

**EXPOSURE SCENARIOS AND UNIT DOSE FACTORS FOR  
HANFORD TANK WASTE PERFORMANCE ASSESSMENTS**

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**Exposure Scenarios and Unit Dose Factors for  
Hanford Tank Waste Performance Assessments**  
by Paul D. Rittmann PhD CHP

## 1.0 INTRODUCTION

Risk assessment calculations involve models and parameters from many disciplines to predict the migration of hazardous materials (both radioactive and non-radioactive) from low-level waste disposal sites and the potential impacts this may have on members of the public some time after the disposal site is closed. Of particular interest in this report are the dose and risk calculations employed for the Hanford Immobilized Low-Activity Tank Waste (ILAW) Performance Assessment (PA). Other risk assessments, such as those supporting tank farm closure, should also find these appropriate. Exposure scenarios and model parameters have been selected that are acceptable to the DOE as well as local technical experts at the Hanford Site. An additional set of modeling assumptions is provided in the Hanford Site Risk Assessment Methodology report (DOE/RL-91-45 Rev 3). All of these exposure models are included in the present document.

The purpose of this document is to provide unit dose factors, unit risk factors, and unit hazard index factors for evaluating potential exposures to tank waste materials long after site closure. The contaminants of concern are listed in Section A1.0 and A2.0. The unit factors are applied to combinations of hazardous materials in the waste to calculate the potential radiation dose, cancer induction risk, and hazard index to individuals or populations exposed to the hazardous materials as a result of various exposure scenarios. The unit factors are derived from standard formulas using data considered to be the most recent.

The particular combination of activities by which an individual accumulates doses of the hazardous materials in a disposal site is known as an exposure scenario. For the tank waste risk assessment the exposure scenarios are constructed from the land use scenarios (HNF-EP-0828, Rev 2), of which there are three general categories. These three are used in the present report to establish exposure scenarios.

- (1) The water infiltration rate at the disposal site is extremely low. Ground water contamination is expected to be insignificant and will be ignored. The main contaminants leaving the waste site are gases and vapors, which diffuse upward through the soil to the ground surface. Potential exposure scenarios involve individuals living 100 meters downwind from the waste, or directly above the waste, where the contaminant emission rate is greatest.
- (2) The water infiltration rate at the disposal site remains similar to present natural infiltration rates. Large-scale irrigation for commercial farming is excluded. Potential exposure scenarios include people living near the waste disposal facility once contamination has reached the groundwater, and individuals living above the waste who drill a well through it.

- (3) The water infiltration rate at the disposal site is much larger than the present natural infiltration rate due to widespread irrigation of the central plateau of the Hanford Site. Potential exposure scenarios involve ways that water from a well near the waste disposal facility may be used.

The radiation dose, cancer induction risk, and hazard index calculated for a given scenario is then compared with the appropriate performance objective for the facility being evaluated. The performance objectives for the ILAW PA are found in RPP-13263, Rev 0. The performance objectives for the tank farm closure risk assessments are found in RPP-14283, Rev 0.

Since many waste disposal site performance assessments have been prepared, both for the Hanford Site and other DOE-managed facilities, there is a body of knowledge associated with these assessments. Future PA documents must be consistent with previous PA documents to a considerable degree. However, there is always room for improvement. One such area is the range of potential doses to individuals who may live on or near the disposal site some time in the future. The reason for doing this is to ensure that potential doses are not underestimated. The low end of the dose range will be zero. The high end depends on the assumed exposure scenarios and the model parameters selected to describe the scenario. This report describes possible exposure scenarios, presents model parameters, and calculates unit dose factors for these scenarios. This approach enables meaningful comparisons between scenarios, and provides assurance that bounding cases have indeed been considered.

## **2.0 EXPOSURE SCENARIOS OVERVIEW**

The potential exposure scenarios are divided into two general categories, away from the disposal site (offsite) and at the disposal site (onsite). These originated by considering the delays between the time of site closure and the time that individuals may be receiving some dose. The time delay affects the amount of radioactivity that may be present because the radioactivity is continually decreasing as isotopes decay. The amount of the hazardous chemicals changes very slowly by comparison.

The offsite location receives the majority of the dose after contaminants have migrated from the disposal site into the groundwater and are brought to the surface through a well. Exposure of the offsite individual requires considerable delay between site closure and the eventual appearance of hazardous substances in the ground water. Only radionuclides with long half-lives, such as technetium-99 and uranium isotopes, will be significant hazards. Radionuclides with shorter half-lives, such as cesium-137 and strontium-90, normally will decay to insignificant amounts before becoming part of the groundwater contamination. In order for the short half-life nuclides to be significant exposure hazards, someone must actively expose themselves to the buried waste by moving onto the disposal site and digging into it. Hence the onsite scenarios were developed.

The offsite exposures occur as a result of the environmental transport of hazardous materials from the waste disposal site. If some form of access control is present in the distant future, the nearest offsite location is the boundary of the controlled area. If access control cannot

be guaranteed, the nearest offsite location is the facility boundary, or 100 meters from the edge of the buried waste. The offsite locations are chosen to maximize the potential exposure to ground water contaminants, consistent with the realities of access and ground water flow.

The principal transport mechanism is the migration of contaminants from the waste through the vadose soil and into the ground water. For most waste materials this involves a considerable time delay (i.e., thousands of years) between site closure and arrival of the contamination. In addition, different substances travel at different rates through the soil, so they arrive at the well at times that may differ by more than the projected 70-year lifetime of the offsite individual. The offsite individual may also be exposed to any airborne emissions from the waste disposal site. The airborne emissions result from the upward migration of gaseous radionuclides and volatile chemicals. The airborne emissions normally lead to considerably less dose than is received from drinking the ground water.

The general features of the exposure scenarios used in performance assessments are summarized in Table 1.

**Table 1. General Features of Performance Assessment Exposure Scenarios.**

<b>Feature</b>	<b>Onsite Receptor</b>	<b>Offsite Receptor</b>
Time delay following site closure	no less than 100 years	any time after site closure
Receptor location	directly over the waste disposal site	no closer than 100 meters from the edge of the buried waste, or the fenceline of the facility
Sources of exposure	(1) gases & vapors that migrate upward from the waste (2) direct radiation exposure (3) well water (4) exhumed waste	(1) gases & vapors carried by the wind to the offsite location (2) well water
Exposure scenarios	(1) well driller - person actually drilling through the waste (2) residential - person living near the well (3) basement excavation - person lives in a dwelling with a foundation directly over the waste	(1) industrial - people working at some commercial enterprise (2) recreational - people who spend time near the site doing typical recreational activities (3) residential - person living near the well (4) farmer - subsistence farming operation that provides a portion of the individual diet (5) native American Indian

The onsite exposures are the result of human activity directly over the buried waste, for example, a residence. Since current regulations would prohibit such activities, the onsite

exposure scenarios are assumed to be delayed for 100 years following site closure. After this delay, it is assumed that knowledge of the disposal site location is lost or ignored, and individuals unknowingly trespass. To establish bounding doses for these individuals, it is assumed that a well is drilled through the waste. The waste materials brought to the surface are not recognized as waste. It is assumed that the appearance of the exhumed waste differs little from the native soil, and it becomes part of a garden. A second onsite situation is the excavation of the foundation for a structure. Direct contact with the waste does not occur because the waste is covered with more than 5 m of soil.

The intent of these exposure assumptions is to establish reasonable bounds on the potential doses resulting from the waste disposal site. The onsite individuals have average intakes, but are in an unlikely situation. Most of the wells and basements will not be near the disposal site. Using maximum consumption parameters for the intruders makes the onsite scenarios unreasonable. The offsite individuals are more likely, but still use average intakes for many of the pathways. The Native American scenario uses bounding intake assumptions for perspective on how significant the exposures might be. Numerous other special groups of individuals can be studied, but the individuals selected are believed to span the range of potential exposures.

## **2.1 NO WATER INFILTRATION EXPOSURE SCENARIOS**

For this land use category, the water infiltration rate is expected to be extremely low. Thus, none of the waste materials in the disposal facility reach the ground water. However, gases and vapors will diffuse from the waste through the soil. These gaseous contaminants enter the air above the disposal site and may be carried by the wind to receptors located near the site. In addition, there may be inadvertent intrusion into the disposal site. To maximize the vertical diffusion out of the waste, no water infiltration into the waste is assumed.

Table 2 summarizes the various exposure scenarios analyzed for the no water infiltration case. Note that dermal absorption refers to materials on the skin being absorbed into the body by passage through the skin. Note also that the first scenario (Offsite Farmer) applies any time after site closure, while the remaining scenarios require a minimum of 100 years delay (for loss of access control) before they can occur.

The first exposure scenario requires modeling the average dilution and dispersion of gases released from the surface as they travel downwind to someone living nearby. Since the airborne emission from the disposal site is in the form of gases and vapors, there will be no appreciable deposition on the ground surface. However, plants and animals do absorb certain gases directly from the air, leading to an ingestion dose to individuals consuming such produce. The emission rate from the ground surface may vary with time as the waste ages and radioactivity decays. The bounding doses for this scenario are achieved sometime after site closure.

A second exposure scenario involves a residence located above the disposal site with a somewhat porous basement floor. Gas concentrations in the dwelling would depend on the emission rate from the soil and the assumed ventilation rate in the dwelling. For an individual to be living above the disposal site, all knowledge of the site must have been lost. The dose

calculation cannot begin until 100 years have elapsed from site closure. The waste will be covered with at least 5 m of soil. Including the coarser components (i.e. rocks) ensures that wind erosion will not lessen this thickness during the first 1000 years. The assumed depth of excavation is less than 3 m. Thus, 2 m of soil still separates the waste and the dwelling. The potential exposures to the basement dweller are very small compared to the other exposure scenarios.

**Table 2. Exposure Scenarios for the No Water Infiltration Case.**

Offsite Farmer -- gas/vapor emanations from the disposal site are carried downwind to a subsistence farm
<ul style="list-style-type: none"> <li>▶ inhalation of plume</li> <li>▶ ingestion (plants &amp; animals)</li> <li>▶ external radiation exposure from plume</li> <li>▶ dermal absorption from air</li> </ul>
Onsite Resident -- gas/vapor emanations into the basement of a residence located over the disposal site
<ul style="list-style-type: none"> <li>▶ inhalation (higher concentrations in a dwelling)</li> <li>▶ external radiation exposure (from buried waste and air)</li> <li>▶ dermal absorption (from air)</li> </ul>
Intruder -- individual present while a well is being drilled through the waste disposal site
<ul style="list-style-type: none"> <li>▶ inhalation (resuspended dust &amp; gaseous emissions)</li> <li>▶ ingestion (trace amounts of soil)</li> <li>▶ external radiation exposure</li> <li>▶ dermal absorption (contact with soil)</li> </ul>
Post-intrusion Resident -- spreads the exhumed waste into an area that is subsequently used in some manner
<ul style="list-style-type: none"> <li>▶ inhalation (resuspended dust &amp; gaseous emissions)</li> <li>▶ ingestion (trace amounts of soil &amp; garden produce or cow's milk)</li> <li>▶ external radiation exposure (working in garden)</li> <li>▶ dermal absorption (contact with soil)</li> </ul>

Notes: "Dermal absorption" refers to materials on the skin being absorbed into the body by passage through the skin. The first scenario applies any time after site closure, while the other three require a delay of at least 100 years before they can occur.

The third and fourth exposure scenarios listed on Table 2 assume the waste is unintentionally disturbed by human activity such as drilling a well through it. It is assumed that such intrusion is prevented for the first 100 years following site closure. After this period, it is assumed that knowledge of the disposal site becomes unavailable or is ignored. In addition, any markers or warnings are ignored. Compliance with performance objectives for the intruder (RPP-14283) is measured through reasonable exposure scenarios during and after the inadvertent intrusion.

Exposure scenario development begins with listing various ways the intruder can be exposed to the exhumed waste. These include inhalation of resuspended dust & gaseous

emissions, ingestion of trace amounts of soil in the course of other activities, ingestion of garden produce, external radiation exposure, and absorption of contaminants that come in contact with skin.

There are two primary exposure scenarios for the intruder (the 3<sup>rd</sup> and 4<sup>th</sup> exposure scenarios in Table 2). The first describes the exposure to an individual digging a well through the disposal site. The second describes the exposure to an individual residing near the well afterward. Other forms of intrusion, such as digging footings for buildings, are considered unlikely due to the depth of the waste.

In this scenario, one or more individuals are exposed to the waste because the waste site has been returned to the public and no restrictions on land use prevent such an event. The drilling of water wells is a fairly common occurrence. However, the likelihood of a driller actually encountering the buried waste is low, since there are many places to drill, but few are over the buried waste. In addition, the presence of a thick soil barrier over the waste raises the surface, making the higher elevation less attractive as a site for a well.

The well extends from the ground surface to the unconfined aquifer. The diameter of the well could range from 4 inches up to 12 inches. The larger the diameter, the more waste will be brought to the surface. Prior Hanford performance assessments assumed that the well diameter is 12 inches (30 cm). This value certainly establishes an upper bound on the volume exhumed by a well-drilling operation. A well diameter of 8 inches (20.3 cm) will be assumed in this report when example calculations are presented. Well diameter is not part of the dose, risk, or hazard index unit factors.

The total volume of soil produced by the well drilling is the product of the well cross sectional area and the thickness of soil between the unconfined aquifer and the ground surface. In the 200 East Area, for example, this thickness is about 100 meters. Thus, the total volume of soil excavated by drilling an 8-inch diameter hole is 3.2 m<sup>3</sup>. In addition, this volume must be adjusted for the decrease in density of the soil. Using an initial density of 2 kg/L and a final density of 1.5 kg/L, the volume of soil on the surface is 4.3 m<sup>3</sup>, as shown below.

$$\text{Soil Volume} = (3.14159)(0.1016 \text{ m})^2(100 \text{ m})\left(\frac{2.0 \text{ kg/L}}{1.5 \text{ kg/L}}\right) = 4.3 \text{ m}^3$$

The volume of waste exhumed is the product of the well cross sectional area and the waste thickness. The disposal facility design will determine the waste thickness. By way of example, if the waste were 8 meters thick, then the total volume of waste excavated by the drilling operation would be 0.26 m<sup>3</sup>. For comparison, the Grouted Waste PA (WHC-SD-WM-EE-004) used a waste volume of 0.64 m<sup>3</sup>.

The individuals doing the drilling are exposed to the waste through inhalation of resuspended dust and gaseous emissions, ingestion of trace amounts, external exposure to the contamination, and dermal contact with the contaminated soil. The total exposure time is assumed to be 5 working days, or 40 hours. At the time of drilling, a portion of the waste may be

in a form that cannot be resuspended and inhaled. An example is waste in the form of glass beads, which are corroding slowly with time.

The dose to the driller depends on the area over which the contamination is spread. In the Grouted Waste PA and the 2001 ILAW PA the area used was 100 m<sup>2</sup>. The 200 West Area Burial Ground performance assessment (WHC-EP-0645, Rev 0) did not consider doses to the driller in detail, because the dose to the driller is less than the dose to the post-drilling resident for all nuclides. Previous PAs that calculate dose to the driller also assumed the activity is uniformly mixed in the top 15 cm of soil. Thus the exhumed waste was diluted to a total volume of (100 m<sup>2</sup>)(0.15 m)=15 m<sup>3</sup>. In the present document, the dose is calculated using the volume of the borehole only. The dose received varies from hour to hour according to the depth of the well. The average dose rate is based on the average concentration of soil and waste removed from the borehole. Because the borehole volume is typically an order of magnitude smaller than 15 m<sup>3</sup>, the unit dose factors are an order of magnitude greater than used in previous performance assessments.

After the drillers leave, the exhumed material is assumed to be spread around to level the area. The contaminated area is then included in a garden, or in a pasture for grazing milk cows, or in a field for production of hay for the cow or some commercial agricultural product. It will be assumed that the exhumed waste appears no different than soil. A number of parameters affect the eventual dose received by the individual who works in the contaminated area. These include the depth of contamination in the soil, the area over which the contamination is spread, the portion of the person's diet that may be contaminated, and the amounts of soil inhaled and ingested. This section discusses these parameters.

The customary tilling to prepare the soil for planting is assumed to only affect the top 15 cm (6 inches) of soil. This 15 cm tilling depth has been used in prior Hanford Site performance assessments. The greatest tilling depth likely to be encountered is about 60 cm, while the most shallow depth would be no tilling at all. The deeper the soil is tilled, the more dilute the waste becomes in the surface layer. The 15 cm depth is typical for root systems of garden vegetables. The nuclide concentration in plants due to root uptake is based on the average concentration to which the roots are exposed. If the tilling depth were greater than the root depth, the lower soil concentration would reduce the doses received. If the tilling depth were less than the root depth, then the plant concentrations would be reduced by the fraction of roots in the contaminated layer, offsetting the effect of the increased soil concentration. The 15 cm tilling depth will be assumed in this report. The upper bound on the soil concentration will be assumed to be the 10 cm depth, while the lower bound will be assumed to be the 60 cm depth. Many garden plants have root systems, which penetrate deeper than 15 cm. However, it will be assumed that most of the nutrients taken from the soil will come from the top 15 cm, so that corrections for root depth will not be necessary.

Having chosen a tilling depth, the dose received by the exposed individual is proportional to the product of the soil concentration and the quantity of soil that is ingested, inhaled, absorbed through the skin, or incorporated into any food items. In addition, there is the external radiation dose from simply being in the contaminated area. These are summarized as the internal (i.e. inside the body) and external (i.e. outside the body) dose contributions. The proportionality with

soil concentration assumes the contaminants are present in trace amounts which neither affect the growth of the plant, nor exceed solubility limits in the plant tissues. The waste in the contaminated area looks and acts like normal soil. This relationship is summarized in the equation below.

$$\text{Resident's Dose} \propto (\text{Soil Conc})(\text{Internal \& External Exposures})$$

In general, the soil concentration is inversely proportional to the area over which the waste is spread. For estimating soil concentration in a garden, the smallest and largest areas can be tied to reasonable spreading thicknesses. The smallest reasonable thickness is 1 cm, because thinner layers require excessive effort to achieve. Spreading a volume of 4.3 m<sup>3</sup> to a uniform depth of 5.08 cm (2 inch) would cover an area of 85 m<sup>2</sup>. The largest useful thickness is the tilling depth, 15 cm (6 inch). Spreading a volume of 4.3 m<sup>3</sup> uniformly to a depth of 15 cm would cover an area of 29 m<sup>2</sup>. Note that an increase in hole diameter from 8 inches to 12 inches would increase the volume exhumed as well as the spreading area by a factor of 2.25. If the hole diameter were decreased from 8 inches to 6 inches, the volume exhumed and the spreading area would decrease by a factor of 0.56.

The garden area may be larger or smaller than the tailings area, depending on how much food will be grown. If the garden is smaller than the tailings area, the garden concentration could be zero if the contamination is located outside the garden. With a garden that is larger than the tailings area, the soil concentration depends on the activity exhumed, the garden area, and the tilling depth. Note that the distribution of exhumed waste materials in the garden will be non-uniform. Some parts will have more contamination than others. However, garden produce is consumed from all parts of the garden. Thus, the average concentration in the garden reflects the average concentration in the food.

The assumed garden area not only determines the average concentration of contaminants in the soil, it also limits the internal and external exposures. Smaller gardens mean less time in the garden and less food from the garden. The smaller exposure times mean smaller inhalation and ingestion intakes, less external exposure, and less contact with skin. The exposure times are discussed in greater length in Appendix A, Section A3.0.

The garden size needed to supply a person's entire annual vegetable, fruit, and grain intake was estimated using two approaches. The first is commercial food production in Washington State (WA Department of Agriculture 1994). Using the statewide food production per acre figures, the estimated garden area can be computed. The computed total garden area (233 m<sup>2</sup>) is mostly for production of grains (138 m<sup>2</sup>).

