage	0.22	0.894	0.19668	0	0.62226	0
hay	0	0.894	0	0	0.97943	0
grain	0	0.6079	0	0	0.97943	0
soil	0.011	0.13333	0.00147	0	0.62226	0
water	0.3	1	0.3	1	1	0.3
total			0.49815			0.3

tritium concentration in waterfowl = $(1.0E-12 \text{ Ci/L})(0.894 \text{ L/kg})(0.60223) = 5.384E-13 \text{ Ci/kg}$

Total dose from waterfowl: $(5.384E-13 \text{ Ci/kg})(32 \text{ kg})(64,000 \text{ mrem/Ci}) = 1.103E-6 \text{ mrem}$

tritium concentration in bird eggs = $(1.0E-12 \text{ Ci/L})(0.9834 \text{ L/kg})(0.60223) = 5.922E-13 \text{ Ci/kg}$

Total dose from bird eggs: $(5.922E-13 \text{ Ci/kg})(16 \text{ kg})(64,000 \text{ mrem/Ci}) = 6.064E-7 \text{ mrem}$

Ingestion Dose: (fish)

$(1.0E-12 \text{ Ci/L})(1 \text{ L/kg})(197 \text{ kg})(64,000 \text{ mrem/Ci})(1 \text{ y}) = 1.261E-5 \text{ mrem}$

Ingestion Dose: (shoreline sediment)

$(1.0E-12 \text{ Ci/L})(0.1333 \text{ L/kg})(0.054 \text{ kg})(64,000 \text{ mrem/Ci})(1 \text{ y}) = 4.608E-10 \text{ mrem}$

Total Dose for the Native American (irrigation from the Columbia River):

$$1.045\text{E-}4 + 6.236\text{E-}7 + 1.103\text{E-}6 + 6.064\text{E-}7 + 1.261\text{E-}5 + 4.608\text{E-}10 \text{ mrem} \\ = 1.189\text{E-}4 \text{ mrem per pCi/L}$$

Note that the Native American's total dose factor from Table 16 is $1.19\text{E-}4$ mrem/y per pCi/L.

BA.2.3 Columbia River Population

The collective doses for each pathway are calculated in the same manner as the All Pathways Irrigator case scaled up for a population of 5 million, with a lower irrigation rate, and reduced by a factor of 1000 to convert from mrem to rem. The inhalation and ingestion doses are adjusted for the population and unit conversion as shown below. The new soil concentration during the irrigation period is shown also. The decay and leaching factors during the non-irrigation season are not changed.

$$\text{Inhalation: } (9.60\text{E-}8 \text{ mrem/pCi})(5.0\text{E}+6)(0.001 \text{ rem/mrem}) = 4.80\text{E-}4 \text{ person-rem/pCi}$$

$$\text{Ingestion: } (6.40\text{E-}8 \text{ mrem/pCi})(5.0\text{E}+6)(0.001 \text{ rem/mrem}) = 3.20\text{E-}4 \text{ person-rem/pCi}$$

$$C_{s,H3} = (8.94)(0.022)(1 \text{ pCi/L})(63.5 \text{ cm}) / (63.5 + 5.766 \text{ cm}) / (1 \text{ kg/L})$$

$$C_{s,H3} = 0.1222 \text{ pCi/kg}$$

Inhalation Dose: (showering and ambient humidity)

$$(46 \text{ L/y})(1 \text{ pCi/L})(4.80\text{E-}4 \text{ person-rem/pCi})(1 \text{ y}) = 2.208\text{E-}2 \text{ person-rem}$$

Ingestion Dose: (drinking)

$$(545 \text{ L/y})(1 \text{ pCi/L})(3.20\text{E-}4 \text{ person-rem/pCi})(1 \text{ y}) = 0.1744 \text{ person-rem}$$

Ingestion Dose: (soil)

$$(0.0365 \text{ kg/y})(0.1222 \text{ pCi/kg})(3.20\text{E-}4 \text{ person-rem/pCi})(0.62226 \text{ y}) = 8.884\text{E-}7 \text{ person-rem}$$

External Dose:

$$(4380 \text{ h/y})(0.1222 \text{ pCi/kg})(225 \text{ kg/m}^2)(0 \text{ mrem/h per Ci/m}^2)(0.99304 \text{ y}) = 0 \text{ mrem}$$

With a lower irrigation rate, the irrigation dilution factor changes to become $(63.5 \text{ cm}) / (63.5 + 5.23 \text{ cm}) = 0.9168$. The common factor used in the garden produce calculation is shown below.

$$(0.9168)(1 \text{ pCi/L})(3.20\text{E-}4 \text{ person-rem/pCi}) = 2.934\text{E-}4 \text{ person-rem/L}$$

Ingestion Dose: (garden produce)

$$(2.934\text{E-}4 \text{ person-rem/L})(0.894 \text{ L/kg})(8.90 \text{ kg})(1.0000) = 2.334\text{E-}3 \text{ person-rem}$$

$$(2.934\text{E-}4 \text{ person-rem/L})(0.894 \text{ L/kg})(43.25 \text{ kg})(0.9931) = 1.127\text{E-}2 \text{ person-rem}$$

$$(2.934\text{E-}4 \text{ person-rem/L})(0.894 \text{ L/kg})(42.90 \text{ kg})(0.9931) = 1.117\text{E-}2 \text{ person-rem}$$

$$\text{Total from garden produce: } 2.477\text{E-}2 \text{ person-rem}$$

The dose for each pathway is the sum of contributions to the animal's diet. In particular, there is fresh feed, stored hay, stored grain, soil, and drinking water. Each of these has a common factor made of the water concentration, the effective water fraction in the animal product, the annual amount consumed by the individual, the ingestion dose factor, and the

ingestion period. The fraction of water intake that is contaminated is multiplied by this common factor to obtain the ingestion dose from consumption of the animal product.

Ingestion Dose: (beef)

Contaminated water fraction for the beef cow: $84.52 / 88.558 = 0.94311$

source	animal intake kg/d	water fraction	total water intake, L/d	rain dilution	decay	contaminated water intake
forage	27	0.894	24.138	0.9168	1	22.13
hay	14	0.894	12.516	0.9168	0.98623	11.317
grain	3	0.6079	1.824	0	0.98623	0
soil	0.6	0.13333	0.08	0.9168	1	0.073
water	50	1	50	1	1	50
	total		88.558			83.52

tritium concentration in beef = $(1.0E-12 \text{ Ci/L})(0.894 \text{ L/kg})(0.94311) = 8.431E-13 \text{ Ci/kg}$

Total dose from beef:

$(8.431E-13 \text{ Ci/kg})(25.15 \text{ kg})(3.20E-4 \text{ person-rem/Ci})(0.99082) = 6.723E-3 \text{ person-rem}$

Ingestion Dose: (milk)

Contaminated water fraction for the milk cow: $102.506 / 101.702 = 0.85154$

source	animal intake kg/d	water fraction	total water intake, L/d	rain dilution	decay	contaminated water intake
forage	36	0.894	32.184	0.9168	0.62226	18.361
hay	29	0.894	25.926	0.9168	0.97943	23.28
grain	2	0.6079	1.216	0	0.97943	0
soil	0.8	0.13333	0.107	0.9168	0.62226	0.061
water	60	1	60	1	1	60
	total		119.433			101.702

tritium concentration in milk = $(1.0E-12 \text{ Ci/L})(0.9834 \text{ L/kg})(0.85154) = 8.374E-13 \text{ Ci/kg}$

Total dose from milk:

$(8.374E-13 \text{ Ci/kg})(58 \text{ kg})(3.20E-4 \text{ person-rem/Ci}) = 1.554E-2 \text{ person-rem}$

Ingestion Dose: (poultry)Contaminated water fraction for the chicken: $0.36714 / 0.47240 = 0.77718$

source	animal intake kg/d	water fraction	total water intake, L/d	rain dilution	decay	contaminated water intake
forage	0.13	0.894	0.11622	0.9168	0.62226	0.0663
hay	0	0.894	0	0.9168	0.97943	0
grain	0.09	0.6079	0.05471	0	0.97943	0
soil	0.011	0.13333	0.00147	0.9168	0.62226	0.00084
water	0.3	1	0.3	1	1	0.3
total			0.4724			0.36714

tritium concentration in poultry = $(1.0E-12 \text{ Ci/L})(0.894 \text{ L/kg})(0.77718) = 6.948E-13 \text{ Ci/kg}$

Total dose from poultry:

$$(6.948E-13 \text{ Ci/kg})(14.7 \text{ kg})(3.20E-4 \text{ person-rem/Ci}) = 3.268E-3 \text{ person-rem}$$

tritium concentration in eggs = $(1.0E-12 \text{ Ci/L})(0.9834 \text{ L/kg})(0.77718) = 7.643E-13 \text{ Ci/kg}$

Total dose from eggs:

$$(7.643E-13 \text{ Ci/kg})(6.8 \text{ kg})(3.20E-4 \text{ person-rem/Ci}) = 1.663E-3 \text{ person-rem}$$

Ingestion Dose: (fish)

$$(1.0 \text{ pCi/L})(1 \text{ L/kg})(0.003 \text{ kg})(3.20E-4 \text{ person-rem/pCi})(1 \text{ y}) = 9.600E-7 \text{ person-rem}$$

Total dose for all animal pathways = $2.272E-2 \text{ person-rem}$ Ingestion Dose: (shoreline sediment)

$$(1.0 \text{ pCi/L})(0.1333 \text{ L/kg})(0.0005 \text{ kg})(3.20E-4 \text{ person-rem/pCi})(1 \text{ y}) = 2.133E-8 \text{ person-rem}$$

Total Collective Dose to the Population:

$$0.02208 + 0.1744 + 8.884E-7 + 0.02477 + 0.02272 = \underline{0.2485 \text{ person-rem per pCi/L}}$$

Note that the Columbia River Population dose factor from Table 19 is $0.248 \text{ person-rem/y per pCi/L}$.**BA.2.4 HSRAM and Other Scenarios**

The other scenarios require calculating a lifetime cancer morbidity risk. Because tritium is removed from the soil rapidly, there is essentially no carryover from year to year. Each year the soil contamination starts at zero. In the case of contaminated surface water, the sediment concentration does not change from year to year. Thus the cumulative dose (or lifetime risk) is the sum of the doses (or cancer risks) calculated for each year.

The next attachment shows the lifetime cancer risk calculation for the All Pathways Farmer to illustrate the method used.

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**ATTACHMENT B2.
HAND CALCULATIONS FOR TC-99**

Four of the exposure scenarios will be evaluated for Tc-99 in this section. These four scenarios are the well drilling, suburban garden, rural pasture, and all pathways irrigator. They exercise all of the relevant calculations used for nuclides other than tritium.

The nuclide selected (Tc-99) has a very long half life (211,097 y), so its radioactive decay has little effect on the doses, even after 70 years. The leaching factor for Tc-99 (0.208 per year) is large enough to affect the calculated intakes. Tc-99 decays to stable Ru-99 so decay chain formulas are not needed.

Normally, three significant digits are kept during calculations. Because the spreadsheet software keeps several digits, agreement with the spreadsheet can only be obtained if 4 or 5 significant digits are retained. This is particularly true in the calculation of decay factors.

BB.1 Intruder (Well Driller)

The unit dose factors for the Well Driller use an average soil concentration of 1 Ci/kg. This is calculated as the activity removed from the borehole divided by the mass of soil and waste removed. A mass loading approach is used, so that the driller inhales a total of 4.84 mg (4.84E-06 kg) of soil (Table A10). He ingests a total of 500 mg (5.0E-4 kg) soil (Table A8). His external exposure time is 40 hours (Table A15). The inhalation, ingestion, and external dose calculations are shown below.

Inhalation Dose:

$$(1 \text{ Ci/kg})(4.84\text{E-}06 \text{ kg inhaled})(8,330,000 \text{ mrem/Ci}) = 40.32 \text{ mrem}$$

External Dose:

Note that the well tailings have a density of 1,500 kg/m³ and are spread to an average thickness of 5 cm. The worker spends 40 hours in the middle of this radiation source. The intake factor for external exposure is (40 h)(1,500 kg/m³)(0.05 m) = 3,000 h·kg/m².

$$(1 \text{ Ci/kg})(3,000 \text{ h·kg/m}^2)(0.1632 \text{ mrem/h per Ci/m}^2) = 489.5 \text{ mrem}$$

Ingestion Dose:

$$(1 \text{ Ci/kg})(5.0\text{E-}04 \text{ kg ingested})(1,460,000 \text{ mrem/Ci}) = 730.0 \text{ mrem}$$

Total Dose to Driller:

$$40.32 \text{ mrem} + 489.5 \text{ mrem} + 730.0 \text{ mrem} = 1260 \text{ mrem per Ci/kg}$$

Note that the well driller dose factor from Table 7 is 1260 mrem per Ci/kg.

BB.2 Post-Intrusion Suburban Gardener

The unit dose factors for the suburban garden scenario assume 1 curie Tc-99 is exhumed from the well and spread over an area of 100 m². The initial average soil concentration is computed as shown below. For the external dose calculation, the soil concentration is 0.01 Ci/m².

$$C_s = (1 \text{ Ci}) / (100 \text{ m}^2) / (225 \text{ kg/m}^2) = 4.444\text{E-}5 \text{ Ci/kg}$$

This concentration decreases rapidly with time due to leaching from the surface layer (during the irrigation season) and radioactive decay. Decay and leaching factors used in the dose calculations are computed below using equations from Table B2. Tc-99 has a very long half life with a modest leaching factor. For all practical purposes, there is no radioactive decay.

$$\lambda_r = (0.69315) / (211,097 \text{ y}) = 3.28355\text{E-}6 \text{ y}^{-1}$$

During the irrigation season :

$$\lambda_s = (10 \text{ cm}) / [(15 \text{ cm})(0.2 + (1.5 \text{ g/ml})(2 \text{ ml/g}))] = 0.208333 \text{ y}^{-1} \text{ (Section A6.0)}$$

$$\lambda_t = \lambda_r + \lambda_s = 0.208336 \text{ y}^{-1}$$

Midway through the irrigation season :

$$DS(T_h) = \text{Exp}[-(0.208336 \text{ y}^{-1})(0.25 \text{ y})] = 0.949249$$

At the end of the irrigation season:

$$\lambda_r T_{irr} = (0.208336 \text{ y}^{-1})(0.5 \text{ y}) = 0.104168$$

$$DS(T_{irr}) = \text{Exp}(-0.104168) = 0.90107$$

$$IDS(T_{irr}) = [1 - \text{Exp}(-0.104168)] / (0.104168) = 0.949678$$

During the no-irrigation season:

$$\lambda_r T_{no} = (3.28355\text{E-}6 \text{ y}^{-1})(0.5 \text{ y}) = 1.64178\text{E-}6$$

$$DR(T_{no}) = \text{Exp}(-1.64178\text{E-}6) = 0.999998$$

$$IDR(T_{no}) = [1 - \text{Exp}(-1.64178\text{E-}6)] / (1.64178\text{E-}6) = 1$$

Time integral over the first year:

$$T_{irr} \cong IDS(T_{irr}) + T_{no} \cong DS(T_{irr}) \cong IDR(T_{no}) = \\ (0.5\text{y})(0.949678) + (0.5\text{y})(0.90107)(1) = 0.925376 \text{ y}$$

Time integral during the vegetable consumption period :

$$\lambda_r T_{veg} = (3.28355\text{E-}6 \text{ y}^{-1})(90 \text{ d}) / (365 \text{ d/y}) = 8.09642\text{E-}7$$

$$IDR(T_{veg}) = [1 - \text{Exp}(-8.09642\text{E-}7)] / (8.09642\text{E-}7) = 1$$

Harvest midway through the irrigation season followed by the consumption period:

$$DS(T_h) \cong IDR(T_{veg}) = (0.949249)(1) = 0.949249$$

The inhalation, external, and ingestion doses from the soil contamination are calculated as shown below. These match the numbers shown in Table D1.

Inhalation Dose: (suspended soil, Table A9)

Note that the decay factor assumes the exposure occurs during the entire year.

$$(4.444\text{E-}5 \text{ Ci/kg})(8.70\text{E-}5 \text{ kg/y inhaled})(0.925376 \text{ y})(8,330,000 \text{ mrem/Ci}) = 0.0298 \text{ mrem}$$

External Dose: (Table A15)

Note that the decay factor assumes the exposure occurs during the first half of the year.

$$(1 \text{ Ci}/100 \text{ m}^2)(180 \text{ h/y})(0.949678 \text{ y})(0.0635 \text{ mrem/h per Ci/m}^2) = 0.1085 \text{ mrem}$$

Ingestion Dose: (soil only, Table A8)

Note that the decay factor assumes the exposure occurs during the first half of the year.
 $(4.444E-5 \text{ Ci/kg})(0.018 \text{ kg/y ingested})(0.949678 \text{ y})(1,460,000 \text{ mrem/Ci}) = 1.1091 \text{ mrem}$

Ingestion Dose: (garden produce, Section A5.0)

The concentration in vegetable produce from the garden is calculated using root uptake and rain splash (soil adherence). The human intakes from vegetables by way of rain splash are calculated using the table below. The rain splash factor must be included to obtain the numbers shown for annual intake. This rain splash factor is $2.7E-4 \text{ kg/m}^2$ per day as discussed in Section A5.2. Note that none of the factors on this table are unique to technetium.

Vegetable	Interception Fraction	Effective Growing Period (days)	Translocation Factor	Crop Yield (kg/m^2)	Annual Food Consumption (kg/y)	Annual Soil Intake (kg/y)
leafy	0.4067	18.02	1	2	4.45	4.403E-03
other	0.8347	19.96	0.1	2	21.625	4.864E-03
fruit	0.8569	19.96	0.1	3	21.45	3.302E-03
grain	0.3712	19.96	0.1	0.8	20.475	5.120E-03

The Annual Soil Intake from Rain Splash is calculated as
 $(\text{Splash factor})(\text{Interception fraction})(\text{Translocation})(\text{Growing Time})(\text{Annual food eaten}) / (\text{Biomass})$
 The splash factor is $2.7E-4 \text{ kg/m}^2$ per day as discussed in the text.

The human intakes from vegetables by way of root uptake are calculated using the table below. The only numbers unique to technetium are the concentration ratios. This table also shows the combined intakes for Tc-99 from root uptake and rain splash.

	Concentration Ratio for Tc	dry-to-wet ratio	Annual Food Consumption (kg/y)	Annual Soil Intake (kg/y)	Total Soil Intake (kg/y)
leafy	180	0.09	4.45	72.0900	72.0944
other	0.77	0.25	21.625	4.1628	4.1677
fruit	1.5	0.18	21.45	5.7915	5.7948
grain	0.73	0.91	20.475	13.6015	13.6066

The Annual Soil Intake from Root Uptake into plants is calculated as
 $(\text{Conc ratio})(\text{dry-to-wet ratio})(\text{Annual food eaten})$
 The "Total Soil Intake" is the sum of the intakes from rain splash (previous table) and root uptake.

The ingestion dose is the product of the soil concentration, the annual soil intake, the appropriate decay and leaching factor, and the ingestion dose factor, as shown below. The first row shows the dose from leafy vegetables. The second row shows the dose from fruit and other vegetables. Note that the fruit and other vegetable intakes have been combined. Also note that grains have been omitted due to their absence from the garden.

$$(4.444E-5 \text{ Ci/kg})(72.0944 \text{ kg/y})(0.949678 \text{ y})(1,460,000 \text{ mrem/Ci}) = 4,442.3 \text{ mrem}$$

$$(4.444E-5 \text{ Ci/kg})(9.9625 \text{ kg/y})(0.949249 \text{ y})(1,460,000 \text{ mrem/Ci}) = 613.6 \text{ mrem}$$

Total Dose: Suburban Garden Scenario:

$$0.0298 + 0.1085 + 1.1091 + 5,055.9 \text{ mrem} = \underline{5,057 \text{ mrem per Ci exhumed}}$$

Note that the suburban gardener's dose factor from Table 8 is 5,060 mrem/y per Ci exhumed.

BB.3 Post-Intrusion Rural Pasture Scenario

The unit dose factors for the rural pasture scenario assume 1 curie Tc-99 is exhumed from the well and spread over an area of 5,000 m². The initial average soil concentration is computed as shown below. For the external dose calculation, the soil concentration is 0.0002 Ci/m².

$$C_s = (1 \text{ Ci}) / (5,000 \text{ m}^2) / (225 \text{ kg/m}^2) = 8.889\text{E-}7 \text{ Ci/kg}$$

This concentration decreases rapidly with time due to leaching from the surface layer (during the irrigation season) and radioactive decay. Decay and leaching factors used in the dose calculations are from the previous section.

The inhalation, external, and ingestion doses from the soil contamination are calculated as shown below. These match the numbers shown in Table D2.

Inhalation Dose: (suspended soil, Table A9)

Note that the decay factor assumes the exposure occurs during the entire year.

$$(8.889\text{E-}7 \text{ Ci/kg})(1.69\text{E-}4 \text{ kg/y inhaled})(0.925376 \text{ y})(8,330,000 \text{ mrem/Ci}) = 1.158\text{E-}3 \text{ mrem}$$

External Dose: (Table A15)

Note that the decay factor assumes the exposure occurs during the first half of the year.

$$(1 \text{ Ci}/5,000 \text{ m}^2)(360 \text{ h/y})(0.949678 \text{ y})(0.0635 \text{ mrem/h per Ci/m}^2) = 4.342\text{E-}3 \text{ mrem}$$

Ingestion Dose: (soil only, Table A8)

Note that the decay factor assumes the exposure occurs during the first half of the year.

$$(8.889\text{E-}7 \text{ Ci/kg})(0.018 \text{ kg/y ingested})(0.949678 \text{ y})(1,460,000 \text{ mrem/Ci}) = 0.02218 \text{ mrem}$$

Ingestion Dose: (milk, Section A4.0)

The dose for each pathway is the sum of contributions to the animal's diet. In particular, there is fresh feed (like leafy vegetables), stored hay (also like leafy vegetables, but is harvested and stored), stored grain (like grains), and soil. The feed, hay, and grain have two components, root uptake and rain splash. The rain splash is shown first. The root uptake factor is calculated using the information in the second table below. The third table shows the calculation of ingestion dose from milk the first year after the start of irrigation.

Rain Splash Intake Factors for Milk Cows						
Animal Feed Type	Interception Fraction	Effective Growing Period (days)	Translocation Factor	Crop Yield (kg/m ²)	Daily Feed Intake by Animal (kg/d)	Annual Soil Intake (kg/y)
fresh forage	0.6160	15.62	1	1.5	36	5.0628E-04
stored hay	0.4717	18.02	1	1	29	5.4043E-04
stored grain	0.4717	19.96	0.1	1	2	4.1283E-06
soil					0.8	0.0064960

The last column shows the effective annual soil intake by humans from rain splash onto the vegetation eaten by the milk cow. It is calculated using the formula below.
 $(\text{Annual milk})(\text{Transfer})(\text{Splash})(\text{Interception})(\text{Translocation})(\text{Growing Time})(\text{Daily feed}) / (\text{Yield})$
 The annual amount of contaminated milk eaten is 58 kg from Table A5. The equilibrium transfer factor for milk is 1.4E-4 d/kg from Table A33. The splash factor is 0.00027 kg/m² per day as discussed in Section A5.2. The annual soil intake by humans from soil eaten by the milk cow (0.8 kg/d from Table A32) is calculated as $(\text{Annual milk})(\text{Transfer})(\text{Soil intake})$

Root Uptake Intake Factors for Milk Cows					
	Concentration Ratio for Tc	dry-to-wet ratio	Annual Milk Consumption (kg/y)	Annual Soil Intake (kg/y)	Total Soil Intake (kg/y)
fresh forage	180	0.22	58	11.57587	11.5764
stored hay	180	0.22	58	9.32501	9.3256
stored grain	0.73	0.22	58	0.002608	0.002612

The second last column shows the effective annual soil intake by humans from root uptake into the vegetation eaten by the milk cow. It is calculated using the formula below.
 $(\text{Annual milk})(\text{Transfer})(\text{Conc ratio})(\text{dry-to-wet ratio})(\text{Daily feed intake})$
 The Daily feed intakes are shown in the previous table. The equilibrium transfer factor for milk is 1.4E-4 d/kg from Table A33.
 The "Total Soil Intake" is the sum of the intakes from rain splash (previous table) and root uptake.

Calculation of the Annual Dose by Pathway					
Component	Soil Concentration (Ci/kg)	Soil Intake Factor (kg/y)	Decay & Leaching Factor	Ingestion Dose Factor (mrem/Ci)	Annual Dose (mrem/y)
soil	8.8890E-07	0.006496	0.925376	1.46E+06	7.801E-03
forage - root uptake & rain splash	8.8890E-07	11.5764	0.925376	1.46E+06	13.90
stored hay - root uptake & rain splash	8.8890E-07	9.3256	0.949249	1.46E+06	11.49
stored grain - root uptake & rain splash	8.8890E-07	0.002612	0.949249	1.46E+06	3.218E-03
				Total dose	25.40

The annual dose is the product of the soil concentration, the effective mass of soil ingested per year, the decay and leaching factor, and the ingestion dose factor.

Total Dose: Rural Pasture Scenario:

$$0.001158 + 0.004342 + 0.02218 + 25.40 \text{ mrem} = \underline{25.43 \text{ mrem per Ci exhumed}}$$

Note that the dose factor from Table 10 is 25.4 mrem/y per Ci exhumed.

BB.4 All Pathways Farmer

The Tc-99 concentration in the irrigation water is assumed constant during the irrigation season. As a result, the Tc-99 concentration in the surface soil is increasing. The increase is offset by leaching from the surface layer during the irrigation season and radioactive decay. This section shows calculations for both annual dose and lifetime cancer risk for Tc-99. The numbers used for dose accumulation in the presence of decay and leaching are shown below.

$$T_{irr} + T_{no} \cong IDR(T_{no}) = (0.5y) + (0.5y)(0.244528) = 0.62226 y$$

At the end of the irrigation season:

$$\lambda_r T_{irr} = (0.208336 y^{-1})(0.5 y) = 0.104168$$

$$DI(T_{irr}) = [1 - \text{Exp}(-0.104168)]/(0.104168) = 0.949678$$

$$IDI(T_{irr}) = [(0.104168) - 1 + \text{Exp}(-0.104168)]/(0.104168)^2 = 0.483081$$

Time integral over the first year:

$$T_{irr} \cong IDI(T_{irr}) + T_{no} \cong DI(T_{irr}) \cong IDR(T_{no}) = \\ (0.5y)(0.483081) + (0.5y)(0.949678)(1) = 0.716379 y$$

Decay during storage:

$$\lambda_r T_{sto} = (3.28355E-6 y^{-1})(90 d)/(365 d/y) = 8.09642E-7$$

$$DR(T_{sto}) = \text{Exp}(-8.09642E-7) = 1$$

Time integral during the beef consumption period :

$$\lambda_r T_{beef} = (3.28355E-6 y^{-1})(120 d)/(365 d/y) = 1.07952E-6$$

$$IDR(T_{beef}) = [1 - \text{Exp}(-1.07952E-6)]/(1.07952E-6) = 1$$

Harvest after the irrigation season followed by the consumption period:

$$DI(T_{irr}) \cong IDR(T_{beef}) = (0.949678)(1) = 0.949678$$

The numbers used for the accumulated risk in the presence of radioactive decay and leaching from the soil are shown below.

Decay and leaching during the year for contamination present at the start of the year:

$$W = (0.90107)(0.999998) = 0.90107$$

Lifetime average soil concentration factor (30 y):

$$[30 - (1 - 0.90107)^{30}]/(1 - 0.90107) = 205.56$$

The rate of increase of the soil concentration during the irrigation season is calculated as shown below. Also shown is the soil concentration at the end of the irrigation season. After 30 years of irrigation, the cumulative soil concentration is calculated as shown.

Deposition rate during the irrigation season:

$$ID = (1.0E-12 \text{ Ci/L})(82.3 \text{ cm})(10 \text{ L/m}^2 \text{ per cm}) / (0.5 y) = 1.646E-9 \text{ Ci/m}^2 \text{ per year}$$

End of year soil concentration - without decay and leaching:

$$C_{so} = (1.646E-9 \text{ Ci/m}^2 \text{ per y})(0.5 y) / (225 \text{ kg/m}^2) = 3.6578E-12 \text{ Ci/kg}$$

Lifetime cumulative soil concentration:

$$C_{S30} = (3.6578E-12 \text{ Ci/kg})(30 \text{ y}) = 1.0973E-10 \text{ Ci/kg}$$

End of year soil concentration - with decay and leaching:

$$C_{S1} = (3.6578E-12 \text{ Ci/kg})(0.949678)(0.999998) = 3.4737E-12 \text{ Ci/kg}$$

Lifetime cumulative soil concentration:

$$C_{S1}^{\text{Cum}} = (3.4737E-12 \text{ Ci/kg})(205.56) = 7.1405E-10 \text{ Ci/kg}$$

The inhalation, external, and ingestion doses and cancer risks from the soil contamination are calculated as shown below. Note the water only pathways calculate the incremental cancer risk using the cumulative water concentration, $(30)(1.0E-12 \text{ Ci/L})=3.0E-11 \text{ Ci/L}$. Note that the soil pathways calculate incremental cancer risk as the sum of two parts. The first part is 30 times the risk from water added to the soil that year (C_{S30}). The second part is the risk from residual soil contamination (C_{S1}^{Cum}). The doses match the numbers shown in Table D3.

Inhalation Dose: (shower plus ambient, Table A13)

$$(1.0E-12 \text{ Ci/L})(0.0011 \text{ L inhaled})(8,330,000 \text{ mrem/Ci}) = 9.163E-9 \text{ mrem}$$

$$(3.0E-11 \text{ Ci/L})(0.0011 \text{ L inhaled})(14.1 \text{ risk/Ci}) = 4.653E-13 \text{ risk}$$

Inhalation Dose: (suspended soil, Table A9)

$$(3.6578E-12 \text{ Ci/kg})(5.39E-4 \text{ kg/y})(0.716379 \text{ y})(8.33E6 \text{ mrem/Ci}) = 1.177E-8 \text{ mrem}$$

$$(1.0973E-10 \text{ Ci/kg})(5.39E-4 \text{ kg/y inhaled})(0.716379 \text{ y})(14.1 \text{ risk/Ci}) = 5.974E-13 \text{ risk}$$

$$(7.1405E-10 \text{ Ci/kg})(5.39E-4 \text{ kg/y inhaled})(0.925376 \text{ y})(14.1 \text{ risk/Ci}) = 5.022E-12 \text{ risk}$$

$$\text{Total lifetime cancer risk from dust inhalation} = 5.619E-12$$

External Dose: (Table A15)

Note that the soil concentrations are multiplied by 225 kg/m^2 to convert them into area concentrations (Ci/m^2) suitable for the external dose rate factor.

$$(8.230E-10 \text{ Ci/m}^2)(4,120 \text{ h/y})(0.716379 \text{ y})(0.0635 \text{ mrem/h per Ci/m}^2) = 1.542 \text{ E-7 mrem}$$

$$(1.4690E-8 \text{ Ci/m}^2)(4,120 \text{ h/y})(0.716379 \text{ y})(4.13E-8 \text{ risk/h per Ci/m}^2) = 3.010E-12 \text{ risk}$$

$$(1.6066E-7 \text{ Ci/m}^2)(4,120 \text{ h/y})(0.925376 \text{ y})(4.13E-8 \text{ risk/h per Ci/m}^2) = 2.530E-11 \text{ risk}$$

$$\text{Total lifetime cancer risk from external exposure} = 2.831E-11$$

Ingestion Dose: (soil only, Table A8)

$$(3.6578E-12 \text{ Ci/kg})(0.0365 \text{ kg/y})(0.716379 \text{ y})(1.46E6 \text{ mrem/Ci}) = 1.396E-7 \text{ mrem}$$

$$(1.0973E-10 \text{ Ci/kg})(0.0365 \text{ kg/y ingested})(0.716379 \text{ y})(7.66 \text{ risk/Ci}) = 2.198E-11 \text{ risk}$$

$$(7.1405E-10 \text{ Ci/kg})(0.0365 \text{ kg/y ingested})(0.925376 \text{ y})(7.66 \text{ risk/Ci}) = 1.847E-10 \text{ risk}$$

$$\text{Total lifetime cancer risk from soil ingestion} = 2.067E-10$$

Ingestion Dose: (drinking water, Table A5)

$$(1.0E-12 \text{ Ci/L})(545 \text{ L})(1.46E6 \text{ mrem/Ci}) = 7.957E-4 \text{ mrem}$$

$$(3.0E-11 \text{ Ci/L})(545 \text{ L})(7.66 \text{ risk/Ci}) = 4.496E-8 \text{ risk}$$

Ingestion Dose: (garden produce, Section A5.0)

The intake factor for direct deposition of contaminants in irrigation water on foliage is calculated as shown in the table below.

Vegetable	Interception Fraction	Effective Growing Period (days)	Translocation Factor	Crop Yield (kg/m ²)	Annual Food Consumption (kg/y)	Annual Water Intake (m ²)
leafy	0.25	18.02	1	2	4.45	0.027462
other	0.25	19.96	0.1	2	21.625	0.014782
fruit	0.25	19.96	0.1	3	21.45	0.009775
grain	0.25	19.96	0.1	0.8	20.475	0.034990

The Water Intake from Direct Deposition on Foliage is calculated as
 (Interception fraction)(Translocation Factor)(Growing Time)(Annual food eaten) / (Biomass) / (365 d/y)

The ingestion dose calculation is shown below. Note that the first lines show doses from leafy vegetables while the second lines combine fruit and other vegetable intakes. The root uptake and rain splash soil intake numbers are from Section BB.2 (Suburban Garden). Also note that grains have been omitted because they are not irrigated.