The second approach to estimating garden size uses garden production estimates published by the Washington State University (WSU) Cooperative Extension (1980). The document provides estimates of pounds of produce per 10-foot row in a garden. In addition, it gives recommended row spacings. The spacing was treated as the row width to compute production per unit area. The WSU production estimates are higher than the commercial production averages hence the needed garden area is smaller (207 m<sup>2</sup>). Again, the grains occupy most of this area (140 m<sup>2</sup>).

From these references it will be assumed that an efficiently planned and maintained garden of 100 m<sup>2</sup> can supply most of one average person's vegetable needs. This is a typical residential garden containing various vegetables and some fruit, but no grains. The quantity of food obtained from the garden by one person is proportional to the area of the garden up to a maximum of 100 m<sup>2</sup>. Beyond 100 m<sup>2</sup> there is more food than the individual can eat. With more than one person in the household, the needed garden area increases proportionately. However, as discussed in Appendix A Section A3.1.1, the typical gardener obtains about 25% of his vegetable diet from a garden. A family of four would likely have a garden no larger than 100 m<sup>2</sup>.

Recall that (1) the soil concentration is inversely proportional to the area over which the tailings are spread, (2) the garden area is typically larger than the tailings area, and (3) the quantity eaten is directly proportional to the garden area. Thus, the gardener's ingestion dose is largely independent of the garden area up to a maximum area of about 100 m<sup>2</sup>. When the garden area exceeds this maximum area, the amount of food consumed does not increase, but the concentration of the soil decreases. Thus, the ingestion dose decreases in proportion to the area. This maximum garden area of 100 m<sup>2</sup> for the post-intrusion suburban garden scenario will be used in this document.

The chosen garden area of 100 m<sup>2</sup> differs considerably from prior Hanford performance assessments (e.g., WHC-SD-WM-EE-004 and WHC-EP-0645), which have used a garden area of 2,500 m<sup>2</sup>. The more realistic area of 100 m<sup>2</sup> leads to average soil concentrations that are about 25 times greater for the same volume of waste exhumed. One justification for the larger area assumption used in prior performance assessments is that after a few hundred years the waste has not yet decomposed into fine particles suitable for uptake into plants or suspension in air. In effect, the dilution factor is one or more orders of magnitude greater. In the present performance assessment, the unavailable portion will be estimated from waste corrosion characteristics.

The chosen garden area is consistent with recent performance assessments at other DOE sites. The Class L-II disposal facility at the Oak Ridge Reservation has an intruder garden area of 200 m<sup>2</sup> (ORNL-TM/13401). This garden area was judged adequate "to provide half the entire yearly intake of vegetables" (page G-50). A performance assessment for the Nevada Test Site (SAND2001-2977) uses an intruder garden area of 70 m<sup>2</sup> based on food consumption.

The tilling assumption affects the dose calculations only by making the surface soil concentrations more uniform. Without tilling, the contaminant concentrations in the surface soil could range from that of the waste matrix to zero (exposure to naturally occurring hazardous materials such as radon are not considered). Conceivably some plants might be unable to grow in certain parts of the garden due to the high waste concentration. The tilling assumption ensures sufficient dilution occurs.

The suburban garden assumption is unlikely because the 200 Area plateau has never been the site of a permanent community. Historically, people settle near the Columbia River. Areas like the 200 Area plateau are most likely to end up as a commercial farm in which some agricultural product is raised for sale. With the rural setting in mind, two additional post-intrusion scenarios were developed, the rural pasture and commercial farm.

One alternate use for the tailings that would generate some food chain dose is to spread them into a cow pasture. The area needed for the cow is 5,000 m<sup>2</sup>, as estimated in Section A4.1. About half of this is used for grazing during the irrigation season. The other half is used to raise hay and grain for the non-irrigation season. These are approximate areas derived from the milk cow parameters presented in Table A31. It is assumed the cow tramples 40% of the standing biomass, making it unavailable. It is also assumed the cow eats only half of the remaining biomass. The cow grazes in different parts of the pasture to allow time for the grass to regrow. The pasture area is much larger than the spreading area for the well tailings. Thus, the averaging is not based on physical mixing of the contamination into the pasture, but rather on the grazing habits of the cow.

The most likely alternate use for the tailings is based on historical land use in areas surrounding the Hanford Site, namely, a commercial farm. The tailings are assumed to be present in a field producing some crop for the market. The field area is assumed to be a typical land unit, 160 acres (647,500 m<sup>2</sup>). The exposed individual spends time in various parts of the field, so his average dose is based on the average concentration in the field. The individual consumes none of the crop produced in this manner.

In summary, it is unlikely that a well would be driven through the waste disposal site due to its elevation above the surrounding land, and due to the small fraction of the available land surface that lies above the waste. The presence of an asphalt layer, that might be part of a RCRA surface barrier for the disposal site, would cause the driller to reconsider this location. In addition, it is unlikely that the tailings would end up in a vegetable garden. First, because material from deeper layers contains gravel and such coarse material is undesirable in a garden. Second, because typical land use near Hanford indicates the tailings would be spread in a field of a commercial farm.

## **2.2 LOW WATER INFILTRATION EXPOSURE SCENARIOS**

In this land use category, the natural water infiltration causes contaminants in the disposal site to migrate into the ground water. This would be the situation after a water infiltration barrier placed over the waste disposal site begins to degrade, allowing natural precipitation to migrate through the waste. Two general categories for the exposure scenarios are human intrusion by well-drilling through the waste and ground water use following well-drilling down gradient from the waste.

The intrusion scenarios discussed in the preceding section can be used here with the same results. However, at great times after disposal, i.e., more than 1000 years, the mobile chemicals will begin to reach the ground water and can thus contribute dose to the intruder. Calculating such doses is outside the scope of this report. Performance assessments required by the U.S. Department of Energy (DOE Order 435.1) use intruder analyses at times less than 1000 y. Groundwater contamination is evaluated at later times. In addition, down-gradient locations are chosen rather than onsite locations because these are more likely to occur.

The offsite scenarios establish compliance with performance objectives at the point of highest projected dose or concentration beyond a buffer zone surrounding the disposal site (RPP-14283). Exposure scenario development begins with listing various ways the well water could be used and selecting those activities that could lead to significant radiation exposure. Table 3 lists potential dose contributors. Some of the listed pathways turn out to be insignificant. Because the irrigation activities are not directly over the disposal site water infiltration at the disposal site is not affected. Also note that dermal absorption refers to materials on the skin being absorbed into the body by passage through the skin.

**Table 3. Exposure Pathways for the Low Water Infiltration Case.**

(1) Drinking the water (also cooking with it)
▶ ingestion
(2) Showering, bathing, swimming and boating
▶ inhalation (sprays and vapors)
▶ ingestion (small amounts)
▶ external radiation exposure (from water & shoreline sediments)
▶ dermal absorption (contact with water and shoreline sediments)
(3) Irrigation (and working the soil)
▶ inhalation (sprays & resuspended dust)
▶ ingestion (produce & trace amounts of soil)
▶ external radiation exposure
▶ dermal absorption (contact with soil)
(4) Water used by animals
▶ ingestion (e.g., eggs, poultry, beef, milk, fish, deer, and waterfowl)
▶ external radiation exposure (proximity to domesticated animals)
(5) Irrigating livestock pastures
▶ inhalation (sprays & resuspended dust)
▶ ingestion (e.g., beef and milk)
▶ external radiation exposure (while in pasture)
(6) Sweat lodge/wet sauna
▶ inhalation (steam)
▶ dermal absorption (contact with steam)
▶ external radiation exposure (soil, walls, steam)

The per capita water withdrawal rate from domestic wells mentioned on page 27 of Miller (1980) is 65 gallons per day, or 90,000 liters per year. This number covers the principal domestic uses, namely, washing and bathing, drinking and cooking for one person. For the farming operation, the expected irrigation rate of 82.3 cm/year (32.4 inches/year) is applied over a minimum area of 2 hectare (5 acres), the total annual water need for the farmer is approximately  $1.7 \times 10^7$  liters. This value was assumed in prior Hanford performance assessments. The ability of a well to supply water at this rate must be confirmed before dose calculations based on it are carried out.

As ground water enters the Columbia River, it is diluted by the large flow of surface water. From 1989 to 1999 the average flow rate measured at Priest Rapids Dam is about 3,360 cubic meters per second (PNNL-6415). Hazardous materials in the ground water would then be transported to various water intakes for use as irrigation and public drinking supplies. Due to the dilution that occurs when the ground water enters the Columbia River, doses to an individual irrigating from the river are orders of magnitude smaller than doses to the same farmer irrigating from a well down gradient from the waste site. The addition of the fish pathway offsets this decrease somewhat. Finally, since a large number of people would be affected by contamination in the river, a total population dose will be estimated.

As in prior performance assessments (e.g., WHC-SD-WM-EE-004, WHC-EP-0645, and DOE/ORP-2000-24) a total population of 5 million people between the Hanford Site and the Pacific Ocean will be assumed to derive all of their drinking water from the Columbia River. The population estimate is a realistic upper bound and will be used in this report also.

Offsite exposure scenarios will use one or more of the listed pathways. Some pathways may be ruled out by characteristics of the environmental setting. For example, irrigation of a garden from a well is reasonable, but irrigation of pastures may not be possible, depending on the bounding pumping rate from the well. Possible exposure scenarios have been selected to represent future uses of the land. They are listed in Table 4. The contaminated water source may be either a well or the Columbia River.

**Table 4. Exposure Scenarios for the Low Water Infiltration Case.**

Industrial Scenario - represents potential doses to workers in a commercial industrial setting. Exposure pathways include drinking water (1), showering (2), and contact with irrigated portions (3) of the property.
Recreational Scenario - represents potential doses to individuals visiting a recreation area. Exposure pathways include drinking water (1), showering and swimming (2), contact with irrigated portions and shoreline sediment (3), and game animals (4).
Residential Scenario - represents potential doses to individuals living in a community near the disposal site. Exposure pathways include drinking water (1), showering and swimming (2), irrigating a garden (3), and fishing (4).
Agricultural Scenario - represents potential doses to individuals who may take up residence on the Hanford Site to operate a subsistence farm. Exposure pathways include drinking water (1), showering and swimming (2), irrigating a garden (3), and fishing (4), and raising livestock (5). This scenario includes all of the pathways listed in Table 3 except the sauna.
Native American Scenario - represents bounding doses to special groups of individuals. Exposure pathways include hunting, fishing, gathering wild produce, and using a sweat lodge. All of the pathways listed in Table 3 are used.

The exposure scenarios listed in Table 4 use the naming convention of DOE/RL-91-45, *Hanford Site Risk Assessment Methodology (HSRAM)*, Revision 3. The customary disposal site

performance assessment all-pathways scenarios are included as an alternate for the agricultural scenario. Differences in modeling assumptions are discussed in later sections.

The Native American is based on discussions presented in the Columbia River Comprehensive Impact Assessment (CRCIA) (DOE/RL-96-16). This individual represents a bounding case whose intakes of contaminated foodstuffs and exposures to environmental contamination are maximized.

### **2.3 HIGH WATER INFILTRATION EXPOSURE SCENARIOS**

In this land use category, the water infiltration rate at the disposal site is much larger than the present natural infiltration rate due to irrigation of the land over the waste disposal site. The higher infiltration rate changes the rate at which hazardous materials are released from the disposal site in addition to the rate at which they travel through the vadose zone. The higher infiltration rate also acts to dilute the waste materials that enter the ground water. Thus the resulting ground water concentrations could be higher or lower than in the low infiltration case.

As with the low infiltration case, compliance with performance objectives is measured at the point of highest projected dose or concentration beyond a buffer zone surrounding the disposal site (RPP-14283). The offsite exposure scenarios discussed for the low water infiltration case also apply here. The only difference is the contaminant concentration in the ground water pumped from the well. Since water concentrations determine the dose, it is essential to have a credible model for the release and transport of waste contaminants through the soil.

Intrusion scenarios at locations that are irrigated is generally not consistent. Theoretically, a well could be driven through the waste to obtain water to irrigate nearby fields and pastures. Due to the depth of the water table and the proximity of surface water, it is likely that large scale irrigation water would be derived from surface water rather than a well.

### 3.0 EXPOSURE SCENARIO DESCRIPTIONS

This section describes the exposure scenarios selected for the Hanford tank waste risk assessments. Each description includes the basic formulas used to calculate the radiation dose, incremental cancer risk, or hazard index. All of the input data for the calculations are listed in Appendix A. Additional detail about the time dependence of the calculations for radionuclides is provided in Appendix B. Each description also includes the unit dose or risk or hazard index factors for each radionuclide and chemical of concern. These unit factors must be multiplied by the concentration of the waste material in some medium (usually water) and summed to give the total dose or risk or hazard index for the mixture.

Table 5 summarizes the exposure pathways for the typical performance assessment scenarios. There are 9 scenarios presented in Table 5. The first four are the waste intruder cases, namely, the well driller and the post-intrusion residents. The next four are individuals exposed to a contaminated water source, either a well to groundwater or the Columbia River. The final scenario considers the collective effect on the population residing down river from Hanford.

The intruder scenarios (the Well Driller, Suburban Garden, Rural Pasture, and Commercial Farm) consider only the impact of radionuclides. For the Well Driller, the total effective dose equivalent (TEDE) is calculated based on a unit concentration averaged over all the material removed from the well hole. For the other post-intrusion cases, the TEDE is calculated during the first year after the well is drilled. The dose is based on a unit quantity of activity removed from the well and spread on the ground in either a garden, a cow pasture, or an agricultural field. Lifetime cancer risks and hazard quotients cannot be calculated for the well driller due to the short exposure to a healthy worker. The performance objectives for the post-intrusion scenarios are annual radionuclide doses, so the lifetime risk and hazard quotient calculations were not carried out.

The next two exposure scenarios have individuals who are users of contaminated water. The contaminated water may be obtained from either a well or the Columbia River. When the Columbia River is the source of contaminated water, the risk calculations include the fish pathway and exposure to shoreline sediments. Otherwise, they are identical. This situation occurs long in the future, when the hazardous materials have migrated into the ground water and the Columbia River. The two individuals are the All Pathways Farmer and the Native American. The All Pathways Farmer is a representative average individual who grows much of his own food. His intakes of food and water, for example, are population averages. The Native American represents a bounding individual, particularly with regard to fish consumption. The risk from hazardous chemicals is included in these calculations. For the All Pathways Farmer, the averaging time is 30 years, based on population relocation frequencies. The averaging time for the Native American is 70 years.

The collective exposure to millions of individuals living near the Columbia River is evaluated in the Columbia River Population scenario. This situation occurs long in the future, when the hazardous materials have migrated with the ground water to the Columbia River.

There are no performance objectives for total population dose, but it is a general indicator of collective harm under the linear, no-threshold theory of health effects. In this theory, any amount of exposure to a hazardous material carries some detriment. Even small doses among large numbers of people can sum to a significant detriment.

Table 6 summarizes the exposure pathways for the HSRAM scenarios (DOE/RL-91-45 Rev 3) used to assess human health risks associated with specific waste disposal options. The scenarios are consistent with EPA guidance and the Tri-Party Agreement. For these scenarios, the annual radiation dose is not calculated. Only the lifetime average cancer risk and hazard index are of interest. The final two columns in Table 6 show the exposure pathways used for the State of Washington groundwater and surface water cleanup calculations (WAC 173-340 Part VII -- Cleanup Standards). Method B is a residential setting, while Method C uses an occupational setting.

The hazard index for chemicals and the incremental cancer risk for both chemicals and radionuclides are calculated for each scenario in Table 6, and all of the irrigation scenarios in Table 5. The lifetime radiation dose (in mrem) resulting from the first year of exposure is calculated for all of the exposure scenarios shown in Table 5. This dose is primarily received during the year of exposure. For nuclides that are retained in the body for many years (eg Sr-90 and Pu-239) a portion of the dose is received in following years. This is how radiation doses are calculated under the system of dose limitation developed by the International Commission on Radiological Protection (ICRP). The internal dose is referred to as the effective dose equivalent. Because the dose factors include external dose received during the year of exposure, it is also known as a total effective dose equivalent (TEDE).

There is one difference between radiological and chemical exposure pathways that is not apparent from Tables 5 and 6. The radiological exposures do not include dermal pathways. This is discussed in greater length in Section A3.4. Radioactive materials generally are found as inorganic compounds which tend to have lower dermal absorption. It is argued in Section A3.4 that the dermal exposures are small compared to the ingestion dose and therefore can be neglected. The only exception in the list of radionuclides being analyzed is tritium, which is assumed to be in the form of tritiated water. Dermal absorption of tritiated water is included in all the inhalation calculations for tritium.

Each exposure scenario is presented in a subsection below. In every case the scenario factors include removal mechanisms from the surface layer of soil. To simplify the presentation, the treatment of decay chains is discussed in Appendix B. In most cases, the decay chains have no effect on the resulting unit factors. In keeping with the general strategy of simplifying formulas, the Greek prefixes that are part of some parameters are not explicitly converted. Also, the time unit conversions are omitted. Note that more significant digits are presented than are reasonable. This is done to permit duplication of the numbers in this document. The final unit dose, risk, and hazard index factors are shown with three significant digits, which is also too many. The user of these unit factors should round their calculated doses, risks, or hazard indices to one, or possibly two significant digits.

**Table 5. Exposure Pathway Summary for Standard Performance Assessment Scenarios.**

Exposure Scenarios →  Exposure Pathways		Standard Performance Assessment Exposure Scenarios								
		Waste Intruders				All Pathways Farmer		Native American		Columbia River Population
		Driller	Suburban Garden	Rural Pasture	Commercial Farm	GW	River	GW	River	
Water	Ingestion					•	•	•	•	•
	Vapor Inhalation					•	•	•	•	•
	Shower, dermal					•	•	•	•	•
	Swimming, dermal								•	•
	Sweat Lodge, inhalation							•	•	
Shore Sediments	Ingestion						•		•	•
	Inhalation									
	Dermal Contact						•		•	•
	External Radiation Dose						•		•	•
Soil	Ingestion	•	•	•	•	•	•	•	•	•
	Inhalation	•	•	•	•	•	•	•	•	•
	Dermal Contact					•	•	•	•	•
	External Radiation Dose	•	•	•	•	•	•	•	•	•
	Tritium Vapor Inhalation		•			•	•	•	•	•
Food Chain	Garden Produce		•			•	•	•	•	•
	Grains									
	Beef & Milk			milk only		•	•	•	•	•
	Poultry & Egg					•	•	•	•	•
	Fish						•		•	•
	Wild Game								•	

The annual dose equivalent (in mrem) is calculated for all of the exposure scenarios shown on this table. This is the only risk quantifier for the waste intruders. The other exposure scenarios also have incremental cancer risk from a lifetime exposure for both radionuclides and chemicals, and hazard index for chemicals.

**Table 6. Exposure Pathway Summary for HSRAM and MTCA Scenarios.**

Exposure Scenarios → Exposure Pathways		Hanford Site Risk Assessment Methodology (HSRAM)						WAC 173-340		
		Indus- trial	Recreational		Residential		Agricultural		MTCA B & C	
			GW	River	GW	River	GW	River	GW	River
Water	Ingestion	•	•	•	•	•	•	•	•	•
	Vapor Inhalation	•	•	•	•	•	•	•		
	Shower, dermal	•	•	•	•	•	•	•		
	Swimming, dermal			•		•		•		
	Sweat Lodge, inhalation									
Shore Sediments	Ingestion			•		•		•		
	Inhalation									
	Dermal Contact			•		•		•		
	External Radiation Dose			•		•		•		
Soil	Ingestion	•	•	•	•	•	•	•		
	Inhalation	•	•	•	•	•	•	•		
	Dermal Contact	•	•	•	•	•	•	•		
	External Radiation Dose	•	•	•	•	•	•	•		
	Tritium Vapor Inhalation	•	•	•	•	•	•	•		
Food Chain	Garden Produce				•	•	•	•		
	Grains									
	Beef & Milk						•	•		
	Poultry & Egg									
	Fish			•		•		•		•
	Wild Game			•				•		

The annual dose equivalent (in mrem) is not calculated for the exposure scenarios shown on this table. The risk quantifiers for these scenarios are incremental cancer risk from a lifetime exposure for both radionuclides and chemicals, and hazard index for chemicals.