Ingestion dose from root uptake and rain splash:

$$(3.6578E-12 \text{ Ci/kg})(72.0944 \text{ kg/y})(0.483081 \text{ y})(1.46E6 \text{ mrem/Ci}) = 1.860E-4 \text{ mrem}$$

$$(3.6578E-12 \text{ Ci/kg})(9.9625 \text{ kg/y})(0.949678 \text{ y})(1.46E6 \text{ mrem/Ci}) = 5.053E-5 \text{ mrem}$$

Ingestion dose from direct deposition:

$$(1.646E-9 \text{ Ci/m}^2 \text{ per y})(0.027462 \text{ m}^2)(1 \text{ y})(1.46E6 \text{ mrem/Ci}) = 6.600E-5 \text{ mrem}$$

$$(4.938E-8 \text{ Ci/m}^2 \text{ per y})(0.024557 \text{ m}^2)(1 \text{ y})(1.46E6 \text{ mrem/Ci}) = 5.901E-5 \text{ mrem}$$

$$\text{Total ingestion dose from garden vegetables} = 3.615E-4 \text{ mrem}$$

Ingestion risk from root uptake and rain splash:

$$(1.0973E-10 \text{ Ci/kg})(72.0944 \text{ kg/y})(0.483081 \text{ y})(4.00 \text{ risk/Ci}) = 1.529E-8 \text{ mrem}$$

$$(1.0973E-10 \text{ Ci/kg})(9.9625 \text{ kg/y})(0.949678 \text{ y})(4.00 \text{ risk/Ci}) = 4.153E-9 \text{ mrem}$$

$$(7.1405E-10 \text{ Ci/kg})(72.0944 \text{ kg/y})(0.949678 \text{ y})(4.00 \text{ risk/Ci}) = 1.956E-7 \text{ mrem}$$

$$(7.1405E-10 \text{ Ci/kg})(9.9625 \text{ kg/y})(0.949249 \text{ y})(4.00 \text{ risk/Ci}) = 2.701E-8 \text{ mrem}$$

Ingestion risk from direct deposition:

$$(4.938E-8 \text{ Ci/m}^2 \text{ per y})(0.027462 \text{ m}^2)(1 \text{ y})(4.00 \text{ risk/Ci}) = 5.424E-9 \text{ mrem}$$

$$(4.938E-8 \text{ Ci/m}^2 \text{ per y})(0.024557 \text{ m}^2)(1 \text{ y})(4.00 \text{ risk/Ci}) = 4.850E-9 \text{ mrem}$$

$$\text{Total lifetime cancer risk from garden vegetables} = 2.523E-7 \text{ mrem}$$

Ingestion Dose: (beef, Section A4.0)

The dose for each pathway is the sum of contributions to the animal's diet. In particular, there is fresh feed (like leafy vegetables), stored hay (also like leafy vegetables, but is harvested and stored), stored grain (like grains), soil, and drinking water. The feed, hay, and grain have three components, root uptake, rain splash, and direct deposition. The direct deposition and rain splash are shown first.

Direct Deposition Intake Factors for Beef Cattle						
Animal Feed Type	Interception Fraction	Effective Growing Period (days)	Translocation Factor	Crop Yield (kg/m ²)	Daily Feed Intake by Animal (kg/d)	Annual Water Intake (m ²)
fresh forage	0.25	15.62	1	1.5	27	4.8433E-4
stored hay	0.25	18.02	1	1	14	4.3458E-4
stored grain	0.25	19.96	0.1	1	3	1.0315E-5
water					50	0.12575
Rain Splash Intake Factors for Beef Cattle						
Animal Feed Type	Interception Fraction	Effective Growing Period (days)	Translocation Factor	Crop Yield (kg/m ²)	Daily Feed Intake by Animal (kg/d)	Annual Soil Intake (kg/y)
fresh forage	0.6160	15.62	1	1.5	27	1.1761E-04
stored hay	0.4717	18.02	1	1	14	8.0807E-05
stored grain	0.4717	19.96	0.1	1	3	1.9180E-06
soil					0.6	1.509E-03

For direct deposition, the last column shows the effective annual water intake by humans from direct deposition onto the vegetation eaten by the beef cattle. It is calculated using the formula below.
 $(\text{Annual beef})(\text{Transfer})(\text{Interception})(\text{Translocation})(\text{Growing Time})(\text{Daily feed}) / (\text{Yield}) / (365 \text{ d/y})$
 For rain splash, the last column shows the effective annual soil intake by humans from rain splash onto the vegetation eaten by the beef cattle. It is calculated using the formula below.
 $(\text{Annual beef})(\text{Transfer})(\text{Splash})(\text{Interception})(\text{Translocation})(\text{Growing Time})(\text{Daily feed}) / (\text{Yield})$
 The annual amount of contaminated beef eaten is 25.15 kg from Table A5. The equilibrium transfer factor for beef is 1.0E-4 d/kg from Table A33. The splash factor is 0.00027 kg/m² per day as discussed in Section A5.2. The annual soil intake by humans from soil eaten by the beef cattle (0.6 kg/d from Table A32) is calculated as $(\text{Annual beef})(\text{Transfer})(\text{Soil intake})$

The root uptake factor is calculated using the information in the table below.

Root Uptake Intake Factors for Beef Cattle					
	Concentration Ratio for Tc	dry-to-wet ratio	Annual Food Consumption (kg/y)	Annual Soil Intake (kg/y)	Total Soil Intake (kg/y)
fresh forage	180	0.22	25.15	2.689038	2.68916
stored hay	180	0.22	25.15	1.394316	1.3944
stored grain	0.73	0.22	25.15	0.0012117	0.0012136

The second last column shows the effective annual soil intake by humans from root uptake into the vegetation eaten by the beef cattle. It is calculated using the formula below.
 $(\text{Annual beef})(\text{Transfer})(\text{Conc ratio})(\text{dry-to-wet ratio})(\text{Daily feed intake})$
 The daily feed intakes are shown in the previous table. The equilibrium transfer factor for beef is 1.0E-4 d/kg from Table A33.
 The "Total Soil Intake" is the sum of the intakes from rain splash (previous table) and root uptake.

The calculation of ingestion dose the first year after the start of irrigation from the consumption of contaminated beef is summarized in the table below.

Calculation of Ingestion Dose from Beef					
Component	Media Concentration	Intake Factor	Decay & Leaching Factor	Ingestion Dose Factor (mrem/Ci)	Annual Dose (mrem)
water	1.0E-12	0.12575	0.999999	1.46E+06	1.836E-07
soil	3.6578E-12	0.001509	0.949678	1.46E+06	7.653E-09
forage - root uptake & rain splash	3.6578E-12	2.68916	0.949678	1.46E+06	1.364E-05
forage - direct deposition	1.6460E-09	4.8433E-04	0.999999	1.46E+06	1.164E-06
stored hay - root uptake & rain splash	3.6578E-12	1.3944	0.949677	1.46E+06	7.072E-06
stored hay - direct deposition	1.6460E-09	4.3458E-04	0.999999	1.46E+06	1.044E-06
				Total dose	2.311E-05

The calculation of lifetime cancer risk from consumption of beef is summarized in the table below. The lower portion of the table has the contribution from residual contamination due to prior irrigation. The upper portion of the table shows the contribution from 30 years of active irrigation.

Calculation of Lifetime Cancer Risk from Beef					
Component	Media Concentration	Intake Factor	Decay & Leaching Factor	Ingestion Risk Factor (risk/Ci)	Lifetime Cancer Risk
water	3.0E-11	0.12575	0.999999	4.00	1.509E-11
soil	1.0973E-10	0.001509	0.949678	4.00	6.290E-13
forage - root uptake & rain splash	1.0973E-10	2.68916	0.949678	4.00	1.121E-09
forage - direct deposition	4.9380E-08	4.8433E-04	0.999999	4.00	9.566E-11
stored hay - root uptake & rain splash	1.0973E-10	1.3944	0.949677	4.00	5.812E-10
stored hay - direct deposition	4.9380E-08	4.3458E-04	0.999999	4.00	8.584E-11
soil	7.1405E-10	0.001509	0.949248	4.00	4.091E-12
forage - root uptake & rain splash	7.1405E-10	2.68916	0.949248	4.00	7.291E-09
stored hay - root uptake & rain splash	7.1405E-10	1.3944	0.949248	4.00	3.781E-09
				Total risk	1.298E-08

Ingestion Dose: (milk, Section A4.0)

The dose for each pathway is calculated using the same approach as used for beef cattle.

Direct Deposition Intake Factors for Milk Cows						
Animal Feed Type	Interception Fraction	Effective Growing Period (days)	Translocation Factor	Crop Yield (kg/m ²)	Daily Feed Intake by Animal (kg/d)	Annual Water Intake (m ²)
fresh forage	0.25	15.62	1	1.5	36	2.0849E-03
stored hay	0.25	18.02	1	1	29	2.9064E-03
stored grain	0.25	19.96	0.1	1	2	2.2202E-05
water					60	0.48720

Rain Splash Intake Factors for Milk Cows						
Animal Feed Type	Interception Fraction	Effective Growing Period (days)	Translocation Factor	Crop Yield (kg/m ²)	Daily Feed Intake by Animal (kg/d)	Annual Soil Intake (kg/y)
fresh forage	0.6160	15.62	1	1.5	36	5.0628E-04
stored hay	0.4717	18.02	1	1	29	5.4043E-04
stored grain	0.4717	19.96	0.1	1	2	4.1283E-06
soil					0.8	0.006496

For direct deposition, the last column shows the effective annual water intake by humans from direct deposition onto the vegetation eaten by the milk cow. It is calculated using the formula below.
 $(\text{Annual milk})(\text{Transfer})(\text{Interception})(\text{Translocation})(\text{Growing Time})(\text{Daily feed}) / (\text{Yield}) / (365 \text{ d/y})$
 For rain splash, the last column shows the effective annual soil intake by humans from rain splash onto the vegetation eaten by the milk cow. It is calculated using the formula below.
 $(\text{Annual milk})(\text{Transfer})(\text{Splash})(\text{Interception})(\text{Translocation})(\text{Growing Time})(\text{Daily feed}) / (\text{Yield})$
 The annual amount of contaminated milk intake is 58 kg from Table A5. The equilibrium transfer factor for milk is 1.4E-4 d/kg from Table A33. The splash factor is 0.00027 kg/m² per day as discussed in Section A5.2. The annual soil intake by humans from soil eaten by the milk cow (0.8 kg/d from Table A32) is calculated as
 $(\text{Annual milk})(\text{Transfer})(\text{Soil intake})$

Root Uptake Intake Factors for Milk Cows					
	Concentration Ratio for Tc	dry-to-wet ratio	Annual Food Consumption (kg/y)	Annual Soil Intake (kg/y)	Total Soil Intake (kg/y)
fresh forage	180	0.22	58	11.575872	11.576378
stored hay	180	0.22	58	9.325008	9.325548
stored grain	0.73	0.22	58	0.002608	0.0026121

The second last column shows the effective annual soil intake by humans from root uptake into the vegetation eaten by the milk cow. It is calculated using the formula below.
 $(\text{Annual milk})(\text{Transfer})(\text{Conc ratio})(\text{dry-to-wet ratio})(\text{Daily feed intake})$
 The daily feed intakes are shown in the previous table. The equilibrium transfer factor for milk is 1.4E-4 d/kg from Table A33.
 The "Total Soil Intake" is the sum of the intakes from rain splash (previous table) and root uptake.

The calculation of ingestion dose the first year after the start of irrigation from the consumption of contaminated milk is summarized in the table below.

Calculation of Ingestion Dose from Milk					
Component	Media Concentration	Intake Factor	Decay & Leaching Factor	Ingestion Dose Factor (mrem/Ci)	Annual Dose (mrem)
water	1.0E-12	0.4872	1	1.46E+06	7.113E-07
soil	3.6578E-12	0.006496	0.716379	1.46E+06	2.485E-08
forage - root uptake & rain splash	3.6578E-12	11.576378	0.716379	1.46E+06	4.429E-05
forage - direct deposition	1.6460E-09	2.0849E-03	1	1.46E+06	5.010E-06
stored hay - root uptake & rain splash	3.6578E-12	9.325548	0.949677	1.46E+06	4.730E-05
stored hay - direct deposition	1.6460E-09	2.9064E-03	0.999999	1.46E+06	6.985E-06
				Total dose	1.043E-04

The calculation of lifetime cancer risk from consumption of milk is summarized in the table below. The lower portion of the table has the contribution from residual contamination due to prior irrigation. The upper portion of the table shows the contribution from 30 years of active irrigation.

Calculation of Lifetime Cancer Risk from Milk					
Component	Media Concentration	Intake Factor	Decay & Leaching Factor	Ingestion Risk Factor (risk/Ci)	Lifetime Cancer Risk
water	3.0E-11	0.4872	1	4.00	5.846E-11
soil	1.0973E-10	0.006496	0.716379	4.00	2.043E-12
forage - root uptake & rain splash	1.0973E-10	11.576378	0.716379	4.00	3.640E-09
forage - direct deposition	4.9380E-08	2.0849E-03	1	4.00	4.118E-10
stored hay - root uptake & rain splash	1.0973E-10	9.325548	0.949677	4.00	3.887E-09
stored hay - direct deposition	4.9380E-08	2.9064E-03	0.999999	4.00	5.741E-10
soil	7.1405E-10	0.006496	0.925376	4.00	1.717E-11
forage - root uptake & rain splash	7.1405E-10	11.576378	0.925376	4.00	3.060E-08
stored hay - root uptake & rain splash	7.1405E-10	9.325548	0.949248	4.00	2.528E-08
				Total risk	6.447E-08

Ingestion Dose: (poultry, Section A4.0)

The dose for each pathway is calculated using the same approach as used for beef cattle.

Direct Deposition Intake Factors for Poultry						
Animal Feed Type	Interception Fraction	Effective Growing Period (days)	Translocation Factor	Crop Yield (kg/m ²)	Daily Feed Intake by Animal (kg/d)	Annual Water Intake (m ²)
fresh forage	0.25	15.62	1	1.5	0.13	4.0890E-04
stored hay	0.25	18.02	1	1	0	0
stored grain	0.25	19.96	0.1	1	0.09	5.4261E-05
water					0.3	0.1323
Rain Splash Intake Factors for Poultry						
Animal Feed Type	Interception Fraction	Effective Growing Period (days)	Translocation Factor	Crop Yield (kg/m ²)	Daily Feed Intake by Animal (kg/d)	Annual Soil Intake (kg/y)
fresh forage	0.6160	15.62	1	1.5	0.13	9.9292E-05
stored hay	0.4717	18.02	1	1	0	0
stored grain	0.4717	19.96	0.1	1	0.09	1.0090E-05
soil					0.011	0.004851

For direct deposition, the last column shows the effective annual water intake by humans from direct deposition onto the vegetation eaten by the chicken. It is calculated using the formula below.
 $(\text{Annual poultry})(\text{Transfer})(\text{Interception})(\text{Translocation})(\text{Growing Time})(\text{Daily feed}) / (\text{Yield}) / (365 \text{ d/y})$
 For rain splash, the last column shows the effective annual soil intake by humans from rain splash onto the vegetation eaten by the chicken. It is calculated using the formula below.
 $(\text{Annual poultry})(\text{Transfer})(\text{Splash})(\text{Interception})(\text{Translocation})(\text{Growing Time})(\text{Daily feed}) / (\text{Yield})$
 The annual amount of poultry intake is 11.7 kg from Table A5. The equilibrium transfer factor for poultry is 0.03 d/kg from Table A33. The splash factor is 0.00027 kg/m² per day as discussed in Section A5.2.
 The annual soil intake by humans from soil eaten by the chicken (0.011 kg/d from Table A32) is calculated as $(\text{Annual poultry})(\text{Transfer})(\text{Soil intake})$

Root Uptake Intake Factors for Poultry					
	Concentration Ratio for Tc	dry-to-wet ratio	Annual Food Consumption (kg/y)	Annual Soil Intake (kg/y)	Total Soil Intake (kg/y)
fresh forage	180	0.22	14.7	2.270268	2.2703673
stored hay	180	0.22	14.7	0	0
stored grain	0.73	0.22	14.7	0.006374	0.0063841

The second last column shows the effective annual soil intake by humans from root uptake into the vegetation eaten by the chicken. It is calculated using the formula below.
 $(\text{Annual poultry})(\text{Transfer})(\text{Conc ratio})(\text{dry-to-wet ratio})(\text{Daily feed intake})$
 The daily feed intakes are shown in the previous table. The equilibrium transfer factor for poultry is 0.03 d/kg from Table A33.
 The "Total Soil Intake" is the sum of the intakes from rain splash (previous table) and root uptake.

The calculation of ingestion dose the first year after the start of irrigation from the consumption of contaminated poultry is summarized in the table below.

Calculation of Ingestion Dose from Poultry					
Component	Media Concentration	Intake Factor	Decay & Leaching Factor	Ingestion Dose Factor (mrem/Ci)	Annual Dose (mrem)
water	1.0E-12	0.1323	1	1.46E+06	1.932E-07
soil	3.6578E-12	0.004851	0.716379	1.46E+06	1.856E-08
forage - root uptake & rain splash	3.6578E-12	2.2703673	0.716379	1.46E+06	8.686E-06
forage - direct deposition	1.6460E-09	4.0890E-04	1	1.46E+06	9.827E-07
stored hay - root uptake & rain splash	3.6578E-12	0	0.949677	1.46E+06	0
stored hay - direct deposition	1.6460E-09	0	0.999999	1.46E+06	0
				Total dose	9.880E-06

The calculation of lifetime cancer risk from consumption of poultry is summarized in the table below. The lower portion of the table has the contribution from residual contamination due to prior irrigation. The upper portion of the table shows the contribution from 30 years of active irrigation.

Calculation of Lifetime Cancer Risk from Poultry					
Component	Media Concentration	Intake Factor	Decay & Leaching Factor	Ingestion Risk Factor (risk/Ci)	Lifetime Cancer Risk
water	3.0E-11	0.1323	1	4.00	1.588E-11
soil	1.0973E-10	0.004851	0.716379	4.00	1.525E-12
forage - root uptake & rain splash	1.0973E-10	2.2703673	0.716379	4.00	7.139E-10
forage - direct deposition	4.9380E-08	4.0890E-04	1	4.00	8.077E-11
stored hay - root uptake & rain splash	1.0973E-10	0	0.949677	4.00	0
stored hay - direct deposition	4.9380E-08	0	0.999999	4.00	0
soil	7.1405E-10	0.004851	0.925376	4.00	1.282E-11
forage - root uptake & rain splash	7.1405E-10	2.2703673	0.925376	4.00	6.001E-09
stored hay - root uptake & rain splash	7.1405E-10	0	0.949248	4.00	0
				Total risk	6.826E-09

Ingestion Dose: (eggs, Section A4.0)

The dose for each pathway is calculated using the same data used for poultry since both are chickens. The difference is only in the equilibrium transfer factor (3.0 d/kg for eggs) and the annual consumption (6.8 kg egg per year). These lead to different intake factors than the poultry tables. The resulting doses and risks are shown in the tables below.

Calculation of Ingestion Dose from Eggs					
Component	Media Concentration	Intake Factor	Decay & Leaching Factor	Ingestion Dose Factor (mrem/Ci)	Annual Dose (mrem)
water	1.0E-12	6.12	1	1.46E+06	8.935E-06
soil	3.6578E-12	0.2244	0.716379	1.46E+06	8.585E-07
forage - root uptake & rain splash	3.6578E-12	105.02379	0.716379	1.46E+06	4.018E-04
forage - direct deposition	1.6460E-09	1.8915E-02	1	1.46E+06	4.546E-05
stored hay - root uptake & rain splash	3.6578E-12	0	0.949677	1.46E+06	0
stored hay - direct deposition	1.6460E-09	0	0.999999	1.46E+06	0
				Total dose	4.570E-04

Calculation of Lifetime Cancer Risk from Eggs					
Component	Media Concentration	Intake Factor	Decay & Leaching Factor	Ingestion Risk Factor (risk/Ci)	Lifetime Cancer Risk
water	3.0E-11	6.12	1	4.00	7.344E-10
soil	1.0973E-10	0.2244	0.716379	4.00	7.056E-11
forage - root uptake & rain splash	1.0973E-10	105.02379	0.716379	4.00	3.302E-08
forage - direct deposition	4.9380E-08	1.8915E-02	1	4.00	3.736E-09
stored hay - root uptake & rain splash	1.0973E-10	0	0.949677	4.00	0
stored hay - direct deposition	4.9380E-08	0	0.999999	4.00	0
soil	7.1405E-10	0.2244	0.925376	4.00	5.931E-10
forage - root uptake & rain splash	7.1405E-10	105.02379	0.925376	4.00	2.776E-07
stored hay - root uptake & rain splash	7.1405E-10	0	0.949248	4.00	0
				Total risk	3.157E-07

Total dose and risk for the animal pathways:

$$2.311E-5 + 1.043E-4 + 9.880E-6 + 4.570E-4 = \underline{5.943E-4 \text{ mrem}}$$

$$1.298E-8 + 6.447E-8 + 6.826E-9 + 3.157E-7 = \underline{4.000E-7}$$

Total Dose for the All Pathways Farmer (irrigation from a well):

$$4.498E-7 + 1.177E-8 + 1.542E-7 + 1.396E-7 + 7.957E-4 + 3.615E-4 + 5.943E-4 \text{ mrem} = \underline{1.752E-3 \text{ mrem per pCi/L}}$$

Note that the all pathways farmer's total dose factor from Table 12 is 1.75E-3 mrem/y per pCi/L.

Total Lifetime Cancer Risk for the All Pathways Farmer (irrigation from a well):

$$2.284E-11 + 5.619E-12 + 2.831E-11 + 2.067E-10 + 4.496E-8 + 2.523E-7 + 4.000E-7 = \underline{6.975E-7 \text{ per pCi/L}}$$

Note that the all pathways farmer's total risk factor from Table 14 is 6.97E-7 per pCi/L.

The above total applies to the inland well situation in which does not include a dose from fish. When the Columbia River is the source of Tc-99, the fish dose is calculated as shown below and added to the above total. The concentration ratio for technetium in fish is 20 L/kg. The intake factor is this concentration ratio multiplied by the annual intake of fish, 3.29 kg.

Ingestion Dose: (fish, Table A5)

$$(1.0E-12 \text{ Ci/L})(65.8 \text{ L})(1.46E6 \text{ mrem/Ci}) = 9.607E-5 \text{ mrem}$$

$$(3.0E-11 \text{ Ci/L})(65.8 \text{ L})(4.00 \text{ risk/Ci}) = 7.896E-9 \text{ risk}$$

Note that the all pathways farmer's fish dose factor from Table 11 is 9.61E-5 mrem/y per pCi/L.

The cumulative concentration of Tc-99 in sediment after a 20-year accumulation period is calculated as shown below. The first three rows are for a one-year exposure. The second three rows are for a 30-year exposure.

$$\begin{aligned} \text{Exp}[-(20)(0.208336 \text{ y}^{-1})] &= 0.0155030 & \text{Exp}[-(21)(0.208336 \text{ y}^{-1})] &= 0.0125874 \\ \text{1-year case} &= [(1\text{y}) - (0.0155030 - 0.0125874)/(0.208336 \text{ y}^{-1})]/(0.208336) &= 4.73277 \text{ y} \\ \text{Sediment Conc} &= (1.0E-12 \text{ Ci/L})(25,300 \text{ L/m}^2/\text{y})(4.73277 \text{ y}) &= 1.1974E-7 \text{ Ci/m}^2 \end{aligned}$$

$$\begin{aligned} \text{Exp}[-(50)(0.208336 \text{ y}^{-1})] &= 0.00002993 \\ \text{30-year case} &= [(30\text{y}) - (0.0155030 - 0.00002993)/(0.208336 \text{ y}^{-1})]/(0.208336) &= 143.642 \text{ y} \\ \text{Sediment Conc} &= (1.0E-12 \text{ Ci/L})(25,300 \text{ L/m}^2/\text{y})(4.73277 \text{ y}) &= 3.6341E-6 \text{ Ci/m}^2 \end{aligned}$$

External Dose: (shoreline sediment)

$$(1.197E-7 \text{ Ci/m}^2)(11 \text{ h})(0.0635 \text{ mrem/h per Ci/m}^2) = 8.364E-8 \text{ mrem}$$

$$(3.634E-6 \text{ Ci/m}^2)(11 \text{ h})(4.13E-8 \text{ risk/h per Ci/m}^2) = 1.651E-12 \text{ risk}$$

Ingestion Dose: (soil only, Table A8)

Note that the sediment concentrations used for external dose are divided by 225 kg/m² to convert them into mass concentrations (Ci/kg).

$$(5.322E-10 \text{ Ci/kg})(0.0007 \text{ kg})(1.46E6 \text{ mrem/Ci}) = 5.439E-7 \text{ mrem}$$

$$(1.615E-8 \text{ Ci/kg})(0.0007 \text{ kg})(7.66 \text{ risk/Ci}) = 8.661E-11 \text{ risk}$$

Total Dose for the All Pathways Farmer (irrigation from the Columbia River):

$$1.752E-3 + 9.607E-5 + 8.364E-8 + 5.439E-7 = \underline{1.849E-3 \text{ mrem per pCi/L}}$$

Note that the all pathways farmer's total dose factor from Table 13 is 1.85E-3 mrem/y per pCi/L.

Total Lifetime Cancer Risk for the All Pathways Farmer (irrigation from the Columbia River):

$$6.975E-7 + 7.896E-9 + 1.651E-12 + 8.661E-11 = \underline{7.055E-7 \text{ per pCi/L}}$$

Note that the all pathways farmer's total dose factor from Table 14 is 7.05E-7 per pCi/L.

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APPENDIX C
IMPORTANCE OF MISSING TOXICITY PARAMETERS

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IMPORTANCE OF MISSING TOXICITY PARAMETERS

The hazard index and cancer risk for chemicals are calculated using both ingestion and inhalation exposures. However, many chemicals lack either the inhalation or ingestion benchmark against which to calculate the hazard index or cancer risk. In Section 3.0 of the main text, the calculations are carried out using the assumption that the missing route will have no effect on the final hazard index or slope factor. In other words, the calculation ignores the route of entry (inhalation or ingestion) for which there is no toxicity guidance.

This appendix presents estimates of the missing toxicity parameters for chemicals that have a reference dose or slope factor for ingestion, but none for inhalation, or vice versa. The hazard index and increased cancer risks for unit water concentrations were recalculated for each scenario using the new toxicity parameters. The new unit factors are listed in this appendix along with ratios of the new unit factors divided by the old. This helps identify chemicals for which the missing route may be a significant contributor to the final result. This is consistent with the recommendations found in Section 2.1 and Appendix B of the *Soil Screening Guidance: Technical Background Document*, (EPA/540/R95/128).

ROUTE-TO-ROUTE EXTRAPOLATION

Several chemicals have a reference dose or slope factor given for ingestion, but none for inhalation, or vice-versa. In this appendix, the missing value was estimated using the given value. If no toxicity estimates are available for either route (inhalation or ingestion) then no extrapolation is made. The estimated values are presented in Table C1. In the EPA *Soil Screening Guidance: Technical Background Document* (EPA/540/R95/128) this process of imputing the missing value from the given value is referred to as "route-to-route extrapolation". Appendix B of EPA/540/R95/128 illustrates the process by using the same value for inhalation as was determined for ingestion. The extrapolated values are noted with "x" in Table C1. Note that all chemical are listed in Table C1, even if no route-to-route extrapolation was used. The "x" entries are the new toxicity information.

Table C1. Imputed Values for Reference Doses and Cancer Induction Slope Factors.

CASRN	Chemical Name	Reference Dose (RfD) (mg/kg-day)		Cancer Slope Factor (SF) (mg/kg-day) ⁻¹	
		Ingestion	Inhalation	Ingestion	Inhalation
50-32-8	Benzo[a]pyrene	na	na	7.30E+00 e	3.08E+00 t
53-70-3	Dibenz[a,h]anthracene	na	na	7.30E+00 o	3.08E+00 t
56-23-5	Carbon tetrachloride	7.00E-04 e	1.40E-03 x	1.30E-01 e	5.20E-02 e
57-12-5	Cyanide, free	2.00E-02 e	4.00E-02 x	na	na
57-14-7	1,1-Dimethylhydrazine	na	na	3.00E+00 o	1.72E+01 o
57-55-6	Propylene glycol (1,2-Propanediol)	5.00E-01 s	8.57E-04 s	na	na
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)	3.00E-04 e	6.00E-04 x	1.30E+00 h	6.50E-01 x
60-29-7	Ethyl ether (Diethyl ether)	2.00E-01 e	4.00E-01 x	na	na

Table C1. Imputed Values for Reference Doses and Cancer Induction Slope Factors.

CASRN	Chemical Name	Reference Dose (RfD) (mg/kg-day)		Cancer Slope Factor (SF) (mg/kg-day) ⁻¹	
		Ingestion	Inhalation	Ingestion	Inhalation
60-34-4	Methylhydrazine	na	na	3.00E+00 o	1.72E+01 o
60-57-1	Dieldrin	5.00E-05 e	1.00E-04 x	1.60E+01 e	1.60E+01 e
62-75-9	N-Nitrosodimethylamine	8.00E-06 s	1.60E-05 x	5.10E+01 e	5.10E+01 e
64-18-6	Formic acid	2.00E+00 h	4.00E+00 x	na	na
67-56-1	Methanol (Methyl alcohol)	5.00E-01 e	1.00E+00 x	na	na
67-64-1	Acetone (2-Propanone)	9.00E-01 e	1.80E+00 x	na	na
67-66-3	Chloroform	1.00E-02 e	8.60E-04 n	2.30E-04 e	8.05E-02 e
67-72-1	Hexachloroethane	1.00E-03 e	2.00E-03 x	1.40E-02 e	1.40E-02 e
71-36-3	n-Butyl alcohol (n-Butanol)	1.00E-01 e	2.60E-03 n	na	na
71-43-2	Benzene	4.00E-03 e	8.57E-03 e	5.50E-02 e	2.73E-02 e
71-55-6	1,1,1-Trichloroethane (Methyl chloroform)	2.80E-01 n	6.29E-01 o	na	na
72-20-8	Endrin	3.00E-04 e	6.00E-04 x	na	na
74-83-9	Bromomethane	1.40E-03 e	1.43E-03 e	na	na
74-87-3	Methyl chloride (Chloromethane)	1.29E-02 x	2.57E-02 e	1.30E-02 h	6.30E-03 h
75-00-3	Ethyl Chloride	4.00E-01 n	2.86E+00 e	2.90E-03 n	na
75-01-4	Vinyl chloride (Chloroethene)	3.00E-03 e	2.86E-02 e	1.40E+00 e	3.08E-02 e
75-05-8	Acetonitrile	8.55E-03 x	1.71E-02 e	na	na
75-07-0	Acetaldehyde	1.29E-03 x	2.57E-03 e	1.54E-02 x	7.70E-03 e
75-09-2	Dichloromethane (Methylene chloride)	6.00E-02 e	8.57E-01 h	7.50E-03 e	1.65E-03 e
75-15-0	Carbon disulfide	1.00E-01 e	2.00E-01 e	na	na
75-21-8	Ethylene Oxide (Oxirane)	na	na	1.02E+00 h	3.50E-01 h
75-34-3	1,1-Dichloroethane (Ethylidene chloride)	1.00E-01 h	1.43E-01 h	na	na
75-35-4	1,1-Dichloroethylene	5.00E-02 e	5.71E-02 e	na	na
75-45-6	Chlorodifluoromethane	7.15E+00 x	1.43E+01 e	na	na
75-68-3	Chloro-1,1-difluoroethane, 1-	7.15E+00 x	1.43E+01 e	na	na
75-69-4	Trichlorofluoromethane	3.00E-01 e	2.00E-01 h	na	na
75-71-8	Dichlorodifluoromethane	2.00E-01 e	5.71E-02 h	na	na
76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane (CFC-113)	3.00E+01 e	8.57E+00 h	na	na
76-44-8	Heptachlor	5.00E-04 e	1.00E-03 x	4.50E+00 e	4.50E+00 e
78-83-1	Isobutanol	3.00E-01 e	6.00E-01 x	na	na
78-87-5	1,2-Dichloropropane	5.70E-04 x	1.14E-03 e	6.80E-02 h	3.40E-02 x
78-93-3	Methyl ethyl ketone (2-Butanone)	6.00E-01 e	1.43E+00 e	na	na
79-00-5	1,1,2-Trichloroethane	4.00E-03 e	8.00E-03 x	5.70E-02 e	5.70E-02 e
79-01-6	Trichloroethylene	3.00E-04 n	1.14E-02 n	4.00E-01 o	4.00E-01 o
79-10-7	2-Propenoic acid (Acrylic acid)	5.00E-01 e	2.86E-04 e	na	na
79-34-5	1,1,2,2-Tetrachloroethane (Acetylene tetrachloride)	6.00E-02 n	1.20E-01 x	2.00E-01 e	2.00E-01 e
79-46-9	2-Nitropropane	2.86E-03 x	5.71E-03 e	1.88E+01 x	9.40E+00 h
82-68-8	Pentachloronitrobenzene (PCNB)	3.00E-03 e	6.00E-03 x	2.60E-01 h	1.30E-01 x
83-32-9	Acenaphthene	6.00E-02 e	1.20E-01 x	na	na
84-66-2	Diethyl phthalate	8.00E-01 e	1.60E+00 x	na	na
84-74-2	Dibutyl phthalate	1.00E-01 e	2.00E-01 x	na	na
85-68-7	Butyl benzyl phthalate	2.00E-01 e	4.00E-01 x	na	na

Table C1. Imputed Values for Reference Doses and Cancer Induction Slope Factors.

CASRN	Chemical Name	Reference Dose (RfD) (mg/kg-day)		Cancer Slope Factor (SF) (mg/kg-day) ⁻¹	
		Ingestion	Inhalation	Ingestion	Inhalation
87-68-3	Hexachlorobutadiene	3.00E-04 n	6.00E-04 x	7.80E-02 e	7.80E-02 e
87-86-5	Pentachlorophenol	3.00E-02 e	6.00E-02 x	1.20E-01 e	6.00E-02 x
88-06-2	2,4,6-Trichlorophenol	1.00E-04 n	2.00E-04 x	1.10E-02 e	1.10E-02 e
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)	1.00E-03 e	2.00E-03 x	na	na
91-20-3	Naphthalene	2.00E-02 e	8.57E-04 e	na	na
92-52-4	1,1'-Biphenyl	5.00E-02 e	1.00E-01 x	na	na
95-47-6	o-Xylene	2.00E-01 e	2.86E-02 e	na	na
95-48-7	2-Methylphenol (o-Cresol)	5.00E-02 e	1.00E-01 x	na	na
95-50-1	1,2-Dichlorobenzene (ortho-)	9.00E-02 e	5.71E-02 h	na	na
95-57-8	2-Chlorophenol	5.00E-03 e	1.00E-02 x	na	na
95-63-6	1,2,4-Trimethylbenzene	5.00E-02 o	1.71E-03 o	na	na
95-95-4	2,4,5-Trichlorophenol	1.00E-01 e	2.00E-01 x	na	na
98-86-2	Acetophenone	1.00E-01 e	2.00E-01 x	na	na
98-95-3	Nitrobenzene	5.00E-04 e	5.71E-04 h	na	na
100-25-4	1,4-Dinitrobenzene (para-)	1.00E-04 o	2.00E-04 x	na	na
100-41-4	Ethyl benzene	1.00E-01 e	2.86E-01 e	7.70E-03 x	3.85E-03 n
100-42-5	Styrene	2.00E-01 e	2.86E-01 e	na	na
100-51-6	Benzyl alcohol	3.00E-01 h	6.00E-01 x	na	na
106-42-3	p-Xylene	2.00E-01 e	2.86E-02 e	na	na
106-44-5	4-Methylphenol (p-Cresol)	5.00E-03 h	1.00E-02 x	na	na
106-46-7	1,4-Dichlorobenzene (para-)	3.00E-02 n	2.29E-01 e	2.40E-02 h	2.20E-02 n
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	2.86E-05 x	5.71E-05 h	8.50E+01 e	7.70E-01 e
106-99-0	1,3-Butadiene	2.86E-04 x	5.71E-04 e	2.10E-01 x	1.05E-01 e
107-02-8	2-Propenal (Acrolein)	5.00E-04 e	5.71E-06 e	na	na
107-05-1	3-Chloropropene (Allyl chloride)	5.00E-02 h	2.86E-04 e	na	na
107-06-2	1,2-Dichloroethane (Ethylene chloride)	3.00E-02 n	1.40E-03 n	9.10E-02 e	9.10E-02 e
107-13-1	Acrylonitrile	1.00E-03 h	5.71E-04 e	5.40E-01 e	2.38E-01 e
108-10-1	Methyl isobutyl ketone (4-Methyl-2-pentanone)	8.00E-02 h	8.57E-01 e	na	na
108-38-3	m-Xylene	2.00E-01 e	2.86E-02 e	na	na
108-39-4	3-Methylphenol (m-Cresol)	5.00E-02 e	1.00E-01 x	na	na
108-67-8	1,3,5-Trimethylbenzene	5.00E-02 o	1.71E-03 o	na	na
108-87-2	Methyl cyclohexane	4.29E-01 x	8.57E-01 o	na	na
108-88-3	Toluene (Methyl benzene)	2.00E-01 e	1.14E-01 e	na	na
108-90-7	Chlorobenzene	2.00E-02 e	1.70E-02 n	na	na
108-94-1	Cyclohexanone	5.00E+00 e	1.00E+01 x	na	na
108-95-2	Phenol (Carbolic acid)	3.00E-01 e	6.00E-01 x	na	na
109-99-9	Tetrahydrofuran	2.10E-01 n	8.57E-02 n	7.60E-03 n	6.80E-03 n
110-00-9	Furan (Oxacyclopentadiene)	1.00E-03 e	2.00E-03 x	na	na
110-54-3	n-Hexane	6.00E-02 h	5.71E-02 e	na	na
110-80-5	2-Ethoxyethanol	4.00E-01 h	5.71E-02 e	na	na
110-82-7	Cyclohexane	8.55E-01 x	1.71E+00 e	na	na
110-86-1	Pyridine	1.00E-03 e	2.00E-03 x	na	na

Table C1. Imputed Values for Reference Doses and Cancer Induction Slope Factors.