### 3.1 WELL DRILLER

In this exposure scenario the restrictions and warnings are lost or not effective and someone drills a well that passes through the buried waste to obtain ground water. Radiation dose is the only hazard considered for this individual. The intrusion occurs before the radioactivity has migrated significantly from the waste site to maximize the impact. The exposure occurs during a drilling operation that lasts 40 hours spread over 5 days. Most of the material removed from the hole is uncontaminated soil. As an example, if the waste thickness is about 10% of the distance to the water table, the actual exposure to the waste takes place over a period of about 4 hours.

During the period that the buried waste is coming out of the hole, the driller is exposed to airborne particulate and elevated dose rates. If the well tailings are placed in one pile, the waste is covered with uncontaminated soil that lies below the buried waste, which reduces or eliminates the exposures. If the well tailings are spread around, the exhumed waste may lie exposed on the surface for some time. Water may or may not be present to control dust at the work site.

For modeling purposes, the driller is assumed to be exposed to average concentrations in soil and air for the entire 40 hour drilling operation. In this way, the challenge of estimating actual exposures during a future drilling operation can be avoided. The average concentration in the well tailings (activity per unit mass) is the activity exhumed divided by the total mass of the tailings. Two methods for calculating this average concentration will be discussed. The first may apply when the total inventory in all or part of the disposal site is known. The second may apply if the average waste concentration is known.

If the waste site, or a portion of the site, is known to have a particular number of curies distributed over a given area, then the average radionuclide concentration in the well tailings is calculated as shown below. This method assumes the waste has a uniform thickness. It should not be applied to a trench with sloping walls, for example.

$$C_{\text{TAIL}} = \frac{A_{\text{WELL}} Q_{\text{SITE}} / A_{\text{SITE}}}{A_{\text{WELL}} [\rho_{\text{WASTE}} L_{\text{WASTE}} + \rho_{\text{WELL}} (L_{\text{WELL}} - L_{\text{WASTE}})]}$$

$$= \frac{Q_{\text{SITE}} / A_{\text{SITE}}}{\rho_{\text{WASTE}} L_{\text{WASTE}} + \rho_{\text{WELL}} (L_{\text{WELL}} - L_{\text{WASTE}})}$$

where,

- $A_{\text{SITE}}$  = horizontal area occupied by the disposal site, in  $\text{m}^2$
- $A_{\text{WELL}}$  = cross-sectional area of the well, in  $\text{m}^2$ . Note that  $A_{\text{WELL}} < A_{\text{SITE}}$
- $C_{\text{TAIL}}$  = average radionuclide concentration in the well tailings, in Ci/kg
- $L_{\text{WELL}}$  = depth of the well from surface to groundwater, in m
- $L_{\text{WASTE}}$  = thickness of the waste, in m
- $Q_{\text{SITE}}$  = total activity of a radionuclide in the disposal site, in Ci
- $\rho_{\text{WELL}}$  = average density of the soil in the well, in  $\text{kg}/\text{m}^3$
- $\rho_{\text{WASTE}}$  = average density of the waste, in  $\text{kg}/\text{m}^3$

If the waste density and soil density in the well are nearly the same, then the average concentration in the well tailings can be written in the simpler form shown below. The tailings concentration depends on the activity per unit area in the site, the well depth, and the density of the compacted soil. It does not depend on the well diameter.

$$C_{\text{TAIL}} \cong \frac{Q_{\text{SITE}}}{A_{\text{SITE}} \rho_{\text{WELL}} L_{\text{WELL}}} \quad \text{if } \rho_{\text{WASTE}} \cong \rho_{\text{WELL}}$$

As an alternative, the activity concentration in the waste may be known. In this case, the average radionuclide concentration in the well tailings is calculated as shown below. The approximate form when the waste density and soil density are nearly the same is also shown. The approximate formula shows that the tailings concentration is the waste concentration multiplied by the ratio of the waste thickness to the well depth. It does not depend on the well diameter.

$$\begin{aligned} C_{\text{TAIL}} &= \frac{A_{\text{WELL}} L_{\text{WASTE}} \rho_{\text{WASTE}} C_{\text{WASTE}}}{A_{\text{WELL}} [\rho_{\text{WASTE}} L_{\text{WASTE}} + \rho_{\text{WELL}} (L_{\text{WELL}} - L_{\text{WASTE}})]} \\ &= \frac{\rho_{\text{WASTE}} L_{\text{WASTE}} C_{\text{WASTE}}}{\rho_{\text{WASTE}} L_{\text{WASTE}} + \rho_{\text{WELL}} (L_{\text{WELL}} - L_{\text{WASTE}})} \\ &\cong C_{\text{WASTE}} \frac{L_{\text{WASTE}}}{L_{\text{WELL}}} \quad \text{if } \rho_{\text{WASTE}} \cong \rho_{\text{WELL}} \end{aligned}$$

where,

- $A_{\text{WELL}}$  = cross-sectional area of the well, in  $\text{m}^2$
- $C_{\text{TAIL}}$  = average radionuclide concentration in the well tailings, in Ci/kg
- $C_{\text{WASTE}}$  = concentration of a radionuclide in the disposal site, in Ci/kg
- $L_{\text{WELL}}$  = depth of the well from surface to groundwater, in m
- $L_{\text{WASTE}}$  = thickness of the waste, in m
- $\rho_{\text{WELL}}$  = average density of the soil in the well, in  $\text{kg}/\text{m}^3$
- $\rho_{\text{WASTE}}$  = average density of the waste, in  $\text{kg}/\text{m}^3$

### External Dose to the Driller

The driller is exposed to external radiation from this average well tailings concentration. The well tailings are assumed spread around enough to be represented by a layer of contaminated soil that surrounds the worker. It is assumed that this layer is about 5 cm thick. If the volume of soil taken from the well is about  $4 \text{ m}^3$ , then the well tailings are spread over an area of  $80 \text{ m}^2$ . The external dose to the driller is calculated using external dose rate factors for a layer 5 cm thick and of very great extent in all directions. These values are shown in Appendix A, Section A3.6.1. The equation used to calculate the external dose is shown below. Note that the assumed density of the well tailings ( $1,500 \text{ kg}/\text{m}^3$ ) is lower than typically found underground due to the loosening of the soil during drilling. The conversion from pCi to Ci is not explicitly shown in the equation.

$$H_{\text{X,K}} = C_{\text{TAIL,K}} \rho_{\text{TAIL}} L_{\text{TAIL}} D_{\text{X,5,K}} T$$

where,

- $C_{TAIL,K}$  = average concentration of the Kth radionuclide in the well tailings, in Ci/kg  
 $L_{TAIL}$  = average thickness of the well tailings, 0.05 m  
 $D_{X,5,K}$  = external dose rate factor for the Kth radionuclide to a person standing on a layer 0.05 m thick and of great extent in all directions, in mrem/h per Ci/m<sup>2</sup>. Values from EPA Federal Guidance Report Number 12 for a 5 cm thickness are listed in Table A25.  
 $H_{X,K}$  = external dose to the driller from the Kth radionuclide, mrem  
 $T$  = time of exposure from Table A15, 40 h  
 $\rho_{TAIL}$  = average density of the well tailings, 1,500 kg/m<sup>3</sup>

#### Inhalation Dose to the Driller

The driller is exposed to airborne particulate during the 40-hour drilling period as described in Appendix A Section A.3.2. The average air concentration is 0.1 mg/m<sup>3</sup> in the air based on moderately dusty conditions. The concentration of radionuclides in the suspended particulate is assumed to be the same as the average concentration of radionuclides in the well tailings. The driller breathes at the outdoor activity rate of 1.21 m<sup>3</sup>/h (ICRP 66, 1994) and thus inhales 4.84 mg soil.

$$H_{B,K} = C_{TAIL,K} M_B D_{B,K}$$

where,

- $C_{TAIL,K}$  = average concentration of the Kth radionuclide in the well tailings, in Ci/kg  
 $D_{B,K}$  = inhalation dose factor from Table A22, in mrem/pCi inhaled  
 $H_{B,K}$  = inhalation dose to the driller from the Kth radionuclide, mrem  
 $M_B$  = total mass of well tailings inhaled during the well-drilling from Table A10, 4.84x10<sup>-6</sup> kg

#### Ingestion Dose to the Driller

Finally, the driller ingests small amounts of soil in the course of his work, as described in Appendix A, Section A.3.1.3. The soil ingestion occurs as a result of occasional hand-to-face contact, licking the lips, and similar motions. The typical adult soil ingestion rate is 100 mg/d. Thus the driller ingests 500 mg in the course of drilling the well.

$$H_{G,K} = C_{TAIL,K} M_G D_{G,K}$$

where,

- $C_{TAIL,K}$  = average concentration of the Kth radionuclide in the well tailings, in Ci/kg  
 $D_{G,K}$  = ingestion dose factor from Table A21, in mrem/pCi ingested  
 $H_{G,K}$  = ingestion dose to the driller from the Kth radionuclide, mrem  
 $M_G$  = total mass of well tailings ingested during the well-drilling from Table A8, 0.0005 kg

#### Dermal Absorption Dose to the Driller

The absorption of material on the skin into the body is shown to be a minor contributor for radionuclides in Section A3.4.1. In this section, the dose from radionuclides absorbed through

the skin is compared with the soil ingestion dose. The dose from dermal absorption is not calculated for radionuclides.

### Total Dose to the Driller

Scenario dose factors for the driller are presented in Table 7 as the dose per unit concentration in the well tailings. These unit dose factors must be multiplied by the average concentration in the well tailings to calculate the actual dose. As discussed above, this average concentration is calculated as the activity exhumed divided by the total mass of the tailings. Other forms are possible, as shown in the discussion above.

In the event that the chemical form of the waste at the time of intrusion allows only a fraction of the material to be inhaled or ingested, the internal doses must be reduced. An example of this is vitrified waste material. After site closure, the radionuclides are decaying and the waste is releasing trapped activity. Thus, the tailings activity concentration and the fraction available depend on the elapsed time since closure. The external dose will be delivered regardless of the waste form. The total dose to the driller can be written as shown below.

$$H_{\text{DRILLER}} = \sum_K [H_{\text{X,K}} + F_{\text{AVAIL}} (H_{\text{B,K}} + H_{\text{G,K}})]$$

where,

- $F_{\text{AVAIL}}$  = fraction of the waste that is available for ingestion and inhalation at the time of intrusion by the well driller (Table 7 assumes  $F_{\text{AVAIL}}=1$  in the “Total” columns)
- $H_{\text{DRILLER}}$  = total effective dose equivalent received by the driller from all radionuclides in the waste at the time of intrusion, in mrem
- $H_{\text{B,K}}$  = inhalation dose to the driller from the Kth radionuclide, in mrem
- $H_{\text{G,K}}$  = ingestion dose to the driller from the Kth radionuclide, in mrem
- $H_{\text{X,K}}$  = external dose to the driller from the Kth radionuclide, in mrem

The fraction of exhumed waste that is available for inhalation and ingestion ( $F_{\text{AVAIL}}$ ) depends on the nature of the waste matrix at the time of drilling. Organic materials in low level waste may be fully decomposed, so that  $F_{\text{AVAIL}}=100\%$ . Grouted waste may be exhumed as chunks that still contain much of the waste embedded in the grout matrix. Finely ground material is expected to be minimized by drilling practices, so that a reasonable value for  $F_{\text{AVAIL}}$  is 10%. Finally, waste that is contained in a glass matrix (vitrified) should have the smallest fraction available because even fine particles will chemically contain the waste. For vitrified waste, a reasonable value for  $F_{\text{AVAIL}}$  is 1%.

The scenario dose factors for the driller are calculated assuming the average concentration in the well tailings is 1 Ci/kg. Values listed in Table 7 are separated into the external component and the internal component. The column labeled “Total” is the sum of the internal and external in the event that 100% of the exhumed waste is available for inhalation and ingestion.

**Table 7. Unit Dose Factors for the Well Drilling Intruder (mrem per Ci/kg)**

<b>Nuclide</b>	<b>Total</b>	<b>External</b>	<b>Internal</b>	<b>Nuclide</b>	<b>Total</b>	<b>External</b>	<b>Internal</b>
H-3	3.25E+01	0.00E+00	3.25E+01	Gd-152	1.26E+06	0.00E+00	1.26E+06
Be-10	7.84E+03	3.79E+03	4.04E+03	Ho-166m	2.69E+07	2.69E+07	7.78E+03
C-14	1.11E+03	5.76E+01	1.06E+03	Re-187	5.02E+00	0.00E+00	5.02E+00
Na-22	3.37E+07	3.37E+07	5.79E+03	Tl-204	1.71E+04	1.54E+04	1.69E+03
Al-26	4.04E+07	4.04E+07	7.36E+03	Pb-205	8.66E+02	3.22E+01	8.34E+02
Si-32+D	4.70E+04	3.66E+04	1.05E+04	Pb-210+D	2.77E+06	2.28E+04	2.75E+06
Cl-36	9.18E+03	7.56E+03	1.62E+03	Bi-207	2.34E+07	2.34E+07	2.84E+03
K-40	2.38E+06	2.37E+06	9.36E+03	Po-209	1.29E+06	5.17E+04	1.24E+06
Ca-41	6.43E+02	0.00E+00	6.43E+02	Po-210	9.92E+05	1.31E+02	9.92E+05
Ti-44+D	3.44E+07	3.44E+07	1.45E+04	Ra-226+D	2.75E+07	2.68E+07	7.07E+05
V-49	3.24E+01	0.00E+00	3.24E+01	Ra-228+D	1.55E+07	1.48E+07	7.44E+05
Mn-54	1.29E+07	1.29E+07	1.42E+03	Ac-227+D	2.17E+07	5.89E+06	1.58E+07
Fe-55	3.10E+02	0.00E+00	3.10E+02	Th-228+D	2.51E+07	2.31E+07	2.06E+06
Fe-60+D	1.39E+05	6.16E+04	7.75E+04	Th-229+D	1.50E+07	4.57E+06	1.04E+07
Co-60	3.80E+07	3.79E+07	1.36E+04	Th-230	1.55E+06	4.45E+03	1.54E+06
Ni-59	1.09E+02	0.00E+00	1.09E+02	Th-232	6.93E+06	2.01E+03	6.93E+06
Ni-63	3.00E+02	0.00E+00	3.00E+02	Pa-231	1.20E+07	5.51E+05	1.15E+07
Se-79	4.46E+03	7.92E+01	4.38E+03	U-232	7.30E+05	3.30E+03	7.27E+05
Rb-87	3.03E+03	5.51E+02	2.48E+03	U-233	1.88E+05	4.52E+03	1.83E+05
Sr-90+D	1.51E+05	7.34E+04	7.77E+04	U-234	1.81E+05	1.55E+03	1.80E+05
Zr-93	1.23E+03	0.00E+00	1.23E+03	U-235+D	2.56E+06	2.40E+06	1.69E+05
Nb-91	3.29E+04	3.27E+04	2.77E+02	U-236	1.71E+05	8.61E+02	1.71E+05
Nb-93m	7.52E+02	4.75E+02	2.77E+02	U-238+D	5.28E+05	3.60E+05	1.68E+05
Nb-94	2.44E+07	2.44E+07	3.74E+03	Np-237+D	8.11E+06	3.28E+06	4.83E+06
Mo-93	3.51E+03	2.69E+03	8.12E+02	Pu-236	1.29E+06	9.38E+02	1.29E+06
Tc-99	1.26E+03	4.89E+02	7.70E+02	Pu-238	3.50E+06	6.48E+02	3.50E+06
Ru-106+D	3.37E+06	3.35E+06	1.43E+04	Pu-239	3.85E+06	9.81E+02	3.85E+06
Pd-107	1.36E+02	0.00E+00	1.36E+02	Pu-240	3.85E+06	6.34E+02	3.85E+06
Ag-108m+D	2.52E+07	2.52E+07	3.93E+03	Pu-241+D	7.42E+04	6.30E+01	7.42E+04
Cd-109	6.57E+04	5.86E+04	7.10E+03	Pu-242	3.67E+06	5.48E+02	3.67E+06
Cd-113m	9.02E+04	2.31E+03	8.79E+04	Pu-244+D	8.78E+06	5.17E+06	3.61E+06
In-115	9.86E+04	1.47E+03	9.71E+04	Am-241	4.15E+06	1.86E+05	3.97E+06
Sn-121m+D	1.07E+04	9.53E+03	1.18E+03	Am-242m+D	4.04E+06	2.20E+05	3.82E+06
Sn-126+D	3.09E+07	3.09E+07	1.10E+04	Am-243+D	6.89E+06	2.94E+06	3.94E+06
Sb-125	6.53E+06	6.53E+06	1.46E+03	Cm-242	1.42E+05	7.33E+02	1.41E+05
Te-125m	6.98E+04	6.80E+04	1.87E+03	Cm-243	4.57E+06	1.82E+06	2.74E+06
I-129	1.98E+05	5.90E+04	1.39E+05	Cm-244	2.21E+06	5.75E+02	2.21E+06
Cs-134	2.42E+07	2.41E+07	3.69E+04	Cm-245	5.24E+06	1.17E+06	4.07E+06
Cs-135	3.71E+03	1.58E+02	3.56E+03	Cm-246	4.03E+06	5.30E+02	4.03E+06
Cs-137+D	8.80E+06	8.78E+06	2.52E+04	Cm-247+D	8.92E+06	5.21E+06	3.71E+06

**Table 7. Unit Dose Factors for the Well Drilling Intruder (mrem per Ci/kg)**

Nuclide	Total	External	Internal	Nuclide	Total	External	Internal
Ba-133	5.66E+06	5.66E+06	1.74E+03	Cm-248	1.48E+07	4.01E+02	1.48E+07
Pm-147	9.10E+02	1.95E+02	7.15E+02	Cm-250+D	8.93E+07	4.96E+06	8.43E+07
Sm-147	4.54E+05	0.00E+00	4.54E+05	Bk-247	6.54E+06	1.42E+06	5.13E+06
Sm-151	3.44E+02	4.49E+00	3.40E+02	Cf-248	3.82E+05	5.69E+02	3.82E+05
Eu-150	2.29E+07	2.29E+07	4.48E+03	Cf-249	1.03E+07	5.17E+06	5.16E+06
Eu-152	1.73E+07	1.73E+07	4.31E+03	Cf-250	2.33E+06	5.41E+02	2.33E+06
Eu-154	1.89E+07	1.88E+07	6.16E+03	Cf-251	6.98E+06	1.71E+06	5.27E+06
Eu-155	6.78E+05	6.77E+05	9.65E+02	Cf-252	1.20E+06	7.37E+02	1.20E+06

Notes:

- These scenario dose factors for the intruder must be multiplied by the average radionuclide concentration in the well tailings. This concentration is the activity exhumed divided by the total mass of the well tailings.
- The "Total" column is the sum of the "Internal" and "External" columns. External and internal doses are separated because the waste matrix may prevent a portion of the exhumed activity from giving an internal dose.

### 3.2 POST-INTRUSION SUBURBAN GARDEN

This scenario assumes that an individual lives near the well tailings and manages to spread the well tailings in his garden. The individual obtains one-fourth of his fruit and vegetable (but not grain) supply each year from the garden. In addition, he inhales resuspended garden soil and ingests small amounts of it each day. His external dose comes from spending time in or near the garden. The radiation dose to this individual is the 50 year committed effective dose equivalent from the first year of exposure after the well was drilled.

The descriptions below include the factors that take into account radioactive decay and leaching from the garden soil. They do not show the method used to represent decay chains. The treatment of decay chains is presented in Appendix B.

#### Concentration of Soil in the Garden

The garden area is 100 m<sup>2</sup> based on the discussion in Appendix A, Section A3.1.2. The depth of soil contaminated is 0.15 m, a traditional representation of the tilling depth. Thus the volume of soil in the garden is 15 m<sup>3</sup>. The density of the garden soil is assumed to be 1,500 kg/m<sup>3</sup>. Thus, the mass of the garden soil is 22,500 kg. The exhumed waste is distributed over this amount of soil. The concentration of radionuclides in the garden is the concentration in the waste (activity per unit mass) multiplied by the ratio of the volume of waste exhumed by the well-drilling operation divided by the volume of soil in the garden, 15 m<sup>3</sup>. Equivalently, the garden soil concentration is the activity exhumed divided by the mass of soil in the garden. The soil concentration in this scenario clearly depends on the diameter of the well. If the total activity and the horizontal area of the disposal site are known, then the activity exhumed is just the site inventory of one nuclide times the ratio of the well cross-sectional area to the site horizontal area. This is summarized in the equations below.

$$Q_{\text{EXHUMED}} = A_{\text{WELL}} L_{\text{WASTE}} \rho_{\text{WASTE}} C_{\text{WASTE}}$$

or

$$Q_{\text{EXHUMED}} = Q_{\text{SITE}} \frac{A_{\text{WELL}}}{A_{\text{SITE}}}$$

and

$$C_{\text{GARDEN}} = \frac{Q_{\text{EXHUMED}}}{A_{\text{GARDEN}} L_{\text{GARDEN}} \rho_{\text{GARDEN}}}$$

where,

- $A_{\text{GARDEN}}$  = cultivated area of a garden, 100 m<sup>2</sup>
- $A_{\text{SITE}}$  = horizontal area occupied by the disposal site, in m<sup>2</sup>
- $A_{\text{WELL}}$  = cross-sectional area of the well, in m<sup>2</sup>
- $C_{\text{GARDEN}}$  = initial concentration of a radionuclide in the garden, in Ci/kg
- $C_{\text{WASTE}}$  = concentration of a radionuclide in the disposal site, in Ci/kg
- $L_{\text{GARDEN}}$  = thickness of the contaminated layer of surface soil in the garden, 0.15 m
- $L_{\text{WASTE}}$  = thickness of the waste in the well, in m
- $Q_{\text{EXHUMED}}$  = activity of a radionuclide brought to the surface by the well-drilling, in Ci
- $Q_{\text{SITE}}$  = total activity of a radionuclide in the disposal site, in Ci
- $\rho_{\text{GARDEN}}$  = average density of the soil in the garden, 1,500 kg/m<sup>3</sup>
- $\rho_{\text{WASTE}}$  = average density of the waste, in kg/m<sup>3</sup>

During the year, the concentration of each isotope in the garden decreases due to leaching from the surface layer and radioactive decay. The first half of the year the garden is irrigated, so both processes are in effect. The second half of the year the garden is not irrigated, so only radioactive decay occurs. This is represented mathematically using the formulas below.

$$C_{\text{GRDN,K}}(t) = C_{\text{GARDEN,K}} \text{Exp}(-\lambda_{\text{K}} t) \quad \text{for } 0 < t < T_{\text{irr}}$$

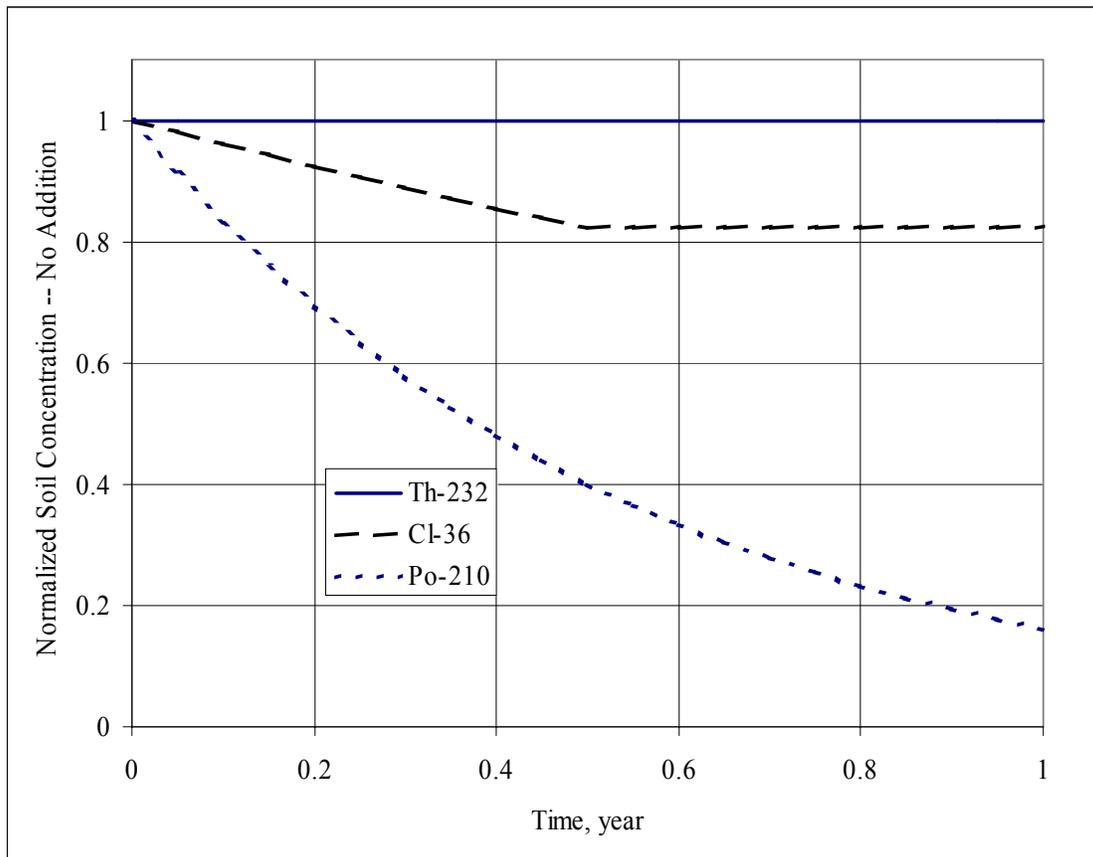
$$C_{\text{GRDN,K}}(t) = C_{\text{GARDEN,K}} \text{Exp}(-\lambda_{\text{K}} T_{\text{irr}}) \text{Exp}(-\lambda_{\text{R,K}} t) \quad \text{for } T_{\text{irr}} < t < 1 \text{ y}$$

where,

- $C_{\text{GARDEN,K}}$  = initial average concentration of the Kth radionuclide in the garden soil, in Ci/kg
- $C_{\text{GRDN,K}}(t)$  = concentration of the Kth radionuclide in garden soil as a function of time (t) during the year, in Ci/kg.
- Exp = the exponential function (e raised to some power)
- $T_{\text{irr}}$  = irrigation period (the 1<sup>st</sup> half of the year), 0.5 y
- $\lambda_{\text{K}}$  = total removal constant for the Kth radionuclide, per year,  $\lambda_{\text{K}} = \lambda_{\text{S,K}} + \lambda_{\text{R,K}}$
- $\lambda_{\text{R,K}}$  = radioactive decay constant for the Kth radionuclide, per year. These are calculated as  $\ln(2)=0.6931472$  divided by the material half life (in years).
- $\lambda_{\text{S,K}}$  = average soil leaching coefficient for the Kth radionuclide, fraction removed from the surface layer of soil, per year (see Table A40)

The soil concentration as a function of time for three radionuclides is shown in Figure 1. The soil concentration is normalized by the garden soil concentration at the start of the year. The first isotope (Th-232) illustrates the case with little decay and little leaching. Th-232 has a very

long half life ( $1.405 \times 10^{10}$  years) and a very large retardation in the surface soil ( $K_d=600,000$  ml/g). The Th-232 concentration is therefore constant during the year. The second isotope (Cl-36) has a long half life (300,992 years) but is only slightly retarded in the soil ( $K_d=1.0$  ml/g). The Cl-36 concentration decreases during the irrigation season, but is constant during the non-irrigation season. The third isotope (Po-210) has a short half life (138.38 days) but is significantly retarded in the soil ( $K_d=1,100$  ml/g). It shows only the effect of radioactive decay during the year.



**Figure 1. Fraction of Garden Soil Concentration Remaining During the Year.**

#### External Dose to the Suburban Gardener

External exposure occurs when the individual is on or near the garden. The limited size of the garden means the external exposure must be limited. The contamination is not generally present everywhere in the resident's environment. The exposure time chosen for this scenario (in Section A3.3) is 180 hours per year.

The external exposure time is spread evenly over the first half of the year, with none in the second half. The decrease in soil concentration is described using an exponential function (see Section A6.2). Hence, the time integral of the dose rate over the year of exposure leads to the form shown below.

$$H_{X,K} = C_{\text{GARDEN},K} \rho_{\text{GARDEN}} L_{\text{GARDEN}} D_{X,K} T_X F_{X,N,K}$$

$$F_{X,N,K} = \frac{1 - \text{Exp}(-\lambda_K T_{\text{irr}})}{\lambda_K T_{\text{irr}}}$$

where,

- $C_{\text{GARDEN},K}$  = average concentration of the Kth radionuclide in the garden soil, in Ci/kg  
 $L_{\text{GARDEN}}$  = thickness of the contaminated layer of surface soil in the garden, 0.15 m  
 $D_{X,K}$  = external dose rate factor for the Kth radionuclide to a person standing on a layer 0.15 m thick and of great extent in all directions, in mrem/h per Ci/m<sup>2</sup>. Values from EPA Federal Guidance Report Number 12 for a 15 cm thickness are listed in Table A25.  
 $\text{Exp}$  = the exponential function (e raised to some power)  
 $F_{X,N,K}$  = factor that results from the time integral of the dose rate for the Kth radionuclide over the first half of the year (X=external calculation, N=the irrigation water adds no contaminants, and K=radionuclide index)  
 $H_{X,K}$  = external dose to the suburban gardener from the Kth radionuclide during the first year after the well is drilled, mrem/y  
 $T_X$  = time of exposure from Table A15, 180 h/y. All of this occurs during the first half of the year.  
 $T_{\text{irr}}$  = irrigation period, 0.5 y (the first half of the year)  
 $\lambda_K$  = total removal constant for the Kth radionuclide, per year,  $\lambda_K = \lambda_{S,K} + \lambda_{R,K}$   
 $\lambda_{R,K}$  = radioactive decay constant for the Kth radionuclide, per year. These are calculated as  $\ln(2)=0.6931472$  divided by the material half life (in years).  
 $\lambda_{S,K}$  = average soil leaching coefficient for the Kth radionuclide, fraction removed from the surface layer of soil, per year (see Table A40)  
 $\rho_{\text{GARDEN}}$  = average density of the garden soil, 1,500 kg/m<sup>3</sup>

### Inhalation Dose to the Suburban Gardener

The gardener is exposed to airborne particulate during the year, as described in Section A.3.2.1. The suburban gardener inhales 87 mg over the course of a year. The concentration of radionuclides in the suspended particulate is assumed to be the same as the average concentration of radionuclides in the garden. The inhalation dose to the gardener is calculated using the formula below. The decay and leaching factor ( $F_{B,N,K}$ ) is the sum of two terms. The first is the time integral during the irrigation period. The second is the product of the factor representing soil concentration at the end of the irrigation period and the time integral during the non-irrigation period.

$$H_{B,K} = C_{\text{GARDEN},K} M_B D_{B,K} F_{B,N,K}$$

$$F_{B,N,K} = \frac{1 - \text{Exp}(-\lambda_K T_{\text{irr}})}{(1 \text{ y})\lambda_K} + \text{Exp}(-\lambda_K T_{\text{irr}}) \frac{1 - \text{Exp}(-\lambda_{R,K} T_{\text{no}})}{(1 \text{ y})\lambda_{R,K}}$$

where,

- $C_{\text{GARDEN},K}$  = average concentration of the Kth radionuclide in the garden soil, in Ci/kg  
 $D_{B,K}$  = inhalation dose factor for the Kth radionuclide from Table A22, in mrem/pCi inhaled

- $F_{B,N,K}$  = factor that results from the time integral of the inhalation dose rate for the Kth radionuclide over the full year (B=inhalation calculation, N=the irrigation water adds no contaminants, and K=radionuclide index)  
 $H_{B,K}$  = inhalation dose to the suburban gardener from the Kth radionuclide, mrem/y  
 $M_B$  = total mass of garden soil inhaled during the year from Table A10,  $8.7 \times 10^{-5}$  kg/y  
 $T_{irr}$  = irrigation period (the 1<sup>st</sup> half of the year), 0.5 y  
 $T_{no}$  = no irrigation period (the 2<sup>nd</sup> half of the year),  $T_{irr} + T_{no} = 1$  y  
 $\lambda_K$  = total removal constant for the Kth radionuclide, per year,  $\lambda_K = \lambda_{S,K} + \lambda_{R,K}$   
 $\lambda_{R,K}$  = radioactive decay constant for the Kth radionuclide, per year. These are calculated as  $\ln(2)=0.6931472$  divided by the material half life (in years).  
 $\lambda_{S,K}$  = average soil leaching coefficient for the Kth radionuclide, fraction removed from the surface layer of soil, per year (see Table A40)

A special model for tritium emanation from the soil and subsequent inhalation is based on the water evaporation rates estimated for the Hanford Site. The tritium model is derived in Section A.3.2.1. All of the tritium exhumed is regarded as tritiated water.

#### Ingestion Dose to the Suburban Gardener

In addition to the small amounts of soil that are ingested during the irrigation season, the gardener also eats fruits and vegetables from his garden. The garden supplies 25% of the fruit and vegetable intake (Section A3.11). Grains are obtained from uncontaminated sources. The ingestion dose for one nuclide that results from these intakes is shown below.

Note that there are four types of garden produce that must be calculated individually and summed. These four types are leafy vegetables, other vegetables, fruit, and grains. Consumption amounts are shown in Table A5 in the column labeled "All Pathways Farmer". It is assumed that no grains are grown in a home garden. Both scenarios use the same garden vegetable consumption amounts.

$$H_{G,K} = \left( C_{GARDEN,K} M_G F_{X,N,K} + \sum_p C_{V,p,K} M_{V,p} \right) D_{G,K}$$

where,

- $C_{GARDEN,K}$  = initial average concentration of the Kth radionuclide in the garden soil, in Ci/kg  
 $C_{V,p,K}$  = time-integrated radionuclide concentration in garden produce type p, in Ci/kg wet weight  
 $D_{G,K}$  = ingestion dose factor for the Kth radionuclide from Table A21, in mrem/pCi ingested  
 $F_{X,N,K}$  = factor that results from the time integral of the dose rate for the Kth radionuclide over the first half of the year (X=external calculation, N=the irrigation water adds no contaminants, and K=radionuclide index)  
 $H_{G,K}$  = ingestion dose to the suburban gardener from the Kth radionuclide, mrem/y  
 $M_G$  = total mass of garden soil ingested during the irrigation season from Table A8, 0.018 kg/y  
 $M_{V,p}$  = mass of garden produce type p eaten during the year, in kg/y. These amounts are shown in Table A5 under the heading "All Pathways Farmer".

p = index to the four types of garden produce, i.e., fruit, protected vegetables, exposed vegetables, and grains

The garden produce becomes contaminated by root uptake from the soil and by soil adhering to the foliage. The concentration of a radionuclide in a garden food item is shown in the equation below. Leafy vegetables are produced in the garden and eaten continuously during the first half of the year. Leafy vegetables eaten during the second half of the year are obtained from uncontaminated sources. Thus, all of the ingestion dose from leafy vegetables accumulates during the irrigation season. The other items are harvested midway through the irrigation season (at 0.25 year). The plant concentrations are proportional to the soil concentration at this time. They are then consumed over a 90-day period. The ingestion dose accumulates during the consumption period. Note that some parameters depend on the food type, while others are the same for all types. Similarly, some parameters depend on the radionuclide while others are the same for all radionuclides.

$$C_{V,p,K} = C_{GARDEN,K} \left( F_{DRY,p} B_{V,p,K} + \frac{J_{SPLASH} F_{INT,p} F_{TRANS,p} T_{W,p}}{Y_{V,p}} \right) F_{V,N,K,p}$$

$$T_{W,p} = \frac{1 - \text{Exp}(-\lambda_W T_{GROW,p})}{\lambda_W}$$

$$F_{V,N,K,Leafy} = \frac{1 - \text{Exp}(-\lambda_K T_{irr})}{\lambda_K T_{irr}}$$

$$F_{V,N,K,Other} = \text{Exp}(-\lambda_K T_{harvest}) \frac{1 - \text{Exp}(-\lambda_{R,K} T_{veg})}{\lambda_{R,K} T_{veg}}$$

where,

- $B_{V,p,K}$  = soil-to-plant transfer factor for the Kth radionuclide in garden produce type p from Table A37
- $C_{GARDEN,K}$  = average concentration of the Kth radionuclide in the garden soil, in Ci/kg
- $C_{V,p,K}$  = time-integrated radionuclide concentration in garden produce type P, in Ci/kg wet weight
- $F_{DRY,p}$  = dry-to-wet ratio for garden produce type p from Table A39
- $F_{INT,p}$  = interception fraction for airborne dust on exposed surfaces of garden produce type p, from Table A39
- $F_{TRANS,p}$  = translocation factor from exposed surfaces to the edible portion of garden produce type p, from Table A39
- $F_{V,N,K,p}$  = factor that results from the time integral of the daily dose from garden produce for the Kth radionuclide (V=garden produce calculation, N=the irrigation water adds no contaminants, K=radionuclide index, and p= plant index). Specific cases are shown for leafy vegetables and all other types of garden produce.
- $J_{SPLASH}$  = average soil deposition rate due to rain splash (see Section A5.2),  $2.7 \times 10^{-4}$  kg/m<sup>2</sup> per day
- p = index to the four types of garden produce, i.e., fruit, protected vegetables, exposed vegetables, and grains
- $T_{GROW,p}$  = growing period of garden produce type p from Table A39

- $T_{\text{harvest}}$  = time at which harvest occurs, 0.25 y (midway through the irrigation season)  
 $T_{\text{irr}}$  = irrigation period (the 1<sup>st</sup> half of the year), 0.5 y  
 $T_{\text{veg}}$  = consumption period for all garden produce except leafy vegetables, 90 d (0.2466 y)  
 $T_{W,p}$  = effective exposure time for garden produce type p, days. Calculated values are listed in Table B1.  
 $Y_{V,p}$  = yield of garden produce type p, from Table A39, in kg(wet)/m<sup>2</sup>  
 $\lambda_K$  = total removal constant for the Kth radionuclide, per year,  $\lambda_K = \lambda_{S,K} + \lambda_{R,K}$   
 $\lambda_{R,K}$  = radioactive decay constant for the Kth radionuclide, per year. These are calculated as  $\ln(2)=0.6931472$  divided by the material half life (in years).  
 $\lambda_{S,K}$  = average soil leaching coefficient for the Kth radionuclide, fraction removed from the surface layer of soil, per year (see Table A40)  
 $\lambda_W$  = weathering constant for all type of garden produce, 0.04951 per day. This is based on a weathering half time of 14 days.