CASRN	Chemical Name	Reference Dose (RfD) (mg/kg-day)		Cancer Slope Factor (SF) (mg/kg-day) ⁻¹	
		Ingestion	Inhalation	Ingestion	Inhalation
111-76-2	2-Butoxyethanol (Ethylene Glycol Monobutyl Ether)	5.00E-01 e	3.71E+00 e	na	na
111-90-0	2-(2-Ethoxyethoxy)-ethanol (Diethylene Glycol Monoethyl Ether)	6.00E-02 s	8.60E-04 s	na	na
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)	2.00E-02 e	4.00E-02 x	1.40E-02 e	7.00E-03 x
117-84-0	Di-n-octylphthalate	4.00E-02 o	8.00E-02 x	na	na
118-74-1	Hexachlorobenzene	8.00E-04 e	1.60E-03 x	1.60E+00 e	1.60E+00 e
120-82-1	1,2,4-Trichlorobenzene	1.00E-02 e	1.14E-03 o	na	na
121-14-2	2,4-Dinitrotoluene	2.00E-03 e	4.00E-03 x	na	na
121-44-8	Triethylamine	1.00E-03 x	2.00E-03 e	na	na
122-39-4	Diphenylamine	2.50E-02 e	5.00E-02 x	na	na
123-91-1	1,4-Dioxane (Diethylene oxide)	na	na	1.10E-02 e	5.50E-03 x
126-73-8	Tributyl Phosphate	2.00E-01 o	4.00E-01 x	5.40E-03 o	2.70E-03 x
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)	1.00E-04 e	2.00E-04 h	na	na
127-18-4	Tetrachloroethylene	1.00E-02 e	1.70E-01 n	5.20E-02 o	2.03E-03 o
129-00-0	Pyrene	3.00E-02 e	6.00E-02 x	na	na
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	9.00E-01 e	1.80E+00 x	na	na
156-59-2	cis-1,2-Dichloroethylene	1.00E-02 h	2.00E-02 x	na	na
206-44-0	Fluoranthene (1,2-Benzacenaphthene)	4.00E-02 e	8.00E-02 x	na	na
309-00-2	Aldrin	3.00E-05 e	6.00E-05 x	1.70E+01 e	1.70E+01 e
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	5.00E-04 n	1.00E-03 x	6.30E+00 e	6.30E+00 e
319-85-7	beta-Benzene hexachloride (beta-Lindane)	2.00E-04 n	4.00E-04 x	1.80E+00 e	1.80E+00 e
541-73-1	1,3-Dichlorobenzene	9.00E-04 n	1.80E-03 x	na	na
542-75-6	1,3-Dichloropropene (cis & trans)	3.00E-02 e	5.71E-03 e	1.00E-01 e	1.40E-02 e
621-64-7	N-Nitrosodi-N-propylamine	na	na	7.00E+00 e	3.50E+00 x
1314-62-1	Vanadium pentoxide	9.00E-03 e	1.80E-02 x	na	na
1330-20-7	Xylenes (mixtures)	2.00E-01 e	2.86E-02 e	na	na
1336-36-3	Polychlorinated Biphenyls	na	na	4.00E-01 e	4.00E-01 e
1336-36-3	Polychlorinated Biphenyls (lowest risk)	na	na	7.00E-02 e	7.00E-02 e
6533-73-9	Thallium carbonate	8.00E-05 e	1.60E-04 x	na	na
7429-90-5	Aluminum	1.00E+00 o	1.43E-03 o	na	na
7439-89-6	Iron	3.00E-01 n	6.00E-01 x	na	na
7439-93-2	Lithium	2.00E-02 w	4.00E-02 x	na	na
7439-96-5	Manganese	4.67E-02 e	1.43E-05 e	na	na
7439-97-6	Mercury metal vapor	4.29E-05 x	8.57E-05 e	na	na
7439-98-7	Molybdenum	5.00E-03 e	1.00E-02 x	na	na
7440-02-0	Nickel (soluble salts)	2.00E-02 e	4.00E-02 x	na	na
7440-22-4	Silver	5.00E-03 e	1.00E-02 x	na	na
7440-24-6	Strontium, Stable	6.00E-01 e	1.20E+00 x	na	na
7440-28-0	Thallium metal	6.60E-05 ix	1.32E-04 x	na	na
7440-31-5	Tin	6.00E-01 h	1.20E+00 x	na	na
7440-36-0	Antimony	4.00E-04 e	8.00E-04 x	na	na
7440-38-2	Arsenic (inorganic)	3.00E-04 e	6.00E-04 x	1.50E+00 e	1.51E+01 e

Table C1. Imputed Values for Reference Doses and Cancer Induction Slope Factors.

CASRN	Chemical Name	Reference Dose (RfD) (mg/kg-day)		Cancer Slope Factor (SF) (mg/kg-day) ⁻¹	
		Ingestion	Inhalation	Ingestion	Inhalation
7440-39-3	Barium	7.00E-02 e	1.43E-04 h	na	na
7440-41-7	Beryllium and compounds	2.00E-03 e	5.71E-06 e	0.0 x	8.40E+00 e
7440-42-8	Boron and borates only	9.00E-02 e	5.71E-03 h	na	na
7440-43-9	Cadmium	5.00E-04 e	1.00E-03 x	0.0 x	6.30E+00 e
7440-45-1	Cerium (Ceric oxide 1306-38-3)	2.86E-05 x	5.71E-05 o	na	na
7440-48-4	Cobalt	2.00E-02 o	5.71E-06 o	0.0 x	9.80E+00 o
7440-50-8	Copper	4.00E-02 h	8.00E-02 x	na	na
7440-62-2	Vanadium metal	7.00E-03 h	1.40E-02 x	na	na
7440-66-6	Zinc and compounds	3.00E-01 e	6.00E-01 x	na	na
7487-94-7	Mercuric chloride	3.00E-04 e	6.00E-04 x	na	na
7664-41-7	Ammonia	1.43E-02 x	2.86E-02 e	na	na
7723-14-0	Phosphorus, white	2.00E-05 e	4.00E-05 x	na	na
7782-41-4	Fluorine (soluble fluoride)	6.00E-02 e	1.20E-01 x	na	na
7782-49-2	Selenium and compounds	5.00E-03 e	1.00E-02 x	na	na
8001-35-2	Toxaphene	na	na	1.10E+00 e	1.10E+00 e
11096-82-5	Aroclor 1260	na	na	4.00E-01 e	4.00E-01 e
11097-69-1	Aroclor 1254	2.00E-05 e	4.00E-05 x	4.00E-01 e	4.00E-01 e
11104-28-2	Aroclor 1221	na	na	4.00E-01 e	4.00E-01 e
11141-16-5	Aroclor 1232	na	na	4.00E-01 e	4.00E-01 e
12672-29-6	Aroclor 1248	na	na	4.00E-01 e	4.00E-01 e
12674-11-2	Aroclor 1016	7.00E-05 e	1.40E-04 x	7.00E-02 e	7.00E-02 e
14797-55-8	Nitrate	1.60E+00 e	3.20E+00 x	na	na
14797-65-0	Nitrite	1.00E-01 e	2.00E-01 x	na	na
16065-83-1	Chromium (III) (insoluble salts)	1.50E+00 e	3.00E+00 x	na	na
16984-48-8	Fluorine anion	6.00E-02 e	1.20E-01 x	na	na
18540-29-9	Chromium (VI) (soluble salts)	3.00E-03 e	2.29E-06 e	0.0 x	4.20E+01 e
53469-21-9	Aroclor 1242	na	na	4.00E-01 e	4.00E-01 e
na	Uranium (soluble salts)	6.00E-04 c	1.20E-03 x	na	na

Table C1. Imputed Values for Reference Doses and Cancer Induction Slope Factors.

CASRN	Chemical Name	Reference Dose (RfD) (mg/kg-day)		Cancer Slope Factor (SF) (mg/kg-day) ⁻¹	
		Ingestion	Inhalation	Ingestion	Inhalation
Notes:					
<ul style="list-style-type: none"> • CASRN = Chemical Abstract Service Reference Number • "e" means the number is from Integrated Risk Information System (IRIS) as of March, 2004. Internet address is http://www.epa.gov/iris/ • "o" means the number is from Oak Ridge Risk Assessment Information System (RAIS) as of March, 2004. Internet address is http://risk.lsd.ornl.gov • "h" means the number is from the Health Effects Assessment Summary Tables (HEAST) FY 1997 Update (EPA-540/R-97/036). • "n" means National Center for Environmental Assessment (NCEA). Internet address is http://www.epa.gov/ncea. • "c" means the RfD for Uranium is from the Federal Register, December 2000 • "s" means the number is from the EPA Superfund Risk Assessment web site. Internet address is http://www.epa.gov/superfund/index.htm • "t" means the number was estimated using toxicity equivalency factors (TEF) • "w" means the RfD for Lithium (7439-93-2) was withdrawn by EPA • "x" means the toxicity number was created using the route-to-route extrapolations described in the text. • "ix" means this is provisional guidance from EPA Region 9 for Thallium metal (CAS 7440-28-0). Internet address is www.epa.gov/docs/region09/waste/sfund/prg/index.html • Slope factors give an upper bound on the probability that some type of cancer develops as a result of a lifetime exposed to a given chemical. The slope factor is multiplied by the lifetime average daily chemical dose to give the lifetime risk. Two special cases are noted below. <ul style="list-style-type: none"> • The slope factors for vinyl chloride (CAS 75-01-4) apply to the general population. When applying these to occupationally exposed individuals (industrial exposure scenario), the values are reduced by a factor of 2. • The slope factors for PCBs (CAS 1336-36-3) and the Aroclors are reduced for population (collective) exposures. The slope factors used for normal and lowest risk PCBs are 0.3 (1.0 for dietary intakes) and 0.04 per mg/kg per day. • Reference dose is an estimate of a daily dose to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. Special cases are noted below. <ul style="list-style-type: none"> • The RfD for manganese in dietary pathways is 3 times the drinking water RfD shown on the table. • The RfD for dietary cadmium is twice the drinking water RfD shown on the table. • The RfD for airborne particulate containing chromium (VI) is 2.86E-05 mg/kg per day. 					

Note that route-to-route extrapolation is used in the IRIS database for some chemicals. Examples are summarized in Table C2. In this table "SFo" is the slope factor for ingestion (oral) while "SFi" is the slope factor for inhalation.

Table C2. Examples of Route-to-Route Extrapolation in the IRIS Database

CASRN	Chemical Name	Rev. Date	Method of Route-to-Route Extrapolation
71-43-2	Benzene	Apr-03	$SF_o = 2 * SF_i$ The factor of 2 comes from the lower absorption via inhalation.
56-23-5	Carbon tetrachloride	Jun-91	$SF_i = 0.4 * SF_o$ The factor of 0.4 comes from the lower absorption via inhalation.
60-57-1	Dieldrin	Sep-93	$SF_i = SF_o$ The inhalation slope factor is assumed to be no different than the ingestion slope factor.
62-75-9	N-Nitrosodimethylamine	Jul-93	
67-72-1	Hexachloroethane	Feb-94	
76-44-8	Heptachlor	Jul-93	
79-00-5	1,1,2-Trichloroethane	Feb-94	
79-34-5	1,1,2,2-Tetrachloroethane	Feb-94	
87-68-3	Hexachlorobutadiene	Apr-91	
88-06-2	2,4,6-Trichlorophenol	Feb-94	
107-06-2	1,2-Dichloroethane	Jan-91	
118-74-1	Hexachlorobenzene	Nov-96	
309-00-2	Aldrin	Jul-93	
319-84-6	alpha-Hexachlorocyclohexane (alpha-Lindane)	Jul-93	
319-85-7	beta-Hexachlorocyclohexane (beta-Lindane)	Jul-93	
1336-36-3	Polychlorinated Biphenyls	Jun-97	
8001-35-2	Toxaphene	Jan-91	

There are two extrapolation methods used in the present report to estimate the missing slope factors or reference doses. The first method follows the recent (4/17/2003) example from the IRIS database for benzene. It is assumed that inhalation slope factors are half as large as ingestion slope factors because only half the amount inhaled is actually absorbed into body fluids. Equivalently, the ingestion reference dose is regarded as half the inhalation reference dose. Thus, there is always a factor of 2 in the route-to-route extrapolations. This differs from the method used in HNF-SD-WM-TI-707 Revision 3 in that cases where the ingestion toxicity factor is imputed will have larger unit factors for hazard index and cancer induction.

The second extrapolation method is applied only to beryllium compounds (CAS 7440-41-7), cadmium compounds (CAS 7440-43-9), cobalt compounds (CAS 7440-48-4), and chromium (VI) compounds (CAS 18540-29-9). For these inorganic compounds, the observed cancers from the inhalation route are all lung cancers. From this observation it will be inferred that the ingestion slope factor is much smaller than the inhalation slope factor. The reason has to do with what happens to contaminants that are inhaled. Material that is inhaled is exhaled or deposits in the respiratory system. The deposited material is either absorbed into body fluids or mechanically removed from the lung and swallowed. Thus, the inhalation route includes an ingestion route. If beryllium, cadmium, cobalt, and chromium (VI) compounds were significant

oral hazards than other types of cancer would have been observed. It should be noted that there are cancers with longer latency periods than lung cancer. Thus the ingestion slope factor may not be zero. However, the ingestion slope factors for these chemicals are believed to be orders of magnitude smaller than the inhalation slope factor, so the value of zero will be used in the present report.

The unit hazard index and unit cancer risk factors are shown in the remaining tables in this appendix, namely, Tables C3, C5, C7, C9, C11, C13, C15, and C16. The last two tables are the unit factors using the State of Washington's MTCA methodology. The even numbered tables (C4, C6, C8, C10, C12, and C14) show comparisons ratios between the new unit factors and those from the main text (without route-to-route extrapolation). For example, Table C4 compares the unit factors shown in Table C3 with those shown in Table 15. To highlight significant changes induced by adding the missing route, all ratios less than 1.2 have been removed from the comparison tables. In other words, the unit factor had to increase more than 20% before the ratio is shown in the comparison tables.

To summarize the many comparisons in this appendix, Table 17 shows the largest ratios found on any of the comparison tables. This facilitates assessment of whether a chemical's missing toxicity information may be important in any of the exposure scenarios. From Table C17, there are several chemicals that deserve further analysis regarding the missing toxicity parameter. If the risk assessment is driven by any of these chemicals, the missing toxicity parameter should be determined in a manner that is both technically sound and acceptable to the appropriate regulatory authority.

Table C3. Unit Factors for the All Pathways Farmer Scenario.

CASRN	Chemical Name	Well Water Only, per mg/L		Columbia River, per mg/L	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
50-32-8	Benzo[a]pyrene	na	7.01E-01	na	4.93E+00
53-70-3	Dibenz[a,h]anthracene	na	1.37E+00	na	1.40E+01
56-23-5	Carbon tetrachloride	1.53E+02	5.07E-03	1.58E+02	5.29E-03
57-12-5	Cyanide, free	3.52E+01	na	3.53E+01	na
57-14-7	1,1-Dimethylhydrazine	na	4.58E+00	na	4.58E+00
57-55-6	Propylene glycol (1,2-Propanediol)	2.29E+00	na	2.29E+00	na
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)	2.49E+02	4.16E-02	3.14E+02	5.24E-02
60-29-7	Ethyl ether (Diethyl ether)	6.07E-01	na	6.09E-01	na
60-34-4	Methylhydrazine	na	3.43E+00	na	3.43E+00
60-57-1	Dieldrin	1.49E+03	7.32E-01	8.92E+03	3.28E+00
62-75-9	N-Nitrosodimethylamine	2.10E+05	3.69E+01	2.11E+05	3.69E+01
64-18-6	Formic acid	4.82E-01	na	4.83E-01	na
67-56-1	Methanol (Methyl alcohol)	1.26E+00	na	1.26E+00	na
67-64-1	Acetone (2-Propanone)	3.08E-01	na	3.09E-01	na
67-66-3	Chloroform	1.87E+02	5.47E-03	1.87E+02	5.47E-03
67-72-1	Hexachloroethane	1.11E+02	1.14E-03	1.51E+02	1.38E-03
71-36-3	n-Butyl alcohol (n-Butanol)	2.30E+01	na	2.30E+01	na
71-43-2	Benzene	2.62E+01	2.58E-03	2.65E+01	2.61E-03
71-55-6	1,1,1-Trichloroethane (Methyl chloroform)	3.51E-01	na	3.59E-01	na
72-20-8	Endrin	4.68E+02	na	1.39E+03	na
74-83-9	Bromomethane	1.36E+02	na	1.36E+02	na
74-87-3	Methyl chloride (Chloromethane)	9.19E+00	6.45E-04	9.23E+00	6.47E-04
75-00-3	Ethyl Chloride	1.36E-01	4.00E-05	1.37E-01	4.04E-05
75-01-4	Vinyl chloride (Chloroethene)	1.58E+01	2.06E-02	1.60E+01	2.08E-02
75-05-8	Acetonitrile	4.10E+01	na	4.10E+01	na
75-07-0	Acetaldehyde	2.01E+02	1.70E-03	2.01E+02	1.70E-03
75-09-2	Dichloromethane (Methylene chloride)	7.84E-01	2.28E-04	7.88E-01	2.28E-04
75-15-0	Carbon disulfide	1.08E+00	na	1.09E+00	na
75-21-8	Ethylene Oxide (Oxirane)	na	8.51E-02	na	8.52E-02
75-34-3	1,1-Dichloroethane (Ethylidene chloride)	1.42E+00	na	1.42E+00	na
75-35-4	1,1-Dichloroethylene	3.35E+00	na	3.37E+00	na
75-45-6	Chlorodifluoromethane	1.61E-02	na	1.61E-02	na
75-68-3	Chloro-1,1-difluoroethane, 1-	1.51E-02	na	1.52E-02	na
75-69-4	Trichlorofluoromethane	8.90E-01	na	8.98E-01	na
75-71-8	Dichlorodifluoromethane	2.92E+00	na	2.93E+00	na
76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane (CFC-113)	1.94E-02	na	1.96E-02	na
76-44-8	Heptachlor	3.01E+02	4.43E-01	2.86E+03	2.91E+00
78-83-1	Isobutanol	4.75E-01	na	4.76E-01	na
78-87-5	1,2-Dichloropropane	1.94E+02	3.23E-03	1.96E+02	3.25E-03
78-93-3	Methyl ethyl ketone (2-Butanone)	3.22E-01	na	3.23E-01	na
79-00-5	1,1,2-Trichloroethane	2.90E+01	4.76E-03	2.91E+01	4.78E-03

Table C3. Unit Factors for the All Pathways Farmer Scenario.

CASRN	Chemical Name	Well Water Only, per mg/L		Columbia River, per mg/L	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
79-01-6	Trichloroethylene	1.18E+02	3.25E-02	1.24E+02	3.28E-02
79-10-7	2-Propenoic acid (Acrylic acid)	8.83E+00	na	8.83E+00	na
79-34-5	1,1,2,2-Tetrachloroethane (Acetylene tetrachloride)	1.93E+00	1.67E-02	1.96E+00	1.69E-02
79-46-9	2-Nitropropane	5.70E+01	1.31E+00	5.71E+01	1.31E+00
82-68-8	Pentachloronitrobenzene (PCNB)	3.82E+01	1.28E-02	7.03E+01	2.35E-02
83-32-9	Acenaphthene	2.17E+00	na	2.62E+00	na
84-66-2	Diethyl phthalate	1.17E-01	na	1.19E-01	na
84-74-2	Dibutyl phthalate	4.32E-01	na	1.19E+00	na
85-68-7	Butyl benzyl phthalate	2.33E-01	na	8.06E-01	na
87-68-3	Hexachlorobutadiene	3.80E+02	6.46E-03	7.90E+02	1.06E-02
87-86-5	Pentachlorophenol	1.42E+00	2.19E-03	4.44E+00	6.85E-03
88-06-2	2,4,6-Trichlorophenol	6.23E+02	3.33E-04	7.00E+02	3.69E-04
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)	7.14E+01	na	8.68E+01	na
91-20-3	Naphthalene	1.87E+02	na	1.87E+02	na
92-52-4	1,1'-Biphenyl	2.46E+00	na	3.06E+00	na
95-47-6	o-Xylene	5.69E+00	na	5.72E+00	na
95-48-7	2-Methylphenol (o-Cresol)	3.93E+00	na	3.95E+00	na
95-50-1	1,2-Dichlorobenzene (ortho-)	3.12E+00	na	3.24E+00	na
95-57-8	2-Chlorophenol	3.09E+01	na	3.12E+01	na
95-63-6	1,2,4-Trimethylbenzene	9.33E+01	na	9.36E+01	na
95-95-4	2,4,5-Trichlorophenol	5.88E-01	na	6.69E-01	na
98-86-2	Acetophenone	1.45E+00	na	1.45E+00	na
98-95-3	Nitrobenzene	4.73E+02	na	4.75E+02	na
100-25-4	1,4-Dinitrobenzene (para-)	3.01E+03	na	3.01E+03	na
100-41-4	Ethyl benzene	8.53E-01	3.60E-04	9.21E-01	3.83E-04
100-42-5	Styrene	7.13E-01	na	7.38E-01	na
100-51-6	Benzyl alcohol	6.12E-01	na	6.13E-01	na
106-42-3	p-Xylene	5.69E+00	na	5.72E+00	na
106-44-5	4-Methylphenol (p-Cresol)	3.84E+01	na	3.86E+01	na
106-46-7	1,4-Dichlorobenzene (para-)	1.70E+00	1.80E-03	2.08E+00	1.92E-03
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	4.25E+03	1.59E+00	4.28E+03	1.62E+00
106-99-0	1,3-Butadiene	3.80E+02	9.76E-03	3.83E+02	9.84E-03
107-02-8	2-Propenal (Acrolein)	2.80E+04	na	2.80E+04	na
107-05-1	3-Chloropropene (Allyl chloride)	5.54E+02	na	5.54E+02	na
107-06-2	1,2-Dichloroethane (Ethylene chloride)	1.14E+02	7.64E-03	1.14E+02	7.65E-03
107-13-1	Acrylonitrile	3.80E+02	3.98E-02	3.80E+02	3.99E-02
108-10-1	Methyl isobutyl ketone (4-Methyl-2-pentanone)	8.24E-01	na	8.28E-01	na
108-38-3	m-Xylene	5.69E+00	na	5.73E+00	na
108-39-4	3-Methylphenol (m-Cresol)	3.78E+00	na	3.80E+00	na
108-67-8	1,3,5-Trimethylbenzene	9.33E+01	na	9.35E+01	na
108-87-2	Methyl cyclohexane	2.63E-01	na	2.99E-01	na
108-88-3	Toluene (Methyl benzene)	1.54E+00	na	1.55E+00	na

Table C3. Unit Factors for the All Pathways Farmer Scenario.

CASRN	Chemical Name	Well Water Only, per mg/L		Columbia River, per mg/L	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
108-90-7	Chlorobenzene	1.10E+01	na	1.12E+01	na
108-94-1	Cyclohexanone	4.17E-02	na	4.18E-02	na
108-95-2	Phenol (Carbolic acid)	1.02E+00	na	1.02E+00	na
109-99-9	Tetrahydrofuran	2.31E+00	7.75E-04	2.31E+00	7.77E-04
110-00-9	Furan (Oxacyclopentadiene)	1.16E+02	na	1.16E+02	na
110-54-3	n-Hexane	3.45E+00	na	3.88E+00	na
110-80-5	2-Ethoxyethanol	1.33E+00	na	1.33E+00	na
110-82-7	Cyclohexane	1.30E-01	na	1.43E-01	na
110-86-1	Pyridine	2.96E+02	na	2.96E+02	na
111-76-2	2-Butoxyethanol (Ethylene Glycol Monobutyl Ether)	2.59E-01	na	2.60E-01	na
111-90-0	2-(2-Ethoxyethoxy)-ethanol (Diethylene Glycol Monoethyl Ether)	1.23E+01	na	1.23E+01	na
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)	9.23E+01	1.11E-02	9.46E+01	1.13E-02
117-84-0	Di-n-octylphthalate	1.19E+02	na	1.20E+02	na
118-74-1	Hexachlorobenzene	1.74E+02	1.50E-01	1.00E+03	6.05E-01
120-82-1	1,2,4-Trichlorobenzene	1.42E+02	na	1.45E+02	na
121-14-2	2,4-Dinitrotoluene	9.88E+01	na	9.94E+01	na
121-44-8	Triethylamine	1.56E+02	na	1.56E+02	na
122-39-4	Diphenylamine	2.90E+00	na	3.44E+00	na
123-91-1	1,4-Dioxane (Diethylene oxide)	na	1.51E-03	na	1.51E-03
126-73-8	Tributyl Phosphate	2.50E-01	1.16E-04	2.80E-01	1.29E-04
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)	1.51E+03	na	1.51E+03	na
127-18-4	Tetrachloroethylene	3.70E+00	7.54E-04	4.77E+00	9.92E-04
129-00-0	Pyrene	3.83E+00	na	8.83E+00	na
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	1.68E-01	na	1.69E-01	na
156-59-2	cis-1,2-Dichloroethylene	1.10E+01	na	1.11E+01	na
206-44-0	Fluoranthene (1,2-Benzacenaphthene)	3.16E+00	na	9.28E+00	na
309-00-2	Aldrin	8.21E+03	2.37E+00	9.49E+04	2.13E+01
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	1.84E+02	3.55E-01	2.29E+02	4.16E-01
319-85-7	beta-Benzene hexachloride (beta-Lindane)	2.96E+02	4.68E-02	4.06E+02	6.36E-02
541-73-1	1,3-Dichlorobenzene	1.22E+02	na	1.37E+02	na
542-75-6	1,3-Dichloropropene (cis & trans)	2.88E+01	2.31E-03	2.88E+01	2.35E-03
621-64-7	N-Nitrosodi-N-propylamine	na	1.09E+00	na	1.09E+00
1314-62-1	Vanadium pentoxide	3.77E+00	na	7.04E+00	na
1330-20-7	Xylenes (mixtures)	5.69E+00	na	5.72E+00	na
1336-36-3	Polychlorinated Biphenyls	na	8.01E-02	na	6.48E+00
1336-36-3	Polychlorinated Biphenyls (lowest risk)	na	7.20E-02	na	6.47E+00
6533-73-9	Thallium carbonate	6.44E+02	na	1.68E+04	na
7429-90-5	Aluminum	3.93E-02	na	1.08E-01	na
7439-89-6	Iron	1.44E-01	na	2.42E-01	na
7439-93-2	Lithium	3.73E+00	na	3.90E+00	na
7439-96-5	Manganese	1.78E+00	na	2.27E+00	na

Table C3. Unit Factors for the All Pathways Farmer Scenario.

CASRN	Chemical Name	Well Water Only, per mg/L		Columbia River, per mg/L	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
7439-97-6	Mercury metal vapor	7.56E+03	na	1.21E+04	na
7439-98-7	Molybdenum	3.85E+01	na	3.90E+01	na
7440-02-0	Nickel (soluble salts)	4.15E+00	na	4.97E+00	na
7440-22-4	Silver	7.36E+00	na	8.17E+00	na
7440-24-6	Strontium, Stable	3.53E-01	na	3.72E-01	na
7440-28-0	Thallium metal	7.79E+02	na	2.03E+04	na
7440-31-5	Tin	1.23E-01	na	7.73E-01	na
7440-36-0	Antimony	8.28E+01	na	1.34E+02	na
7440-38-2	Arsenic (inorganic)	1.13E+02	2.19E-02	2.29E+02	4.42E-02
7440-39-3	Barium	6.06E-01	na	6.70E-01	na
7440-41-7	Beryllium and compounds	1.82E+01	4.21E-05	3.05E+01	4.21E-05
7440-42-8	Boron and borates only	3.64E+00	na	3.65E+00	na
7440-43-9	Cadmium	9.70E+01	3.10E-05	1.60E+02	3.10E-05
7440-45-1	Cerium (Ceric oxide 1306-38-3)	2.00E+03	na	5.33E+03	na
7440-48-4	Cobalt	4.73E+00	4.79E-05	6.81E+00	4.79E-05
7440-50-8	Copper	6.23E+00	na	6.95E+00	na
7440-62-2	Vanadium metal	5.20E+00	na	1.06E+01	na
7440-66-6	Zinc and compounds	6.81E+01	na	6.82E+01	na
7487-94-7	Mercuric chloride	1.32E+03	na	1.76E+03	na
7664-41-7	Ammonia	1.78E+02	na	1.78E+02	na
7723-14-0	Phosphorus, white	1.10E+05	na	1.20E+05	na
7782-41-4	Fluorine (soluble fluoride)	1.84E+00	na	1.91E+00	na
7782-49-2	Selenium and compounds	1.31E+01	na	1.76E+01	na
8001-35-2	Toxaphene	na	4.58E-02	na	3.89E-01
11096-82-5	Aroclor 1260	na	4.67E+00	na	5.21E+00
11097-69-1	Aroclor 1254	1.58E+04	1.81E-01	9.22E+05	1.57E+01
11104-28-2	Aroclor 1221	na	4.07E-02	na	1.09E-01
11141-16-5	Aroclor 1232	na	4.07E-02	na	1.09E-01
12672-29-6	Aroclor 1248	na	7.84E-02	na	7.07E+00
12674-11-2	Aroclor 1016	1.95E+03	4.25E-02	3.45E+04	1.99E+00
14797-55-8	Nitrate	1.35E-02	na	1.39E-02	na
14797-65-0	Nitrite	2.23E-01	na	2.29E-01	na
16065-83-1	Chromium (III) (insoluble salts)	2.81E-02	na	5.76E-02	na
16984-48-8	Fluorine anion	1.84E+00	na	1.91E+00	na
18540-29-9	Chromium (VI) (soluble salts)	1.02E+01	5.19E-05	1.89E+01	5.19E-05
53469-21-9	Aroclor 1242	na	7.87E-02	na	6.48E+00
na	Uranium (soluble salts)	5.49E+01	na	5.92E+01	na
na	Total Chromium (1:6 ratio CrVI:Cr III)	1.48E+00	7.41E-06	2.75E+00	7.41E-06

Notes:

- CASRN = Chemical Abstract Service Reference Number
- The total risk to the All Pathways Farmer is calculated using intakes from 30 consecutive years. The soil concentration is zero at the start of the exposure.
- These scenario factors must be multiplied by the appropriate water concentration. The "Well Water Only" columns assume all the contaminated water comes from a well. The "Columbia River" columns assume all the contaminated water comes from the Columbia River.

Table C4. Comparison Ratios for the All Pathways Farmer Scenario.

CASRN	Chemical Name	Well Water Ratios		Columbia River Ratios	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
50-32-8	Benzo[a]pyrene				
53-70-3	Dibenz[a,h]anthracene				
56-23-5	Carbon tetrachloride	3.9		3.5	
57-12-5	Cyanide, free				
57-14-7	1,1-Dimethylhydrazine				
57-55-6	Propylene glycol (1,2-Propanediol)				
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)	1.3	1.3	1.2	1.2
60-29-7	Ethyl ether (Diethyl ether)	2.9		2.9	
60-34-4	Methylhydrazine				
60-57-1	Dieldrin	1.8			
62-75-9	N-Nitrosodimethylamine				
64-18-6	Formic acid				
67-56-1	Methanol (Methyl alcohol)				
67-64-1	Acetone (2-Propanone)	1.4		1.4	
67-66-3	Chloroform				
67-72-1	Hexachloroethane	3.5		2.1	
71-36-3	n-Butyl alcohol (n-Butanol)				
71-43-2	Benzene				
71-55-6	1,1,1-Trichloroethane (Methyl chloroform)				
72-20-8	Endrin				
74-83-9	Bromomethane				
74-87-3	Methyl chloride (Chloromethane)	1.5		1.5	
75-00-3	Ethyl Chloride				
75-01-4	Vinyl chloride (Chloroethene)				
75-05-8	Acetonitrile	4.4		4.4	
75-07-0	Acetaldehyde	3.3	3.3	3.3	3.3
75-09-2	Dichloromethane (Methylene chloride)				
75-15-0	Carbon disulfide				
75-21-8	Ethylene Oxide (Oxirane)				
75-34-3	1,1-Dichloroethane (Ethylidene chloride)				
75-35-4	1,1-Dichloroethylene				
75-45-6	Chlorodifluoromethane	1.5		1.5	
75-68-3	Chloro-1,1-difluoroethane, 1-	1.4		1.4	
75-69-4	Trichlorofluoromethane				
75-71-8	Dichlorodifluoromethane				
76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane (CFC-113)				
76-44-8	Heptachlor	2.1			
78-83-1	Isobutanol	1.3		1.3	
78-87-5	1,2-Dichloropropane	1.4	3.5	1.4	3.4
78-93-3	Methyl ethyl ketone (2-Butanone)				
79-00-5	1,1,2-Trichloroethane	3.2		3.1	

Table C4. Comparison Ratios for the All Pathways Farmer Scenario.

CASRN	Chemical Name	Well Water Ratios		Columbia River Ratios	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
79-01-6	Trichloroethylene				
79-10-7	2-Propenoic acid (Acrylic acid)				
79-34-5	1,1,2,2-Tetrachloroethane (Acetylene tetrachloride)	3.2		3.1	
79-46-9	2-Nitropropane	2.1	2.1	2.1	2.1
82-68-8	Pentachloronitrobenzene (PCNB)	3.2	3.2	1.6	1.6
83-32-9	Acenaphthene	2.6		2.0	
84-66-2	Diethyl phthalate				
84-74-2	Dibutyl phthalate				
85-68-7	Butyl benzyl phthalate				
87-68-3	Hexachlorobutadiene	3.3		1.5	
87-86-5	Pentachlorophenol				
88-06-2	2,4,6-Trichlorophenol				
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)				
91-20-3	Naphthalene				
92-52-4	1,1'-Biphenyl	2.8		2.1	
95-47-6	o-Xylene				
95-48-7	2-Methylphenol (o-Cresol)				
95-50-1	1,2-Dichlorobenzene (ortho-)				
95-57-8	2-Chlorophenol	1.3		1.3	
95-63-6	1,2,4-Trimethylbenzene				
95-95-4	2,4,5-Trichlorophenol				
98-86-2	Acetophenone	1.3		1.3	
98-95-3	Nitrobenzene				
100-25-4	1,4-Dinitrobenzene (para-)				
100-41-4	Ethyl benzene		1.4		1.5
100-42-5	Styrene				
100-51-6	Benzyl alcohol				
106-42-3	p-Xylene				
106-44-5	4-Methylphenol (p-Cresol)				
106-46-7	1,4-Dichlorobenzene (para-)				
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	1.5		1.5	
106-99-0	1,3-Butadiene	1.4	1.4	1.4	1.4
107-02-8	2-Propenal (Acrolein)				
107-05-1	3-Chloropropene (Allyl chloride)				
107-06-2	1,2-Dichloroethane (Ethylene chloride)				
107-13-1	Acrylonitrile				
108-10-1	Methyl isobutyl ketone (4-Methyl-2-pentanone)				
108-38-3	m-Xylene				
108-39-4	3-Methylphenol (m-Cresol)				
108-67-8	1,3,5-Trimethylbenzene				
108-87-2	Methyl cyclohexane	1.4		1.6	
108-88-3	Toluene (Methyl benzene)				

Table C4. Comparison Ratios for the All Pathways Farmer Scenario.

CASRN	Chemical Name	Well Water Ratios		Columbia River Ratios	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
108-90-7	Chlorobenzene				
108-94-1	Cyclohexanone				
108-95-2	Phenol (Carbolic acid)				
109-99-9	Tetrahydrofuran				
110-00-9	Furan (Oxacyclopentadiene)	3.2		3.2	
110-54-3	n-Hexane				
110-80-5	2-Ethoxyethanol				
110-82-7	Cyclohexane	1.4		1.5	
110-86-1	Pyridine				
111-76-2	2-Butoxyethanol (Ethylene Glycol Monobutyl Ether)				
111-90-0	2-(2-Ethoxyethoxy)-ethanol (Diethylene Glycol Monoethyl Ether)				
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)				
117-84-0	Di-n-octylphthalate				
118-74-1	Hexachlorobenzene	2.3			
120-82-1	1,2,4-Trichlorobenzene				
121-14-2	2,4-Dinitrotoluene				
121-44-8	Triethylamine	2.0		2.0	
122-39-4	Diphenylamine				
123-91-1	1,4-Dioxane (Diethylene oxide)				
126-73-8	Tributyl Phosphate				
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)				
127-18-4	Tetrachloroethylene				
129-00-0	Pyrene	1.5			
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	2.1		2.1	
156-59-2	cis-1,2-Dichloroethylene	3.5		3.5	
206-44-0	Fluoranthene (1,2-Benzacenaphthene)	1.3			
309-00-2	Aldrin	1.5			
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	1.7		1.5	
319-85-7	beta-Benzene hexachloride (beta-Lindane)				
541-73-1	1,3-Dichlorobenzene	3.6		2.8	
542-75-6	1,3-Dichloropropene (cis & trans)				
621-64-7	N-Nitrosodi-N-propylamine				
1314-62-1	Vanadium pentoxide				
1330-20-7	Xylenes (mixtures)				
1336-36-3	Polychlorinated Biphenyls				
1336-36-3	Polychlorinated Biphenyls (lowest risk)				
6533-73-9	Thallium carbonate				
7429-90-5	Aluminum				
7439-89-6	Iron				
7439-93-2	Lithium				
7439-96-5	Manganese				

Table C4. Comparison Ratios for the All Pathways Farmer Scenario.

CASRN	Chemical Name	Well Water Ratios		Columbia River Ratios	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
7439-97-6	Mercury metal vapor	193,606		310,479	
7439-98-7	Molybdenum				
7440-02-0	Nickel (soluble salts)				
7440-22-4	Silver				
7440-24-6	Strontium, Stable				
7440-28-0	Thallium metal				
7440-31-5	Tin				
7440-36-0	Antimony				
7440-38-2	Arsenic (inorganic)				
7440-39-3	Barium				
7440-41-7	Beryllium and compounds				
7440-42-8	Boron and borates only				
7440-43-9	Cadmium				
7440-45-1	Cerium (Ceric oxide 1306-38-3)	9,702		25,820	
7440-48-4	Cobalt				
7440-50-8	Copper				
7440-62-2	Vanadium metal				
7440-66-6	Zinc and compounds				
7487-94-7	Mercuric chloride				
7664-41-7	Ammonia	228		228	
7723-14-0	Phosphorus, white				
7782-41-4	Fluorine (soluble fluoride)				
7782-49-2	Selenium and compounds				
8001-35-2	Toxaphene				
11096-82-5	Aroclor 1260				
11097-69-1	Aroclor 1254	1.3			
11104-28-2	Aroclor 1221				
11141-16-5	Aroclor 1232				
12672-29-6	Aroclor 1248				
12674-11-2	Aroclor 1016	2.4			
14797-55-8	Nitrate				
14797-65-0	Nitrite				
16065-83-1	Chromium (III) (insoluble salts)				
16984-48-8	Fluorine anion				
18540-29-9	Chromium (VI) (soluble salts)				
53469-21-9	Aroclor 1242				
na	Uranium (soluble salts)				
na	Total Chromium (1:6 ratio CrVI:Cr III)				

Notes:

- CASRN = Chemical Abstract Service Reference Number
- The ratios shown are the unit factors in Table C3 divided by the unit factors in Table 15.
- Ratios less than 1.2 are not listed.

Table C5. Unit Factors for the Native American Scenario.

CASRN	Chemical Name	Well Water Only, per mg/L		Columbia River, per mg/L	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
50-32-8	Benzo[a]pyrene	na	1.04E+01	na	6.14E+02
53-70-3	Dibenz[a,h]anthracene	na	1.80E+01	na	1.81E+03
56-23-5	Carbon tetrachloride	2.61E+02	2.08E-02	6.01E+02	5.17E-02
57-12-5	Cyanide, free	1.16E+02	na	1.18E+02	na
57-14-7	1,1-Dimethylhydrazine	na	3.85E+01	na	3.86E+01
57-55-6	Propylene glycol (1,2-Propanediol)	1.02E+01	na	1.03E+01	na
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)	7.78E+02	3.03E-01	5.16E+03	1.97E+00
60-29-7	Ethyl ether (Diethyl ether)	1.15E+00	na	1.28E+00	na
60-34-4	Methylhydrazine	na	2.88E+01	na	2.89E+01
60-57-1	Dieldrin	3.59E+03	3.59E+00	4.56E+05	3.63E+02
62-75-9	N-Nitrosodimethylamine	7.55E+05	3.09E+02	7.60E+05	3.10E+02
64-18-6	Formic acid	1.72E+00	na	1.74E+00	na
67-56-1	Methanol (Methyl alcohol)	4.38E+00	na	4.44E+00	na
67-64-1	Acetone (2-Propanone)	8.77E-01	na	9.06E-01	na
67-66-3	Chloroform	2.68E+02	1.80E-02	2.74E+02	1.80E-02
67-72-1	Hexachloroethane	2.11E+02	4.52E-03	2.61E+03	3.81E-02
71-36-3	n-Butyl alcohol (n-Butanol)	3.43E+01	na	3.46E+01	na
71-43-2	Benzene	4.62E+01	1.05E-02	6.40E+01	1.44E-02
71-55-6	1,1,1-Trichloroethane (Methyl chloroform)	6.01E-01	na	1.07E+00	na
72-20-8	Endrin	2.74E+03	na	7.72E+04	na
74-83-9	Bromomethane	2.24E+02	na	2.34E+02	na
74-87-3	Methyl chloride (Chloromethane)	1.70E+01	2.79E-03	1.90E+01	3.13E-03
75-00-3	Ethyl Chloride	2.86E-01	2.41E-04	3.40E-01	3.03E-04
75-01-4	Vinyl chloride (Chloroethene)	3.40E+01	1.17E-01	4.38E+01	1.58E-01
75-05-8	Acetonitrile	1.23E+02	na	1.26E+02	na
75-07-0	Acetaldehyde	5.60E+02	1.11E-02	5.80E+02	1.15E-02
75-09-2	Dichloromethane (Methylene chloride)	1.86E+00	1.09E-03	2.12E+00	1.20E-03
75-15-0	Carbon disulfide	1.87E+00	na	2.46E+00	na
75-21-8	Ethylene Oxide (Oxirane)	na	5.58E-01	na	5.83E-01
75-34-3	1,1-Dichloroethane (Ethylidene chloride)	2.34E+00	na	2.73E+00	na
75-35-4	1,1-Dichloroethylene	5.33E+00	na	6.73E+00	na
75-45-6	Chlorodifluoromethane	2.91E-02	na	3.07E-02	na
75-68-3	Chloro-1,1-difluoroethane, 1-	2.57E-02	na	3.43E-02	na
75-69-4	Trichlorofluoromethane	1.40E+00	na	1.89E+00	na
75-71-8	Dichlorodifluoromethane	4.31E+00	na	4.71E+00	na
76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane (CFC-113)	2.83E-02	na	4.24E-02	na
76-44-8	Heptachlor	6.94E+02	2.06E+00	1.55E+05	3.48E+02
78-83-1	Isobutanol	1.36E+00	na	1.46E+00	na
78-87-5	1,2-Dichloropropane	3.39E+02	1.31E-02	4.34E+02	1.68E-02
78-93-3	Methyl ethyl ketone (2-Butanone)	8.58E-01	na	9.02E-01	na
79-00-5	1,1,2-Trichloroethane	5.26E+01	1.84E-02	6.43E+01	2.10E-02

Table C5. Unit Factors for the Native American Scenario.

CASRN	Chemical Name	Well Water Only, per mg/L		Columbia River, per mg/L	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
79-01-6	Trichloroethylene	3.37E+02	1.27E-01	7.68E+02	1.79E-01
79-10-7	2-Propenoic acid (Acrylic acid)	1.34E+01	na	1.34E+01	na
79-34-5	1,1,2,2-Tetrachloroethane (Acetylene tetrachloride)	3.52E+00	6.45E-02	5.39E+00	8.68E-02
79-46-9	2-Nitropropane	1.32E+02	7.10E+00	1.42E+02	7.61E+00
82-68-8	Pentachloronitrobenzene (PCNB)	7.23E+01	5.64E-02	2.03E+03	1.57E+00
83-32-9	Acenaphthene	5.51E+00	na	3.46E+01	na
84-66-2	Diethyl phthalate	3.83E-01	na	5.73E-01	na
84-74-2	Dibutyl phthalate	1.22E+00	na	4.74E+01	na
85-68-7	Butyl benzyl phthalate	8.08E-01	na	3.70E+01	na
87-68-3	Hexachlorobutadiene	8.01E+02	2.74E-02	2.55E+04	6.06E-01
87-86-5	Pentachlorophenol	5.14E+00	1.85E-02	1.93E+02	6.89E-01
88-06-2	2,4,6-Trichlorophenol	2.00E+03	2.33E-03	7.89E+03	8.34E-03
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)	2.80E+02	na	1.44E+03	na
91-20-3	Naphthalene	2.66E+02	na	2.94E+02	na
92-52-4	1,1'-Biphenyl	5.65E+00	na	4.32E+01	na
95-47-6	o-Xylene	8.25E+00	na	1.03E+01	na
95-48-7	2-Methylphenol (o-Cresol)	1.41E+01	na	1.68E+01	na
95-50-1	1,2-Dichlorobenzene (ortho-)	4.90E+00	na	1.26E+01	na
95-57-8	2-Chlorophenol	9.14E+01	na	1.16E+02	na
95-63-6	1,2,4-Trimethylbenzene	1.33E+02	na	1.52E+02	na
95-95-4	2,4,5-Trichlorophenol	1.96E+00	na	8.14E+00	na
98-86-2	Acetophenone	4.17E+00	na	4.34E+00	na
98-95-3	Nitrobenzene	1.05E+03	na	1.16E+03	na
100-25-4	1,4-Dinitrobenzene (para-)	1.09E+04	na	1.18E+04	na
100-41-4	Ethyl benzene	1.64E+00	1.52E-03	5.86E+00	4.77E-03
100-42-5	Styrene	1.24E+00	na	2.74E+00	na
100-51-6	Benzyl alcohol	2.09E+00	na	2.14E+00	na
106-42-3	p-Xylene	8.25E+00	na	1.04E+01	na
106-44-5	4-Methylphenol (p-Cresol)	1.37E+02	na	1.61E+02	na
106-46-7	1,4-Dichlorobenzene (para-)	3.85E+00	6.98E-03	2.71E+01	2.37E-02
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	8.04E+03	1.02E+01	9.91E+03	1.47E+01
106-99-0	1,3-Butadiene	6.57E+02	3.94E-02	8.57E+02	5.13E-02
107-02-8	2-Propenal (Acrolein)	3.99E+04	na	3.99E+04	na
107-05-1	3-Chloropropene (Allyl chloride)	7.82E+02	na	7.83E+02	na
107-06-2	1,2-Dichloroethane (Ethylene chloride)	1.63E+02	2.95E-02	1.64E+02	3.16E-02
107-13-1	Acrylonitrile	7.24E+02	2.33E-01	7.50E+02	2.47E-01
108-10-1	Methyl isobutyl ketone (4-Methyl-2-pentanone)	2.14E+00	na	2.37E+00	na
108-38-3	m-Xylene	8.26E+00	na	1.06E+01	na
108-39-4	3-Methylphenol (m-Cresol)	1.36E+01	na	1.62E+01	na
108-67-8	1,3,5-Trimethylbenzene	1.32E+02	na	1.46E+02	na
108-87-2	Methyl cyclohexane	5.43E-01	na	2.78E+00	na
108-88-3	Toluene (Methyl benzene)	2.37E+00	na	3.39E+00	na

Table C5. Unit Factors for the Native American Scenario.

CASRN	Chemical Name	Well Water Only, per mg/L		Columbia River, per mg/L	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
108-90-7	Chlorobenzene	1.84E+01	na	3.14E+01	na
108-94-1	Cyclohexanone	1.30E-01	na	1.37E-01	na
108-95-2	Phenol (Carbolic acid)	3.72E+00	na	3.96E+00	na
109-99-9	Tetrahydrofuran	4.09E+00	3.89E-03	4.22E+00	4.09E-03
110-00-9	Furan (Oxacyclopentadiene)	2.10E+02	na	2.29E+02	na
110-54-3	n-Hexane	6.87E+00	na	3.37E+01	na
110-80-5	2-Ethoxyethanol	4.59E+00	na	4.67E+00	na
110-82-7	Cyclohexane	2.54E-01	na	1.08E+00	na
110-86-1	Pyridine	9.53E+02	na	9.89E+02	na
111-76-2	2-Butoxyethanol (Ethylene Glycol Monobutyl Ether)	8.59E-01	na	9.20E-01	na
111-90-0	2-(2-Ethoxyethoxy)-ethanol (Diethylene Glycol Monoethyl Ether)	4.58E+01	na	4.64E+01	na
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)	4.14E+02	1.16E-01	8.81E+02	2.33E-01
117-84-0	Di-n-octylphthalate	4.47E+02	na	7.39E+02	na
118-74-1	Hexachlorobenzene	5.20E+02	8.44E-01	5.04E+04	6.47E+01
120-82-1	1,2,4-Trichlorobenzene	2.06E+02	na	3.99E+02	na
121-14-2	2,4-Dinitrotoluene	3.63E+02	na	4.24E+02	na
121-44-8	Triethylamine	3.54E+02	na	3.80E+02	na
122-39-4	Diphenylamine	9.53E+00	na	4.68E+01	na
123-91-1	1,4-Dioxane (Diethylene oxide)	na	1.19E-02	na	1.22E-02
126-73-8	Tributyl Phosphate	8.75E-01	9.41E-04	3.65E+00	3.57E-03
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)	3.34E+03	na	3.61E+03	na
127-18-4	Tetrachloroethylene	8.62E+00	4.26E-03	7.32E+01	3.78E-02
129-00-0	Pyrene	1.63E+01	na	3.46E+02	na
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	3.74E-01	na	4.04E-01	na
156-59-2	cis-1,2-Dichloroethylene	1.92E+01	na	2.37E+01	na
206-44-0	Fluoranthene (1,2-Benzacenaphthene)	1.60E+01	na	4.09E+02	na
309-00-2	Aldrin	2.61E+04	1.52E+01	5.25E+06	2.68E+03
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	4.73E+02	1.84E+00	3.39E+03	1.08E+01
319-85-7	beta-Benzene hexachloride (beta-Lindane)	1.08E+03	3.93E-01	8.46E+03	2.97E+00
541-73-1	1,3-Dichlorobenzene	2.26E+02	na	1.14E+03	na
542-75-6	1,3-Dichloropropene (cis & trans)	4.19E+01	1.15E-02	4.39E+01	1.75E-02
621-64-7	N-Nitrosodi-N-propylamine	na	9.02E+00	na	9.60E+00
1314-62-1	Vanadium pentoxide	1.18E+01	na	3.14E+02	na
1330-20-7	Xylenes (mixtures)	8.24E+00	na	1.02E+01	na
1336-36-3	Polychlorinated Biphenyls	na	4.74E-01	na	8.95E+02
1336-36-3	Polychlorinated Biphenyls (lowest risk)	na	3.64E-01	na	8.95E+02
6533-73-9	Thallium carbonate	1.73E+03	na	9.89E+05	na
7429-90-5	Aluminum	1.37E+00	na	6.64E+00	na
7439-89-6	Iron	3.61E-01	na	9.74E+00	na
7439-93-2	Lithium	1.72E+01	na	6.71E+01	na
7439-96-5	Manganese	1.34E+02	na	2.02E+02	na

Table C5. Unit Factors for the Native American Scenario.

CASRN	Chemical Name	Well Water Only, per mg/L		Columbia River, per mg/L	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
7439-97-6	Mercury metal vapor	3.40E+04	na	7.85E+05	na
7439-98-7	Molybdenum	2.01E+02	na	2.82E+02	na
7440-02-0	Nickel (soluble salts)	2.49E+01	na	1.18E+02	na
7440-22-4	Silver	1.81E+01	na	2.40E+02	na
7440-24-6	Strontium, Stable	2.36E+00	na	4.94E+00	na
7440-28-0	Thallium metal	2.06E+03	na	1.19E+06	na
7440-31-5	Tin	3.20E-01	na	4.12E+01	na
7440-36-0	Antimony	3.08E+02	na	1.08E+04	na
7440-38-2	Arsenic (inorganic)	3.09E+02	1.65E-01	9.89E+03	4.38E+00
7440-39-3	Barium	1.48E+01	na	3.41E+01	na
7440-41-7	Beryllium and compounds	3.77E+02	1.55E-02	3.57E+03	1.55E-02
7440-42-8	Boron and borates only	1.67E+01	na	1.87E+01	na
7440-43-9	Cadmium	5.08E+02	1.16E-02	2.03E+04	1.16E-02
7440-45-1	Cerium (Ceric oxide 1306-38-3)	1.50E+04	na	1.79E+06	na
7440-48-4	Cobalt	3.31E+02	1.80E-02	4.88E+02	1.80E-02
7440-50-8	Copper	3.83E+01	na	9.60E+01	na
7440-62-2	Vanadium metal	1.95E+01	na	1.08E+03	na
7440-66-6	Zinc and compounds	3.36E+02	na	3.47E+02	na
7487-94-7	Mercuric chloride	3.21E+03	na	3.09E+04	na
7664-41-7	Ammonia	6.37E+02	na	6.39E+02	na
7723-14-0	Phosphorus, white	5.35E+05	na	1.14E+06	na
7782-41-4	Fluorine (soluble fluoride)	4.39E+00	na	2.07E+01	na
7782-49-2	Selenium and compounds	2.69E+01	na	3.58E+02	na
8001-35-2	Toxaphene	na	2.92E-01	na	4.90E+01
11096-82-5	Aroclor 1260	na	3.00E+01	na	1.35E+02
11097-69-1	Aroclor 1254	4.92E+04	1.10E+00	5.44E+07	2.17E+03
11104-28-2	Aroclor 1221	na	2.05E-01	na	9.86E+00
11141-16-5	Aroclor 1232	na	2.05E-01	na	9.86E+00
12672-29-6	Aroclor 1248	na	4.61E-01	na	9.78E+02
12674-11-2	Aroclor 1016	5.19E+03	2.00E-01	1.96E+06	2.73E+02
14797-55-8	Nitrate	2.80E-02	na	6.51E-02	na
14797-65-0	Nitrite	4.49E-01	na	1.04E+00	na
16065-83-1	Chromium (III) (insoluble salts)	1.16E-01	na	7.15E+00	na
16984-48-8	Fluorine anion	4.39E+00	na	2.07E+01	na
18540-29-9	Chromium (VI) (soluble salts)	8.06E+02	7.53E-02	1.36E+03	7.53E-02
53469-21-9	Aroclor 1242	na	4.64E-01	na	8.95E+02
na	Uranium (soluble salts)	1.37E+02	na	7.55E+02	na
na	Total Chromium (1:6 ratio CrVI:Cr III)	1.15E+02	1.08E-02	2.01E+02	1.08E-02

Notes:

- CASRN = Chemical Abstract Service Reference Number
- The total risk to the Native American is calculated using intakes from 70 consecutive years. The soil concentration is zero at the start of the exposure.
- These scenario factors must be multiplied by the appropriate water concentration. The "Well Water" columns assume all the contaminated water comes from the well. The "Columbia River" columns assume all contaminated water comes from the Columbia River.

Table C6. Unit Factor Ratios for the Native American Scenario.

CASRN	Chemical Name	Well Water Ratios		Columbia River Ratios	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
50-32-8	Benzo[a]pyrene				
53-70-3	Dibenz[a,h]anthracene				
56-23-5	Carbon tetrachloride	2.6		1.4	
57-12-5	Cyanide, free				
57-14-7	1,1-Dimethylhydrazine				
57-55-6	Propylene glycol (1,2-Propanediol)				
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)				
60-29-7	Ethyl ether (Diethyl ether)	1.9		1.8	
60-34-4	Methylhydrazine				
60-57-1	Dieldrin	1.3			
62-75-9	N-Nitrosodimethylamine				
64-18-6	Formic acid				
67-56-1	Methanol (Methyl alcohol)				
67-64-1	Acetone (2-Propanone)				
67-66-3	Chloroform				
67-72-1	Hexachloroethane	2.1			
71-36-3	n-Butyl alcohol (n-Butanol)				
71-43-2	Benzene				
71-55-6	1,1,1-Trichloroethane (Methyl chloroform)				
72-20-8	Endrin				
74-83-9	Bromomethane				
74-87-3	Methyl chloride (Chloromethane)	2.0		2.2	
75-00-3	Ethyl Chloride				
75-01-4	Vinyl chloride (Chloroethene)				
75-05-8	Acetonitrile	9.4		9.7	
75-07-0	Acetaldehyde	6.4	6.4	6.7	6.7
75-09-2	Dichloromethane (Methylene chloride)				
75-15-0	Carbon disulfide				
75-21-8	Ethylene Oxide (Oxirane)				
75-34-3	1,1-Dichloroethane (Ethylidene chloride)				
75-35-4	1,1-Dichloroethylene				
75-45-6	Chlorodifluoromethane	1.9		2.0	
75-68-3	Chloro-1,1-difluoroethane, 1-	1.6		2.2	
75-69-4	Trichlorofluoromethane				
75-71-8	Dichlorodifluoromethane				
76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane (CFC-113)				
76-44-8	Heptachlor	1.5			
78-83-1	Isobutanol				
78-87-5	1,2-Dichloropropane	1.7	2.4	2.2	1.8
78-93-3	Methyl ethyl ketone (2-Butanone)				
79-00-5	1,1,2-Trichloroethane	2.1		1.8	

Table C6. Unit Factor Ratios for the Native American Scenario.

CASRN	Chemical Name	Well Water Ratios		Columbia River Ratios	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
79-01-6	Trichloroethylene				
79-10-7	2-Propenoic acid (Acrylic acid)				
79-34-5	1,1,2,2-Tetrachloroethane (Acetylene tetrachloride)	2.1		1.5	
79-46-9	2-Nitropropane	3.4	3.4	3.6	3.6
82-68-8	Pentachloronitrobenzene (PCNB)	2.1	2.1		
83-32-9	Acenaphthene	1.5			
84-66-2	Diethyl phthalate				
84-74-2	Dibutyl phthalate				
85-68-7	Butyl benzyl phthalate				
87-68-3	Hexachlorobutadiene	1.9			
87-86-5	Pentachlorophenol				
88-06-2	2,4,6-Trichlorophenol				
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)				
91-20-3	Naphthalene				
92-52-4	1,1'-Biphenyl	1.7			
95-47-6	o-Xylene				
95-48-7	2-Methylphenol (o-Cresol)				
95-50-1	1,2-Dichlorobenzene (ortho-)				
95-57-8	2-Chlorophenol				
95-63-6	1,2,4-Trimethylbenzene				
95-95-4	2,4,5-Trichlorophenol				
98-86-2	Acetophenone				
98-95-3	Nitrobenzene				
100-25-4	1,4-Dinitrobenzene (para-)				
100-41-4	Ethyl benzene		1.8		5.5
100-42-5	Styrene				
100-51-6	Benzyl alcohol				
106-42-3	p-Xylene				
106-44-5	4-Methylphenol (p-Cresol)				
106-46-7	1,4-Dichlorobenzene (para-)				
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	2.1		2.5	
106-99-0	1,3-Butadiene	1.7	1.7	2.2	2.2
107-02-8	2-Propenal (Acrolein)				
107-05-1	3-Chloropropene (Allyl chloride)				
107-06-2	1,2-Dichloroethane (Ethylene chloride)				
107-13-1	Acrylonitrile				
108-10-1	Methyl isobutyl ketone (4-Methyl-2-pentanone)				
108-38-3	m-Xylene				
108-39-4	3-Methylphenol (m-Cresol)				
108-67-8	1,3,5-Trimethylbenzene				
108-87-2	Methyl cyclohexane	2.1		10.7	
108-88-3	Toluene (Methyl benzene)				

Table C6. Unit Factor Ratios for the Native American Scenario.

CASRN	Chemical Name	Well Water Ratios		Columbia River Ratios	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
108-90-7	Chlorobenzene				
108-94-1	Cyclohexanone				
108-95-2	Phenol (Carbolic acid)				
109-99-9	Tetrahydrofuran				
110-00-9	Furan (Oxacyclopentadiene)	2.1		2.0	
110-54-3	n-Hexane				
110-80-5	2-Ethoxyethanol				
110-82-7	Cyclohexane	1.9		8.3	
110-86-1	Pyridine				
111-76-2	2-Butoxyethanol (Ethylene Glycol Monobutyl Ether)				
111-90-0	2-(2-Ethoxyethoxy)-ethanol (Diethylene Glycol Monoethyl Ether)				
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)				
117-84-0	Di-n-octylphthalate				
118-74-1	Hexachlorobenzene	1.4			
120-82-1	1,2,4-Trichlorobenzene				
121-14-2	2,4-Dinitrotoluene				
121-44-8	Triethylamine	3.2		3.4	
122-39-4	Diphenylamine				
123-91-1	1,4-Dioxane (Diethylene oxide)				
126-73-8	Tributyl Phosphate				
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)				
127-18-4	Tetrachloroethylene				
129-00-0	Pyrene				
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	1.5		1.4	
156-59-2	cis-1,2-Dichloroethylene	2.4		1.9	
206-44-0	Fluoranthene (1,2-Benzacenaphthene)				
309-00-2	Aldrin				
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	1.3			
319-85-7	beta-Benzene hexachloride (beta-Lindane)				
541-73-1	1,3-Dichlorobenzene	2.2			
542-75-6	1,3-Dichloropropene (cis & trans)				
621-64-7	N-Nitrosodi-N-propylamine				
1314-62-1	Vanadium pentoxide				
1330-20-7	Xylenes (mixtures)				
1336-36-3	Polychlorinated Biphenyls				
1336-36-3	Polychlorinated Biphenyls (lowest risk)				
6533-73-9	Thallium carbonate				
7429-90-5	Aluminum				
7439-89-6	Iron				
7439-93-2	Lithium				
7439-96-5	Manganese				

Table C6. Unit Factor Ratios for the Native American Scenario.

CASRN	Chemical Name	Well Water Ratios		Columbia River Ratios	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
7439-97-6	Mercury metal vapor	1,623		37,501	
7439-98-7	Molybdenum				
7440-02-0	Nickel (soluble salts)				
7440-22-4	Silver				
7440-24-6	Strontium, Stable				
7440-28-0	Thallium metal				
7440-31-5	Tin				
7440-36-0	Antimony				
7440-38-2	Arsenic (inorganic)				
7440-39-3	Barium				
7440-41-7	Beryllium and compounds				
7440-42-8	Boron and borates only				
7440-43-9	Cadmium				
7440-45-1	Cerium (Ceric oxide 1306-38-3)	464		55,627	
7440-48-4	Cobalt				
7440-50-8	Copper				
7440-62-2	Vanadium metal				
7440-66-6	Zinc and compounds				
7487-94-7	Mercuric chloride				
7664-41-7	Ammonia	578		580	
7723-14-0	Phosphorus, white				
7782-41-4	Fluorine (soluble fluoride)				
7782-49-2	Selenium and compounds				
8001-35-2	Toxaphene				
11096-82-5	Aroclor 1260				
11097-69-1	Aroclor 1254				
11104-28-2	Aroclor 1221				
11141-16-5	Aroclor 1232				
12672-29-6	Aroclor 1248				
12674-11-2	Aroclor 1016	1.4			
14797-55-8	Nitrate				
14797-65-0	Nitrite				
16065-83-1	Chromium (III) (insoluble salts)				
16984-48-8	Fluorine anion				
18540-29-9	Chromium (VI) (soluble salts)				
53469-21-9	Aroclor 1242				
na	Uranium (soluble salts)				
na	Total Chromium (1:6 ratio CrVI:Cr III)				

Notes:

- CASRN = Chemical Abstract Service Reference Number
- The ratios shown are the unit factors in Table C5 divided by the unit factors in Table 18.
- Ratios less than 1.2 are not listed.

Table C7. Unit Factors: Columbia River Population & HSRAM Industrial Scenarios.

CASRN	Chemical Name	Columbia River Population (per mg/L)		HSRAM Industrial (per mg/L)	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
50-32-8	Benzo[a]pyrene	na	1.01E+07	na	2.95E-01
53-70-3	Dibenz[a,h]anthracene	na	2.14E+07	na	3.91E-01
56-23-5	Carbon tetrachloride	7.84E+08	6.10E+04	8.62E+01	1.87E-03
57-12-5	Cyanide, free	2.61E+08	na	2.97E+00	na
57-14-7	1,1-Dimethylhydrazine	na	8.35E+07	na	9.79E-03
57-55-6	Propylene glycol (1,2-Propanediol)	1.77E+07	na	2.04E-02	na
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)	1.82E+09	7.06E+05	7.06E+01	7.87E-03
60-29-7	Ethyl ether (Diethyl ether)	3.33E+06	na	2.97E-01	na
60-34-4	Methylhydrazine	na	6.24E+07	na	9.04E-03
60-57-1	Dieldrin	8.67E+09	9.45E+06	6.60E+02	2.43E-01
62-75-9	N-Nitrosodimethylamine	1.64E+12	6.71E+08	1.69E+03	2.50E-01
64-18-6	Formic acid	3.73E+06	na	5.08E-03	na
67-56-1	Methanol (Methyl alcohol)	9.59E+06	na	3.80E-02	na
67-64-1	Acetone (2-Propanone)	2.09E+06	na	6.58E-02	na
67-66-3	Chloroform	9.39E+08	6.38E+04	1.16E+02	2.27E-03
67-72-1	Hexachloroethane	5.74E+08	1.36E+04	6.31E+01	4.50E-04
71-36-3	n-Butyl alcohol (n-Butanol)	1.17E+08	na	1.38E+01	na
71-43-2	Benzene	1.37E+08	3.15E+04	1.42E+01	9.35E-04
71-55-6	1,1,1-Trichloroethane (Methyl chloroform)	1.81E+06	na	1.94E-01	na
72-20-8	Endrin	3.04E+09	na	3.21E+02	na
74-83-9	Bromomethane	7.09E+08	na	7.62E+01	na
74-87-3	Methyl chloride (Chloromethane)	4.97E+07	8.15E+03	4.62E+00	2.15E-04
75-00-3	Ethyl Chloride	7.52E+05	5.51E+02	5.98E-02	8.38E-06
75-01-4	Vinyl chloride (Chloroethene)	8.74E+07	2.75E+05	6.84E+00	2.52E-03
75-05-8	Acetonitrile	2.86E+08	na	6.93E+00	na
75-07-0	Acetaldehyde	1.34E+09	2.66E+04	4.61E+01	2.61E-04
75-09-2	Dichloromethane (Methylene chloride)	4.59E+06	2.96E+03	2.81E-01	6.79E-05
75-15-0	Carbon disulfide	5.62E+06	na	6.00E-01	na
75-21-8	Ethylene Oxide (Oxirane)	na	1.33E+06	na	1.27E-02
75-34-3	1,1-Dichloroethane (Ethylidene chloride)	7.34E+06	na	7.92E-01	na
75-35-4	1,1-Dichloroethylene	1.71E+07	na	1.94E+00	na
75-45-6	Chlorodifluoromethane	8.63E+04	na	8.30E-03	na
75-68-3	Chloro-1,1-difluoroethane, 1-	7.82E+04	na	8.35E-03	na
75-69-4	Trichlorofluoromethane	4.50E+06	na	5.35E-01	na
75-71-8	Dichlorodifluoromethane	1.47E+07	na	1.79E+00	na
76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane (CFC-113)	9.74E+04	na	1.19E-02	na
76-44-8	Heptachlor	1.57E+09	5.30E+06	1.38E+02	1.52E-01
78-83-1	Isobutanol	3.21E+06	na	9.88E-02	na
78-87-5	1,2-Dichloropropane	1.02E+09	3.95E+04	1.05E+02	1.16E-03
78-93-3	Methyl ethyl ketone (2-Butanone)	2.10E+06	na	8.55E-02	na

Table C7. Unit Factors: Columbia River Population & HSRAM Industrial Scenarios.