An equilibrium model is used to estimate tritium concentrations in plants. It assumes the tritium exhumed is in the form of tritiated water (HTO). The concentration of tritium in the surface moisture is assumed the same as the tritium concentration in the water contained in the plant. The tritium concentration in garden produce is shown in the equation below. The product of the soil concentration and the first ratio gives the tritium concentration in the soil water. The factor 8.94 is calculated from the ratio of the atomic weights of water and hydrogen. It converts the hydrogen fractions ( $F_{H,p}$ ) from Table A34 to water fractions. Because the hydrogen fractions include organically bound hydrogen, the water fraction calculated is an upper bound. Note also that the tritium concentration in the plants follows the tritium concentration in the soil, which is decreasing rapidly due to applied irrigation water and evaporation.

$$C_{V,p,H-3} = C_{\text{GARDEN},H-3} \left( \frac{\rho_{\text{GARDEN}}}{\theta \rho_W} \right) \left( \frac{8.94 \text{ kg water}}{\text{kg hydrogen}} \right) F_{H,p} F_{V,N,H-3,p}$$

where,

- $C_{\text{GARDEN},H-3}$  = initial average concentration of tritium (H-3) in the garden soil, in Ci/kg  
 $C_{V,p,H-3}$  = time-integrated tritium concentration in garden produce type P, in Ci/kg wet weight  
 $F_{H,p}$  = mass fraction of hydrogen in garden produce type p from Table A34, in kg hydrogen per kg plant (wet)  
 $F_{V,N,H-3,p}$  = factor that results from the time integral of the daily dose from garden produce for tritium (V=garden produce calculation, N=the irrigation water adds no contaminants, H-3=tritium, and p= plant index).  
p = index to the four types of garden produce, i.e., fruit, protected vegetables, exposed vegetables, and grains  
 $\rho_{\text{GARDEN}}$  = average density of the garden soil, 1.5 kg soil per liter of soil  
 $\rho_W$  = density of water, 1.0 kg water per liter of water  
 $\theta$  = volumetric water content of the surface soil, liters of water per liter of soil. A value of 0.2 is assumed. Because the total soil porosity is about 0.4, the saturation ratio is about 50%.

### Dermal Absorption Dose to the Suburban Gardener

The absorption of material on the skin into the body is shown to be a minor contributor for radionuclides in Section A3.4.1. In this section, the dose from radionuclides absorbed through the skin is compared with the soil ingestion dose. The dose from dermal absorption is not calculated for radionuclides.

### Total Dose to the Suburban Gardener

Scenario dose factors for the suburban gardener are presented in Table 8 as the dose received during the first year per curie that is exhumed. These unit dose factors must be multiplied by the activity exhumed to calculate the first year dose. The radiation dose to this individual is the 50 year committed effective dose equivalent from one year of exposure.

The internal doses must be reduced in the event that the chemical form of the waste at the time of intrusion allows only a fraction of the material to be inhaled, ingested, or absorbed by plants. An example of this is vitrified waste material. After site closure, the radionuclides are decaying and the waste is releasing trapped activity. Thus, the tailings activity concentration and the fraction available depend on the elapsed time since closure. The external dose will be delivered regardless of the waste form. The total dose to the suburban gardener can be written as shown below.

$$H_{\text{GARDNER}} = \sum_K [H_{\text{X,K}} + F_{\text{AVAIL}} (H_{\text{B,K}} + H_{\text{G,K}})]$$

where,

- $F_{\text{AVAIL}}$  = fraction of the waste that is available for ingestion, inhalation, and absorption by plants at the time of suburban gardener exposures (Table 8 assumes  $F_{\text{AVAIL}}=1$  in the "Total" columns)
- $H_{\text{GARDNER}}$  = total effective dose equivalent received by the suburban gardener from all radionuclides in the exhumed waste material, in mrem/y
- $H_{\text{B,K}}$  = inhalation dose to the suburban gardener from the Kth radionuclide, in mrem/y
- $H_{\text{G,K}}$  = ingestion dose to the suburban gardener from the Kth radionuclide, in mrem/y
- $H_{\text{X,K}}$  = external dose to the suburban gardener from the Kth radionuclide, in mrem/y

The scenario dose factors for the suburban gardener assume that 1 Ci of each isotope comes out of the well. Values listed in Table 8 are separated into the external component and the internal component. The column labeled "Total" is the sum of the internal and external in the event that 100% of the exhumed waste is available for inhalation and ingestion. Additional detail on the doses by pathway is shown in Appendix D.

**Table 8. Unit Dose Factors for the Suburban Gardener (mrem/y per Ci exhumed)**

Nuclide	Total	External	Internal	Nuclide	Total	External	Internal
H-3	3.04E+00	0.00E+00	3.04E+00	Gd-152	1.45E+03	0.00E+00	1.45E+03
Be-10	1.24E+01	9.66E-01	1.14E+01	Ho-166m	8.38E+03	8.35E+03	2.87E+01
C-14	6.22E+02	1.21E-02	6.22E+02	Re-187	1.64E+00	0.00E+00	1.64E+00
Na-22	1.14E+04	1.01E+04	1.36E+03	Tl-204	8.49E+00	3.51E+00	4.98E+00
Al-26	1.32E+04	1.32E+04	2.48E+01	Pb-205	7.47E+00	6.44E-03	7.47E+00
Si-32+D	4.13E+02	1.02E+01	4.03E+02	Pb-210+D	2.72E+04	5.37E+00	2.72E+04
Cl-36	8.26E+04	1.90E+00	8.26E+04	Bi-207	7.38E+03	7.36E+03	2.20E+01
K-40	5.29E+03	7.71E+02	4.52E+03	Po-209	7.46E+03	1.61E+01	7.44E+03
Ca-41	2.61E+02	0.00E+00	2.61E+02	Po-210	3.03E+03	2.74E-02	3.03E+03
Ti-44+D	1.08E+04	1.08E+04	6.76E+01	Ra-226+D	1.41E+04	8.60E+03	5.51E+03
V-49	1.25E-01	0.00E+00	1.25E-01	Ra-228+D	1.09E+04	5.21E+03	5.73E+03
Mn-54	3.59E+03	3.36E+03	2.35E+02	Ac-227+D	3.12E+04	1.72E+03	2.95E+04
Fe-55	1.70E+00	0.00E+00	1.70E+00	Th-228+D	9.05E+03	6.91E+03	2.13E+03
Fe-60+D	9.13E+02	4.15E+02	4.98E+02	Th-229+D	1.40E+04	1.34E+03	1.26E+04
Co-60	1.25E+04	1.19E+04	5.85E+02	Th-230	1.82E+03	2.02E+00	1.82E+03
Ni-59	5.70E+00	0.00E+00	5.70E+00	Th-232	8.85E+03	1.53E+02	8.70E+03
Ni-63	1.56E+01	0.00E+00	1.56E+01	Pa-231	2.15E+04	1.78E+02	2.13E+04
Se-79	9.98E+01	1.61E-02	9.98E+01	U-232	7.58E+03	6.38E+02	6.94E+03
Rb-87	1.91E+03	1.28E-01	1.91E+03	U-233	1.47E+03	1.25E+00	1.47E+03
Sr-90+D	3.57E+04	2.09E+01	3.57E+04	U-234	1.44E+03	3.60E-01	1.44E+03
Zr-93	3.36E+00	1.01E-03	3.36E+00	U-235+D	2.02E+03	6.63E+02	1.36E+03
Nb-91	1.49E+01	1.03E+01	4.53E+00	U-236	1.37E+03	1.91E-01	1.37E+03
Nb-93m	4.55E+00	9.40E-02	4.46E+00	U-238+D	1.47E+03	1.04E+02	1.36E+03
Nb-94	7.78E+03	7.72E+03	6.19E+01	Np-237+D	3.44E+04	9.46E+02	3.34E+04
Mo-93	4.60E+02	5.31E-01	4.59E+02	Pu-236	2.13E+03	1.24E+00	2.13E+03
Tc-99	5.06E+03	1.09E-01	5.06E+03	Pu-238	6.34E+03	1.37E-01	6.34E+03
Ru-106+D	1.35E+03	8.89E+02	4.62E+02	Pu-239	7.02E+03	2.59E-01	7.02E+03
Pd-107	3.10E+00	0.00E+00	3.10E+00	Pu-240	7.02E+03	1.34E-01	7.02E+03
Ag-108m+D	7.86E+03	7.85E+03	1.39E+01	Pu-241+D	1.38E+02	3.24E-02	1.38E+02
Cd-109	7.98E+02	1.17E+01	7.86E+02	Pu-242	6.68E+03	1.17E-01	6.68E+03
Cd-113m	1.15E+04	5.75E-01	1.15E+04	Pu-244+D	8.21E+03	1.63E+03	6.59E+03
In-115	2.67E+02	3.62E-01	2.66E+02	Am-241	7.24E+03	3.99E+01	7.20E+03
Sn-121m+D	1.17E+01	1.92E+00	9.82E+00	Am-242m+D	7.10E+03	5.90E+01	7.04E+03
Sn-126+D	9.74E+03	9.65E+03	9.20E+01	Am-243+D	7.97E+03	7.96E+02	7.17E+03
Sb-125	1.92E+03	1.90E+03	2.84E+01	Cm-242	1.43E+02	1.08E-01	1.43E+02
Te-125m	8.75E+00	5.61E+00	3.14E+00	Cm-243	5.37E+03	5.12E+02	4.86E+03
I-129	2.88E+03	1.17E+01	2.87E+03	Cm-244	3.89E+03	1.14E-01	3.89E+03
Cs-134	1.21E+04	7.02E+03	5.10E+03	Cm-245	7.62E+03	3.08E+02	7.32E+03
Cs-135	5.55E+02	3.49E-02	5.55E+02	Cm-246	7.24E+03	1.06E-01	7.24E+03
Cs-137+D	6.63E+03	2.74E+03	3.89E+03	Cm-247+D	8.25E+03	1.57E+03	6.68E+03
Ba-133	1.71E+03	1.65E+03	5.43E+01	Cm-248	2.66E+04	8.01E-02	2.66E+04
Pm-147	3.19E+00	4.27E-02	3.15E+00	Cm-250+D	1.53E+05	1.54E+03	1.52E+05
Sm-147	8.77E+02	0.00E+00	8.77E+02	Bk-247	9.69E+03	3.85E+02	9.30E+03
Sm-151	1.35E+00	8.96E-04	1.35E+00	Cf-248	1.59E+03	9.56E-02	1.59E+03

**Table 8. Unit Dose Factors for the Suburban Gardener (mrem/y per Ci exhumed)**

Nuclide	Total	External	Internal	Nuclide	Total	External	Internal
Eu-150	7.11E+03	7.09E+03	2.11E+01	Cf-249	3.06E+04	1.57E+03	2.90E+04
Eu-152	5.44E+03	5.42E+03	2.10E+01	Cf-250	1.28E+04	1.07E-01	1.28E+04
Eu-154	5.92E+03	5.89E+03	3.05E+01	Cf-251	3.02E+04	4.71E+02	2.97E+04
Eu-155	1.65E+02	1.60E+02	4.75E+00	Cf-252	5.99E+03	1.50E-01	5.99E+03

Notes:

- The radiation dose to this individual is the 50 year committed effective dose equivalent from the first year of exposure.
- These scenario dose factors must be multiplied by the activity exhumed by the well drilling, in curies.
- The "Total" column is the sum of the "Internal" and "External" columns. External and internal doses are separated because the waste matrix may prevent a portion of the exhumed activity from giving an internal dose.

Comparison of the Driller and Suburban Gardener Doses. To compare the driller and the suburban gardener, note that the dose depends on both the effective annual intake and the soil concentration. The effective annual intakes are discussed in Appendix A Section A3.1. For the well-driller, the soil concentration is the average concentration in the well tailings. For the suburban gardener the soil concentration is the average concentration in the garden.

For a few nuclides there are additional differences due to radioactive decay and leaching from the garden soil. These processes are not included in the driller scenario due to the short exposure time (5 days). The factors that adjust the garden doses for decay and leaching have values between 0 and 1, with most nuclides very close to 1. These factors are not included in this comparison so that the results do not depend on the specific radionuclide. The equations below show the dose ratios, assuming the waste density is similar to the density of the compacted soil in the well.

$$\frac{C_{\text{GARDEN},K}}{C_{\text{TAIL},K}} = \frac{A_{\text{WELL}} L_{\text{WELL}} \rho_{\text{WELL}}}{A_{\text{GARDEN}} L_{\text{GARDEN}} \rho_{\text{GARDEN}}}$$

$$\text{Internal Dose Ratio} = \left( \frac{M_{\text{GARDEN}}}{M_{\text{TAIL}}} \right) \left( \frac{C_{\text{GARDEN},K}}{C_{\text{TAIL},K}} \right)$$

$$\text{External Dose Ratio} = \left( \frac{L_{\text{GARDEN}} T_{\text{GARDEN}} D_{X,K}}{L_{\text{TAIL}} T_{\text{WELL}} D_{X,5,K}} \right) \left( \frac{C_{\text{GARDEN},K}}{C_{\text{TAIL},K}} \right)$$

where,

- $A_{\text{GARDEN}}$  = cultivated area of a garden, 100 m<sup>2</sup>
- $A_{\text{WELL}}$  = cross-sectional area of the well, in m<sup>2</sup>
- $C_{\text{GARDEN},K}$  = average concentration of the Kth radionuclide in the garden soil, in Ci/kg
- $C_{\text{TAIL},K}$  = average concentration of the Kth radionuclide in the well tailings, in Ci/kg

$D_{X,K}$	=	external dose rate factor for the Kth radionuclide to a person standing on a layer 0.15 m thick and of great extent in all directions, in mrem/h per Ci/m <sup>2</sup> . Values from EPA Federal Guidance Report Number 12 for a 15 cm thickness are listed in Table A25.
$D_{X,5,K}$	=	external dose rate factor for the Kth radionuclide to a person standing on a layer 0.05 m thick and of great extent in all directions, in mrem/h per Ci/m <sup>2</sup> . Values from EPA Federal Guidance Report Number 12 for a 5 cm thickness are listed in Table A25.
$L_{GARDEN}$	=	depth of the contaminated soil layer in the suburban garden, 0.15 m
$L_{TAIL}$	=	depth of the contaminated soil layer in the well-drilling scenario, 0.05 m
$L_{WELL}$	=	depth of the well from surface to groundwater, in m
$M_{GARDEN}$	=	mass of contaminated soil inhaled (0.087 g) or ingested (18 g) in the suburban garden
$M_{TAIL}$	=	mass of contaminated soil inhaled (0.00484 g) or ingested (0.5 g) in the well-drilling scenario
Ratio	=	the dose to the suburban gardener divided by the dose to the well-driller
$T_{GARDEN}$	=	external exposure time in the suburban garden, 180 h
$T_{WELL}$	=	external exposure time in the well-drilling scenario, 40 h
$\rho_{GARDEN}$	=	average density of the soil in the garden, 1,500 kg/m <sup>3</sup>
$\rho_{WELL}$	=	average density of the soil in the well, 2,000 kg/m <sup>3</sup>

Notice that the gardener-to-driller dose ratios do not depend on the waste thickness, provided that the waste density is about the same as the soil density in the borehole. The internal ratios are essentially independent of the radionuclide. The external dose ratios do contain an explicit reference to the radionuclide in the external dose rate factors from Federal Guidance Report Number 12. However, the ratio of 5 cm to 15 cm dose rate factors shown in Table A25 ranges from 1.8 to 3.0. Nearly all of the dose rate factors that are greater than 1,000 mrem/h per Ci/m<sup>2</sup> have ratios less than 2.0. Thus, for the sake of the comparison, the ratio of dose rate factors can be replaced with 1/2.

Assuming the well is 100 m (328 ft) deep, has a diameter of 0.203 m (8 in.), and the compacted soil density in the well is 2,000 kg/m<sup>3</sup>, then the soil concentration ratio (gardener/driller) is 0.288. The mass of soil inhaled or ingested is from Tables A8 and A10. The external exposure times are shown in Table A15. The ratio of the post-intrusion dose to the well-driller dose is shown in Table 9 for each exposure pathway. Ingestion of garden vegetables is not shown because the driller does not consume any.

Also shown in Table 9 is the well depth at which the dose to the driller equals the dose to the suburban gardener, assuming the well diameter is 0.203 m (8 in.). The general conclusion is that wells shallower than about 20 m may have driller doses larger than the suburban gardener dose. The actual depth depends on the combination of radionuclides present in the waste, and must include the garden produce contribution, as well.

**Table 9. Comparison of the Well Driller and Suburban Gardener.**

Pathway	Gardener to Driller Dose Ratio	Well Depth for Driller Dose Equal to Suburban Gardener Dose
Soil Ingestion	10.4	10 m
Soil Inhalation	5.2	19 m
External Exposure	1.9	51 m

Notes:

- The Gardener to Driller Dose Ratio ignores differences in density between the buried waste and the soil in the well. Both are assumed to be 2,000 kg/m<sup>3</sup>. The ratio applies to the pathway indicated in the first column. Ingestion of garden vegetables is not included. The assumed well is 0.203 m diameter and 100 m deep.
- The minimum well depth assumes a 0.203 m diameter well, in addition to an in situ density of 2,000 kg/m<sup>3</sup>.

### 3.3 POST-INTRUSION RURAL PASTURE

This scenario assumes that an individual lives near the well tailings and spreads the well tailings in his pasture and hay field. The individual obtains half of his annual intake of milk from the cow. In addition, he inhales resuspended soil and ingests small amounts of it each day. His external dose comes from spending time in or near the pasture and hay field. The radiation dose to this individual is the 50 year committed effective dose equivalent from the first year of exposure after the well was drilled.

The pasture and hay field areas are discussed in Section A4.1. The total pasture and hay field area is about 5,000 m<sup>2</sup>. This total area will be used as the averaging area. Realistically, the well tailings will not be spread in both the pasture and hay field. Only one will receive the contaminated soil. Since the two areas are about half the total, the average soil concentration would double. Thus, either the pasture grass or the stored hay would have twice the concentration, while the other crop would be uncontaminated. The net effect on the cow's milk is small. Hence, the total area will be used, and all of the cow's solid food will be contaminated based on an averaging area of 5,000 m<sup>2</sup>.

The depth of soil contaminated is 0.15 m, a traditional representation of the tilling depth. Thus the volume of soil used for the average soil concentration is 750 m<sup>3</sup>. Since the density of the surface soil is assumed to be 1,500 kg/m<sup>3</sup>, the mass of soil is 1,125 MT. When calculating the average doses, the exhumed waste is distributed over this amount of soil. Assuming a unit activity is exhumed, the average concentration in the pasture and hay field is 889 pCi/g soil.

The descriptions for the external, inhalation, and soil ingestion routes are very similar to those presented earlier for the Suburban Gardener. Instead of garden vegetables, there is a pasture and milk cow. The equations for the milk dose include the effects of decay and leaching, but do not show the method used to represent decay chains. The treatment of decay chains is presented in Appendix B.

### External and Inhalation Dose in the Rural Pasture Scenario

The external and inhalation doses are calculated using the same equations given for the suburban gardener. The external exposure time has increased to 360 h/y, and the annual soil inhalation has increased to 169 mg/y. Both of these are approximately twice the values used for the suburban gardener. Since the soil concentration is a factor of 50 smaller, the rural pasture external and inhalation doses are a factor of 25 smaller than for the suburban garden.

### Ingestion Dose in the Rural Pasture Scenario

In addition to the small amounts of soil that are ingested during the irrigation season, the pasture owner also consumes milk from his cow. The person consumes 58 L of milk during the year, which is 50% of the annual milk consumption shown in Table A4. The ingestion dose for one nuclide that results from these intakes is shown below. Note that the formula shown applies to all animal products. The rural pasture scenario only uses the milk. The other formulas will be needed when calculating lifetime intakes for the All Pathways Farmer scenario.

$$H_{G,K} = \left( C_{\text{Pasture},K} M_G F_{X,N,K} + \sum_q C_{A,q,K} M_{A,q} \right) D_{G,K}$$

where,

- $C_{A,q,K}$  = time-integrated concentration of the Kth radionuclide in animal product type q, in Ci/kg
- $C_{\text{Pasture},K}$  = average concentration of the Kth radionuclide in the soil in the pasture and hay field, in Ci/kg
- $D_{G,K}$  = ingestion dose factor for the Kth radionuclide from Table A21, in mrem/pCi ingested
- $F_{X,N,K}$  = factor that results from the time integral of the dose rate for the Kth radionuclide over the first half of the year (X=external calculation, N=the irrigation water adds no contaminants, and K=radionuclide index)
- $H_{G,K}$  = ingestion dose for the rural pasture scenario from the Kth radionuclide, mrem/y
- $M_{A,q}$  = mass of animal product type q eaten during the year, in kg/y. These amounts are shown in Table A5.
- $M_G$  = total mass of soil ingested during the irrigation season from Table A8, 0.018 kg/y
- q = index to the four types of animal products, i.e., beef, milk, poultry, and eggs

Animal products (beef, milk, poultry, and eggs) become contaminated when some portion of the animal's diet is contaminated. All of the animals modeled are assumed to ingest soil, water, and fodder. The fodder is either fresh pasture grass or stored hay and grain. The fresh pasture grass is assumed to be eaten throughout the year because animals forage during most of the year. The hay and grain are harvested at various times throughout the irrigation season, stored for a period of time and then consumed. The simplified model to represent this assumes harvest midway through the irrigation season (at 0.25 year). The plant concentrations are proportional to the soil concentration at this time. They are stored for 90 days and then consumed over a 90-day period. The ingestion dose accumulates during the consumption period.