CASRN	Chemical Name	Columbia River Population (per mg/L)		HSRAM Industrial (per mg/L)	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
79-00-5	1,1,2-Trichloroethane	1.55E+08	5.80E+04	1.49E+01	1.77E-03
79-01-6	Trichloroethylene	6.53E+08	3.87E+05	5.27E+01	1.28E-02
79-10-7	2-Propenoic acid (Acrylic acid)	4.53E+07	na	5.25E+00	na
79-34-5	1,1,2,2-Tetrachloroethane (Acetylene tetrachloride)	1.03E+07	2.03E+05	9.94E-01	6.23E-03
79-46-9	2-Nitropropane	3.45E+08	1.85E+07	2.08E+01	3.18E-01
82-68-8	Pentachloronitrobenzene (PCNB)	2.03E+08	1.58E+05	2.06E+01	4.58E-03
83-32-9	Acenaphthene	1.17E+07	na	1.22E+00	na
84-66-2	Diethyl phthalate	8.51E+05	na	1.40E-02	na
84-74-2	Dibutyl phthalate	2.66E+06	na	1.55E-01	na
85-68-7	Butyl benzyl phthalate	1.72E+06	na	7.67E-02	na
87-68-3	Hexachlorobutadiene	1.95E+09	7.65E+04	2.24E+02	2.60E-03
87-86-5	Pentachlorophenol	8.89E+06	3.18E+04	5.43E-01	5.59E-04
88-06-2	2,4,6-Trichlorophenol	4.25E+09	5.12E+03	1.84E+02	7.42E-05
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)	6.12E+08	na	1.22E+01	na
91-20-3	Naphthalene	9.36E+08	na	1.16E+02	na
92-52-4	1,1'-Biphenyl	1.31E+07	na	1.38E+00	na
95-47-6	o-Xylene	2.85E+07	na	3.52E+00	na
95-48-7	2-Methylphenol (o-Cresol)	3.09E+07	na	2.58E-01	na
95-50-1	1,2-Dichlorobenzene (ortho-)	1.58E+07	na	1.87E+00	na
95-57-8	2-Chlorophenol	2.13E+08	na	6.63E+00	na
95-63-6	1,2,4-Trimethylbenzene	4.67E+08	na	5.81E+01	na
95-95-4	2,4,5-Trichlorophenol	4.07E+06	na	1.65E-01	na
98-86-2	Acetophenone	9.82E+06	na	3.10E-01	na
98-95-3	Nitrobenzene	2.82E+09	na	1.90E+02	na
100-25-4	1,4-Dinitrobenzene (para-)	2.39E+10	na	1.07E+02	na
100-41-4	Ethyl benzene	4.44E+06	4.33E+03	4.68E-01	1.36E-04
100-42-5	Styrene	3.68E+06	na	4.06E-01	na
100-51-6	Benzyl alcohol	4.58E+06	na	3.53E-02	na
106-42-3	p-Xylene	2.85E+07	na	3.52E+00	na
106-44-5	4-Methylphenol (p-Cresol)	3.01E+08	na	2.47E+00	na
106-46-7	1,4-Dichlorobenzene (para-)	9.08E+06	2.15E+04	8.39E-01	7.05E-04
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	2.32E+10	2.34E+07	2.08E+03	2.63E-01
106-99-0	1,3-Butadiene	1.97E+09	1.18E+05	2.11E+02	3.61E-03
107-02-8	2-Propenal (Acrolein)	1.40E+11	na	1.73E+04	na
107-05-1	3-Chloropropene (Allyl chloride)	2.77E+09	na	3.46E+02	na
107-06-2	1,2-Dichloroethane (Ethylene chloride)	5.73E+08	9.31E+04	7.09E+01	2.83E-03
107-13-1	Acrylonitrile	2.12E+09	5.86E+05	1.83E+02	8.24E-03
108-10-1	Methyl isobutyl ketone (4-Methyl-2-pentanone)	5.15E+06	na	2.40E-01	na
108-38-3	m-Xylene	2.85E+07	na	3.52E+00	na
108-39-4	3-Methylphenol (m-Cresol)	2.97E+07	na	2.45E-01	na
108-67-8	1,3,5-Trimethylbenzene	4.67E+08	na	5.81E+01	na

Table C7. Unit Factors: Columbia River Population & HSRAM Industrial Scenarios.

CASRN	Chemical Name	Columbia River Population (per mg/L)		HSRAM Industrial (per mg/L)	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
108-87-2	Methyl cyclohexane	1.35E+06	na	1.55E-01	na
108-88-3	Toluene (Methyl benzene)	7.78E+06	na	9.25E-01	na
108-90-7	Chlorobenzene	5.60E+07	na	6.52E+00	na
108-94-1	Cyclohexanone	2.97E+05	na	5.61E-03	na
108-95-2	Phenol (Carbolic acid)	8.12E+06	na	3.57E-02	na
109-99-9	Tetrahydrofuran	1.25E+07	1.06E+04	1.20E+00	2.13E-04
110-00-9	Furan (Oxacyclopentadiene)	6.20E+08	na	5.95E+01	na
110-54-3	n-Hexane	1.75E+07	na	2.12E+00	na
110-80-5	2-Ethoxyethanol	1.01E+07	na	5.78E-02	na
110-82-7	Cyclohexane	6.64E+05	na	7.54E-02	na
110-86-1	Pyridine	2.15E+09	na	3.21E+01	na
111-76-2	2-Butoxyethanol (Ethylene Glycol Monobutyl Ether)	1.89E+06	na	2.15E-02	na
111-90-0	2-(2-Ethoxyethoxy)-ethanol (Diethylene Glycol Monoethyl Ether)	9.51E+07	na	1.64E-01	na
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)	6.35E+08	1.77E+05	1.75E+01	1.40E-03
117-84-0	Di-n-octylphthalate	8.52E+08	na	4.42E+00	na
118-74-1	Hexachlorobenzene	8.97E+08	1.78E+06	1.07E+02	6.18E-02
120-82-1	1,2,4-Trichlorobenzene	7.12E+08	na	8.80E+01	na
121-14-2	2,4-Dinitrotoluene	7.92E+08	na	5.04E+00	na
121-44-8	Triethylamine	9.33E+08	na	5.94E+01	na
122-39-4	Diphenylamine	2.03E+07	na	8.10E-01	na
123-91-1	1,4-Dioxane (Diethylene oxide)	na	2.63E+04	na	6.13E-05
126-73-8	Tributyl Phosphate	1.86E+06	1.99E+03	6.11E-02	1.89E-05
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)	8.92E+09	na	5.93E+02	na
127-18-4	Tetrachloroethylene	1.98E+07	9.49E+03	1.72E+00	2.26E-04
129-00-0	Pyrene	2.38E+07	na	2.27E+00	na
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	9.97E+05	na	6.59E-02	na
156-59-2	cis-1,2-Dichloroethylene	5.78E+07	na	5.97E+00	na
206-44-0	Fluoranthene (1,2-Benzacenaphthene)	1.91E+07	na	2.05E+00	na
309-00-2	Aldrin	4.77E+10	3.09E+07	2.99E+03	6.76E-01
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	1.19E+09	4.99E+06	7.09E+01	1.08E-01
319-85-7	beta-Benzene hexachloride (beta-Lindane)	2.39E+09	8.71E+05	5.88E+01	6.51E-03
541-73-1	1,3-Dichlorobenzene	6.31E+08	na	6.93E+01	na
542-75-6	1,3-Dichloropropene (cis & trans)	1.45E+08	2.97E+04	1.77E+01	6.94E-04
621-64-7	N-Nitrosodi-N-propylamine	na	1.99E+07	na	4.22E-02
1314-62-1	Vanadium pentoxide	2.83E+07	na	1.45E+00	na
1330-20-7	Xylenes (mixtures)	2.85E+07	na	3.52E+00	na
1336-36-3	Polychlorinated Biphenyls	na	6.11E+05	na	1.63E-02
1336-36-3	Polychlorinated Biphenyls (lowest risk)	na	5.33E+05	na	1.22E-02
6533-73-9	Thallium carbonate	5.10E+09	na	1.24E+02	na
7429-90-5	Aluminum	2.94E+05	na	1.32E-02	na
7439-89-6	Iron	1.13E+06	na	3.32E-02	na

Table C7. Unit Factors: Columbia River Population & HSRAM Industrial Scenarios.

CASRN	Chemical Name	Columbia River Population (per mg/L)		HSRAM Industrial (per mg/L)	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
7439-93-2	Lithium	2.86E+07	na	4.96E-01	na
7439-96-5	Manganese	1.71E+07	na	4.93E-01	na
7439-97-6	Mercury metal vapor	4.69E+10	na	2.82E+03	na
7439-98-7	Molybdenum	4.18E+08	na	1.99E+00	na
7440-02-0	Nickel (soluble salts)	3.85E+07	na	4.97E-01	na
7440-22-4	Silver	5.52E+07	na	2.00E+00	na
7440-24-6	Strontium, Stable	4.81E+06	na	1.67E-02	na
7440-28-0	Thallium metal	5.99E+09	na	1.51E+02	na
7440-31-5	Tin	9.59E+05	na	1.81E-02	na
7440-36-0	Antimony	8.12E+08	na	2.95E+01	na
7440-38-2	Arsenic (inorganic)	8.93E+08	3.99E+05	3.35E+01	4.32E-03
7440-39-3	Barium	5.38E+06	na	1.70E-01	na
7440-41-7	Beryllium and compounds	1.74E+08	6.50E+02	6.77E+00	8.80E-06
7440-42-8	Boron and borates only	3.39E+07	na	1.11E-01	na
7440-43-9	Cadmium	1.34E+09	4.65E+02	2.11E+01	6.52E-06
7440-45-1	Cerium (Ceric oxide 1306-38-3)	4.80E+10	na	8.65E+02	na
7440-48-4	Cobalt	3.83E+07	7.13E+02	1.13E+00	1.01E-05
7440-50-8	Copper	8.23E+07	na	2.48E-01	na
7440-62-2	Vanadium metal	5.08E+07	na	2.07E+00	na
7440-66-6	Zinc and compounds	7.30E+08	na	3.32E-02	na
7487-94-7	Mercuric chloride	9.73E+09	na	3.31E+01	na
7664-41-7	Ammonia	1.38E+09	na	1.17E+00	na
7723-14-0	Phosphorus, white	9.49E+11	na	5.01E+02	na
7782-41-4	Fluorine (soluble fluoride)	1.40E+07	na	1.66E-01	na
7782-49-2	Selenium and compounds	6.86E+07	na	1.98E+00	na
8001-35-2	Toxaphene	na	6.69E+05	na	1.22E-02
11096-82-5	Aroclor 1260	na	2.98E+07	na	3.53E-02
11097-69-1	Aroclor 1254	8.46E+10	1.26E+06	5.31E+03	1.79E-02
11104-28-2	Aroclor 1221	na	3.59E+05	na	1.34E-02
11141-16-5	Aroclor 1232	na	3.59E+05	na	1.34E-02
12672-29-6	Aroclor 1248	na	5.95E+05	na	1.66E-02
12674-11-2	Aroclor 1016	1.03E+10	4.36E+05	1.11E+03	1.19E-02
14797-55-8	Nitrate	6.84E+04	na	6.18E-03	na
14797-65-0	Nitrite	1.13E+06	na	1.03E-01	na
16065-83-1	Chromium (III) (insoluble salts)	2.93E+05	na	1.12E-02	na
16984-48-8	Fluorine anion	1.40E+07	na	1.66E-01	na
18540-29-9	Chromium (VI) (soluble salts)	5.51E+07	3.79E+02	3.88E+00	1.50E-05
53469-21-9	Aroclor 1242	na	6.00E+05	na	1.63E-02
na	Uranium (soluble salts)	3.47E+08	na	1.65E+01	na
na	Total Chromium (1:6 ratio CrVI:Cr III)	8.12E+06	5.41E+01	5.64E-01	2.14E-06

Table C7. Unit Factors: Columbia River Population & HSRAM Industrial Scenarios.

CASRN	Chemical Name	Columbia River Population (per mg/L)		HSRAM Industrial (per mg/L)	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
Notes:					
<ul style="list-style-type: none"> • CASRN = Chemical Abstract Service Reference Number • The total risk to the population along the Columbia River (5 million people) is calculated using intakes from 70 consecutive years. The soil concentration is zero at the start of the exposure. • The total risk to the worker is calculated using intakes from 20 consecutive years. The soil concentration is zero at the start of the exposure. • These scenario factors must be multiplied by the appropriate water concentration. 					

Table C8. Comparison Ratios for the Columbia River Population & HSRAM Industrial Scenarios.

CASRN	Chemical Name	Population Ratios		Industrial Ratios	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
50-32-8	Benzo[a]pyrene				
53-70-3	Dibenz[a,h]anthracene				
56-23-5	Carbon tetrachloride	3.6		5.5	
57-12-5	Cyanide, free			6.0	
57-14-7	1,1-Dimethylhydrazine				
57-55-6	Propylene glycol (1,2-Propanediol)				
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)			2.0	2.0
60-29-7	Ethyl ether (Diethyl ether)	2.5		6.0	
60-34-4	Methylhydrazine				
60-57-1	Dieldrin	1.6		2.6	
62-75-9	N-Nitrosodimethylamine			1.4	
64-18-6	Formic acid				
67-56-1	Methanol (Methyl alcohol)			1.9	
67-64-1	Acetone (2-Propanone)	1.3		6.0	
67-66-3	Chloroform				
67-72-1	Hexachloroethane	3.2		4.6	
71-36-3	n-Butyl alcohol (n-Butanol)				
71-43-2	Benzene				
71-55-6	1,1,1-Trichloroethane (Methyl chloroform)				
72-20-8	Endrin				
74-83-9	Bromomethane				
74-87-3	Methyl chloride (Chloromethane)	1.6		1.2	
75-00-3	Ethyl Chloride				
75-01-4	Vinyl chloride (Chloroethene)				
75-05-8	Acetonitrile	6.2			
75-07-0	Acetaldehyde	4.4	4.4		
75-09-2	Dichloromethane (Methylene chloride)				

Table C8. Comparison Ratios for the Columbia River Population & HSRAM Industrial Scenarios.

CASRN	Chemical Name	Population Ratios		Industrial Ratios	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
75-15-0	Carbon disulfide				
75-21-8	Ethylene Oxide (Oxirane)				
75-34-3	1,1-Dichloroethane (Ethylidene chloride)				
75-35-4	1,1-Dichloroethylene				
75-45-6	Chlorodifluoromethane	1.6		1.2	
75-68-3	Chloro-1,1-difluoroethane, 1-	1.4		1.2	
75-69-4	Trichlorofluoromethane				
75-71-8	Dichlorodifluoromethane				
76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane (CFC-113)				
76-44-8	Heptachlor	2.0		3.5	
78-83-1	Isobutanol			3.0	
78-87-5	1,2-Dichloropropane	1.5	3.1	1.2	5.8
78-93-3	Methyl ethyl ketone (2-Butanone)				
79-00-5	1,1,2-Trichloroethane	2.8		5.9	
79-01-6	Trichloroethylene				
79-10-7	2-Propenoic acid (Acrylic acid)				
79-34-5	1,1,2,2-Tetrachloroethane (Acetylene tetrachloride)	2.8		5.8	
79-46-9	2-Nitropropane	2.5	2.5	1.2	1.2
82-68-8	Pentachloronitrobenzene (PCNB)	2.9	2.9	5.0	5.0
83-32-9	Acenaphthene	2.3		3.1	
84-66-2	Diethyl phthalate				
84-74-2	Dibutyl phthalate			1.3	
85-68-7	Butyl benzyl phthalate				
87-68-3	Hexachlorobutadiene	3.1		3.8	
87-86-5	Pentachlorophenol				
88-06-2	2,4,6-Trichlorophenol			1.4	
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)				
91-20-3	Naphthalene				
92-52-4	1,1'-Biphenyl	2.5		3.6	
95-47-6	o-Xylene				
95-48-7	2-Methylphenol (o-Cresol)			1.2	
95-50-1	1,2-Dichlorobenzene (ortho-)				
95-57-8	2-Chlorophenol	1.2		3.2	
95-63-6	1,2,4-Trimethylbenzene				
95-95-4	2,4,5-Trichlorophenol			1.2	
98-86-2	Acetophenone	1.2		3.1	
98-95-3	Nitrobenzene				
100-25-4	1,4-Dinitrobenzene (para-)				
100-41-4	Ethyl benzene		1.4		1.2
100-42-5	Styrene				
100-51-6	Benzyl alcohol				

Table C8. Comparison Ratios for the Columbia River Population & HSRAM Industrial Scenarios.

CASRN	Chemical Name	Population Ratios		Industrial Ratios	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
106-42-3	p-Xylene				
106-44-5	4-Methylphenol (p-Cresol)				
106-46-7	1,4-Dichlorobenzene (para-)				
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	1.7		1.2	
106-99-0	1,3-Butadiene	1.4	1.4	1.2	1.2
107-02-8	2-Propenal (Acrolein)				
107-05-1	3-Chloropropene (Allyl chloride)				
107-06-2	1,2-Dichloroethane (Ethylene chloride)				
107-13-1	Acrylonitrile				
108-10-1	Methyl isobutyl ketone (4-Methyl-2-pentanone)				
108-38-3	m-Xylene				
108-39-4	3-Methylphenol (m-Cresol)				
108-67-8	1,3,5-Trimethylbenzene				
108-87-2	Methyl cyclohexane	1.5		1.3	
108-88-3	Toluene (Methyl benzene)				
108-90-7	Chlorobenzene				
108-94-1	Cyclohexanone			2.8	
108-95-2	Phenol (Carbolic acid)				
109-99-9	Tetrahydrofuran				
110-00-9	Furan (Oxacyclopentadiene)	2.8		5.9	
110-54-3	n-Hexane				
110-80-5	2-Ethoxyethanol				
110-82-7	Cyclohexane	1.4		1.3	
110-86-1	Pyridine			3.2	
111-76-2	2-Butoxyethanol (Ethylene Glycol Monobutyl Ether)				
111-90-0	2-(2-Ethoxyethoxy)-ethanol (Diethylene Glycol Monoethyl Ether)				
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)				
117-84-0	Di-n-octylphthalate				
118-74-1	Hexachlorobenzene	2.2		2.4	
120-82-1	1,2,4-Trichlorobenzene				
121-14-2	2,4-Dinitrotoluene				
121-44-8	Triethylamine	2.4		1.2	
122-39-4	Diphenylamine			1.5	
123-91-1	1,4-Dioxane (Diethylene oxide)				2.0
126-73-8	Tributyl Phosphate				
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)				
127-18-4	Tetrachloroethylene				
129-00-0	Pyrene	1.4		1.5	
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	1.8		6.0	
156-59-2	cis-1,2-Dichloroethylene	3.2		5.8	

Table C8. Comparison Ratios for the Columbia River Population & HSRAM Industrial Scenarios.

CASRN	Chemical Name	Population Ratios		Industrial Ratios	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
206-44-0	Fluoranthene (1,2-Benzacenaphthene)	1.2		1.3	
309-00-2	Aldrin	1.4		2.2	
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	1.5		3.3	
319-85-7	beta-Benzene hexachloride (beta-Lindane)				
541-73-1	1,3-Dichlorobenzene	3.3		4.8	
542-75-6	1,3-Dichloropropene (cis & trans)				
621-64-7	N-Nitrosodi-N-propylamine				2.1
1314-62-1	Vanadium pentoxide				
1330-20-7	Xylenes (mixtures)				
1336-36-3	Polychlorinated Biphenyls				
1336-36-3	Polychlorinated Biphenyls (lowest risk)				
6533-73-9	Thallium carbonate				
7429-90-5	Aluminum				
7439-89-6	Iron				
7439-93-2	Lithium				
7439-96-5	Manganese				
7439-97-6	Mercury metal vapor	377,717		169,080	
7439-98-7	Molybdenum				
7440-02-0	Nickel (soluble salts)				
7440-22-4	Silver				
7440-24-6	Strontium, Stable				
7440-28-0	Thallium metal				
7440-31-5	Tin				
7440-36-0	Antimony				
7440-38-2	Arsenic (inorganic)				
7440-39-3	Barium				
7440-41-7	Beryllium and compounds				
7440-42-8	Boron and borates only				
7440-43-9	Cadmium				
7440-45-1	Cerium (Ceric oxide 1306-38-3)	34,840		13,409	
7440-48-4	Cobalt				
7440-50-8	Copper				
7440-62-2	Vanadium metal				
7440-66-6	Zinc and compounds				
7487-94-7	Mercuric chloride				
7664-41-7	Ammonia	354		2.4	
7723-14-0	Phosphorus, white				
7782-41-4	Fluorine (soluble fluoride)				
7782-49-2	Selenium and compounds				
8001-35-2	Toxaphene				
11096-82-5	Aroclor 1260				
11097-69-1	Aroclor 1254	1.3		1.9	

Table C8. Comparison Ratios for the Columbia River Population & HSRAM Industrial Scenarios.

CASRN	Chemical Name	Population Ratios		Industrial Ratios	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
11104-28-2	Aroclor 1221				
11141-16-5	Aroclor 1232				
12672-29-6	Aroclor 1248				
12674-11-2	Aroclor 1016	2.2		2.8	
14797-55-8	Nitrate				
14797-65-0	Nitrite				
16065-83-1	Chromium (III) (insoluble salts)				
16984-48-8	Fluorine anion				
18540-29-9	Chromium (VI) (soluble salts)				
53469-21-9	Aroclor 1242				
na	Uranium (soluble salts)				
na	Total Chromium (1:6 ratio CrVI:Cr III)				

Notes:

- CASRN = Chemical Abstract Service Reference Number
- The ratios shown are the unit factors in Table C7 divided by the unit factors in Tables 21 and 23.
- Ratios less than 1.2 are not listed.

Table C9. Unit Factors for the HSRAM Recreational Scenario.

CASRN	Chemical Name	Well Water Only, per mg/L		Columbia River, per mg/L	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
50-32-8	Benzo[a]pyrene	na	1.32E-02	na	1.29E+01
53-70-3	Dibenz[a,h]anthracene	na	1.73E-02	na	3.84E+01
56-23-5	Carbon tetrachloride	1.80E+00	3.29E-05	1.92E+01	7.11E-04
57-12-5	Cyanide, free	6.19E-02	na	1.29E-01	na
57-14-7	1,1-Dimethylhydrazine	na	7.09E-04	na	2.35E-03
57-55-6	Propylene glycol (1,2-Propanediol)	2.42E-03	na	4.93E-03	na
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)	4.19E+00	3.29E-04	1.98E+02	3.25E-02
60-29-7	Ethyl ether (Diethyl ether)	6.16E-03	na	1.26E-02	na
60-34-4	Methylhydrazine	na	7.08E-04	na	2.34E-03
60-57-1	Dieldrin	2.64E+01	4.51E-03	2.23E+04	7.65E+00
62-75-9	N-Nitrosodimethylamine	1.51E+02	1.21E-02	3.16E+02	4.02E-02
64-18-6	Formic acid	6.02E-04	na	1.24E-03	na
67-56-1	Methanol (Methyl alcohol)	2.41E-03	na	4.91E-03	na
67-64-1	Acetone (2-Propanone)	1.37E-03	na	2.75E-03	na
67-66-3	Chloroform	1.93E-01	9.89E-07	5.11E-01	1.30E-06
67-72-1	Hexachloroethane	1.34E+00	4.12E-06	1.22E+02	7.29E-04
71-36-3	n-Butyl alcohol (n-Butanol)	2.02E-02	na	3.35E-02	na
71-43-2	Benzene	3.12E-01	1.37E-05	1.23E+00	1.01E-04
71-55-6	1,1,1-Trichloroethane (Methyl chloroform)	4.44E-03	na	2.82E-02	na
72-20-8	Endrin	1.11E+01	na	2.74E+03	na
74-83-9	Bromomethane	9.01E-01	na	1.40E+00	na
74-87-3	Methyl chloride (Chloromethane)	9.60E-02	3.15E-06	1.97E-01	1.04E-05
75-00-3	Ethyl Chloride	3.04E-03	6.93E-07	5.84E-03	2.08E-06
75-01-4	Vinyl chloride (Chloroethene)	4.05E-01	3.35E-04	9.16E-01	1.25E-03
75-05-8	Acetonitrile	1.44E-01	na	2.90E-01	na
75-07-0	Acetaldehyde	9.57E-01	3.71E-06	1.93E+00	1.19E-05
75-09-2	Dichloromethane (Methylene chloride)	2.01E-02	1.79E-06	3.31E-02	4.30E-06
75-15-0	Carbon disulfide	1.25E-02	na	4.02E-02	na
75-21-8	Ethylene Oxide (Oxirane)	na	2.44E-04	na	7.86E-04
75-34-3	1,1-Dichloroethane (Ethylidene chloride)	1.25E-02	na	3.23E-02	na
75-35-4	1,1-Dichloroethylene	2.53E-02	na	9.74E-02	na
75-45-6	Chlorodifluoromethane	1.72E-04	na	2.54E-04	na
75-68-3	Chloro-1,1-difluoroethane, 1-	1.74E-04	na	6.17E-04	na
75-69-4	Trichlorofluoromethane	4.52E-03	na	3.10E-02	na
75-71-8	Dichlorodifluoromethane	7.27E-03	na	2.88E-02	na
76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane (CFC-113)	4.78E-05	na	7.61E-04	na
76-44-8	Heptachlor	3.06E+00	1.67E-03	7.71E+03	7.43E+00
78-83-1	Isobutanol	4.05E-03	na	8.34E-03	na
78-87-5	1,2-Dichloropropane	2.18E+00	1.67E-05	7.06E+00	9.78E-05
78-93-3	Methyl ethyl ketone (2-Butanone)	2.04E-03	na	4.14E-03	na
79-00-5	1,1,2-Trichloroethane	3.09E-01	1.42E-05	8.92E-01	7.10E-05

Table C9. Unit Factors for the HSRAM Recreational Scenario.

CASRN	Chemical Name	Well Water Only, per mg/L		Columbia River, per mg/L	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
79-01-6	Trichloroethylene	4.32E+00	1.15E-04	2.81E+01	1.34E-03
79-10-7	2-Propenoic acid (Acrylic acid)	5.56E-03	na	8.14E-03	na
79-34-5	1,1,2,2-Tetrachloroethane (Acetylene tetrachloride)	2.07E-02	5.04E-05	1.13E-01	5.26E-04
79-46-9	2-Nitropropane	4.32E-01	4.55E-03	8.82E-01	1.49E-02
82-68-8	Pentachloronitrobenzene (PCNB)	4.39E-01	7.12E-05	9.73E+01	3.24E-02
83-32-9	Acenaphthene	2.73E-02	na	1.48E+00	na
84-66-2	Diethyl phthalate	1.53E-03	na	8.98E-03	na
84-74-2	Dibutyl phthalate	1.28E-02	na	2.28E+00	na
85-68-7	Butyl benzyl phthalate	6.55E-03	na	1.72E+00	na
87-68-3	Hexachlorobutadiene	4.84E+00	2.66E-05	1.25E+03	1.25E-02
87-86-5	Pentachlorophenol	4.68E-02	3.81E-05	9.17E+00	1.41E-02
88-06-2	2,4,6-Trichlorophenol	1.32E+01	3.08E-06	2.48E+02	1.13E-04
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)	1.27E+00	na	4.59E+01	na
91-20-3	Naphthalene	1.33E-01	na	1.54E+00	na
92-52-4	1,1'-Biphenyl	3.02E-02	na	1.91E+00	na
95-47-6	o-Xylene	8.47E-03	na	1.12E-01	na
95-48-7	2-Methylphenol (o-Cresol)	2.48E-02	na	8.77E-02	na
95-50-1	1,2-Dichlorobenzene (ortho-)	1.52E-02	na	4.04E-01	na
95-57-8	2-Chlorophenol	2.50E-01	na	1.06E+00	na
95-63-6	1,2,4-Trimethylbenzene	6.16E-02	na	1.07E+00	na
95-95-4	2,4,5-Trichlorophenol	1.32E-02	na	2.61E-01	na
98-86-2	Acetophenone	1.22E-02	na	1.57E-02	na
98-95-3	Nitrobenzene	2.53E+00	na	7.05E+00	na
100-25-4	1,4-Dinitrobenzene (para-)	1.22E+01	na	2.63E+01	na
100-41-4	Ethyl benzene	1.29E-02	2.08E-06	2.30E-01	7.36E-05
100-42-5	Styrene	6.52E-03	na	8.37E-02	na
100-51-6	Benzyl alcohol	4.03E-03	na	4.85E-03	na
106-42-3	p-Xylene	8.49E-03	na	1.18E-01	na
106-44-5	4-Methylphenol (p-Cresol)	2.47E-01	na	8.48E-01	na
106-46-7	1,4-Dichlorobenzene (para-)	4.26E-02	6.60E-06	1.23E+00	3.72E-04
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	4.32E+01	2.01E-02	1.33E+02	1.14E-01
106-99-0	1,3-Butadiene	4.40E+00	5.29E-05	1.51E+01	3.27E-04
107-02-8	2-Propenal (Acrolein)	1.27E+01	na	1.52E+01	na
107-05-1	3-Chloropropene (Allyl chloride)	2.31E-01	na	2.84E-01	na
107-06-2	1,2-Dichloroethane (Ethylene chloride)	8.23E-02	2.26E-05	1.21E-01	6.73E-05
107-13-1	Acrylonitrile	1.30E+00	1.30E-04	2.56E+00	4.20E-04
108-10-1	Methyl isobutyl ketone (4-Methyl-2-pentanone)	1.51E-02	na	2.60E-02	na
108-38-3	m-Xylene	8.52E-03	na	1.28E-01	na
108-39-4	3-Methylphenol (m-Cresol)	2.48E-02	na	8.84E-02	na
108-67-8	1,3,5-Trimethylbenzene	6.07E-02	na	7.59E-01	na
108-87-2	Methyl cyclohexane	3.33E-03	na	1.19E-01	na
108-88-3	Toluene (Methyl benzene)	6.77E-03	na	5.97E-02	na

Table C9. Unit Factors for the HSRAM Recreational Scenario.

CASRN	Chemical Name	Well Water Only, per mg/L		Columbia River, per mg/L	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
108-90-7	Chlorobenzene	6.95E-02	na	7.58E-01	na
108-94-1	Cyclohexanone	2.43E-04	na	5.03E-04	na
108-95-2	Phenol (Carbolic acid)	4.08E-03	na	8.86E-03	na
109-99-9	Tetrahydrofuran	6.42E-03	1.87E-06	1.25E-02	6.02E-06
110-00-9	Furan (Oxacyclopentadiene)	1.24E+00	na	2.19E+00	na
110-54-3	n-Hexane	2.74E-02	na	1.42E+00	na
110-80-5	2-Ethoxyethanol	3.03E-03	na	6.18E-03	na
110-82-7	Cyclohexane	1.61E-03	na	4.46E-02	na
110-86-1	Pyridine	1.22E+00	na	2.55E+00	na
111-76-2	2-Butoxyethanol (Ethylene Glycol Monobutyl Ether)	2.41E-03	na	5.00E-03	na
111-90-0	2-(2-Ethoxyethoxy)-ethanol (Diethylene Glycol Monoethyl Ether)	2.01E-02	na	4.10E-02	na
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)	5.36E-01	6.04E-05	1.41E+01	1.68E-03
117-84-0	Di-n-octylphthalate	1.44E-01	na	2.61E+00	na
118-74-1	Hexachlorobenzene	2.48E+00	9.08E-04	2.51E+03	1.38E+00
120-82-1	1,2,4-Trichlorobenzene	1.82E-01	na	9.97E+00	na
121-14-2	2,4-Dinitrotoluene	6.12E-01	na	2.15E+00	na
121-44-8	Triethylamine	1.24E+00	na	2.37E+00	na
122-39-4	Diphenylamine	5.30E-02	na	1.68E+00	na
123-91-1	1,4-Dioxane (Diethylene oxide)	na	2.60E-06	na	8.45E-06
126-73-8	Tributyl Phosphate	6.41E-03	1.43E-06	9.38E-02	4.08E-05
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)	1.23E+01	na	2.51E+01	na
127-18-4	Tetrachloroethylene	1.25E-01	1.32E-05	3.40E+00	7.43E-04
129-00-0	Pyrene	7.34E-02	na	1.54E+01	na
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	1.37E-03	na	2.78E-03	na
156-59-2	cis-1,2-Dichloroethylene	1.24E-01	na	3.55E-01	na
206-44-0	Fluoranthene (1,2-Benzacenaphthene)	6.89E-02	na	1.89E+01	na
309-00-2	Aldrin	7.04E+01	1.06E-02	2.61E+05	5.71E+01
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	2.53E+00	1.62E-03	1.36E+02	1.80E-01
319-85-7	beta-Benzene hexachloride (beta-Lindane)	6.27E+00	4.56E-04	3.30E+02	4.99E-02
541-73-1	1,3-Dichlorobenzene	1.47E+00	na	4.79E+01	na
542-75-6	1,3-Dichloropropene (cis & trans)	5.09E-02	2.44E-05	1.55E-01	1.58E-04
621-64-7	N-Nitrosodi-N-propylamine	na	1.71E-03	na	5.45E-03
1314-62-1	Vanadium pentoxide	1.46E-01	na	9.33E+00	na
1330-20-7	Xylenes (mixtures)	8.41E-03	na	1.12E-01	na
1336-36-3	Polychlorinated Biphenyls	na	2.73E-04	na	1.93E+01
1336-36-3	Polychlorinated Biphenyls (lowest risk)	na	6.31E-05	na	1.93E+01
6533-73-9	Thallium carbonate	1.54E+01	na	4.85E+04	na
7429-90-5	Aluminum	1.30E-03	na	1.99E-01	na
7439-89-6	Iron	4.10E-03	na	2.75E-01	na
7439-93-2	Lithium	6.14E-02	na	2.66E-01	na
7439-96-5	Manganese	3.21E-02	na	1.24E+00	na

Table C9. Unit Factors for the HSRAM Recreational Scenario.