The beef cow is slaughtered midway through the irrigation season (at 0.25 year) and consumed over a period of time ( $T_{\text{beef}}$ ). The milk and the chickens (poultry and eggs) are consumed throughout the year with little storage time. The concentration in the animal product is therefore calculated using the equations below. The animal products are divided into beef and other. "Other" refers to milk, poultry, and eggs.

$$C_{A,q,K} = B_{A,q,K} \left( C_{\text{Pasture},K} M_{S,q} F_{V,N,K,q(\text{fresh})} + \sum_p C_{V,p,K} M_{V,p,q} \right) F_{A,K,q}$$

$$C_{V,p,K} = C_{\text{Pasture},K} \left( F_{\text{DRY},p} B_{V,p,K} + \frac{J_{\text{SPLASH}} F_{\text{INT},p} F_{\text{TRANS},p} T_{W,p}}{Y_{V,p}} \right) F_{V,N,K,p}$$

$$F_{A,K,\text{Beef}} = \frac{1 - \text{Exp}(-\lambda_{R,K} T_{\text{beef}})}{\lambda_{R,K} T_{\text{beef}}} \quad \text{and} \quad F_{A,K,\text{Other}} = 1$$

$$F_{V,N,K,\text{Beef}(\text{fresh})} = \text{Exp}(-\lambda_K T_{\text{harvest}}) \quad \text{and} \quad F_{V,N,K,\text{Other}(\text{fresh})} = F_{B,N,K}$$

$$F_{V,N,K,\text{Beef}(\text{stored})} = \text{Exp}(-\lambda_K T_{\text{harvest}}) \text{Exp}(-\lambda_{R,K} T_{\text{sto}}) \quad \text{and}$$

$$F_{V,N,K,\text{Other}(\text{stored})} = \text{Exp}(-\lambda_K T_{\text{harvest}}) \text{Exp}(-\lambda_{R,K} T_{\text{sto}}) \frac{1 - \text{Exp}(-\lambda_{R,K} T_{\text{an}})}{\lambda_{R,K} T_{\text{an}}}$$

where,

- $B_{A,q,K}$  = animal transfer factor for the Kth radionuclide into animal product type q from Table A33, in day/kg
- $B_{V,p,K}$  = soil-to-plant transfer factor for the Kth radionuclide in animal fodder type p from Table A37
- $C_{A,q,K}$  = time-integrated concentration of the Kth radionuclide in animal product type q, in Ci/kg
- $C_{\text{Pasture},K}$  = average concentration of the Kth radionuclide in the soil in the pasture and hay field, in Ci/kg
- $C_{V,p,K}$  = time-integrated radionuclide concentration in animal fodder of type p, in Ci/kg wet weight
- $F_{B,N,K}$  = factor that results from the time integral of the inhalation dose rate for the Kth radionuclide over the full year (B=inhalation calculation, N=the irrigation water adds no contaminants, and K=radionuclide index)
- $F_{\text{DRY},p}$  = dry-to-wet ratio for animal fodder type p from Table A39
- $F_{\text{INT},p}$  = interception fraction for airborne dust on exposed surfaces of animal fodder type p, from Table A39
- $F_{\text{TRANS},p}$  = translocation factor from exposed surfaces to the edible portion of animal fodder type p, from Table A39
- $F_{V,N,K,p}$  = factor that results from the time integral of the daily dose from milk due to the cow's consumption of animal fodder type p for the Kth radionuclide (V=animal fodder calculation, N=the irrigation water adds no contaminants, K=radionuclide index, and p= plant index). Specific cases are shown for fresh pasture grass and stored feed (i.e. hay and grain).
- $J_{\text{SPLASH}}$  = average soil deposition rate due to rain splash (see Section A5.2),  $2.7 \times 10^{-4}$  kg/m<sup>2</sup> per day

- $M_{S,q}$  = daily mass of soil ingested by animal type q in Table A32, in kg/d  
 $M_{V,p,q}$  = daily mass of animal fodder type p eaten by animal type q, in kg (wet)/d. These amounts are shown in Table A32.  
 p = index to the types of animal fodder, fresh pasture grass and stored hay and grain for beef, milk, poultry and eggs  
 $T_{an}$  = consumption period for the animal fodder, 90 d (0.2466 y)  
 $T_{beef}$  = consumption period for beef, 120 d (0.3288 y)  
 $T_{harvest}$  = time at which harvest occurs, 0.25 y (midway through the irrigation season)  
 $T_{irr}$  = irrigation period (the 1<sup>st</sup> half of the year), 0.5 y  
 $T_{sto}$  = storage period for stored fodder, 90 d (0.2466 y)  
 $T_{W,p}$  = effective exposure time for garden produce type p, days. Calculated values are listed in Table B1.  
 $Y_{V,p}$  = yield of garden produce type p, from Table A39, in kg(wet)/m<sup>2</sup>  
 $\lambda_K$  = total removal constant for the Kth radionuclide, per year,  $\lambda_K = \lambda_{S,K} + \lambda_{R,K}$   
 $\lambda_{R,K}$  = radioactive decay constant for the Kth radionuclide, per year. These are calculated as  $\ln(2)=0.6931472$  divided by the material half life (in years).  
 $\lambda_{S,K}$  = average soil leaching coefficient for the Kth radionuclide, fraction removed from the surface layer of soil, per year (see Table A40)

The concentration of tritium in animal products is calculated from an equilibrium model. The concentration of tritium in the animal is based on the assumption that the ratio of contaminated water in the animal product to total water in the animal product is proportional to the ratio of contaminated water in the animal's diet to the total water in the diet. The formula below reflects this. The first four terms in the first equation calculate the tritium concentration in the animal product, just as was done for garden produce. The mass ratio adjusts this concentration for the fraction of the animal's diet that is contaminated. The time-integration factors are the same as shown above.

$$C_{A,q,H-3} = C_{Pasture,H-3} \left( \frac{\rho_{Pasture}}{\theta \rho_W} \right) \left( \frac{8.94 \text{ kg water}}{\text{kg hydrogen}} \right) F_{H,q} \left( \frac{M_{W,C,q}}{M_{W,T,q}} \right) F_{A,H-3,q}$$

$$M_{W,C,q} = \left( \frac{\theta \rho_W}{\rho_{Pasture}} \right) M_{S,q} F_{V,N,H-3,q}(\text{fresh}) + \sum_p \left( \frac{8.94 \text{ kg water}}{\text{kg hydrogen}} \right) F_{H,p} F_{V,N,H-3,p} M_{V,p,q}$$

$$M_{W,T,q} = \left( \frac{\theta \rho_W}{\rho_{Pasture}} \right) M_{S,q} + \sum_p \left( \frac{8.94 \text{ kg water}}{\text{kg hydrogen}} \right) F_{H,p} M_{V,p,q} + \rho_W V_{W,q}$$

where,

- $C_{A,q,H-3}$  = time-integrated tritium concentration in animal product type q, in Ci/kg  
 $C_{Pasture,K}$  = average concentration of the Kth radionuclide in the pasture and hay field, in Ci/kg  
 $F_{A,H-3,q}$  = factor that results from the time integral of the dose rate for tritium over the full year (A=animal calculation, H-3=tritium, and q=animal type).  
 $F_{H,p}$  = mass fraction of hydrogen in animal fodder type p from Table A34, in kg hydrogen per kg plant (wet)

- $F_{H,q}$  = mass fraction of hydrogen in animal product type q from Table A34, in kg hydrogen per kg of the animal product  
 $F_{V,N,H-3,p}$  = factor that results from the time integral of the daily dose from animal products for tritium (V=garden produce calculation, N=the irrigation water adds no contaminants, H-3=tritium, and p= plant index).  
 $M_{S,q}$  = daily mass of soil ingested by animal type q in Table A32, in kg/d  
 $M_{V,p,q}$  = daily mass of animal fodder type p eaten by animal type q, in kg (wet)/d. These amounts are shown in Table A32.  
 $M_{W,C,q}$  = mass of contaminated water ingested daily by the animal, in kg/d  
 $M_{W,T,q}$  = total mass of water ingested daily by the animal, in kg/d  
p = index to the types of animal fodder, i.e., fresh pasture grass and stored hay and grain for beef, milk, poultry, and eggs  
q = index to the four types of animal products, i.e., meat, milk, poultry, and eggs  
 $V_{W,q}$  = daily volume of water ingested by animal type q from Table A32, in L/d  
 $\rho_{\text{Pasture}}$  = average density of the soil in the pasture and hay field, 1.5 kg soil per liter of soil  
 $\rho_w$  = density of water, 1.0 kg water per liter of water  
 $\theta$  = volumetric water content of the surface soil, liters of water per liter of soil. A value of 0.2 is assumed.

Note that the equation for the concentration of tritium in the animal product can be rearranged to indicate an equilibrium concentration ratio for tritium in the animal product. This equation has the same form as the equation used for all the other radionuclides. The equilibrium transfer factor is calculated from the tritium equilibrium model.

$$C_{A,q,H-3} = B_{A,q,H-3} \left( C_{\text{Pasture},H-3} M_{S,q} F_{V,N,H-3,q(\text{fresh})} + \sum_p C_{V,p,H-3} M_{V,p} \right) F_{A,H-3,q}$$

$$B_{A,q,H-3} = \left( \frac{8.94 \text{ kg water}}{\text{kg hydrogen}} \right) \left( \frac{F_{H,q}}{M_{W,T,q}} \right)$$

$$C_{V,p,H-3} = C_{\text{Pasture},H-3} \left( \frac{\rho_{\text{Pasture}}}{\theta \rho_w} \right) \left( \frac{8.94 \text{ kg water}}{\text{kg hydrogen}} \right) F_{H,p} F_{V,N,H-3,p}$$

#### Dermal Absorption Dose in the Rural Pasture Scenario

The absorption of material on the skin into the body is shown to be a minor contributor for radionuclides in Section A3.4.1. In this section, the dose from radionuclides absorbed through the skin is compared with the soil ingestion dose. The dose from dermal absorption is not calculated for radionuclides.

#### Total Dose in the Rural Pasture Scenario

Scenario dose factors from the rural pasture scenario are presented in Table 10 as the dose received during the first year per curie that is exhumed. These unit dose factors must be multiplied by the activity exhumed to calculate the first year dose. The radiation dose to this individual is the 50 year committed effective dose equivalent from one year of exposure.

The internal doses must be reduced in the event that the chemical form of the waste at the time of intrusion allows only a fraction of the material to be inhaled, ingested, or absorbed by plants. An example of this is vitrified waste material. After site closure, the radionuclides are decaying and the waste is releasing trapped activity. Thus, the tailings activity concentration and the fraction available depend on the elapsed time since closure. The external dose will be delivered regardless of the waste form. The total dose to the rural resident with a cow can be written as shown below.

$$H_{RURAL} = \sum_K [H_{X,K} + F_{AVAIL} (H_{B,K} + H_{G,K})]$$

where,

- $F_{AVAIL}$  = fraction of the waste that is available for ingestion, inhalation, and absorption by plants at the time of rural pasture scenario exposures (Table 10 assumes  $F_{AVAIL}=1$  in the “Total” columns)
- $H_{RURAL}$  = total effective dose equivalent received in the rural pasture scenario from all radionuclides in the exhumed waste material, in mrem/y
- $H_{B,K}$  = inhalation dose to the rural pasture scenario from the Kth radionuclide, in mrem/y
- $H_{G,K}$  = ingestion dose to the rural pasture scenario from the Kth radionuclide, in mrem/y
- $H_{X,K}$  = external dose to the rural pasture scenario from the Kth radionuclide, in mrem/y

The scenario dose factors for the rural pasture assume that 1 Ci of each isotope comes out of the well. Values listed in Table 10 are separated into the external component and the internal component. The column labeled “Total” is the sum of the internal and external in the event that 100% of the exhumed waste is available for inhalation and ingestion. Additional detail on the doses by pathway is shown in Appendix D.

**Table 10. Unit Dose Factors for the Rural Pasture Scenario (mrem/y per Ci exhumed)**

Nuclide	Total	External	Internal	Nuclide	Total	External	Internal
H-3	1.33E-01	0.00E+00	1.33E-01	Gd-152	3.92E+01	0.00E+00	3.92E+01
Be-10	1.67E-01	3.86E-02	1.28E-01	Ho-166m	3.34E+02	3.34E+02	2.54E-01
C-14	1.36E+01	4.83E-04	1.36E+01	Re-187	1.71E-02	0.00E+00	1.71E-02
Na-22	4.50E+02	4.03E+02	4.74E+01	Tl-204	5.04E-01	1.40E-01	3.64E-01
Al-26	5.28E+02	5.27E+02	3.84E-01	Pb-205	4.96E-02	2.58E-04	4.94E-02
Si-32+D	8.06E-01	4.09E-01	3.97E-01	Pb-210+D	1.90E+02	2.15E-01	1.89E+02
Cl-36	2.66E+03	7.58E-02	2.66E+03	Bi-207	2.95E+02	2.94E+02	2.91E-01
K-40	1.42E+02	3.08E+01	1.11E+02	Po-209	7.95E+01	6.43E-01	7.88E+01
Ca-41	1.00E+01	0.00E+00	1.00E+01	Po-210	3.47E+01	1.09E-03	3.47E+01
Ti-44+D	4.44E+02	4.30E+02	1.32E+01	Ra-226+D	5.14E+02	3.44E+02	1.70E+02
V-49	9.00E-04	0.00E+00	9.00E-04	Ra-228+D	3.88E+02	2.08E+02	1.80E+02
Mn-54	1.34E+02	1.34E+02	6.87E-02	Ac-227+D	5.76E+02	6.86E+01	5.07E+02
Fe-55	1.01E-02	0.00E+00	1.01E-02	Th-228+D	3.32E+02	2.77E+02	5.51E+01
Fe-60+D	1.95E+01	1.66E+01	2.84E+00	Th-229+D	3.80E+02	5.36E+01	3.27E+02
Co-60	4.80E+02	4.78E+02	2.00E+00	Th-230	4.84E+01	8.08E-02	4.83E+01

**Table 10. Unit Dose Factors for the Rural Pasture Scenario (mrem/y per Ci exhumed)**

Nuclide	Total	External	Internal	Nuclide	Total	External	Internal
Ni-59	3.23E-01	0.00E+00	3.23E-01	Th-232	2.34E+02	6.11E+00	2.28E+02
Ni-63	8.83E-01	0.00E+00	8.83E-01	Pa-231	3.78E+02	7.11E+00	3.71E+02
Se-79	2.36E+00	6.45E-04	2.36E+00	U-232	8.51E+01	2.55E+01	5.96E+01
Rb-87	4.70E+01	5.12E-03	4.69E+01	U-233	1.19E+01	4.99E-02	1.19E+01
Sr-90+D	9.66E+02	8.37E-01	9.65E+02	U-234	1.16E+01	1.44E-02	1.16E+01
Zr-93	3.92E-02	4.05E-05	3.92E-02	U-235+D	3.74E+01	2.65E+01	1.09E+01
Nb-91	4.22E-01	4.13E-01	8.84E-03	U-236	1.10E+01	7.66E-03	1.10E+01
Nb-93m	1.25E-02	3.76E-03	8.74E-03	U-238+D	1.51E+01	4.16E+00	1.09E+01
Nb-94	3.09E+02	3.09E+02	1.20E-01	Np-237+D	1.91E+02	3.78E+01	1.53E+02
Mo-93	1.65E+00	2.13E-02	1.63E+00	Pu-236	3.73E+01	4.95E-02	3.73E+01
Tc-99	2.54E+01	4.34E-03	2.54E+01	Pu-238	1.10E+02	5.50E-03	1.10E+02
Ru-106+D	3.60E+01	3.56E+01	3.97E-01	Pu-239	1.21E+02	1.04E-02	1.21E+02
Pd-107	2.45E-01	0.00E+00	2.45E-01	Pu-240	1.21E+02	5.35E-03	1.21E+02
Ag-108m+D	3.14E+02	3.14E+02	1.49E-01	Pu-241+D	2.37E+00	1.30E-03	2.37E+00
Cd-109	5.22E+00	4.70E-01	4.76E+00	Pu-242	1.16E+02	4.67E-03	1.16E+02
Cd-113m	7.59E+01	2.30E-02	7.59E+01	Pu-244+D	1.79E+02	6.51E+01	1.14E+02
In-115	3.91E+00	1.45E-02	3.89E+00	Am-241	1.27E+02	1.60E+00	1.25E+02
Sn-121m+D	2.72E-01	7.68E-02	1.95E-01	Am-242m+D	1.24E+02	2.36E+00	1.22E+02
Sn-126+D	3.88E+02	3.86E+02	1.83E+00	Am-243+D	1.56E+02	3.18E+01	1.24E+02
Sb-125	7.59E+01	7.58E+01	8.21E-02	Cm-242	2.88E+00	4.31E-03	2.88E+00
Te-125m	2.70E-01	2.24E-01	4.59E-02	Cm-243	1.08E+02	2.05E+01	8.79E+01
I-129	2.23E+02	4.70E-01	2.22E+02	Cm-244	7.05E+01	4.56E-03	7.05E+01
Cs-134	4.70E+02	2.81E+02	1.89E+02	Cm-245	1.44E+02	1.23E+01	1.32E+02
Cs-135	2.19E+01	1.40E-03	2.19E+01	Cm-246	1.31E+02	4.24E-03	1.31E+02
Cs-137+D	2.62E+02	1.10E+02	1.53E+02	Cm-247+D	1.83E+02	6.29E+01	1.20E+02
Ba-133	6.65E+01	6.62E+01	3.08E-01	Cm-248	4.79E+02	3.20E-03	4.79E+02
Pm-147	2.36E-02	1.71E-03	2.19E-02	Cm-250+D	2.79E+03	6.16E+01	2.73E+03
Sm-147	1.44E+01	0.00E+00	1.44E+01	Bk-247	1.77E+02	1.54E+01	1.62E+02
Sm-151	1.12E-02	3.58E-05	1.11E-02	Cf-248	9.99E+00	3.82E-03	9.98E+00
Eu-150	2.84E+02	2.84E+02	1.48E-01	Cf-249	2.25E+02	6.27E+01	1.63E+02
Eu-152	2.17E+02	2.17E+02	1.42E-01	Cf-250	7.20E+01	4.27E-03	7.20E+01
Eu-154	2.36E+02	2.36E+02	2.01E-01	Cf-251	1.85E+02	1.89E+01	1.66E+02
Eu-155	6.44E+00	6.41E+00	3.09E-02	Cf-252	3.43E+01	6.01E-03	3.43E+01

## Notes:

- The radiation dose to this individual is the 50 year committed effective dose equivalent from the first year of exposure.
- These scenario dose factors must be multiplied by the activity exhumed by the well drilling, in curies.
- The "Total" column is the sum of the "Internal" and "External" columns. External and internal doses are separated because the waste matrix may prevent a portion of the exhumed activity from giving an internal dose.