CASRN	Chemical Name	Well Water Only, per mg/L		Columbia River, per mg/L	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
7439-97-6	Mercury metal vapor	1.07E+02	na	1.06E+04	na
7439-98-7	Molybdenum	2.46E-01	na	1.44E+00	na
7440-02-0	Nickel (soluble salts)	6.14E-02	na	2.19E+00	na
7440-22-4	Silver	2.46E-01	na	1.37E+00	na
7440-24-6	Strontium, Stable	2.05E-03	na	4.71E-02	na
7440-28-0	Thallium metal	1.86E+01	na	5.88E+04	na
7440-31-5	Tin	2.09E-03	na	1.95E+00	na
7440-36-0	Antimony	3.21E+00	na	1.14E+02	na
7440-38-2	Arsenic (inorganic)	4.11E+00	3.69E-04	3.32E+02	6.31E-02
7440-39-3	Barium	1.81E-02	na	9.46E-02	na
7440-41-7	Beryllium and compounds	6.64E-01	5.47E-07	2.35E+01	5.47E-07
7440-42-8	Boron and borates only	1.36E-02	na	4.78E-02	na
7440-43-9	Cadmium	2.53E+00	4.02E-07	9.59E+01	4.02E-07
7440-45-1	Cerium (Ceric oxide 1306-38-3)	6.10E+01	na	1.64E+03	na
7440-48-4	Cobalt	7.40E-02	6.22E-07	6.06E+00	6.22E-07
7440-50-8	Copper	3.07E-02	na	2.05E+00	na
7440-62-2	Vanadium metal	1.95E-01	na	1.24E+01	na
7440-66-6	Zinc and compounds	4.10E-03	na	3.42E-01	na
7487-94-7	Mercuric chloride	4.09E+00	na	1.30E+03	na
7664-41-7	Ammonia	8.45E-02	na	1.73E-01	na
7723-14-0	Phosphorus, white	6.15E+01	na	2.92E+04	na
7782-41-4	Fluorine (soluble fluoride)	2.05E-02	na	1.46E-01	na
7782-49-2	Selenium and compounds	2.45E-01	na	1.36E+01	na
8001-35-2	Toxaphene	na	3.34E-04	na	1.03E+00
11096-82-5	Aroclor 1260	na	1.07E-03	na	1.64E+00
11097-69-1	Aroclor 1254	1.29E+02	3.40E-04	2.73E+06	4.67E+01
11104-28-2	Aroclor 1221	na	1.45E-04	na	2.05E-01
11141-16-5	Aroclor 1232	na	1.45E-04	na	2.05E-01
12672-29-6	Aroclor 1248	na	2.83E-04	na	2.10E+01
12674-11-2	Aroclor 1016	2.52E+01	4.96E-05	9.80E+04	5.87E+00
14797-55-8	Nitrate	7.62E-04	na	1.74E-03	na
14797-65-0	Nitrite	1.22E-02	na	2.78E-02	na
16065-83-1	Chromium (III) (insoluble salts)	9.61E-04	na	5.97E-02	na
16984-48-8	Fluorine anion	2.05E-02	na	1.46E-01	na
18540-29-9	Chromium (VI) (soluble salts)	4.24E-01	6.73E-07	2.66E+01	6.73E-07
53469-21-9	Aroclor 1242	na	2.73E-04	na	1.93E+01
na	Uranium (soluble salts)	2.04E+00	na	1.18E+01	na
na	Total Chromium (1:6 ratio CrVI:Cr III)	6.14E-02	9.62E-08	3.85E+00	9.62E-08

Notes:

- CASRN = Chemical Abstract Service Reference Number
- The total risk to the HSRAM Recreational Visitor is calculated using intakes from 30 consecutive years. The soil concentration is zero at the start of the exposure.
- These scenario factors must be multiplied by the appropriate water concentration. The "Inland Well" column assumes all of the contaminated water comes from the well. The "Columbia River" column assumes that all of the contaminated water comes from the Columbia River.

Table C10. Unit Factor Ratios for the HSRAM Recreational Scenario.

CASRN	Chemical Name	Well Water Ratios		Columbia River Ratios	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
50-32-8	Benzo[a]pyrene				
53-70-3	Dibenz[a,h]anthracene				
56-23-5	Carbon tetrachloride				
57-12-5	Cyanide, free				
57-14-7	1,1-Dimethylhydrazine				
57-55-6	Propylene glycol (1,2-Propanediol)				
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)				
60-29-7	Ethyl ether (Diethyl ether)				
60-34-4	Methylhydrazine				
60-57-1	Dieldrin				
62-75-9	N-Nitrosodimethylamine				
64-18-6	Formic acid				
67-56-1	Methanol (Methyl alcohol)				
67-64-1	Acetone (2-Propanone)				
67-66-3	Chloroform				
67-72-1	Hexachloroethane				
71-36-3	n-Butyl alcohol (n-Butanol)				
71-43-2	Benzene				
71-55-6	1,1,1-Trichloroethane (Methyl chloroform)				
72-20-8	Endrin				
74-83-9	Bromomethane				
74-87-3	Methyl chloride (Chloromethane)	41.8		85.9	
75-00-3	Ethyl Chloride				
75-01-4	Vinyl chloride (Chloroethene)				
75-05-8	Acetonitrile	41.7		84.0	
75-07-0	Acetaldehyde	41.7	41.7	83.8	134
75-09-2	Dichloromethane (Methylene chloride)				
75-15-0	Carbon disulfide				
75-21-8	Ethylene Oxide (Oxirane)				
75-34-3	1,1-Dichloroethane (Ethylidene chloride)				
75-35-4	1,1-Dichloroethylene				
75-45-6	Chlorodifluoromethane	41.8		61.6	
75-68-3	Chloro-1,1-difluoroethane, 1-	42.1		150	
75-69-4	Trichlorofluoromethane				
75-71-8	Dichlorodifluoromethane				
76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane (CFC-113)				
76-44-8	Heptachlor				
78-83-1	Isobutanol				
78-87-5	1,2-Dichloropropane	42.1		136	
78-93-3	Methyl ethyl ketone (2-Butanone)				
79-00-5	1,1,2-Trichloroethane				

Table C10. Unit Factor Ratios for the HSRAM Recreational Scenario.

CASRN	Chemical Name	Well Water Ratios		Columbia River Ratios	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
79-01-6	Trichloroethylene				
79-10-7	2-Propenoic acid (Acrylic acid)				
79-34-5	1,1,2,2-Tetrachloroethane (Acetylene tetrachloride)				
79-46-9	2-Nitropropane	41.8	41.9	85.3	137
82-68-8	Pentachloronitrobenzene (PCNB)				
83-32-9	Acenaphthene				
84-66-2	Diethyl phthalate				
84-74-2	Dibutyl phthalate				
85-68-7	Butyl benzyl phthalate				
87-68-3	Hexachlorobutadiene				
87-86-5	Pentachlorophenol				
88-06-2	2,4,6-Trichlorophenol				
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)				
91-20-3	Naphthalene				
92-52-4	1,1'-Biphenyl				
95-47-6	o-Xylene				
95-48-7	2-Methylphenol (o-Cresol)				
95-50-1	1,2-Dichlorobenzene (ortho-)				
95-57-8	2-Chlorophenol				
95-63-6	1,2,4-Trimethylbenzene				
95-95-4	2,4,5-Trichlorophenol				
98-86-2	Acetophenone				
98-95-3	Nitrobenzene				
100-25-4	1,4-Dinitrobenzene (para-)				
100-41-4	Ethyl benzene		46.8		1,654
100-42-5	Styrene				
100-51-6	Benzyl alcohol				
106-42-3	p-Xylene				
106-44-5	4-Methylphenol (p-Cresol)				
106-46-7	1,4-Dichlorobenzene (para-)				
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	41.8		129	
106-99-0	1,3-Butadiene	42.5	43.6	146	269
107-02-8	2-Propenal (Acrolein)				
107-05-1	3-Chloropropene (Allyl chloride)				
107-06-2	1,2-Dichloroethane (Ethylene chloride)				
107-13-1	Acrylonitrile				
108-10-1	Methyl isobutyl ketone (4-Methyl-2-pentanone)				
108-38-3	m-Xylene				
108-39-4	3-Methylphenol (m-Cresol)				
108-67-8	1,3,5-Trimethylbenzene				
108-87-2	Methyl cyclohexane	48.4		1,731	
108-88-3	Toluene (Methyl benzene)				

Table C10. Unit Factor Ratios for the HSRAM Recreational Scenario.

CASRN	Chemical Name	Well Water Ratios		Columbia River Ratios	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
108-90-7	Chlorobenzene				
108-94-1	Cyclohexanone				
108-95-2	Phenol (Carbolic acid)				
109-99-9	Tetrahydrofuran				
110-00-9	Furan (Oxacyclopentadiene)				
110-54-3	n-Hexane				
110-80-5	2-Ethoxyethanol				
110-82-7	Cyclohexane	46.6		1,292	
110-86-1	Pyridine				
111-76-2	2-Butoxyethanol (Ethylene Glycol Monobutyl Ether)				
111-90-0	2-(2-Ethoxyethoxy)-ethanol (Diethylene Glycol Monoethyl Ether)				
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)				
117-84-0	Di-n-octylphthalate				
118-74-1	Hexachlorobenzene				
120-82-1	1,2,4-Trichlorobenzene				
121-14-2	2,4-Dinitrotoluene				
121-44-8	Triethylamine	41.9		80.2	
122-39-4	Diphenylamine				
123-91-1	1,4-Dioxane (Diethylene oxide)				
126-73-8	Tributyl Phosphate				
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)				
127-18-4	Tetrachloroethylene				
129-00-0	Pyrene				
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)				
156-59-2	cis-1,2-Dichloroethylene				
206-44-0	Fluoranthene (1,2-Benzacenaphthene)				
309-00-2	Aldrin				
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)				
319-85-7	beta-Benzene hexachloride (beta-Lindane)				
541-73-1	1,3-Dichlorobenzene				
542-75-6	1,3-Dichloropropene (cis & trans)				
621-64-7	N-Nitrosodi-N-propylamine				
1314-62-1	Vanadium pentoxide				
1330-20-7	Xylenes (mixtures)				
1336-36-3	Polychlorinated Biphenyls				
1336-36-3	Polychlorinated Biphenyls (lowest risk)				
6533-73-9	Thallium carbonate				
7429-90-5	Aluminum				
7439-89-6	Iron				
7439-93-2	Lithium				
7439-96-5	Manganese				

Table C10. Unit Factor Ratios for the HSRAM Recreational Scenario.

CASRN	Chemical Name	Well Water Ratios		Columbia River Ratios	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
7439-97-6	Mercury metal vapor	174,166		17,309,990	
7439-98-7	Molybdenum				
7440-02-0	Nickel (soluble salts)				
7440-22-4	Silver				
7440-24-6	Strontium, Stable				
7440-28-0	Thallium metal				
7440-31-5	Tin				
7440-36-0	Antimony				
7440-38-2	Arsenic (inorganic)				
7440-39-3	Barium				
7440-41-7	Beryllium and compounds				
7440-42-8	Boron and borates only				
7440-43-9	Cadmium				
7440-45-1	Cerium (Ceric oxide 1306-38-3)	48,125		1,292,623	
7440-48-4	Cobalt				
7440-50-8	Copper				
7440-62-2	Vanadium metal				
7440-66-6	Zinc and compounds				
7487-94-7	Mercuric chloride				
7664-41-7	Ammonia	290		595	
7723-14-0	Phosphorus, white				
7782-41-4	Fluorine (soluble fluoride)				
7782-49-2	Selenium and compounds				
8001-35-2	Toxaphene				
11096-82-5	Aroclor 1260				
11097-69-1	Aroclor 1254				
11104-28-2	Aroclor 1221				
11141-16-5	Aroclor 1232				
12672-29-6	Aroclor 1248				
12674-11-2	Aroclor 1016				
14797-55-8	Nitrate				
14797-65-0	Nitrite				
16065-83-1	Chromium (III) (insoluble salts)				
16984-48-8	Fluorine anion				
18540-29-9	Chromium (VI) (soluble salts)				
53469-21-9	Aroclor 1242				
na	Uranium (soluble salts)				
na	Total Chromium (1:6 ratio CrVI:Cr III)				

Notes:

- CASRN = Chemical Abstract Service Reference Number
- The ratios shown are the unit factors in Table C9 divided by the unit factors in Table 25.
- Ratios less than 1.2 are not listed.

Table C11. Unit Factors for the HSRAM Residential Scenario.

CASRN	Chemical Name	Well Water Only, per mg/L		Columbia River, per mg/L	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
50-32-8	Benzo[a]pyrene	na	7.12E-01	na	1.36E+01
53-70-3	Dibenz[a,h]anthracene	na	9.18E-01	na	3.93E+01
56-23-5	Carbon tetrachloride	1.76E+02	4.37E-03	1.93E+02	5.05E-03
57-12-5	Cyanide, free	3.42E+01	na	3.42E+01	na
57-14-7	1,1-Dimethylhydrazine	na	4.30E+00	na	4.30E+00
57-55-6	Propylene glycol (1,2-Propanediol)	2.23E+00	na	2.23E+00	na
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)	3.64E+02	4.16E-02	5.58E+02	7.37E-02
60-29-7	Ethyl ether (Diethyl ether)	6.82E-01	na	6.89E-01	na
60-34-4	Methylhydrazine	na	3.22E+00	na	3.22E+00
60-57-1	Dieldrin	1.96E+03	5.89E-01	2.43E+04	8.23E+00
62-75-9	N-Nitrosodimethylamine	2.02E+05	3.47E+01	2.03E+05	3.47E+01
64-18-6	Formic acid	4.73E-01	na	4.74E-01	na
67-56-1	Methanol (Methyl alcohol)	1.26E+00	na	1.26E+00	na
67-64-1	Acetone (2-Propanone)	3.14E-01	na	3.15E-01	na
67-66-3	Chloroform	1.33E+02	3.75E-03	1.34E+02	3.75E-03
67-72-1	Hexachloroethane	1.29E+02	8.92E-04	2.49E+02	1.62E-03
71-36-3	n-Butyl alcohol (n-Butanol)	1.64E+01	na	1.65E+01	na
71-43-2	Benzene	3.06E+01	2.16E-03	3.15E+01	2.25E-03
71-55-6	1,1,1-Trichloroethane (Methyl chloroform)	4.19E-01	na	4.42E-01	na
72-20-8	Endrin	6.49E+02	na	3.38E+03	na
74-83-9	Bromomethane	1.30E+02	na	1.31E+02	na
74-87-3	Methyl chloride (Chloromethane)	1.04E+01	5.45E-04	1.05E+01	5.52E-04
75-00-3	Ethyl Chloride	2.20E-01	4.83E-05	2.23E-01	4.97E-05
75-01-4	Vinyl chloride (Chloroethene)	2.76E+01	2.40E-02	2.82E+01	2.49E-02
75-05-8	Acetonitrile	4.10E+01	na	4.12E+01	na
75-07-0	Acetaldehyde	2.06E+02	1.52E-03	2.07E+02	1.53E-03
75-09-2	Dichloromethane (Methylene chloride)	1.40E+00	2.13E-04	1.41E+00	2.15E-04
75-15-0	Carbon disulfide	1.25E+00	na	1.27E+00	na
75-21-8	Ethylene Oxide (Oxirane)	na	7.75E-02	na	7.80E-02
75-34-3	1,1-Dichloroethane (Ethylidene chloride)	1.47E+00	na	1.49E+00	na
75-35-4	1,1-Dichloroethylene	3.29E+00	na	3.36E+00	na
75-45-6	Chlorodifluoromethane	1.83E-02	na	1.84E-02	na
75-68-3	Chloro-1,1-difluoroethane, 1-	1.74E-02	na	1.78E-02	na
75-69-4	Trichlorofluoromethane	7.80E-01	na	8.07E-01	na
75-71-8	Dichlorodifluoromethane	2.26E+00	na	2.28E+00	na
76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane (CFC-113)	1.49E-02	na	1.57E-02	na
76-44-8	Heptachlor	2.75E+02	3.03E-01	7.98E+03	7.73E+00
78-83-1	Isobutanol	5.61E-01	na	5.65E-01	na
78-87-5	1,2-Dichloropropane	2.22E+02	2.70E-03	2.27E+02	2.78E-03
78-93-3	Methyl ethyl ketone (2-Butanone)	3.45E-01	na	3.47E-01	na
79-00-5	1,1,2-Trichloroethane	3.28E+01	3.70E-03	3.34E+01	3.76E-03

Table C11. Unit Factors for the HSRAM Residential Scenario.

CASRN	Chemical Name	Well Water Only, per mg/L		Columbia River, per mg/L	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
79-01-6	Trichloroethylene	2.54E+02	2.54E-02	2.78E+02	2.66E-02
79-10-7	2-Propenoic acid (Acrylic acid)	6.25E+00	na	6.25E+00	na
79-34-5	1,1,2,2-Tetrachloroethane (Acetylene tetrachloride)	2.19E+00	1.30E-02	2.28E+00	1.35E-02
79-46-9	2-Nitropropane	6.13E+01	1.14E+00	6.18E+01	1.15E+00
82-68-8	Pentachloronitrobenzene (PCNB)	4.36E+01	1.07E-02	1.40E+02	4.31E-02
83-32-9	Acenaphthene	2.52E+00	na	3.97E+00	na
84-66-2	Diethyl phthalate	1.63E-01	na	1.70E-01	na
84-74-2	Dibutyl phthalate	8.24E-01	na	3.10E+00	na
85-68-7	Butyl benzyl phthalate	4.25E-01	na	2.14E+00	na
87-68-3	Hexachlorobutadiene	4.42E+02	5.11E-03	1.69E+03	1.76E-02
87-86-5	Pentachlorophenol	2.74E+00	2.44E-03	1.19E+01	1.65E-02
88-06-2	2,4,6-Trichlorophenol	1.01E+03	3.39E-04	1.24E+03	4.49E-04
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)	1.10E+02	na	1.55E+02	na
91-20-3	Naphthalene	1.31E+02	na	1.32E+02	na
92-52-4	1,1'-Biphenyl	2.85E+00	na	4.74E+00	na
95-47-6	o-Xylene	4.16E+00	na	4.26E+00	na
95-48-7	2-Methylphenol (o-Cresol)	4.53E+00	na	4.59E+00	na
95-50-1	1,2-Dichlorobenzene (ortho-)	2.71E+00	na	3.10E+00	na
95-57-8	2-Chlorophenol	3.58E+01	na	3.66E+01	na
95-63-6	1,2,4-Trimethylbenzene	6.50E+01	na	6.60E+01	na
95-95-4	2,4,5-Trichlorophenol	9.84E-01	na	1.23E+00	na
98-86-2	Acetophenone	1.71E+00	na	1.71E+00	na
98-95-3	Nitrobenzene	4.61E+02	na	4.66E+02	na
100-25-4	1,4-Dinitrobenzene (para-)	3.25E+03	na	3.26E+03	na
100-41-4	Ethyl benzene	1.10E+00	3.04E-04	1.31E+00	3.75E-04
100-42-5	Styrene	7.47E-01	na	8.24E-01	na
100-51-6	Benzyl alcohol	7.16E-01	na	7.17E-01	na
106-42-3	p-Xylene	4.16E+00	na	4.27E+00	na
106-44-5	4-Methylphenol (p-Cresol)	4.45E+01	na	4.51E+01	na
106-46-7	1,4-Dichlorobenzene (para-)	2.87E+00	1.41E-03	4.06E+00	1.78E-03
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	4.78E+03	1.79E+00	4.87E+03	1.88E+00
106-99-0	1,3-Butadiene	4.37E+02	8.17E-03	4.47E+02	8.44E-03
107-02-8	2-Propenal (Acrolein)	1.93E+04	na	1.93E+04	na
107-05-1	3-Chloropropene (Allyl chloride)	3.81E+02	na	3.81E+02	na
107-06-2	1,2-Dichloroethane (Ethylene chloride)	8.01E+01	5.94E-03	8.02E+01	5.98E-03
107-13-1	Acrylonitrile	3.28E+02	3.52E-02	3.30E+02	3.55E-02
108-10-1	Methyl isobutyl ketone (4-Methyl-2-pentanone)	1.26E+00	na	1.27E+00	na
108-38-3	m-Xylene	4.16E+00	na	4.28E+00	na
108-39-4	3-Methylphenol (m-Cresol)	4.40E+00	na	4.46E+00	na
108-67-8	1,3,5-Trimethylbenzene	6.49E+01	na	6.56E+01	na
108-87-2	Methyl cyclohexane	3.06E-01	na	4.22E-01	na
108-88-3	Toluene (Methyl benzene)	1.31E+00	na	1.36E+00	na

Table C11. Unit Factors for the HSRAM Residential Scenario.

CASRN	Chemical Name	Well Water Only, per mg/L		Columbia River, per mg/L	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
108-90-7	Chlorobenzene	1.02E+01	na	1.09E+01	na
108-94-1	Cyclohexanone	4.61E-02	na	4.64E-02	na
108-95-2	Phenol (Carbolic acid)	1.10E+00	na	1.10E+00	na
109-99-9	Tetrahydrofuran	1.90E+00	6.38E-04	1.91E+00	6.43E-04
110-00-9	Furan (Oxacyclopentadiene)	1.31E+02	na	1.32E+02	na
110-54-3	n-Hexane	3.34E+00	na	4.74E+00	na
110-80-5	2-Ethoxyethanol	1.34E+00	na	1.35E+00	na
110-82-7	Cyclohexane	1.51E-01	na	1.94E-01	na
110-86-1	Pyridine	3.11E+02	na	3.12E+02	na
111-76-2	2-Butoxyethanol (Ethylene Glycol Monobutyl Ether)	3.28E-01	na	3.30E-01	na
111-90-0	2-(2-Ethoxyethoxy)-ethanol (Diethylene Glycol Monoethyl Ether)	1.23E+01	na	1.23E+01	na
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)	2.82E+01	3.18E-03	4.17E+01	4.80E-03
117-84-0	Di-n-octylphthalate	7.74E+00	na	1.02E+01	na
118-74-1	Hexachlorobenzene	2.00E+02	1.24E-01	2.71E+03	1.50E+00
120-82-1	1,2,4-Trichlorobenzene	1.03E+02	na	1.12E+02	na
121-14-2	2,4-Dinitrotoluene	1.14E+02	na	1.16E+02	na
121-44-8	Triethylamine	1.69E+02	na	1.70E+02	na
122-39-4	Diphenylamine	4.40E+00	na	6.03E+00	na
123-91-1	1,4-Dioxane (Diethylene oxide)	na	1.44E-03	na	1.44E-03
126-73-8	Tributyl Phosphate	4.53E-01	1.29E-04	5.40E-01	1.69E-04
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)	1.64E+03	na	1.65E+03	na
127-18-4	Tetrachloroethylene	7.55E+00	8.79E-04	1.08E+01	1.61E-03
129-00-0	Pyrene	5.11E+00	na	2.04E+01	na
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	1.83E-01	na	1.84E-01	na
156-59-2	cis-1,2-Dichloroethylene	1.26E+01	na	1.29E+01	na
206-44-0	Fluoranthene (1,2-Benzacenaphthene)	4.32E+00	na	2.32E+01	na
309-00-2	Aldrin	5.60E+03	1.37E+00	2.67E+05	5.85E+01
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	2.40E+02	3.03E-01	3.73E+02	4.82E-01
319-85-7	beta-Benzene hexachloride (beta-Lindane)	4.93E+02	5.02E-02	8.16E+02	9.97E-02
541-73-1	1,3-Dichlorobenzene	1.41E+02	na	1.88E+02	na
542-75-6	1,3-Dichloropropene (cis & trans)	2.14E+01	2.31E-03	2.15E+01	2.44E-03
621-64-7	N-Nitrosodi-N-propylamine	na	1.03E+00	na	1.03E+00
1314-62-1	Vanadium pentoxide	8.13E+00	na	1.73E+01	na
1330-20-7	Xylenes (mixtures)	4.15E+00	na	4.26E+00	na
1336-36-3	Polychlorinated Biphenyls	na	3.65E-02	na	1.93E+01
1336-36-3	Polychlorinated Biphenyls (lowest risk)	na	2.56E-02	na	1.93E+01
6533-73-9	Thallium carbonate	8.53E+02	na	4.93E+04	na
7429-90-5	Aluminum	7.18E-02	na	2.70E-01	na
7439-89-6	Iron	2.30E-01	na	5.01E-01	na
7439-93-2	Lithium	3.45E+00	na	3.66E+00	na
7439-96-5	Manganese	2.08E+00	na	3.29E+00	na

Table C11. Unit Factors for the HSRAM Residential Scenario.

CASRN	Chemical Name	Well Water Only, per mg/L		Columbia River, per mg/L	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
7439-97-6	Mercury metal vapor	5.69E+03	na	1.62E+04	na
7439-98-7	Molybdenum	3.82E+01	na	3.94E+01	na
7440-02-0	Nickel (soluble salts)	4.00E+00	na	6.12E+00	na
7440-22-4	Silver	1.37E+01	na	1.48E+01	na
7440-24-6	Strontium, Stable	3.10E-01	na	3.55E-01	na
7440-28-0	Thallium metal	1.03E+03	na	5.98E+04	na
7440-31-5	Tin	1.18E-01	na	2.06E+00	na
7440-36-0	Antimony	1.86E+02	na	2.98E+02	na
7440-38-2	Arsenic (inorganic)	2.32E+02	2.28E-02	5.60E+02	8.55E-02
7440-39-3	Barium	1.10E+00	na	1.18E+00	na
7440-41-7	Beryllium and compounds	3.66E+01	2.85E-05	5.95E+01	2.85E-05
7440-42-8	Boron and borates only	3.43E+00	na	3.47E+00	na
7440-43-9	Cadmium	1.67E+02	2.10E-05	2.60E+02	2.10E-05
7440-45-1	Cerium (Ceric oxide 1306-38-3)	3.38E+03	na	4.96E+03	na
7440-48-4	Cobalt	4.60E+00	3.24E-05	1.06E+01	3.24E-05
7440-50-8	Copper	5.43E+00	na	7.45E+00	na
7440-62-2	Vanadium metal	1.08E+01	na	2.30E+01	na
7440-66-6	Zinc and compounds	1.50E+01	na	1.53E+01	na
7487-94-7	Mercuric chloride	3.54E+02	na	1.65E+03	na
7664-41-7	Ammonia	1.70E+02	na	1.70E+02	na
7723-14-0	Phosphorus, white	3.14E+04	na	6.06E+04	na
7782-41-4	Fluorine (soluble fluoride)	1.16E+00	na	1.29E+00	na
7782-49-2	Selenium and compounds	1.40E+01	na	2.74E+01	na
8001-35-2	Toxaphene	na	3.31E-02	na	1.06E+00
11096-82-5	Aroclor 1260	na	7.76E-02	na	1.72E+00
11097-69-1	Aroclor 1254	9.55E+03	3.97E-02	2.74E+06	4.68E+01
11104-28-2	Aroclor 1221	na	3.29E-02	na	2.38E-01
11141-16-5	Aroclor 1232	na	3.29E-02	na	2.38E-01
12672-29-6	Aroclor 1248	na	3.68E-02	na	2.11E+01
12674-11-2	Aroclor 1016	2.15E+03	2.58E-02	1.00E+05	5.90E+00
14797-55-8	Nitrate	3.98E-02	na	4.07E-02	na
14797-65-0	Nitrite	6.41E-01	na	6.56E-01	na
16065-83-1	Chromium (III) (insoluble salts)	5.24E-02	na	1.11E-01	na
16984-48-8	Fluorine anion	1.16E+00	na	1.29E+00	na
18540-29-9	Chromium (VI) (soluble salts)	2.34E+01	3.51E-05	4.96E+01	3.51E-05
53469-21-9	Aroclor 1242	na	3.64E-02	na	1.93E+01
na	Uranium (soluble salts)	1.16E+02	na	1.25E+02	na
na	Total Chromium (1:6 ratio CrVI:Cr III)	3.38E+00	5.02E-06	7.18E+00	5.02E-06

Notes:

- CASRN = Chemical Abstract Service Reference Number
- The total risk to the HSRAM Residential scenario is calculated using intakes from 30 consecutive years. The soil concentration is zero at the start of the exposure.
- These scenario factors must be multiplied by the appropriate water concentration. The "Inland Well" column assumes all of the contaminated water comes from the well. The "Columbia River" column assumes that all of the contaminated water comes from the Columbia River.

Table C12. Unit Factor Ratios for the HSRAM Residential Scenario.

CASRN	Chemical Name	Well Water Ratios		Columbia River Ratios	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
50-32-8	Benzo[a]pyrene				
53-70-3	Dibenz[a,h]anthracene				
56-23-5	Carbon tetrachloride	1.8		1.7	
57-12-5	Cyanide, free				
57-14-7	1,1-Dimethylhydrazine				
57-55-6	Propylene glycol (1,2-Propanediol)				
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)				
60-29-7	Ethyl ether (Diethyl ether)	1.7		1.7	
60-34-4	Methylhydrazine				
60-57-1	Dieldrin	1.3			
62-75-9	N-Nitrosodimethylamine				
64-18-6	Formic acid				
67-56-1	Methanol (Methyl alcohol)				
67-64-1	Acetone (2-Propanone)	1.2		1.2	
67-66-3	Chloroform				
67-72-1	Hexachloroethane	1.7		1.3	
71-36-3	n-Butyl alcohol (n-Butanol)				
71-43-2	Benzene				
71-55-6	1,1,1-Trichloroethane (Methyl chloroform)				
72-20-8	Endrin				
74-83-9	Bromomethane				
74-87-3	Methyl chloride (Chloromethane)	2.5		2.5	
75-00-3	Ethyl Chloride				
75-01-4	Vinyl chloride (Chloroethene)				
75-05-8	Acetonitrile	6.5		6.5	
75-07-0	Acetaldehyde	4.9	4.2	4.9	4.3
75-09-2	Dichloromethane (Methylene chloride)				
75-15-0	Carbon disulfide				
75-21-8	Ethylene Oxide (Oxirane)				
75-34-3	1,1-Dichloroethane (Ethylidene chloride)				
75-35-4	1,1-Dichloroethylene				
75-45-6	Chlorodifluoromethane	2.4		2.4	
75-68-3	Chloro-1,1-difluoroethane, 1-	2.3		2.3	
75-69-4	Trichlorofluoromethane				
75-71-8	Dichlorodifluoromethane				
76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane (CFC-113)				
76-44-8	Heptachlor	1.7			
78-83-1	Isobutanol				
78-87-5	1,2-Dichloropropane	2.3	2.4	2.4	2.3
78-93-3	Methyl ethyl ketone (2-Butanone)				
79-00-5	1,1,2-Trichloroethane	1.7		1.7	

Table C12. Unit Factor Ratios for the HSRAM Residential Scenario.

CASRN	Chemical Name	Well Water Ratios		Columbia River Ratios	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
79-01-6	Trichloroethylene				
79-10-7	2-Propenoic acid (Acrylic acid)				
79-34-5	1,1,2,2-Tetrachloroethane (Acetylene tetrachloride)	1.7		1.7	
79-46-9	2-Nitropropane	3.2	2.6	3.2	2.6
82-68-8	Pentachloronitrobenzene (PCNB)	1.7	2.3		
83-32-9	Acenaphthene	1.6		1.3	
84-66-2	Diethyl phthalate				
84-74-2	Dibutyl phthalate				
85-68-7	Butyl benzyl phthalate				
87-68-3	Hexachlorobutadiene	1.7			
87-86-5	Pentachlorophenol				
88-06-2	2,4,6-Trichlorophenol				
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)				
91-20-3	Naphthalene				
92-52-4	1,1'-Biphenyl	1.6		1.3	
95-47-6	o-Xylene				
95-48-7	2-Methylphenol (o-Cresol)				
95-50-1	1,2-Dichlorobenzene (ortho-)				
95-57-8	2-Chlorophenol				
95-63-6	1,2,4-Trimethylbenzene				
95-95-4	2,4,5-Trichlorophenol				
98-86-2	Acetophenone				
98-95-3	Nitrobenzene				
100-25-4	1,4-Dinitrobenzene (para-)				
100-41-4	Ethyl benzene		1.7		2.1
100-42-5	Styrene				
100-51-6	Benzyl alcohol				
106-42-3	p-Xylene				
106-44-5	4-Methylphenol (p-Cresol)				
106-46-7	1,4-Dichlorobenzene (para-)				
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	2.5		2.6	
106-99-0	1,3-Butadiene	2.3	1.7	2.4	1.7
107-02-8	2-Propenal (Acrolein)				
107-05-1	3-Chloropropene (Allyl chloride)				
107-06-2	1,2-Dichloroethane (Ethylene chloride)				
107-13-1	Acrylonitrile				
108-10-1	Methyl isobutyl ketone (4-Methyl-2-pentanone)				
108-38-3	m-Xylene				
108-39-4	3-Methylphenol (m-Cresol)				
108-67-8	1,3,5-Trimethylbenzene				
108-87-2	Methyl cyclohexane	2.4		3.3	
108-88-3	Toluene (Methyl benzene)				

Table C12. Unit Factor Ratios for the HSRAM Residential Scenario.

CASRN	Chemical Name	Well Water Ratios		Columbia River Ratios	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
108-90-7	Chlorobenzene				
108-94-1	Cyclohexanone				
108-95-2	Phenol (Carbolic acid)				
109-99-9	Tetrahydrofuran				
110-00-9	Furan (Oxacyclopentadiene)	1.7		1.7	
110-54-3	n-Hexane				
110-80-5	2-Ethoxyethanol				
110-82-7	Cyclohexane	2.4		3.0	
110-86-1	Pyridine				
111-76-2	2-Butoxyethanol (Ethylene Glycol Monobutyl Ether)				
111-90-0	2-(2-Ethoxyethoxy)-ethanol (Diethylene Glycol Monoethyl Ether)				
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)				
117-84-0	Di-n-octylphthalate				
118-74-1	Hexachlorobenzene	1.5			
120-82-1	1,2,4-Trichlorobenzene				
121-14-2	2,4-Dinitrotoluene				
121-44-8	Triethylamine	3.1		3.1	
122-39-4	Diphenylamine				
123-91-1	1,4-Dioxane (Diethylene oxide)				
126-73-8	Tributyl Phosphate				
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)				
127-18-4	Tetrachloroethylene				
129-00-0	Pyrene	1.2			
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	1.5		1.5	
156-59-2	cis-1,2-Dichloroethylene	1.8		1.7	
206-44-0	Fluoranthene (1,2-Benzacenaphthene)				
309-00-2	Aldrin	1.5			
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	1.3			
319-85-7	beta-Benzene hexachloride (beta-Lindane)				
541-73-1	1,3-Dichlorobenzene	1.7		1.5	
542-75-6	1,3-Dichloropropene (cis & trans)				
621-64-7	N-Nitrosodi-N-propylamine				
1314-62-1	Vanadium pentoxide				
1330-20-7	Xylenes (mixtures)				
1336-36-3	Polychlorinated Biphenyls				
1336-36-3	Polychlorinated Biphenyls (lowest risk)				
6533-73-9	Thallium carbonate				
7429-90-5	Aluminum				
7439-89-6	Iron				
7439-93-2	Lithium				
7439-96-5	Manganese				

Table C12. Unit Factor Ratios for the HSRAM Residential Scenario.