**3.4 POST-INTRUSION COMMERCIAL FARM**

This scenario assumes that an individual lives near the well tailings and spreads the well tailings in a field used for growing a food crop for market. The individual inhales resuspended

soil and ingests small amounts of it each day. His external dose comes from spending time in or near the field. The radiation dose to this individual is the 50 year committed effective dose equivalent from the first year of exposure after the well was drilled.

The field is assumed to have an area of 160 acres, or 647,000 m<sup>2</sup>. This total area will be used as the averaging area. The depth of soil contaminated is 0.15 m, a traditional representation of the tilling depth. Thus the volume of soil used for the average soil concentration is 97,000 m<sup>3</sup>. Since the density of the surface soil is assumed to be 1,500 kg/m<sup>3</sup>, the mass of soil is 146,000 MT. When calculating the average doses, the exhumed waste is distributed over this amount of soil. Assuming a unit activity is exhumed, the average concentration in the field is 6.87 pCi/g soil.

#### External, Inhalation, and Ingestion Dose

The external and inhalation doses are calculated using the same equations given for the suburban gardener. The external exposure time has increased to 8 h/d or 1,440 h/y, and the annual soil inhalation has increased to 321 mg/y. Both of these are approximately four times larger than the values used for the suburban gardener. Since the soil concentration is a factor of 6,470 smaller, the commercial farm external and inhalation doses are a factor of 1,620 smaller than for the suburban garden.

The only item ingested is trace amounts of soil. The usual exposure of 100 mg/d for 180 days is assumed. Thus, the annual ingestion of contaminated soil is 18 g. This is the same as used in the suburban garden and rural pasture scenarios. Hence, the ingestion dose is lower than the suburban garden dose by a factor of 6,470.

Dermal absorption of radionuclides is not considered, based on the discussion in Section A3.4.1.

#### Total Dose in the Commercial farm Scenario

Scenario dose factors from the commercial farm scenario are presented in Table 11 as the dose received during the first year per curie that is exhumed. These unit dose factors must be multiplied by the activity exhumed to calculate the first year dose. The radiation dose to this individual is the 50 year committed effective dose equivalent from one year of exposure.

The internal doses must be reduced in the event that the chemical form of the waste at the time of intrusion allows only a fraction of the material to be inhaled, ingested, or absorbed by plants. An example of this is vitrified waste material. After site closure, the radionuclides are decaying and the waste is releasing trapped activity. Thus, the tailings activity concentration and the fraction available depend on the elapsed time since closure. The external dose will be delivered regardless of the waste form. The total dose to the rural resident with a cow can be written as shown below.

$$H_{\text{FARM}} = \sum_K [H_{X,K} + F_{\text{AVAIL}} (H_{B,K} + H_{G,K})]$$

where,

- $F_{AVAIL}$  = fraction of the waste that is available for ingestion, inhalation, and absorption by plants at the time of commercial farm scenario exposures (Table 11 assumes  $F_{AVAIL}=1$  in the “Total” columns)
- $H_{FARM}$  = total effective dose equivalent received in the commercial farm scenario from all radionuclides in the exhumed waste material, in mrem/y
- $H_{B,K}$  = inhalation dose to the commercial farm scenario from the Kth radionuclide, in mrem/y
- $H_{G,K}$  = ingestion dose to the commercial farm scenario from the Kth radionuclide, in mrem/y
- $H_{X,K}$  = external dose to the commercial farm scenario from the Kth radionuclide, in mrem/y

The scenario dose factors for the commercial farm assume that 1 Ci of each isotope comes out of the well. Values listed in Table 11 are separated into the external component and the internal component. The column labeled “Total” is the sum of the internal and external in the event that 100% of the exhumed waste is available for inhalation and ingestion.

**Table 11. Unit Dose Factors for the Commercial Farm Scenario (mrem/y per Ci exhumed)**

Nuclide	Total	External	Internal	Nuclide	Total	External	Internal
H-3	1.89E-03	0.00E+00	1.89E-03	Gd-152	5.56E-01	0.00E+00	5.56E-01
Be-10	1.95E-03	5.97E-04	1.36E-03	Ho-166m	5.16E+00	5.16E+00	2.70E-03
C-14	2.66E-04	7.47E-06	2.59E-04	Re-187	1.29E-06	0.00E+00	1.29E-06
Na-22	6.23E+00	6.22E+00	1.34E-03	Tl-204	2.57E-03	2.17E-03	4.02E-04
Al-26	8.15E+00	8.15E+00	1.83E-03	Pb-205	2.14E-04	3.98E-06	2.10E-04
Si-32+D	9.93E-03	6.32E-03	3.61E-03	Pb-210+D	7.82E-01	3.32E-03	7.79E-01
Cl-36	1.55E-03	1.17E-03	3.82E-04	Bi-207	4.55E+00	4.55E+00	7.17E-04
K-40	4.79E-01	4.77E-01	2.30E-03	Po-209	3.26E-01	9.94E-03	3.16E-01
Ca-41	1.58E-04	0.00E+00	1.58E-04	Po-210	1.63E-01	1.69E-05	1.63E-01
Ti-44+D	6.66E+00	6.65E+00	4.02E-03	Ra-226+D	5.51E+00	5.32E+00	1.90E-01
V-49	6.87E-06	0.00E+00	6.87E-06	Ra-228+D	3.53E+00	3.22E+00	3.08E-01
Mn-54	2.08E+00	2.08E+00	2.92E-04	Ac-227+D	6.65E+00	1.06E+00	5.59E+00
Fe-55	7.31E-05	0.00E+00	7.31E-05	Th-228+D	5.00E+00	4.27E+00	7.24E-01
Fe-60+D	2.76E-01	2.57E-01	1.96E-02	Th-229+D	5.16E+00	8.29E-01	4.33E+00
Co-60	7.39E+00	7.39E+00	3.28E-03	Th-230	6.47E-01	1.25E-03	6.46E-01
Ni-59	2.80E-05	0.00E+00	2.80E-05	Th-232	2.98E+00	9.44E-02	2.88E+00
Ni-63	7.63E-05	0.00E+00	7.63E-05	Pa-231	4.32E+00	1.10E-01	4.21E+00
Se-79	1.04E-03	9.98E-06	1.03E-03	U-232	7.13E-01	3.95E-01	3.18E-01
Rb-87	6.93E-04	7.92E-05	6.14E-04	U-233	5.34E-02	7.71E-04	5.26E-02
Sr-90+D	3.23E-02	1.29E-02	1.93E-02	U-234	5.17E-02	2.22E-04	5.14E-02
Zr-93	3.90E-04	6.26E-07	3.90E-04	U-235+D	4.58E-01	4.10E-01	4.82E-02
Nb-91	6.45E-03	6.38E-03	7.16E-05	U-236	4.89E-02	1.18E-04	4.88E-02
Nb-93m	1.29E-04	5.81E-05	7.07E-05	U-238+D	1.12E-01	6.43E-02	4.78E-02
Nb-94	4.77E+00	4.77E+00	9.62E-04	Np-237+D	2.31E+00	5.85E-01	1.73E+00
Mo-93	5.55E-04	3.28E-04	2.27E-04	Pu-236	4.22E-01	7.65E-04	4.22E-01
Tc-99	2.56E-04	6.71E-05	1.88E-04	Pu-238	1.26E+00	8.50E-05	1.26E+00
Ru-106+D	5.53E-01	5.50E-01	3.06E-03	Pu-239	1.38E+00	1.60E-04	1.38E+00
Pd-107	4.65E-05	0.00E+00	4.65E-05	Pu-240	1.38E+00	8.27E-05	1.38E+00

**Table 11. Unit Dose Factors for the Commercial Farm Scenario (mrem/y per Ci exhumed)**

Nuclide	Total	External	Internal	Nuclide	Total	External	Internal
Ag-108m+D	4.85E+00	4.85E+00	9.95E-04	Pu-241+D	2.71E-02	2.00E-05	2.71E-02
Cd-109	8.87E-03	7.26E-03	1.61E-03	Pu-242	1.32E+00	7.22E-05	1.32E+00
Cd-113m	2.33E-02	3.56E-04	2.29E-02	Pu-244+D	2.31E+00	1.01E+00	1.30E+00
In-115	2.80E-02	2.24E-04	2.78E-02	Am-241	1.45E+00	2.47E-02	1.43E+00
Sn-121m+D	1.49E-03	1.19E-03	3.03E-04	Am-242m+D	1.43E+00	3.65E-02	1.39E+00
Sn-126+D	5.97E+00	5.96E+00	2.82E-03	Am-243+D	1.91E+00	4.92E-01	1.42E+00
Sb-125	1.17E+00	1.17E+00	4.12E-04	Cm-242	3.21E-02	6.66E-05	3.20E-02
Te-125m	3.66E-03	3.47E-03	1.88E-04	Cm-243	1.29E+00	3.16E-01	9.77E-01
I-129	4.15E-02	7.26E-03	3.43E-02	Cm-244	7.84E-01	7.04E-05	7.84E-01
Cs-134	4.35E+00	4.34E+00	8.43E-03	Cm-245	1.66E+00	1.90E-01	1.47E+00
Cs-135	9.06E-04	2.16E-05	8.84E-04	Cm-246	1.45E+00	6.55E-05	1.45E+00
Cs-137+D	1.70E+00	1.69E+00	6.22E-03	Cm-247+D	2.31E+00	9.73E-01	1.34E+00
Ba-133	1.02E+00	1.02E+00	4.29E-04	Cm-248	5.32E+00	4.95E-05	5.32E+00
Pm-147	2.24E-04	2.64E-05	1.98E-04	Cm-250+D	3.13E+01	9.51E-01	3.03E+01
Sm-147	1.87E-01	0.00E+00	1.87E-01	Bk-247	2.08E+00	2.38E-01	1.85E+00
Sm-151	1.14E-04	5.54E-07	1.14E-04	Cf-248	1.13E-01	5.91E-05	1.13E-01
Eu-150	4.39E+00	4.38E+00	1.37E-03	Cf-249	2.82E+00	9.69E-01	1.86E+00
Eu-152	3.35E+00	3.35E+00	1.27E-03	Cf-250	8.23E-01	6.60E-05	8.22E-01
Eu-154	3.64E+00	3.64E+00	1.76E-03	Cf-251	2.19E+00	2.91E-01	1.90E+00
Eu-155	9.94E-02	9.91E-02	2.67E-04	Cf-252	3.91E-01	9.29E-05	3.91E-01

## Notes:

- The radiation dose to this individual is the 50 year committed effective dose equivalent from the first year of exposure.
- These scenario dose factors must be multiplied by the activity exhumed by the well drilling, in curies.
- The "Total" column is the sum of the "Internal" and "External" columns. External and internal doses are separated because the waste matrix may prevent a portion of the exhumed activity from giving an internal dose.

**3.5 ALL PATHWAYS FARMER**

This scenario assumes that some of the waste materials have migrated into the ground water. A subsistence farm located down gradient from the disposal site uses ground water for domestic needs (drinking, cooking, showering), for irrigation (garden and pasture), and for watering livestock. The individual obtains one-fourth of his fruit and vegetable intake each year from a garden, and half of his meat, milk, poultry, and egg intake from his livestock. In addition, he inhales resuspended garden soil and ingests small amounts of it each day. His external dose comes from the contaminated soil near his dwelling. The radiation dose to this individual is the 50 year committed effective dose equivalent from one year of exposure. No prior irrigation is assumed. Thus, the calculated annual doses are the lifetime dose that results from exposure during the first year of irrigation with contaminated water.

The number of equations presented in this section is very large. It includes the pathways used for the post-intrusion residents. The equations are modified to reflect the contaminated irrigation water source. An additional version of this scenario assumes the contaminated water

comes from the Columbia River and adds doses from shoreline external exposure and fish. Finally, the increased cancer risks that result from 30 years of continuous exposure are calculated. The various exposure amounts and other parameters are presented in Appendix A.

#### Soil Concentration for the All Pathways Farmer

The garden and pasture are contaminated by the application of irrigation water. The contamination is averaged over the tilling depth, 0.15 m. The land surface area that is contaminated does not enter into the dose calculations. The important quantity is the amount that accumulates in the area that is irrigated, both the rate of deposition and the total deposited. The soil concentration is summarized in the equations below. Decay and leaching factors have been omitted from the soil concentration equation because they are included separately in the dose equations.

$$ID_K = \left( \frac{C_{W,K} I}{T_{irr}} \right) \left( \frac{10 L}{m^2 cm} \right)$$

$$C_{S,K} = \left( \frac{C_{W,K} I}{L_{Garden} \rho_{Garden}} \right) \left( \frac{10 L}{m^2 cm} \right)$$

where,

$10 L/m^2 cm$  = unit conversion factor. When 10 L of water is spread over an area of  $1 m^2$ , it will have a depth of 1 cm.

$C_{S,K}$  = concentration of the Kth radionuclide in irrigated soil at the end of the year with no decay or leaching, in Ci/kg

$C_{W,K}$  = concentration of the Kth radionuclide in the irrigation water, in Ci/L

$L_{Garden}$  = thickness of the contaminated layer of surface soil in the garden, 0.15 m

$I$  = amount of irrigation water applied to plants during the irrigation season, cm. For the Columbia River population, this is 63.5 cm. For all other scenarios this is 82.3 cm. (see Section A6.0)

$ID_K$  = irrigation deposition rate for the Kth radionuclide during the irrigation season,  $Ci/m^2$  per year

$T_{irr}$  = length of irrigation season, 0.5 y

$\rho_{Garden}$  = average density of the surface soil,  $1,500 kg/m^3$

The concentration of tritium in the soil is based on the water content of the surface soil layer. Thus, the tritium concentration in the soil is constant during the irrigation season and decreases rapidly after that due to evaporation. Section A6.2 discusses the soil removal constants for tritium. The concentration of tritium in the soil during the irrigation season is shown below. The final ratio in the formula includes the dilution from natural precipitation.

$$C_{S,H-3} = C_{W,H-3} \left( \frac{\theta}{\rho_{Garden}} \right) \left( \frac{I}{I + P} \right)$$

where,

$C_{S,H-3}$  = concentration of tritium in irrigated soil during the irrigation season, in Ci/kg

$C_{W,H-3}$  = tritium concentration in the irrigation water, in Ci/L

- I = total irrigation water applied during the irrigation season, in cm. For the all pathways farmer it is 82.3 cm (32.4 inches). Nearly all of this is deposited during the 6 month period from April to September.
- P = total precipitation, in centimeters, during the irrigation period. Over the period 1971 to 2000, the precipitation during the 6 month irrigation season (April to September) has been 5.766 cm (PNNL-13859).
- $\rho_{\text{Garden}}$  = average density of the surface soil, 1.5 kg soil per liter of soil
- $\theta$  = volumetric water content of the surface soil, liters of water per liter of soil. A value of 0.2 is assumed. Because the total soil porosity is about 0.4, the saturation ratio is about 50%.

During the year, the concentration of each isotope in the garden and pasture first increases due to irrigation deposition, then decreases due to radioactive decay. The first half of the year the soil is irrigated, so both processes are in effect. The second half of the year the soil is not irrigated, so only radioactive decay occurs. This is represented mathematically using the formulas below.

$$C_{\text{Soil,K}}(t) = C_{\text{S,K}} \frac{1 - \text{Exp}(-\lambda_{\text{K}} t)}{\lambda_{\text{K}} t} \quad \text{for } 0 < t < T_{\text{irr}}$$

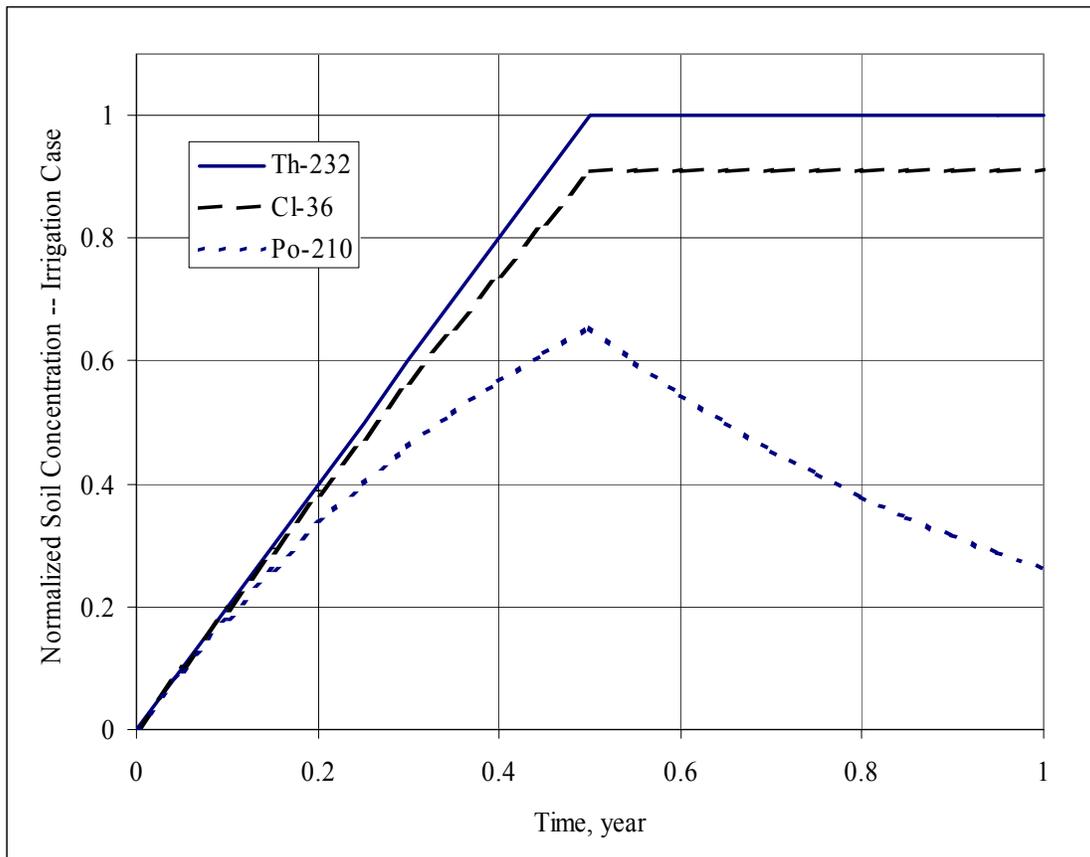
$$C_{\text{Soil,K}}(t) = C_{\text{S,K}} \frac{1 - \text{Exp}(-\lambda_{\text{K}} T_{\text{irr}})}{\lambda_{\text{K}} T_{\text{irr}}} \text{Exp}(-\lambda_{\text{R,K}} t) \quad \text{for } T_{\text{irr}} < t < 1 \text{ y}$$

where,

- $C_{\text{S,K}}$  = concentration of the Kth radionuclide in irrigated soil at the end of the year with no decay or leaching, in Ci/kg
- $C_{\text{Soil,K}}(t)$  = concentration of the Kth radionuclide in irrigated soil as a function of time (t) during the year, in Ci/kg.
- Exp = the exponential function (e raised to some power)
- $T_{\text{irr}}$  = irrigation period (the 1<sup>st</sup> half of the year), 0.5 y
- $\lambda_{\text{K}}$  = total removal constant for the Kth radionuclide, per year,  $\lambda_{\text{K}} = \lambda_{\text{S,K}} + \lambda_{\text{R,K}}$
- $\lambda_{\text{R,K}}$  = radioactive decay constant for the Kth radionuclide, per year. These are calculated as  $\ln(2)=0.6931472$  divided by the material half life (in years).
- $\lambda_{\text{S,K}}$  = average soil leaching coefficient for the Kth radionuclide, fraction removed from the surface layer of soil, per year (see Table A40)

The soil concentration as a function of time for three radionuclides is shown in Figure 2. The soil concentration is normalized by the end-of-year soil concentration in the absence of decay and leaching ( $C_{\text{S,K}}$ ). The first isotope (Th-232) illustrates the case with little decay and little leaching. Th-232 has a very long half life ( $1.405 \times 10^{10}$  years) and a very large retardation in the surface soil ( $K_d=600,000$  ml/g). The Th-232 concentration increases linearly during the irrigation season and is constant the remainder of the year. The second isotope (Cl-36) has a long half life (300,992 years) but is only slightly retarded in the soil ( $K_d=1.0$  ml/g). The Cl-36 concentration increases during the irrigation season, but not as much as Th-232 due to the loss from leaching. The Cl-36 concentration is constant during the non-irrigation season. The third isotope (Po-210) has a very short half life (138.38 days) but is significantly retarded in the soil

( $K_d=1,100$  ml/g). The loss of Po-210 from the surface layer during the year is due almost entirely to its radioactive decay.