CASRN	Chemical Name	Well Water Ratios		Columbia River Ratios	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
7439-97-6	Mercury metal vapor	180,024		512,625	
7439-98-7	Molybdenum				
7440-02-0	Nickel (soluble salts)				
7440-22-4	Silver				
7440-24-6	Strontium, Stable				
7440-28-0	Thallium metal				
7440-31-5	Tin				
7440-36-0	Antimony				
7440-38-2	Arsenic (inorganic)				
7440-39-3	Barium				
7440-41-7	Beryllium and compounds				
7440-42-8	Boron and borates only				
7440-43-9	Cadmium				
7440-45-1	Cerium (Ceric oxide 1306-38-3)	51,591		75,667	
7440-48-4	Cobalt				
7440-50-8	Copper				
7440-62-2	Vanadium metal				
7440-66-6	Zinc and compounds				
7487-94-7	Mercuric chloride				
7664-41-7	Ammonia	317		317	
7723-14-0	Phosphorus, white				
7782-41-4	Fluorine (soluble fluoride)				
7782-49-2	Selenium and compounds				
8001-35-2	Toxaphene				
11096-82-5	Aroclor 1260				
11097-69-1	Aroclor 1254	1.4			
11104-28-2	Aroclor 1221				
11141-16-5	Aroclor 1232				
12672-29-6	Aroclor 1248				
12674-11-2	Aroclor 1016	1.6			
14797-55-8	Nitrate				
14797-65-0	Nitrite				
16065-83-1	Chromium (III) (insoluble salts)				
16984-48-8	Fluorine anion				
18540-29-9	Chromium (VI) (soluble salts)				
53469-21-9	Aroclor 1242				
na	Uranium (soluble salts)				
na	Total Chromium (1:6 ratio CrVI:Cr III)				

Notes:

- CASRN = Chemical Abstract Service Reference Number
- The ratios shown are the unit factors in Table C11 divided by the unit factors in Table 27.
- Ratios less than 1.2 are not listed.

Table C13. Unit Factors for the HSRAM Agricultural Scenario.

CASRN	Chemical Name	Well Water Only, per mg/L		Columbia River, per mg/L	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
50-32-8	Benzo[a]pyrene	na	8.72E-01	na	1.38E+01
53-70-3	Dibenz[a,h]anthracene	na	1.56E+00	na	3.99E+01
56-23-5	Carbon tetrachloride	1.76E+02	4.37E-03	1.93E+02	5.05E-03
57-12-5	Cyanide, free	3.42E+01	na	3.42E+01	na
57-14-7	1,1-Dimethylhydrazine	na	4.30E+00	na	4.30E+00
57-55-6	Propylene glycol (1,2-Propanediol)	2.23E+00	na	2.23E+00	na
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)	3.65E+02	4.18E-02	5.59E+02	7.40E-02
60-29-7	Ethyl ether (Diethyl ether)	6.82E-01	na	6.89E-01	na
60-34-4	Methylhydrazine	na	3.22E+00	na	3.22E+00
60-57-1	Dieldrin	2.14E+03	6.49E-01	2.44E+04	8.29E+00
62-75-9	N-Nitrosodimethylamine	2.02E+05	3.47E+01	2.03E+05	3.47E+01
64-18-6	Formic acid	4.73E-01	na	4.74E-01	na
67-56-1	Methanol (Methyl alcohol)	1.26E+00	na	1.26E+00	na
67-64-1	Acetone (2-Propanone)	3.14E-01	na	3.15E-01	na
67-66-3	Chloroform	1.33E+02	3.75E-03	1.34E+02	3.75E-03
67-72-1	Hexachloroethane	1.29E+02	8.93E-04	2.50E+02	1.62E-03
71-36-3	n-Butyl alcohol (n-Butanol)	1.64E+01	na	1.65E+01	na
71-43-2	Benzene	3.06E+01	2.16E-03	3.15E+01	2.25E-03
71-55-6	1,1,1-Trichloroethane (Methyl chloroform)	4.19E-01	na	4.42E-01	na
72-20-8	Endrin	6.70E+02	na	3.40E+03	na
74-83-9	Bromomethane	1.30E+02	na	1.31E+02	na
74-87-3	Methyl chloride (Chloromethane)	1.04E+01	5.45E-04	1.05E+01	5.52E-04
75-00-3	Ethyl Chloride	2.20E-01	4.83E-05	2.23E-01	4.97E-05
75-01-4	Vinyl chloride (Chloroethene)	2.76E+01	2.40E-02	2.82E+01	2.49E-02
75-05-8	Acetonitrile	4.10E+01	na	4.12E+01	na
75-07-0	Acetaldehyde	2.06E+02	1.52E-03	2.07E+02	1.53E-03
75-09-2	Dichloromethane (Methylene chloride)	1.40E+00	2.13E-04	1.41E+00	2.15E-04
75-15-0	Carbon disulfide	1.25E+00	na	1.27E+00	na
75-21-8	Ethylene Oxide (Oxirane)	na	7.75E-02	na	7.80E-02
75-34-3	1,1-Dichloroethane (Ethylidene chloride)	1.47E+00	na	1.49E+00	na
75-35-4	1,1-Dichloroethylene	3.29E+00	na	3.36E+00	na
75-45-6	Chlorodifluoromethane	1.83E-02	na	1.84E-02	na
75-68-3	Chloro-1,1-difluoroethane, 1-	1.74E-02	na	1.78E-02	na
75-69-4	Trichlorofluoromethane	7.80E-01	na	8.07E-01	na
75-71-8	Dichlorodifluoromethane	2.26E+00	na	2.28E+00	na
76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane (CFC-113)	1.49E-02	na	1.57E-02	na
76-44-8	Heptachlor	3.42E+02	3.68E-01	8.05E+03	7.80E+00
78-83-1	Isobutanol	5.61E-01	na	5.65E-01	na
78-87-5	1,2-Dichloropropane	2.22E+02	2.70E-03	2.27E+02	2.78E-03
78-93-3	Methyl ethyl ketone (2-Butanone)	3.45E-01	na	3.47E-01	na
79-00-5	1,1,2-Trichloroethane	3.28E+01	3.70E-03	3.34E+01	3.76E-03

Table C13. Unit Factors for the HSRAM Agricultural Scenario.

CASRN	Chemical Name	Well Water Only, per mg/L		Columbia River, per mg/L	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
79-01-6	Trichloroethylene	2.54E+02	2.54E-02	2.78E+02	2.66E-02
79-10-7	2-Propenoic acid (Acrylic acid)	6.25E+00	na	6.25E+00	na
79-34-5	1,1,2,2-Tetrachloroethane (Acetylene tetrachloride)	2.19E+00	1.30E-02	2.28E+00	1.35E-02
79-46-9	2-Nitropropane	6.13E+01	1.14E+00	6.18E+01	1.15E+00
82-68-8	Pentachloronitrobenzene (PCNB)	4.40E+01	1.09E-02	1.41E+02	4.32E-02
83-32-9	Acenaphthene	2.53E+00	na	3.98E+00	na
84-66-2	Diethyl phthalate	1.63E-01	na	1.70E-01	na
84-74-2	Dibutyl phthalate	8.35E-01	na	3.11E+00	na
85-68-7	Butyl benzyl phthalate	4.38E-01	na	2.15E+00	na
87-68-3	Hexachlorobutadiene	4.44E+02	5.13E-03	1.69E+03	1.76E-02
87-86-5	Pentachlorophenol	2.89E+00	2.68E-03	1.20E+01	1.67E-02
88-06-2	2,4,6-Trichlorophenol	1.01E+03	3.41E-04	1.25E+03	4.50E-04
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)	1.11E+02	na	1.55E+02	na
91-20-3	Naphthalene	1.31E+02	na	1.32E+02	na
92-52-4	1,1'-Biphenyl	2.86E+00	na	4.74E+00	na
95-47-6	o-Xylene	4.16E+00	na	4.26E+00	na
95-48-7	2-Methylphenol (o-Cresol)	4.53E+00	na	4.59E+00	na
95-50-1	1,2-Dichlorobenzene (ortho-)	2.71E+00	na	3.10E+00	na
95-57-8	2-Chlorophenol	3.58E+01	na	3.66E+01	na
95-63-6	1,2,4-Trimethylbenzene	6.50E+01	na	6.60E+01	na
95-95-4	2,4,5-Trichlorophenol	9.88E-01	na	1.24E+00	na
98-86-2	Acetophenone	1.71E+00	na	1.71E+00	na
98-95-3	Nitrobenzene	4.61E+02	na	4.66E+02	na
100-25-4	1,4-Dinitrobenzene (para-)	3.25E+03	na	3.26E+03	na
100-41-4	Ethyl benzene	1.10E+00	3.04E-04	1.31E+00	3.75E-04
100-42-5	Styrene	7.47E-01	na	8.24E-01	na
100-51-6	Benzyl alcohol	7.16E-01	na	7.17E-01	na
106-42-3	p-Xylene	4.16E+00	na	4.27E+00	na
106-44-5	4-Methylphenol (p-Cresol)	4.45E+01	na	4.51E+01	na
106-46-7	1,4-Dichlorobenzene (para-)	2.87E+00	1.41E-03	4.06E+00	1.78E-03
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	4.78E+03	1.79E+00	4.87E+03	1.88E+00
106-99-0	1,3-Butadiene	4.37E+02	8.17E-03	4.47E+02	8.44E-03
107-02-8	2-Propenal (Acrolein)	1.93E+04	na	1.93E+04	na
107-05-1	3-Chloropropene (Allyl chloride)	3.81E+02	na	3.81E+02	na
107-06-2	1,2-Dichloroethane (Ethylene chloride)	8.01E+01	5.94E-03	8.02E+01	5.98E-03
107-13-1	Acrylonitrile	3.28E+02	3.52E-02	3.30E+02	3.55E-02
108-10-1	Methyl isobutyl ketone (4-Methyl-2-pentanone)	1.26E+00	na	1.27E+00	na
108-38-3	m-Xylene	4.16E+00	na	4.28E+00	na
108-39-4	3-Methylphenol (m-Cresol)	4.40E+00	na	4.46E+00	na
108-67-8	1,3,5-Trimethylbenzene	6.49E+01	na	6.56E+01	na
108-87-2	Methyl cyclohexane	3.07E-01	na	4.23E-01	na
108-88-3	Toluene (Methyl benzene)	1.31E+00	na	1.36E+00	na

Table C13. Unit Factors for the HSRAM Agricultural Scenario.

CASRN	Chemical Name	Well Water Only, per mg/L		Columbia River, per mg/L	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
108-90-7	Chlorobenzene	1.02E+01	na	1.09E+01	na
108-94-1	Cyclohexanone	4.61E-02	na	4.64E-02	na
108-95-2	Phenol (Carbolic acid)	1.10E+00	na	1.10E+00	na
109-99-9	Tetrahydrofuran	1.90E+00	6.38E-04	1.91E+00	6.43E-04
110-00-9	Furan (Oxacyclopentadiene)	1.31E+02	na	1.32E+02	na
110-54-3	n-Hexane	3.34E+00	na	4.74E+00	na
110-80-5	2-Ethoxyethanol	1.34E+00	na	1.35E+00	na
110-82-7	Cyclohexane	1.51E-01	na	1.94E-01	na
110-86-1	Pyridine	3.11E+02	na	3.12E+02	na
111-76-2	2-Butoxyethanol (Ethylene Glycol Monobutyl Ether)	3.28E-01	na	3.30E-01	na
111-90-0	2-(2-Ethoxyethoxy)-ethanol (Diethylene Glycol Monoethyl Ether)	1.23E+01	na	1.23E+01	na
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)	9.63E+01	1.14E-02	1.10E+02	1.30E-02
117-84-0	Di-n-octylphthalate	1.14E+02	na	1.17E+02	na
118-74-1	Hexachlorobenzene	2.09E+02	1.28E-01	2.72E+03	1.51E+00
120-82-1	1,2,4-Trichlorobenzene	1.03E+02	na	1.12E+02	na
121-14-2	2,4-Dinitrotoluene	1.14E+02	na	1.16E+02	na
121-44-8	Triethylamine	1.69E+02	na	1.70E+02	na
122-39-4	Diphenylamine	4.41E+00	na	6.04E+00	na
123-91-1	1,4-Dioxane (Diethylene oxide)	na	1.44E-03	na	1.44E-03
126-73-8	Tributyl Phosphate	4.56E-01	1.31E-04	5.43E-01	1.70E-04
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)	1.64E+03	na	1.65E+03	na
127-18-4	Tetrachloroethylene	7.56E+00	8.80E-04	1.08E+01	1.61E-03
129-00-0	Pyrene	5.23E+00	na	2.06E+01	na
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	1.83E-01	na	1.84E-01	na
156-59-2	cis-1,2-Dichloroethylene	1.26E+01	na	1.29E+01	na
206-44-0	Fluoranthene (1,2-Benzacenaphthene)	4.48E+00	na	2.33E+01	na
309-00-2	Aldrin	9.03E+03	2.12E+00	2.70E+05	5.92E+01
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	2.41E+02	3.05E-01	3.74E+02	4.83E-01
319-85-7	beta-Benzene hexachloride (beta-Lindane)	4.95E+02	5.05E-02	8.19E+02	1.00E-01
541-73-1	1,3-Dichlorobenzene	1.41E+02	na	1.88E+02	na
542-75-6	1,3-Dichloropropene (cis & trans)	2.14E+01	2.31E-03	2.15E+01	2.44E-03
621-64-7	N-Nitrosodi-N-propylamine	na	1.03E+00	na	1.03E+00
1314-62-1	Vanadium pentoxide	8.29E+00	na	1.75E+01	na
1330-20-7	Xylenes (mixtures)	4.15E+00	na	4.26E+00	na
1336-36-3	Polychlorinated Biphenyls	na	7.56E-02	na	1.93E+01
1336-36-3	Polychlorinated Biphenyls (lowest risk)	na	6.47E-02	na	1.93E+01
6533-73-9	Thallium carbonate	1.18E+03	na	4.97E+04	na
7429-90-5	Aluminum	7.32E-02	na	2.71E-01	na
7439-89-6	Iron	2.66E-01	na	5.37E-01	na
7439-93-2	Lithium	6.69E+00	na	6.90E+00	na
7439-96-5	Manganese	2.09E+00	na	3.30E+00	na

Table C13. Unit Factors for the HSRAM Agricultural Scenario.

CASRN	Chemical Name	Well Water Only, per mg/L		Columbia River, per mg/L	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
7439-97-6	Mercury metal vapor	9.32E+03	na	1.98E+04	na
7439-98-7	Molybdenum	4.64E+01	na	4.76E+01	na
7440-02-0	Nickel (soluble salts)	7.98E+00	na	1.01E+01	na
7440-22-4	Silver	1.40E+01	na	1.51E+01	na
7440-24-6	Strontium, Stable	4.58E-01	na	5.04E-01	na
7440-28-0	Thallium metal	1.44E+03	na	6.02E+04	na
7440-31-5	Tin	1.97E-01	na	2.14E+00	na
7440-36-0	Antimony	1.87E+02	na	2.98E+02	na
7440-38-2	Arsenic (inorganic)	2.37E+02	2.36E-02	5.64E+02	8.63E-02
7440-39-3	Barium	1.13E+00	na	1.20E+00	na
7440-41-7	Beryllium and compounds	3.69E+01	2.85E-05	5.97E+01	2.85E-05
7440-42-8	Boron and borates only	4.17E+00	na	4.20E+00	na
7440-43-9	Cadmium	1.75E+02	2.10E-05	2.69E+02	2.10E-05
7440-45-1	Cerium (Ceric oxide 1306-38-3)	3.39E+03	na	4.96E+03	na
7440-48-4	Cobalt	5.06E+00	3.24E-05	1.10E+01	3.24E-05
7440-50-8	Copper	7.39E+00	na	9.41E+00	na
7440-62-2	Vanadium metal	1.10E+01	na	2.32E+01	na
7440-66-6	Zinc and compounds	7.62E+01	na	7.65E+01	na
7487-94-7	Mercuric chloride	1.55E+03	na	2.85E+03	na
7664-41-7	Ammonia	1.70E+02	na	1.70E+02	na
7723-14-0	Phosphorus, white	1.42E+05	na	1.71E+05	na
7782-41-4	Fluorine (soluble fluoride)	2.61E+00	na	2.73E+00	na
7782-49-2	Selenium and compounds	1.69E+01	na	3.02E+01	na
8001-35-2	Toxaphene	na	4.40E-02	na	1.07E+00
11096-82-5	Aroclor 1260	na	4.50E+00	na	6.15E+00
11097-69-1	Aroclor 1254	1.74E+04	1.75E-01	2.74E+06	4.69E+01
11104-28-2	Aroclor 1221	na	3.37E-02	na	2.38E-01
11141-16-5	Aroclor 1232	na	3.37E-02	na	2.38E-01
12672-29-6	Aroclor 1248	na	7.50E-02	na	2.11E+01
12674-11-2	Aroclor 1016	2.30E+03	3.46E-02	1.00E+05	5.91E+00
14797-55-8	Nitrate	3.98E-02	na	4.07E-02	na
14797-65-0	Nitrite	6.41E-01	na	6.56E-01	na
16065-83-1	Chromium (III) (insoluble salts)	5.55E-02	na	1.14E-01	na
16984-48-8	Fluorine anion	2.61E+00	na	2.73E+00	na
18540-29-9	Chromium (VI) (soluble salts)	2.41E+01	3.51E-05	5.03E+01	3.51E-05
53469-21-9	Aroclor 1242	na	7.44E-02	na	1.93E+01
na	Uranium (soluble salts)	1.18E+02	na	1.27E+02	na
na	Total Chromium (1:6 ratio CrVI:Cr III)	3.49E+00	5.02E-06	7.29E+00	5.02E-06

Notes:

- CASRN = Chemical Abstract Service Reference Number
- The total risk to the HSRAM Agricultural scenario is calculated using intakes from 30 consecutive years. The soil concentration is zero at the start of the exposure.
- These scenario factors must be multiplied by the appropriate water concentration. The "Inland Well" column assumes all of the contaminated water comes from the well. The "Columbia River" column assumes that all of the contaminated water comes from the Columbia River.

Table C14. Unit Factor Ratios for the HSRAM Agricultural Scenario.

CASRN	Chemical Name	Well Water Ratios		Columbia River Ratios	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
50-32-8	Benzo[a]pyrene				
53-70-3	Dibenz[a,h]anthracene				
56-23-5	Carbon tetrachloride	1.8		1.7	
57-12-5	Cyanide, free				
57-14-7	1,1-Dimethylhydrazine				
57-55-6	Propylene glycol (1,2-Propanediol)				
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)				
60-29-7	Ethyl ether (Diethyl ether)	1.7		1.7	
60-34-4	Methylhydrazine				
60-57-1	Dieldrin	1.3			
62-75-9	N-Nitrosodimethylamine				
64-18-6	Formic acid				
67-56-1	Methanol (Methyl alcohol)				
67-64-1	Acetone (2-Propanone)	1.2		1.2	
67-66-3	Chloroform				
67-72-1	Hexachloroethane	1.7		1.3	
71-36-3	n-Butyl alcohol (n-Butanol)				
71-43-2	Benzene				
71-55-6	1,1,1-Trichloroethane (Methyl chloroform)				
72-20-8	Endrin				
74-83-9	Bromomethane				
74-87-3	Methyl chloride (Chloromethane)	2.5		2.5	
75-00-3	Ethyl Chloride				
75-01-4	Vinyl chloride (Chloroethene)				
75-05-8	Acetonitrile	6.5		6.5	
75-07-0	Acetaldehyde	4.9	4.2	4.9	4.3
75-09-2	Dichloromethane (Methylene chloride)				
75-15-0	Carbon disulfide				
75-21-8	Ethylene Oxide (Oxirane)				
75-34-3	1,1-Dichloroethane (Ethylidene chloride)				
75-35-4	1,1-Dichloroethylene				
75-45-6	Chlorodifluoromethane	2.4		2.4	
75-68-3	Chloro-1,1-difluoroethane, 1-	2.3		2.3	
75-69-4	Trichlorofluoromethane				
75-71-8	Dichlorodifluoromethane				
76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane (CFC-113)				
76-44-8	Heptachlor	1.5			
78-83-1	Isobutanol				
78-87-5	1,2-Dichloropropane	2.3	2.4	2.4	2.3
78-93-3	Methyl ethyl ketone (2-Butanone)				
79-00-5	1,1,2-Trichloroethane	1.7		1.7	

Table C14. Unit Factor Ratios for the HSRAM Agricultural Scenario.

CASRN	Chemical Name	Well Water Ratios		Columbia River Ratios	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
79-01-6	Trichloroethylene				
79-10-7	2-Propenoic acid (Acrylic acid)				
79-34-5	1,1,2,2-Tetrachloroethane (Acetylene tetrachloride)	1.7		1.7	
79-46-9	2-Nitropropane	3.2	2.6	3.2	2.6
82-68-8	Pentachloronitrobenzene (PCNB)	1.7	2.3		
83-32-9	Acenaphthene	1.6		1.3	
84-66-2	Diethyl phthalate				
84-74-2	Dibutyl phthalate				
85-68-7	Butyl benzyl phthalate				
87-68-3	Hexachlorobutadiene	1.7			
87-86-5	Pentachlorophenol				
88-06-2	2,4,6-Trichlorophenol				
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)				
91-20-3	Naphthalene				
92-52-4	1,1'-Biphenyl	1.6		1.3	
95-47-6	o-Xylene				
95-48-7	2-Methylphenol (o-Cresol)				
95-50-1	1,2-Dichlorobenzene (ortho-)				
95-57-8	2-Chlorophenol				
95-63-6	1,2,4-Trimethylbenzene				
95-95-4	2,4,5-Trichlorophenol				
98-86-2	Acetophenone				
98-95-3	Nitrobenzene				
100-25-4	1,4-Dinitrobenzene (para-)				
100-41-4	Ethyl benzene		1.7		2.1
100-42-5	Styrene				
100-51-6	Benzyl alcohol				
106-42-3	p-Xylene				
106-44-5	4-Methylphenol (p-Cresol)				
106-46-7	1,4-Dichlorobenzene (para-)				
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	2.5		2.6	
106-99-0	1,3-Butadiene	2.3	1.7	2.4	1.7
107-02-8	2-Propenal (Acrolein)				
107-05-1	3-Chloropropene (Allyl chloride)				
107-06-2	1,2-Dichloroethane (Ethylene chloride)				
107-13-1	Acrylonitrile				
108-10-1	Methyl isobutyl ketone (4-Methyl-2-pentanone)				
108-38-3	m-Xylene				
108-39-4	3-Methylphenol (m-Cresol)				
108-67-8	1,3,5-Trimethylbenzene				
108-87-2	Methyl cyclohexane	2.4		3.3	
108-88-3	Toluene (Methyl benzene)				

Table C14. Unit Factor Ratios for the HSRAM Agricultural Scenario.

CASRN	Chemical Name	Well Water Ratios		Columbia River Ratios	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
108-90-7	Chlorobenzene				
108-94-1	Cyclohexanone				
108-95-2	Phenol (Carbolic acid)				
109-99-9	Tetrahydrofuran				
110-00-9	Furan (Oxacyclopentadiene)	1.7		1.7	
110-54-3	n-Hexane				
110-80-5	2-Ethoxyethanol				
110-82-7	Cyclohexane	2.4		3.0	
110-86-1	Pyridine				
111-76-2	2-Butoxyethanol (Ethylene Glycol Monobutyl Ether)				
111-90-0	2-(2-Ethoxyethoxy)-ethanol (Diethylene Glycol Monoethyl Ether)				
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)				
117-84-0	Di-n-octylphthalate				
118-74-1	Hexachlorobenzene	1.5			
120-82-1	1,2,4-Trichlorobenzene				
121-14-2	2,4-Dinitrotoluene				
121-44-8	Triethylamine	3.1		3.1	
122-39-4	Diphenylamine				
123-91-1	1,4-Dioxane (Diethylene oxide)				
126-73-8	Tributyl Phosphate				
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)				
127-18-4	Tetrachloroethylene				
129-00-0	Pyrene	1.2			
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	1.5		1.5	
156-59-2	cis-1,2-Dichloroethylene	1.8		1.7	
206-44-0	Fluoranthene (1,2-Benzacenaphthene)				
309-00-2	Aldrin	1.3			
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	1.3			
319-85-7	beta-Benzene hexachloride (beta-Lindane)				
541-73-1	1,3-Dichlorobenzene	1.7		1.5	
542-75-6	1,3-Dichloropropene (cis & trans)				
621-64-7	N-Nitrosodi-N-propylamine				
1314-62-1	Vanadium pentoxide				
1330-20-7	Xylenes (mixtures)				
1336-36-3	Polychlorinated Biphenyls				
1336-36-3	Polychlorinated Biphenyls (lowest risk)				
6533-73-9	Thallium carbonate				
7429-90-5	Aluminum				
7439-89-6	Iron				
7439-93-2	Lithium				
7439-96-5	Manganese				

Table C14. Unit Factor Ratios for the HSRAM Agricultural Scenario.

CASRN	Chemical Name	Well Water Ratios		Columbia River Ratios	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
7439-97-6	Mercury metal vapor	295,069		627,679	
7439-98-7	Molybdenum				
7440-02-0	Nickel (soluble salts)				
7440-22-4	Silver				
7440-24-6	Strontium, Stable				
7440-28-0	Thallium metal				
7440-31-5	Tin				
7440-36-0	Antimony				
7440-38-2	Arsenic (inorganic)				
7440-39-3	Barium				
7440-41-7	Beryllium and compounds				
7440-42-8	Boron and borates only				
7440-43-9	Cadmium				
7440-45-1	Cerium (Ceric oxide 1306-38-3)	51,659		75,735	
7440-48-4	Cobalt				
7440-50-8	Copper				
7440-62-2	Vanadium metal				
7440-66-6	Zinc and compounds				
7487-94-7	Mercuric chloride				
7664-41-7	Ammonia	317		317	
7723-14-0	Phosphorus, white				
7782-41-4	Fluorine (soluble fluoride)				
7782-49-2	Selenium and compounds				
8001-35-2	Toxaphene				
11096-82-5	Aroclor 1260				
11097-69-1	Aroclor 1254				
11104-28-2	Aroclor 1221				
11141-16-5	Aroclor 1232				
12672-29-6	Aroclor 1248				
12674-11-2	Aroclor 1016	1.5			
14797-55-8	Nitrate				
14797-65-0	Nitrite				
16065-83-1	Chromium (III) (insoluble salts)				
16984-48-8	Fluorine anion				
18540-29-9	Chromium (VI) (soluble salts)				
53469-21-9	Aroclor 1242				
na	Uranium (soluble salts)				
na	Total Chromium (1:6 ratio CrVI:Cr III)				

Notes:

- CASRN = Chemical Abstract Service Reference Number
- The ratios shown are the unit factors in Table C13 divided by the unit factors in Table 29.
- Ratios less than 1.2 are not listed.

Table C15. Hazard Index and Cancer Risk Factors for Chemicals, MTCA Standard Method for Ground Water.

CASRN	Chemical Name	Method B (Residential) per mg/L		Method C (Industrial) per mg/L	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
50-32-8	Benzo[a]pyrene	na	8.34E-02	na	8.34E-02
53-70-3	Dibenz[a,h]anthracene	na	8.34E-02	na	8.34E-02
56-23-5	Carbon tetrachloride	1.79E+02	2.97E-03	8.16E+01	2.97E-03
57-12-5	Cyanide, free	3.13E+00	na	1.43E+00	na
57-14-7	1,1-Dimethylhydrazine	na	3.43E-02	na	3.43E-02
57-55-6	Propylene glycol (1,2-Propanediol)	1.25E-01	na	5.71E-02	na
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)	2.08E+02	1.49E-02	9.52E+01	1.49E-02
60-29-7	Ethyl ether (Diethyl ether)	6.25E-01	na	2.86E-01	na
60-34-4	Methylhydrazine	na	3.43E-02	na	3.43E-02
60-57-1	Dieldrin	1.25E+03	1.83E-01	5.71E+02	1.83E-01
62-75-9	N-Nitrosodimethylamine	7.81E+03	5.83E-01	3.57E+03	5.83E-01
64-18-6	Formic acid	3.13E-02	na	1.43E-02	na
67-56-1	Methanol (Methyl alcohol)	2.50E-01	na	1.14E-01	na
67-64-1	Acetone (2-Propanone)	1.39E-01	na	6.35E-02	na
67-66-3	Chloroform	1.25E+01	5.26E-06	5.71E+00	5.26E-06
67-72-1	Hexachloroethane	6.25E+01	1.60E-04	2.86E+01	1.60E-04
71-36-3	n-Butyl alcohol (n-Butanol)	6.25E-01	na	2.86E-01	na
71-43-2	Benzene	3.13E+01	1.26E-03	1.43E+01	1.26E-03
71-55-6	1,1,1-Trichloroethane (Methyl chloroform)	4.46E-01	na	2.04E-01	na
72-20-8	Endrin	2.08E+02	na	9.52E+01	na
74-83-9	Bromomethane	8.93E+01	na	4.08E+01	na
74-87-3	Methyl chloride (Chloromethane)	9.73E+00	2.97E-04	4.45E+00	2.97E-04
75-00-3	Ethyl Chloride	1.56E-01	3.31E-05	7.14E-02	3.31E-05
75-01-4	Vinyl chloride (Chloroethene)	4.17E+01	3.20E-02	1.90E+01	1.65E-02
75-05-8	Acetonitrile	1.46E+01	na	6.68E+00	na
75-07-0	Acetaldehyde	9.73E+01	3.52E-04	4.45E+01	3.52E-04
75-09-2	Dichloromethane (Methylene chloride)	2.08E+00	1.71E-04	9.52E-01	1.71E-04
75-15-0	Carbon disulfide	1.25E+00	na	5.71E-01	na
75-21-8	Ethylene Oxide (Oxirane)	na	2.33E-02	na	2.33E-02
75-34-3	1,1-Dichloroethane (Ethylidene chloride)	1.25E+00	na	5.71E-01	na
75-35-4	1,1-Dichloroethylene	2.50E+00	na	1.14E+00	na
75-45-6	Chlorodifluoromethane	1.75E-02	na	7.99E-03	na
75-68-3	Chloro-1,1-difluoroethane, 1-	1.75E-02	na	7.99E-03	na
75-69-4	Trichlorofluoromethane	4.17E-01	na	1.90E-01	na
75-71-8	Dichlorodifluoromethane	6.25E-01	na	2.86E-01	na
76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane (CFC-113)	2.08E-03	na	9.52E-04	na
76-44-8	Heptachlor	1.25E+02	5.14E-02	5.71E+01	5.14E-02
78-83-1	Isobutanol	2.08E-01	na	9.52E-02	na
78-87-5	1,2-Dichloropropane	2.19E+02	1.55E-03	1.00E+02	1.55E-03

Table C15. Hazard Index and Cancer Risk Factors for Chemicals, MTCA Standard Method for Ground Water.

CASRN	Chemical Name	Method B (Residential) per mg/L		Method C (Industrial) per mg/L	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
78-93-3	Methyl ethyl ketone (2-Butanone)	2.08E-01	na	9.52E-02	na
79-00-5	1,1,2-Trichloroethane	3.13E+01	1.30E-03	1.43E+01	1.30E-03
79-01-6	Trichloroethylene	4.17E+02	9.14E-03	1.90E+02	9.14E-03
79-10-7	2-Propenoic acid (Acrylic acid)	1.25E-01	na	5.71E-02	na
79-34-5	1,1,2,2-Tetrachloroethane (Acetylene tetrachloride)	2.08E+00	4.57E-03	9.52E-01	4.57E-03
79-46-9	2-Nitropropane	4.38E+01	4.30E-01	2.00E+01	4.30E-01
82-68-8	Pentachloronitrobenzene (PCNB)	2.08E+01	2.97E-03	9.52E+00	2.97E-03
83-32-9	Acenaphthene	1.04E+00	na	4.76E-01	na
84-66-2	Diethyl phthalate	7.81E-02	na	3.57E-02	na
84-74-2	Dibutyl phthalate	6.25E-01	na	2.86E-01	na
85-68-7	Butyl benzyl phthalate	3.13E-01	na	1.43E-01	na
87-68-3	Hexachlorobutadiene	4.17E+02	1.78E-03	1.90E+02	1.78E-03
87-86-5	Pentachlorophenol	2.08E+00	1.37E-03	9.52E-01	1.37E-03
88-06-2	2,4,6-Trichlorophenol	6.25E+02	1.26E-04	2.86E+02	1.26E-04
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)	6.25E+01	na	2.86E+01	na
91-20-3	Naphthalene	6.25E+00	na	2.86E+00	na
92-52-4	1,1'-Biphenyl	1.25E+00	na	5.71E-01	na
95-47-6	o-Xylene	6.25E-01	na	2.86E-01	na
95-48-7	2-Methylphenol (o-Cresol)	1.25E+00	na	5.71E-01	na
95-50-1	1,2-Dichlorobenzene (ortho-)	1.39E+00	na	6.35E-01	na
95-57-8	2-Chlorophenol	1.25E+01	na	5.71E+00	na
95-63-6	1,2,4-Trimethylbenzene	2.50E+00	na	1.14E+00	na
95-95-4	2,4,5-Trichlorophenol	6.25E-01	na	2.86E-01	na
98-86-2	Acetophenone	6.25E-01	na	2.86E-01	na
98-95-3	Nitrobenzene	1.25E+02	na	5.71E+01	na
100-25-4	1,4-Dinitrobenzene (para-)	6.25E+02	na	2.86E+02	na
100-41-4	Ethyl benzene	1.25E+00	1.76E-04	5.71E-01	1.76E-04
100-42-5	Styrene	6.25E-01	na	2.86E-01	na
100-51-6	Benzyl alcohol	2.08E-01	na	9.52E-02	na
106-42-3	p-Xylene	6.25E-01	na	2.86E-01	na
106-44-5	4-Methylphenol (p-Cresol)	1.25E+01	na	5.71E+00	na
106-46-7	1,4-Dichlorobenzene (para-)	4.17E+00	5.49E-04	1.90E+00	5.49E-04
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	4.38E+03	1.94E+00	2.00E+03	1.94E+00
106-99-0	1,3-Butadiene	2.19E+02	2.40E-03	1.00E+02	2.40E-03
107-02-8	2-Propenal (Acrolein)	2.50E+02	na	1.14E+02	na
107-05-1	3-Chloropropene (Allyl chloride)	1.25E+00	na	5.71E-01	na
107-06-2	1,2-Dichloroethane (Ethylene chloride)	4.17E+00	2.08E-03	1.90E+00	2.08E-03
107-13-1	Acrylonitrile	1.25E+02	1.23E-02	5.71E+01	1.23E-02
108-10-1	Methyl isobutyl ketone (4-Methyl-2-pentanone)	1.56E+00	na	7.14E-01	na
108-38-3	m-Xylene	6.25E-01	na	2.86E-01	na

Table C15. Hazard Index and Cancer Risk Factors for Chemicals, MTCA Standard Method for Ground Water.

CASRN	Chemical Name	Method B (Residential) per mg/L		Method C (Industrial) per mg/L	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
108-39-4	3-Methylphenol (m-Cresol)	1.25E+00	na	5.71E-01	na
108-67-8	1,3,5-Trimethylbenzene	2.50E+00	na	1.14E+00	na
108-87-2	Methyl cyclohexane	2.92E-01	na	1.33E-01	na
108-88-3	Toluene (Methyl benzene)	6.25E-01	na	2.86E-01	na
108-90-7	Chlorobenzene	6.25E+00	na	2.86E+00	na
108-94-1	Cyclohexanone	1.25E-02	na	5.71E-03	na
108-95-2	Phenol (Carbolic acid)	2.08E-01	na	9.52E-02	na
109-99-9	Tetrahydrofuran	5.95E-01	1.74E-04	2.72E-01	1.74E-04
110-00-9	Furan (Oxacyclopentadiene)	6.25E+01	na	2.86E+01	na
110-54-3	n-Hexane	2.08E+00	na	9.52E-01	na
110-80-5	2-Ethoxyethanol	1.56E-01	na	7.14E-02	na
110-82-7	Cyclohexane	1.46E-01	na	6.68E-02	na
110-86-1	Pyridine	6.25E+01	na	2.86E+01	na
111-76-2	2-Butoxyethanol (Ethylene Glycol Monobutyl Ether)	2.50E-01	na	1.14E-01	na
111-90-0	2-(2-Ethoxyethoxy)-ethanol (Diethylene Glycol Monoethyl Ether)	2.08E+00	na	9.52E-01	na
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)	3.13E+00	1.60E-04	1.43E+00	1.60E-04
117-84-0	Di-n-octylphthalate	1.56E+00	na	7.14E-01	na
118-74-1	Hexachlorobenzene	7.81E+01	1.83E-02	3.57E+01	1.83E-02
120-82-1	1,2,4-Trichlorobenzene	1.25E+01	na	5.71E+00	na
121-14-2	2,4-Dinitrotoluene	3.13E+01	na	1.43E+01	na
121-44-8	Triethylamine	6.25E+01	na	2.86E+01	na
122-39-4	Diphenylamine	2.50E+00	na	1.14E+00	na
123-91-1	1,4-Dioxane (Diethylene oxide)	na	1.26E-04	na	1.26E-04
126-73-8	Tributyl Phosphate	3.13E-01	6.17E-05	1.43E-01	6.17E-05
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)	6.25E+02	na	2.86E+02	na
127-18-4	Tetrachloroethylene	1.25E+01	1.19E-03	5.71E+00	1.19E-03
129-00-0	Pyrene	2.08E+00	na	9.52E-01	na
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	6.94E-02	na	3.17E-02	na
156-59-2	cis-1,2-Dichloroethylene	1.25E+01	na	5.71E+00	na
206-44-0	Fluoranthene (1,2-Benzacenaphthene)	1.56E+00	na	7.14E-01	na
309-00-2	Aldrin	2.08E+03	1.94E-01	9.52E+02	1.94E-01
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	1.25E+02	7.20E-02	5.71E+01	7.20E-02
319-85-7	beta-Benzene hexachloride (beta-Lindane)	3.13E+02	2.06E-02	1.43E+02	2.06E-02
541-73-1	1,3-Dichlorobenzene	1.39E+02	na	6.35E+01	na
542-75-6	1,3-Dichloropropene (cis & trans)	4.17E+00	2.29E-03	1.90E+00	2.29E-03
621-64-7	N-Nitrosodi-N-propylamine	na	8.00E-02	na	8.00E-02
1314-62-1	Vanadium pentoxide	6.94E+00	na	3.17E+00	na
1330-20-7	Xylenes (mixtures)	6.25E-01	na	2.86E-01	na
1336-36-3	Polychlorinated Biphenyls	na	4.57E-03	na	4.57E-03
1336-36-3	Polychlorinated Biphenyls (lowest risk)	na	8.00E-04	na	8.00E-04

Table C15. Hazard Index and Cancer Risk Factors for Chemicals, MTCA Standard Method for Ground Water.

CASRN	Chemical Name	Method B (Residential) per mg/L		Method C (Industrial) per mg/L	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
6533-73-9	Thallium carbonate	7.81E+02	na	3.57E+02	na
7429-90-5	Aluminum	6.25E-02	na	2.86E-02	na
7439-89-6	Iron	2.08E-01	na	9.52E-02	na
7439-93-2	Lithium	3.13E+00	na	1.43E+00	na
7439-96-5	Manganese	1.34E+00	na	6.12E-01	na
7439-97-6	Mercury metal vapor	1.46E+03	na	6.67E+02	na
7439-98-7	Molybdenum	1.25E+01	na	5.71E+00	na
7440-02-0	Nickel (soluble salts)	3.13E+00	na	1.43E+00	na
7440-22-4	Silver	1.25E+01	na	5.71E+00	na
7440-24-6	Strontium, Stable	1.04E-01	na	4.76E-02	na
7440-28-0	Thallium metal	9.47E+02	na	4.33E+02	na
7440-31-5	Tin	1.04E-01	na	4.76E-02	na
7440-36-0	Antimony	1.56E+02	na	7.14E+01	na
7440-38-2	Arsenic (inorganic)	2.08E+02	1.71E-02	9.52E+01	1.71E-02
7440-39-3	Barium	8.93E-01	na	4.08E-01	na
7440-41-7	Beryllium and compounds	3.13E+01	0.00E+00	1.43E+01	0.00E+00
7440-42-8	Boron and borates only	6.94E-01	na	3.17E-01	na
7440-43-9	Cadmium	1.25E+02	0.00E+00	5.71E+01	0.00E+00
7440-45-1	Cerium (Ceric oxide 1306-38-3)	2.19E+03	na	1.00E+03	na
7440-48-4	Cobalt	3.13E+00	0.00E+00	1.43E+00	0.00E+00
7440-50-8	Copper	1.56E+00	na	7.14E-01	na
7440-62-2	Vanadium metal	8.93E+00	na	4.08E+00	na
7440-66-6	Zinc and compounds	2.08E-01	na	9.52E-02	na
7487-94-7	Mercuric chloride	2.08E+02	na	9.52E+01	na
7664-41-7	Ammonia	4.37E+00	na	2.00E+00	na
7723-14-0	Phosphorus, white	3.13E+03	na	1.43E+03	na
7782-41-4	Fluorine (soluble fluoride)	1.04E+00	na	4.76E-01	na
7782-49-2	Selenium and compounds	1.25E+01	na	5.71E+00	na
8001-35-2	Toxaphene	na	1.26E-02	na	1.26E-02
11096-82-5	Aroclor 1260	na	4.57E-03	na	4.57E-03
11097-69-1	Aroclor 1254	6.25E+03	4.57E-03	2.86E+03	4.57E-03
11104-28-2	Aroclor 1221	na	4.57E-03	na	4.57E-03
11141-16-5	Aroclor 1232	na	4.57E-03	na	4.57E-03
12672-29-6	Aroclor 1248	na	4.57E-03	na	4.57E-03
12674-11-2	Aroclor 1016	8.93E+02	8.00E-04	4.08E+02	8.00E-04
14797-55-8	Nitrate	3.91E-02	na	1.79E-02	na
14797-65-0	Nitrite	6.25E-01	na	2.86E-01	na
16065-83-1	Chromium (III) (insoluble salts)	4.17E-02	na	1.90E-02	na
16984-48-8	Fluorine anion	1.04E+00	na	4.76E-01	na
18540-29-9	Chromium (VI) (soluble salts)	2.08E+01	0.00E+00	9.52E+00	0.00E+00
53469-21-9	Aroclor 1242	na	4.57E-03	na	4.57E-03
na	Uranium (soluble salts)	1.04E+02	na	4.76E+01	na
na	Total Chromium (1:6 ratio CrVI:Cr III)	3.01E+00	0.00E+00	1.38E+00	0.00E+00

Table C15. Hazard Index and Cancer Risk Factors for Chemicals, MTCA Standard Method for Ground Water.

CASRN	Chemical Name	Method B (Residential) per mg/L		Method C (Industrial) per mg/L	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
Notes:					
<ul style="list-style-type: none"> • MTCA refers to Chapter 173-340 of the Washington Administrative Code. • CASRN = Chemical Abstract Service Reference Number • The Method B Hazard Index uses child consumption rates and body mass. All others use the adult numbers. The reference doses and slope factors for ingestion are shown in Table C1. • The Inhale Factor shown in Table 30 is included in the Hazard Index and Cancer Risk factors. In effect, the hazard index and risk factors are doubled for volatile chemicals (Inhale Factor = 2). • Missing values are indicated with "na", which means "not available". 					

Table C16. Hazard Index and Cancer Risk Factors for Chemicals, MTCA Standard Method for Surface Water.

CASRN	Chemical Name	Method B (Residential) per mg/L		Method C (Industrial) per mg/L	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
50-32-8	Benzo[a]pyrene	na	1.18E+01	na	4.72E+00
53-70-3	Dibenz[a,h]anthracene	na	3.54E+01	na	1.42E+01
56-23-5	Carbon tetrachloride	1.79E+02	2.97E-03	8.16E+01	2.97E-03
57-12-5	Cyanide, free	3.13E+00	na	1.43E+00	na
57-14-7	1,1-Dimethylhydrazine	na	3.43E-02	na	3.43E-02
57-55-6	Propylene glycol (1,2-Propanediol)	1.25E-01	na	5.71E-02	na
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)	2.08E+02	2.93E-02	9.52E+01	1.49E-02
60-29-7	Ethyl ether (Diethyl ether)	6.25E-01	na	2.86E-01	na
60-34-4	Methylhydrazine	na	3.43E-02	na	3.43E-02
60-57-1	Dieldrin	2.21E+04	7.09E+00	8.86E+03	2.83E+00
62-75-9	N-Nitrosodimethylamine	7.81E+03	5.83E-01	3.57E+03	5.83E-01
64-18-6	Formic acid	3.13E-02	na	1.43E-02	na
67-56-1	Methanol (Methyl alcohol)	2.50E-01	na	1.14E-01	na
67-64-1	Acetone (2-Propanone)	1.39E-01	na	6.35E-02	na
67-66-3	Chloroform	1.25E+01	5.26E-06	5.71E+00	5.26E-06
67-72-1	Hexachloroethane	1.19E+02	6.64E-04	4.74E+01	2.66E-04
71-36-3	n-Butyl alcohol (n-Butanol)	6.25E-01	na	2.86E-01	na
71-43-2	Benzene	3.13E+01	1.26E-03	1.43E+01	1.26E-03
71-55-6	1,1,1-Trichloroethane (Methyl chloroform)	4.46E-01	na	2.04E-01	na
72-20-8	Endrin	2.59E+03	na	1.04E+03	na
74-83-9	Bromomethane	8.93E+01	na	4.08E+01	na
74-87-3	Methyl chloride (Chloromethane)	9.73E+00	2.97E-04	4.45E+00	2.97E-04
75-00-3	Ethyl Chloride	1.56E-01	3.31E-05	7.14E-02	3.31E-05
75-01-4	Vinyl chloride (Chloroethene)	4.17E+01	3.20E-02	1.90E+01	1.65E-02
75-05-8	Acetonitrile	1.46E+01	na	6.68E+00	na
75-07-0	Acetaldehyde	9.73E+01	3.52E-04	4.45E+01	3.52E-04

Table C16. Hazard Index and Cancer Risk Factors for Chemicals, MTCA Standard Method for Surface Water.

CASRN	Chemical Name	Method B (Residential) per mg/L		Method C (Industrial) per mg/L	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
75-09-2	Dichloromethane (Methylene chloride)	2.08E+00	1.71E-04	9.52E-01	1.71E-04
75-15-0	Carbon disulfide	1.25E+00	na	5.71E-01	na
75-21-8	Ethylene Oxide (Oxirane)	na	2.33E-02	na	2.33E-02
75-34-3	1,1-Dichloroethane (Ethylidene chloride)	1.25E+00	na	5.71E-01	na
75-35-4	1,1-Dichloroethylene	2.50E+00	na	1.14E+00	na
75-45-6	Chlorodifluoromethane	1.75E-02	na	7.99E-03	na
75-68-3	Chloro-1,1-difluoroethane, 1-	1.75E-02	na	7.99E-03	na
75-69-4	Trichlorofluoromethane	4.17E-01	na	1.90E-01	na
75-71-8	Dichlorodifluoromethane	6.25E-01	na	2.86E-01	na
76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane (CFC-113)	2.08E-03	na	9.52E-04	na
76-44-8	Heptachlor	7.66E+03	6.90E+00	3.06E+03	2.76E+00
78-83-1	Isobutanol	2.08E-01	na	9.52E-02	na
78-87-5	1,2-Dichloropropane	2.19E+02	1.55E-03	1.00E+02	1.55E-03
78-93-3	Methyl ethyl ketone (2-Butanone)	2.08E-01	na	9.52E-02	na
79-00-5	1,1,2-Trichloroethane	3.13E+01	1.30E-03	1.43E+01	1.30E-03
79-01-6	Trichloroethylene	4.17E+02	9.14E-03	1.90E+02	9.14E-03
79-10-7	2-Propenoic acid (Acrylic acid)	1.25E-01	na	5.71E-02	na
79-34-5	1,1,2,2-Tetrachloroethane (Acetylene tetrachloride)	2.08E+00	4.57E-03	9.52E-01	4.57E-03
79-46-9	2-Nitropropane	4.38E+01	4.30E-01	2.00E+01	4.30E-01
82-68-8	Pentachloronitrobenzene (PCNB)	9.59E+01	2.99E-02	3.84E+01	1.20E-02
83-32-9	Acenaphthene	1.34E+00	na	5.35E-01	na
84-66-2	Diethyl phthalate	7.81E-02	na	3.57E-02	na
84-74-2	Dibutyl phthalate	2.25E+00	na	8.98E-01	na
85-68-7	Butyl benzyl phthalate	1.69E+00	na	6.75E-01	na
87-68-3	Hexachlorobutadiene	2.46E+03	2.30E-02	9.84E+02	9.21E-03
87-86-5	Pentachlorophenol	8.94E+00	1.29E-02	3.58E+00	5.15E-03
88-06-2	2,4,6-Trichlorophenol	6.25E+02	1.26E-04	2.86E+02	1.26E-04
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)	6.25E+01	na	2.86E+01	na
91-20-3	Naphthalene	6.25E+00	na	2.86E+00	na
92-52-4	1,1'-Biphenyl	1.79E+00	na	7.14E-01	na
95-47-6	o-Xylene	6.25E-01	na	2.86E-01	na
95-48-7	2-Methylphenol (o-Cresol)	1.25E+00	na	5.71E-01	na
95-50-1	1,2-Dichlorobenzene (ortho-)	1.39E+00	na	6.35E-01	na
95-57-8	2-Chlorophenol	1.25E+01	na	5.71E+00	na
95-63-6	1,2,4-Trimethylbenzene	2.50E+00	na	1.14E+00	na
95-95-4	2,4,5-Trichlorophenol	6.25E-01	na	2.86E-01	na
98-86-2	Acetophenone	6.25E-01	na	2.86E-01	na
98-95-3	Nitrobenzene	1.25E+02	na	5.71E+01	na
100-25-4	1,4-Dinitrobenzene (para-)	6.25E+02	na	2.86E+02	na
100-41-4	Ethyl benzene	1.25E+00	1.76E-04	5.71E-01	1.76E-04

Table C16. Hazard Index and Cancer Risk Factors for Chemicals, MTCA Standard Method for Surface Water.

CASRN	Chemical Name	Method B (Residential) per mg/L		Method C (Industrial) per mg/L	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
100-42-5	Styrene	6.25E-01	na	2.86E-01	na
100-51-6	Benzyl alcohol	2.08E-01	na	9.52E-02	na
106-42-3	p-Xylene	6.25E-01	na	2.86E-01	na
106-44-5	4-Methylphenol (p-Cresol)	1.25E+01	na	5.71E+00	na
106-46-7	1,4-Dichlorobenzene (para-)	4.17E+00	6.58E-04	1.90E+00	5.49E-04
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	4.38E+03	1.94E+00	2.00E+03	1.94E+00
106-99-0	1,3-Butadiene	2.19E+02	2.40E-03	1.00E+02	2.40E-03
107-02-8	2-Propenal (Acrolein)	2.50E+02	na	1.14E+02	na
107-05-1	3-Chloropropene (Allyl chloride)	1.25E+00	na	5.71E-01	na
107-06-2	1,2-Dichloroethane (Ethylene chloride)	4.17E+00	2.08E-03	1.90E+00	2.08E-03
107-13-1	Acrylonitrile	1.25E+02	1.23E-02	5.71E+01	1.23E-02
108-10-1	Methyl isobutyl ketone (4-Methyl-2-pentanone)	1.56E+00	na	7.14E-01	na
108-38-3	m-Xylene	6.25E-01	na	2.86E-01	na
108-39-4	3-Methylphenol (m-Cresol)	1.25E+00	na	5.71E-01	na
108-67-8	1,3,5-Trimethylbenzene	2.50E+00	na	1.14E+00	na
108-87-2	Methyl cyclohexane	2.92E-01	na	1.33E-01	na
108-88-3	Toluene (Methyl benzene)	6.25E-01	na	2.86E-01	na
108-90-7	Chlorobenzene	6.25E+00	na	2.86E+00	na
108-94-1	Cyclohexanone	1.25E-02	na	5.71E-03	na
108-95-2	Phenol (Carbolic acid)	2.08E-01	na	9.52E-02	na
109-99-9	Tetrahydrofuran	5.95E-01	1.74E-04	2.72E-01	1.74E-04
110-00-9	Furan (Oxacyclopentadiene)	6.25E+01	na	2.86E+01	na
110-54-3	n-Hexane	2.58E+00	na	1.03E+00	na
110-80-5	2-Ethoxyethanol	1.56E-01	na	7.14E-02	na
110-82-7	Cyclohexane	1.46E-01	na	6.68E-02	na
110-86-1	Pyridine	6.25E+01	na	2.86E+01	na
111-76-2	2-Butoxyethanol (Ethylene Glycol Monobutyl Ether)	2.50E-01	na	1.14E-01	na
111-90-0	2-(2-Ethoxyethoxy)-ethanol (Diethylene Glycol Monoethyl Ether)	2.08E+00	na	9.52E-01	na
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)	5.93E+00	6.64E-04	2.37E+00	2.66E-04
117-84-0	Di-n-octylphthalate	1.56E+00	na	7.14E-01	na
118-74-1	Hexachlorobenzene	2.48E+03	1.27E+00	9.94E+02	5.09E-01
120-82-1	1,2,4-Trichlorobenzene	1.92E+01	na	7.67E+00	na
121-14-2	2,4-Dinitrotoluene	3.13E+01	na	1.43E+01	na
121-44-8	Triethylamine	6.25E+01	na	2.86E+01	na
122-39-4	Diphenylamine	2.50E+00	na	1.14E+00	na
123-91-1	1,4-Dioxane (Diethylene oxide)	na	1.26E-04	na	1.26E-04
126-73-8	Tributyl Phosphate	3.13E-01	6.17E-05	1.43E-01	6.17E-05
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)	6.25E+02	na	2.86E+02	na
127-18-4	Tetrachloroethylene	1.25E+01	1.33E-03	5.71E+00	1.19E-03
129-00-0	Pyrene	1.47E+01	na	5.87E+00	na

Table C16. Hazard Index and Cancer Risk Factors for Chemicals, MTCA Standard Method for Surface Water.

CASRN	Chemical Name	Method B (Residential) per mg/L		Method C (Industrial) per mg/L	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	6.94E-02	na	3.17E-02	na
156-59-2	cis-1,2-Dichloroethylene	1.25E+01	na	5.71E+00	na
206-44-0	Fluoranthene (1,2-Benzacenaphthene)	1.81E+01	na	7.24E+00	na
309-00-2	Aldrin	2.60E+05	5.29E+01	1.04E+05	2.12E+01
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	1.30E+02	1.64E-01	5.71E+01	7.20E-02
319-85-7	beta-Benzene hexachloride (beta-Lindane)	3.13E+02	4.51E-02	1.43E+02	2.06E-02
541-73-1	1,3-Dichlorobenzene	1.39E+02	na	6.35E+01	na
542-75-6	1,3-Dichloropropene (cis & trans)	4.17E+00	2.29E-03	1.90E+00	2.29E-03
621-64-7	N-Nitrosodi-N-propylamine	na	8.00E-02	na	8.00E-02
1314-62-1	Vanadium pentoxide	8.57E+00	na	3.43E+00	na
1330-20-7	Xylenes (mixtures)	6.25E-01	na	2.86E-01	na
1336-36-3	Polychlorinated Biphenyls	na	1.79E+01	na	7.16E+00
1336-36-3	Polychlorinated Biphenyls (lowest risk)	na	1.79E+01	na	7.16E+00
6533-73-9	Thallium carbonate	4.82E+04	na	1.93E+04	na
7429-90-5	Aluminum	1.93E-01	na	7.71E-02	na
7439-89-6	Iron	2.57E-01	na	1.03E-01	na
7439-93-2	Lithium	3.13E+00	na	1.43E+00	na
7439-96-5	Manganese	1.34E+00	na	6.12E-01	na
7439-97-6	Mercury metal vapor	9.00E+03	na	3.60E+03	na
7439-98-7	Molybdenum	1.25E+01	na	5.71E+00	na
7440-02-0	Nickel (soluble salts)	3.13E+00	na	1.43E+00	na
7440-22-4	Silver	1.25E+01	na	5.71E+00	na
7440-24-6	Strontium, Stable	1.04E-01	na	4.76E-02	na
7440-28-0	Thallium metal	5.84E+04	na	2.34E+04	na
7440-31-5	Tin	1.93E+00	na	7.71E-01	na
7440-36-0	Antimony	1.56E+02	na	7.14E+01	na
7440-38-2	Arsenic (inorganic)	3.14E+02	5.65E-02	1.25E+02	2.26E-02
7440-39-3	Barium	8.93E-01	na	4.08E-01	na
7440-41-7	Beryllium and compounds	3.13E+01	0.00E+00	1.43E+01	0.00E+00
7440-42-8	Boron and borates only	6.94E-01	na	3.17E-01	na
7440-43-9	Cadmium	1.54E+02	0.00E+00	6.17E+01	0.00E+00
7440-45-1	Cerium (Ceric oxide 1306-38-3)	2.19E+03	na	1.00E+03	na
7440-48-4	Cobalt	5.79E+00	0.00E+00	2.31E+00	0.00E+00
7440-50-8	Copper	1.93E+00	na	7.71E-01	na
7440-62-2	Vanadium metal	1.10E+01	na	4.41E+00	na
7440-66-6	Zinc and compounds	3.24E-01	na	1.30E-01	na
7487-94-7	Mercuric chloride	1.29E+03	na	5.14E+02	na
7664-41-7	Ammonia	4.37E+00	na	2.00E+00	na
7723-14-0	Phosphorus, white	2.89E+04	na	1.16E+04	na
7782-41-4	Fluorine (soluble fluoride)	1.04E+00	na	4.76E-01	na
7782-49-2	Selenium and compounds	1.31E+01	na	5.71E+00	na
8001-35-2	Toxaphene	na	9.56E-01	na	3.82E-01

Table C16. Hazard Index and Cancer Risk Factors for Chemicals, MTCA Standard Method for Surface Water.

CASRN	Chemical Name	Method B (Residential) per mg/L		Method C (Industrial) per mg/L	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
11096-82-5	Aroclor 1260	na	1.51E+00	na	6.05E-01
11097-69-1	Aroclor 1254	5.43E+06	8.68E+01	2.17E+06	3.47E+01
11104-28-2	Aroclor 1221	na	3.79E-01	na	1.52E-01
11141-16-5	Aroclor 1232	na	3.79E-01	na	1.52E-01
12672-29-6	Aroclor 1248	na	1.96E+01	na	7.82E+00
12674-11-2	Aroclor 1016	9.74E+04	5.45E+00	3.90E+04	2.18E+00
14797-55-8	Nitrate	3.91E-02	na	1.79E-02	na
14797-65-0	Nitrite	6.25E-01	na	2.86E-01	na
16065-83-1	Chromium (III) (insoluble salts)	5.14E-02	na	2.06E-02	na
16984-48-8	Fluorine anion	1.04E+00	na	4.76E-01	na
18540-29-9	Chromium (VI) (soluble salts)	2.57E+01	0.00E+00	1.03E+01	0.00E+00
53469-21-9	Aroclor 1242	na	1.79E+01	na	7.16E+00
na	Uranium (soluble salts)	1.04E+02	na	4.76E+01	na
na	Total Chromium (1:6 ratio CrVI:Cr III)	3.72E+00	0.00E+00	1.49E+00	0.00E+00

Notes:

- MTCA refers to Chapter 173-340 of the Washington Administrative Code.
- CASRN = Chemical Abstract Service Reference Number
- The fish bioaccumulation factors are shown in Table A35. The reference doses and slope factors for ingestion are shown in Table C1. The larger of the drinking water and fish are shown in this table.
- The Inhale Factor shown in Table 30 is included in the Hazard Index and Cancer Risk factors. In effect, the hazard index and risk factors are doubled for volatile chemicals (Inhale Factor = 2).
- Missing values are indicated with "na", which means "not available".

The purpose for generating the unit hazard index and cancer risk factors is to identify chemicals that need further evaluation regarding the importance of the missing toxicity parameter. Because all the above numbers were copied from tables in a spreadsheet, it is possible to summarize all the comparison ratio tables in one table. Table C17 shows the largest ratio listed on any of the comparison tables. Because the extrapolation scheme is rather crude, no ratio is listed in Tabel C17 unless it is greater than 2.0.

From Table C17, there are several chemicals that deserve further analysis regarding the missing toxicity parameter. If the risk assessment is driven by any of these chemicals, the missing toxicity parameter should be determined in a manner that is both technically sound and acceptable to the appropriate regulatory authority.

Table C17. Summary of Unit Factor Comparison Ratios in All Scenarios.

CASRN	Chemical Name	Well Water Ratios		Columbia River Ratios	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
50-32-8	Benzo[a]pyrene				
53-70-3	Dibenz[a,h]anthracene				
56-23-5	Carbon tetrachloride	5.5		5.5	
57-12-5	Cyanide, free	6.0		6.0	
57-14-7	1,1-Dimethylhydrazine				
57-55-6	Propylene glycol (1,2-Propanediol)				
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)				
60-29-7	Ethyl ether (Diethyl ether)	6.0		6.0	
60-34-4	Methylhydrazine				
60-57-1	Dieldrin	2.6		2.6	
62-75-9	N-Nitrosodimethylamine				
64-18-6	Formic acid				
67-56-1	Methanol (Methyl alcohol)				
67-64-1	Acetone (2-Propanone)	6.0		6.0	
67-66-3	Chloroform				
67-72-1	Hexachloroethane	4.6		4.6	
71-36-3	n-Butyl alcohol (n-Butanol)				
71-43-2	Benzene				
71-55-6	1,1,1-Trichloroethane (Methyl chloroform)				
72-20-8	Endrin				
74-83-9	Bromomethane				
74-87-3	Methyl chloride (Chloromethane)	41.8		85.9	
75-00-3	Ethyl Chloride				
75-01-4	Vinyl chloride (Chloroethene)				
75-05-8	Acetonitrile	41.7		84.0	
75-07-0	Acetaldehyde	41.7	41.7	83.8	134
75-09-2	Dichloromethane (Methylene chloride)				
75-15-0	Carbon disulfide				
75-21-8	Ethylene Oxide (Oxirane)				

Table C17. Summary of Unit Factor Comparison Ratios in All Scenarios.

CASRN	Chemical Name	Well Water Ratios		Columbia River Ratios	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
75-34-3	1,1-Dichloroethane (Ethylidene chloride)				
75-35-4	1,1-Dichloroethylene				
75-45-6	Chlorodifluoromethane	41.8		61.6	
75-68-3	Chloro-1,1-difluoroethane, 1-	42.1		150	
75-69-4	Trichlorofluoromethane				
75-71-8	Dichlorodifluoromethane				
76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane (CFC-113)				
76-44-8	Heptachlor	3.5		3.5	
78-83-1	Isobutanol	3.0		3.0	
78-87-5	1,2-Dichloropropane	42.1	5.8	136	5.8
78-93-3	Methyl ethyl ketone (2-Butanone)				
79-00-5	1,1,2-Trichloroethane	5.9		5.9	
79-01-6	Trichloroethylene				
79-10-7	2-Propenoic acid (Acrylic acid)				
79-34-5	1,1,2,2-Tetrachloroethane (Acetylene tetrachloride)	5.8		5.8	
79-46-9	2-Nitropropane	41.8	41.9	85.3	137
82-68-8	Pentachloronitrobenzene (PCNB)	5.0	5.0	5.0	5.0
83-32-9	Acenaphthene	3.1		3.1	
84-66-2	Diethyl phthalate				
84-74-2	Dibutyl phthalate				
85-68-7	Butyl benzyl phthalate				
87-68-3	Hexachlorobutadiene	3.8		3.8	
87-86-5	Pentachlorophenol				
88-06-2	2,4,6-Trichlorophenol				
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)				
91-20-3	Naphthalene				
92-52-4	1,1'-Biphenyl	3.6		3.6	
95-47-6	o-Xylene				
95-48-7	2-Methylphenol (o-Cresol)				
95-50-1	1,2-Dichlorobenzene (ortho-)				
95-57-8	2-Chlorophenol	3.2		3.2	
95-63-6	1,2,4-Trimethylbenzene				
95-95-4	2,4,5-Trichlorophenol				
98-86-2	Acetophenone	3.1		3.1	
98-95-3	Nitrobenzene				
100-25-4	1,4-Dinitrobenzene (para-)				
100-41-4	Ethyl benzene		46.8		1,654
100-42-5	Styrene				
100-51-6	Benzyl alcohol				
106-42-3	p-Xylene				
106-44-5	4-Methylphenol (p-Cresol)				
106-46-7	1,4-Dichlorobenzene (para-)				

Table C17. Summary of Unit Factor Comparison Ratios in All Scenarios.

CASRN	Chemical Name	Well Water Ratios		Columbia River Ratios	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	41.8		129	
106-99-0	1,3-Butadiene	42.5	43.6	146	269
107-02-8	2-Propenal (Acrolein)				
107-05-1	3-Chloropropene (Allyl chloride)				
107-06-2	1,2-Dichloroethane (Ethylene chloride)				
107-13-1	Acrylonitrile				
108-10-1	Methyl isobutyl ketone (4-Methyl-2-pentanone)				
108-38-3	m-Xylene				
108-39-4	3-Methylphenol (m-Cresol)				
108-67-8	1,3,5-Trimethylbenzene				
108-87-2	Methyl cyclohexane	48.4		1,731	
108-88-3	Toluene (Methyl benzene)				
108-90-7	Chlorobenzene				
108-94-1	Cyclohexanone	2.8		2.8	
108-95-2	Phenol (Carbolic acid)				
109-99-9	Tetrahydrofuran				
110-00-9	Furan (Oxacyclopentadiene)	5.9		5.9	
110-54-3	n-Hexane				
110-80-5	2-Ethoxyethanol				
110-82-7	Cyclohexane	46.6		1,292	
110-86-1	Pyridine	3.2		3.2	
111-76-2	2-Butoxyethanol (Ethylene Glycol Monobutyl Ether)				
111-90-0	2-(2-Ethoxyethoxy)-ethanol (Diethylene Glycol Monoethyl Ether)				
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)				
117-84-0	Di-n-octylphthalate				
118-74-1	Hexachlorobenzene	2.4		2.4	
120-82-1	1,2,4-Trichlorobenzene				
121-14-2	2,4-Dinitrotoluene				
121-44-8	Triethylamine	41.9		80.2	
122-39-4	Diphenylamine				
123-91-1	1,4-Dioxane (Diethylene oxide)				
126-73-8	Tributyl Phosphate				
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)				
127-18-4	Tetrachloroethylene				
129-00-0	Pyrene				
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	6.0		6.0	
156-59-2	cis-1,2-Dichloroethylene	5.8		5.8	
206-44-0	Fluoranthene (1,2-Benzacenaphthene)				
309-00-2	Aldrin	2.2		2.2	
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	3.3		3.3	

Table C17. Summary of Unit Factor Comparison Ratios in All Scenarios.

CASRN	Chemical Name	Well Water Ratios		Columbia River Ratios	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
319-85-7	beta-Benzene hexachloride (beta-Lindane)				
541-73-1	1,3-Dichlorobenzene	4.8		4.8	
542-75-6	1,3-Dichloropropene (cis & trans)				
621-64-7	N-Nitrosodi-N-propylamine		2.1		2.1
1314-62-1	Vanadium pentoxide				
1330-20-7	Xylenes (mixtures)				
1336-36-3	Polychlorinated Biphenyls				
1336-36-3	Polychlorinated Biphenyls (lowest risk)				
6533-73-9	Thallium carbonate				
7429-90-5	Aluminum				
7439-89-6	Iron				
7439-93-2	Lithium				
7439-96-5	Manganese				
7439-97-6	Mercury metal vapor	295,069		17,309,990	
7439-98-7	Molybdenum				
7440-02-0	Nickel (soluble salts)				
7440-22-4	Silver				
7440-24-6	Strontium, Stable				
7440-28-0	Thallium metal				
7440-31-5	Tin				
7440-36-0	Antimony				
7440-38-2	Arsenic (inorganic)				
7440-39-3	Barium				
7440-41-7	Beryllium and compounds				
7440-42-8	Boron and borates only				
7440-43-9	Cadmium				
7440-45-1	Cerium (Ceric oxide 1306-38-3)	51,659		1,292,623	
7440-48-4	Cobalt				
7440-50-8	Copper				
7440-62-2	Vanadium metal				
7440-66-6	Zinc and compounds				
7487-94-7	Mercuric chloride				
7664-41-7	Ammonia	578		595	
7723-14-0	Phosphorus, white				
7782-41-4	Fluorine (soluble fluoride)				
7782-49-2	Selenium and compounds				
8001-35-2	Toxaphene				
11096-82-5	Aroclor 1260				
11097-69-1	Aroclor 1254				
11104-28-2	Aroclor 1221				
11141-16-5	Aroclor 1232				
12672-29-6	Aroclor 1248				
12674-11-2	Aroclor 1016	2.8		2.8	
14797-55-8	Nitrate				

Table C17. Summary of Unit Factor Comparison Ratios in All Scenarios.

CASRN	Chemical Name	Well Water Ratios		Columbia River Ratios	
		Hazard Index	Increased Cancer Risk	Hazard Index	Increased Cancer Risk
14797-65-0	Nitrite				
16065-83-1	Chromium (III) (insoluble salts)				
16984-48-8	Fluorine anion				
18540-29-9	Chromium (VI) (soluble salts)				
53469-21-9	Aroclor 1242				
na	Uranium (soluble salts)				
na	Total Chromium (1:6 ratio CrVI:Cr III)				

Notes:

- CASRN = Chemical Abstract Service Reference Number
- The table shows the largest ratio found in all of the exposure scenarios. Ratios less than 2.0 are not listed.

REFERENCES

EPA-540/R95/128, 1996, *Soil Screening Guidances: Technical Background Document*, U.S. Environmental Protection Agency, Washington, DC.

IRIS Database, June, 2003, U.S. Environmental Protection Agency, internet address:
<http://www.epa.gov/iris/>

RAIS Database, June, 2003, Oak Ridge National Laboratory, internet address:
<http://risk.lsd.ornl.gov/index.shtml>

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