**Figure 2. Fraction of Irrigation-Deposited Contamination Present in Surface Soil.**

#### External Dose to the All Pathways Farmer

The external dose received by the farmer is larger every day during the irrigation season due to the increase in soil concentration that is occurring. During the non-irrigation season the dose rate decreases slowly because the soil contamination is undergoing radioactive decay without leaching. Note that the effective external exposure time is greater than the previous scenario because the contamination is more widespread. In addition, the exposure is spread uniformly throughout the year. Section A3.3 discusses external exposure times. The external dose is calculated using the equation shown below. The decay and leaching factor ( $F_{X,I,K}$ ) is the time-integral of the soil concentration fraction shown in Figure 2. The formula has two parts corresponding to the irrigation and non-irrigation seasons. The first part of the formula is the time integral during the irrigation period. The second part is the product of the factor representing soil concentration at the end of the irrigation period and the time integral during the non-irrigation period.

$$H_{X,K} = C_{S,K} \rho_{\text{GARDEN}} L_{\text{GARDEN}} D_{X,K} T_X F_{X,I,K}$$

$$F_{X,I,K} = \frac{\lambda_K T_{\text{irr}} - 1 + \text{Exp}(-\lambda_K T_{\text{irr}})}{(1 \text{ y}) \lambda_K^2 T_{\text{irr}}} + \left( \frac{1 - \text{Exp}(-\lambda_K T_{\text{irr}})}{\lambda_K T_{\text{irr}}} \right) \left( \frac{1 - \text{Exp}(-\lambda_{R,K} T_{\text{no}})}{(1 \text{ y}) \lambda_{R,K}} \right)$$

where,

- $C_{S,K}$  = concentration of the Kth radionuclide in irrigated soil at the end of the year with no decay or leaching, in Ci/kg
- $D_{X,K}$  = external dose rate factor for the Kth radionuclide to a person standing on a layer 0.15 m thick and of great extent in all directions, in mrem/h per Ci/m<sup>2</sup>. Values are listed in Table A25.
- $F_{X,I,K}$  = factor that results from the time integral of the dose rate for the Kth radionuclide over the full year (X=external calculation, I=the irrigation water is contaminated, and K=radionuclide index). If  $\lambda_K$  is very small,  $F_{X,I,K}=0.75$ .
- $H_{X,K}$  = external dose to the all pathways farmer from the Kth radionuclide, mrem/y
- $L_{\text{GARDEN}}$  = thickness of the contaminated layer of surface soil in the garden, 0.15 m
- $T_{\text{irr}}$  = irrigation period (the 1<sup>st</sup> half of the year), 0.5 y
- $T_{\text{no}}$  = no irrigation period (the 2<sup>nd</sup> half of the year),  $T_{\text{irr}} + T_{\text{no}} = 1 \text{ y}$
- $T_X$  = time of exposure each year from Table A15, 4,120 h/y
- $\lambda_K$  = total removal constant for the Kth radionuclide, per year,  $\lambda_K = \lambda_{S,K} + \lambda_{R,K}$
- $\lambda_{R,K}$  = radioactive decay constant for the Kth radionuclide, per year. These are calculated as  $\ln(2)=0.6931472$  divided by the material half life (in years).
- $\lambda_{S,K}$  = average soil leaching coefficient for the Kth radionuclide, fraction removed from the surface layer of soil, per year (see Table A40)
- $\rho_{\text{GARDEN}}$  = average density of the garden, 1,500 kg/m<sup>3</sup>

#### Inhalation Dose to the All Pathways Farmer

The gardener is exposed to airborne particulate during the year, as described in Section A.3.2. Some of the material inhaled is contaminated soil (539 mg/y from Table A10) while the rest is from the water becoming airborne (0.054 L/y from Table A13). The inhalation intakes occur over the course of one year. The concentration of radionuclides in the suspended particulate is assumed to be the same as the average concentration of radionuclides in the soil. The total inhalation dose to the farmer is calculated using the formula below. Tritium is not calculated using this formula. Since the tritium is in the form of tritiated water (HTO), the water inhalation calculation for tritium includes all soil contributions.

$$H_{B,K} = (C_{S,K} M_B F_{X,I,K} + C_{W,K} V_B) D_{B,K}$$

where,

- $C_{S,K}$  = concentration of the Kth radionuclide in irrigated soil at the end of the year with no decay or leaching, in Ci/kg
- $C_{W,K}$  = concentration of the Kth radionuclide in the irrigation water, in Ci/L
- $D_{B,K}$  = inhalation dose factor for the Kth radionuclide from Table A22, in mrem/pCi inhaled
- $F_{X,I,K}$  = factor that results from the time integral of the dose rate for the Kth radionuclide over the full year (X=external calculation, I=the irrigation water is contaminated, and K=radionuclide index). If  $\lambda_K$  is very small,  $F_{X,I,K}=0.75$ .

$$\begin{aligned}
 H_{B,K} &= \text{inhalation dose to the all pathways farmer from the Kth radionuclide, mrem/y} \\
 M_B &= \text{total mass of soil inhaled during the year from Table A10, } 5.39 \times 10^{-4} \text{ kg/y} \\
 V_B &= \text{total volume of water inhaled during the year from Table A13, 0.054 L/y}
 \end{aligned}$$

### Ingestion Dose to the All Pathways Farmer

In addition to the small amounts of soil that are ingested in the course of the year, the farmer also eats fruits and vegetables from his garden, and meat, milk, poultry, and eggs from his livestock. The ingestion dose for one nuclide from these intakes is shown below. Note the summations over plant types and animal types. The decay and leaching factors for plants and animals are not shown in this equation because the direct deposition from overhead irrigation portion has a different factor than the root uptake and rain splash terms. These decay and leaching factors for the ingestion dose are included in the description of the plant and animal concentration (next equations).

$$H_{G,K} = \left( C_{S,K} M_G F_{X,I,K} + \sum_p C_{V,p,K} M_{V,p} + \sum_q C_{A,q,K} M_{A,q} + C_{W,K} V_G \right) D_{G,K}$$

where,

- $C_{A,q,K}$  = concentration of the Kth radionuclide in animal product type q, in Ci/kg
- $C_{S,K}$  = concentration of the Kth radionuclide in irrigated soil at the end of the year with no decay or leaching, in Ci/kg
- $C_{V,p,K}$  = time-integrated concentration of the Kth radionuclide in garden produce type p, in Ci/kg wet weight
- $C_{W,K}$  = concentration of the Kth radionuclide in the irrigation water, in Ci/L
- $D_{G,K}$  = ingestion dose factor for the Kth radionuclide from Table A21, in mrem/pCi ingested
- $F_{X,I,K}$  = factor that results from the time integral of the dose rate for the Kth radionuclide over the full year (X=external calculation, I=the irrigation water is contaminated, and K=radionuclide index). If  $\lambda_K$  is very small,  $F_{X,I,K}=0.75$ .
- $H_{G,K}$  = ingestion dose to the all pathways farmer from the Kth radionuclide, mrem/y
- p = index to the four types of garden produce, i.e., fruit, protected vegetables, exposed vegetables, and grains
- q = index to the four types of animal products, i.e., meat, milk, poultry, and eggs
- $M_{A,q}$  = mass of animal product type q eaten during the year, in kg/y. These amounts are 50% of the values shown in Table A4 under the heading "USDA".
- $M_G$  = total mass of soil ingested during the year from Table A8, 0.0365 kg/y
- $M_{V,p}$  = mass of garden produce type p eaten by the farmer during the year, in kg/y. These amounts are 25% of the values shown in Table A4 under the heading "USDA". Because grains consumed are not typically irrigated, the mass of grains is set to zero.
- $V_G$  = total volume of water ingested during the year from Table A4, 545 L/y

### Concentration in Garden Produce

The garden produce becomes contaminated by root uptake from the soil and by soil adhering to the foliage. In addition, overhead irrigation puts some contamination directly on the foliage. All three mechanisms of contamination apply to the plants grown to feed the livestock.

The concentration of a radionuclide in garden produce or animal fodder is shown in the equations below. Note that some parameters depend on the food type, while others are the same for all types. Leafy vegetables are consumed throughout the irrigation season, while other garden produce is harvested at the end of the growing season and consumed over a 90 day period. Vegetation fed to beef cattle has a decay and leaching factor based on slaughter at the end of the irrigation season. Vegetation fed to milk cows has a decay and leaching factor based on continuous consumption throughout the year. Stored feed for all the animals is harvested at the end of the growing season to maximize contamination levels. Note that the conversion of time units for  $T_{W,p}$  and  $ID_K$  is not explicitly shown in the first equation.

$$C_{V,p,K} = F_{V,I,K,p} C_{S,K} \left( F_{DRY,p} B_{V,p,K} + \frac{J_{SPLASH} F_{INT,p} F_{TRANS,p} T_{W,p}}{Y_{V,p}} \right) + \frac{0.25 ID_K F_{TRANS,p} T_{W,p}}{Y_{V,p}}$$

$$F_{V,I,K,Leafy} = \frac{\lambda_K T_{irr} - 1 + \text{Exp}(-\lambda_K T_{irr})}{(\lambda_K T_{irr})^2} \quad \text{and} \quad T_{W,p} = \frac{1 - \text{Exp}(-\lambda_W T_{GROW,p})}{\lambda_W}$$

$$F_{V,I,K,Other} = \left( \frac{1 - \text{Exp}(-\lambda_K T_{irr})}{\lambda_K T_{irr}} \right) \left( \frac{1 - \text{Exp}(-\lambda_{R,K} T_{veg})}{\lambda_{R,K} T_{veg}} \right)$$

$$F_{V,I,K,Fresh(beef)} = \frac{1 - \text{Exp}(-\lambda_K T_{irr})}{\lambda_K T_{irr}}$$

$$F_{V,I,K,Fresh(other)} = \frac{\lambda_K T_{irr} - 1 + \text{Exp}(-\lambda_K T_{irr})}{(1 y) \lambda_K^2 T_{irr}} + \left( \frac{1 - \text{Exp}(-\lambda_K T_{irr})}{\lambda_K T_{irr}} \right) \left( \frac{1 - \text{Exp}(-\lambda_{R,K} T_{no})}{(1 y) \lambda_{R,K}} \right)$$

$$F_{V,I,K,Stored(beef)} = \left( \frac{1 - \text{Exp}(-\lambda_K T_{irr})}{\lambda_K T_{irr}} \right) \text{Exp}(-\lambda_{R,K} T_{sto})$$

$$F_{V,I,K,Stored(other)} = \left( \frac{1 - \text{Exp}(-\lambda_K T_{irr})}{\lambda_K T_{irr}} \right) \text{Exp}(-\lambda_{R,K} T_{sto}) \left( \frac{1 - \text{Exp}(-\lambda_{R,K} T_{an})}{\lambda_{R,K} T_{an}} \right)$$

where,

- $B_{V,p,K}$  = soil-to-plant transfer factor for the Kth radionuclide in plant type p from Table A37
- $C_{S,K}$  = concentration of the Kth radionuclide in irrigated soil at the end of the year with no decay or leaching, in Ci/kg
- $C_{V,p,K}$  = time-integrated radionuclide concentration in plant type p, in Ci/kg wet weight
- $F_{DRY,p}$  = dry-to-wet ratio for plant type p from Table A39
- $F_{INT,p}$  = interception fraction for airborne dust on exposed surfaces of plant type p, from Table A39
- $F_{TRANS,p}$  = translocation factor from exposed surfaces to the edible portion of plant type p, from Table A39

- $F_{V,I,K,p}$  = factor that results from the time integral of the dose rate for the Kth radionuclide over the full year (V=plant calculation, I=the irrigation water is contaminated, K=radionuclide index, and p=plant index). Specific cases are shown for leafy vegetables, all other vegetables, fresh fodder for beef cattle and other animal products (milk, poultry, and eggs), and stored feed for beef and the other products.
- $ID_K$  = irrigation deposition rate for the Kth radionuclide during the irrigation season, Ci/m<sup>2</sup> per year (1 y = 365 d)
- $J_{SPLASH}$  = average soil deposition rate due to rain splash (see Section A5.2),  $2.7 \times 10^{-4}$  kg/m<sup>2</sup> per day
- p = index to the various types of garden produce (leafy, protected, fruit and grain) and animal fodder (fresh and stored fodder for beef, milk, poultry and egg) listed in Table A39
- $T_{an}$  = consumption period for the animal fodder, 90 d (0.2466 y)
- $T_{GROW,p}$  = growing period of plant type p from Table A39
- $T_{irr}$  = irrigation period (the 1<sup>st</sup> half of the year), 0.5 y
- $T_{no}$  = no irrigation period (the 2<sup>nd</sup> half of the year),  $T_{irr} + T_{no} = 1$  y
- $T_{sto}$  = storage period for stored fodder, 90 d (0.2466 y)
- $T_{veg}$  = consumption period for all garden produce except leafy vegetables, 90 d (0.2466 y)
- $T_{W,p}$  = effective exposure time for plant type p, in days
- $Y_{V,p}$  = yield of plant type p, from Table A39, in kg(wet)/m<sup>2</sup>
- $\lambda_K$  = total removal constant for the Kth radionuclide, per year,  $\lambda_K = \lambda_{S,K} + \lambda_{R,K}$
- $\lambda_{R,K}$  = radioactive decay constant for the Kth radionuclide, per year. These are calculated as  $\ln(2)=0.6931472$  divided by the material half life (in years).
- $\lambda_{S,K}$  = average soil leaching coefficient for the Kth radionuclide, fraction removed from the surface layer of soil, per year (see Table A40)
- $\lambda_W$  = weathering constant for all type of plants, 0.04951 per day. This is based on a weathering half time of 14 days.

The tritium concentration in garden produce and animal fodder is calculated using the equilibrium model equation shown below. The first ratio expresses the water concentration in Ci/kg water. The factor 8.94 is calculated from the ratio of the atomic weights of water and hydrogen. It is used to convert the hydrogen fractions ( $F_{H,p}$ ) to water fractions. Since the hydrogen fractions include organically bound hydrogen as well as water, the produce concentration is a bounding value. The ratio containing the natural precipitation amount (P) adjusts for the presence of uncontaminated water in the environment.

$$C_{V,p,H-3} = \left( \frac{C_{W,H-3}}{\rho_W} \right) \left( \frac{8.94 \text{ kg water}}{\text{kg hydrogen}} \right) F_{H,p} \left( \frac{I}{P + I} \right) F_{V,I,H-3,p}$$

$$F_{V,I,H-3,Leafy} = 1 \quad \text{and} \quad F_{V,I,H-3,Other} = \frac{1 - \text{Exp}(-\lambda_{R,H-3} T_{veg})}{\lambda_{R,H-3} T_{veg}}$$

$$F_{V,I,H-3,Fresh(beef)} = 1 \quad \text{and} \quad F_{V,I,H-3,Fresh(other)} = 0.5 + \left( \frac{1 - \text{Exp}(-\lambda_{N,H-3} T_{no})}{(1 y)\lambda_{N,H-3}} \right)$$

$$F_{V,I,H-3,Stored(beef)} = \text{Exp}(-\lambda_{R,K} T_{sto})$$

$$F_{V,I,H-3,Stored(other)} = \text{Exp}(-\lambda_{R,K} T_{sto}) \left( \frac{1 - \text{Exp}(-\lambda_{N,H-3} T_{an})}{\lambda_{N,H-3} T_{an}} \right)$$

where,

- $C_{V,p,H-3}$  = time-integrated tritium concentration in garden produce type p, in Ci/kg wet weight
- $C_{W,H-3}$  = tritium concentration in the irrigation water, in Ci/L
- $F_{H,p}$  = mass fraction of hydrogen in garden produce type p from Table A34, in kg hydrogen per kg plant (wet)
- $F_{V,I,H-3,p}$  = factor that results from the time integral of the dose rate for tritium over the full year (V=plant calculation, I=the irrigation water is contaminated, H-3=tritium, and p=plant type). Specific cases are shown for leafy vegetables, all other vegetables, fresh fodder for beef cattle, fresh fodder for all other animal products, and stored feed for beef and all other animal products.
- I = total irrigation water applied during the irrigation season, in cm. For the all pathways farmer it is 82.3 cm (32.4 inches). Nearly all of this is deposited during the 6 month period from April to September.
- P = total precipitation, in centimeters, during the irrigation period. Over the period 1971 to 2000, the precipitation during the 6 month irrigation season (April to September) has been 5.766 cm (PNNL-13859).
- p = index to the various types of garden produce (leafy, protected, fruit and grain) and animal fodder (fresh and stored for beef, milk, poultry and egg) listed in Table A39
- $T_{an}$  = consumption period for the animal fodder, 90 d (0.2466 y)
- $T_{no}$  = no-irrigation period (the 2<sup>nd</sup> half of the year),  $T_{no} = 0.5 y$
- $T_{sto}$  = storage period for stored fodder, 90 d (0.2466 y)
- $T_{veg}$  = consumption period for all garden produce except leafy vegetables, 90 d (0.2466 y)
- $\lambda_{N,H-3}$  = total removal constant for tritium during the no-irrigation period, 8.032 per year
- $\lambda_{R,H-3}$  = radioactive decay constant for tritium, 0.05622 per year. This is calculated as  $\ln(2)=0.6931472$  divided by the material half life, 12.33 years.
- $\rho_W$  = density of water, 1.0 kg/L

### Concentration in Animal Products

Animal products (meat, milk, poultry, and eggs) become contaminated when the animals ingest soil, water, and fodder. The soil ingested by the animal uses the same decay and leaching factor as the fresh fodder. The beef cow is slaughtered at the end of the irrigation period and consumed over a period of time ( $T_{\text{beef}}$ ). However, the milk and the chickens (meat and eggs) are consumed throughout the year with little storage time. The concentration in the animal product is calculated using the equations below.

$$C_{A,q,K} = B_{A,q,K} \left( C_{S,K} M_{S,q} F_{V,I,K,q(\text{fresh})} + \sum_p C_{V,p,K} M_{V,p,q} + C_{W,K} V_{W,q} \right) F_{A,K,q}$$

$$F_{A,K,\text{Beef}} = \frac{1 - \text{Exp}(-\lambda_{R,K} T_{\text{beef}})}{\lambda_{R,K} T_{\text{beef}}} \quad \text{and} \quad F_{A,K,\text{Other}} = 1$$

where,

- $B_{A,q,K}$  = animal transfer factor for the Kth radionuclide into animal product type q from Table A33, in day/kg
- $C_{A,q,K}$  = time-integrated concentration of the Kth radionuclide in animal product type q, in Ci/kg
- $C_{S,K}$  = concentration of the Kth radionuclide in irrigated soil at the end of the year with no decay or leaching, in Ci/kg
- $C_{V,p,K}$  = time-integrated radionuclide concentration in plant type p, in Ci/kg wet weight
- $C_{W,K}$  = concentration of the Kth radionuclide in the irrigation water, in Ci/L
- $F_{A,K,q}$  = factor that results from the time integral of the dose rate for the Kth radionuclide over the full year (A=animal calculation, K=radionuclide index, and q=animal type).
- $F_{V,I,K,q(\text{fresh})}$  = factor that results from the time integral of the dose rate for the Kth radionuclide over the full year (V=fodder calculation, I=the irrigation water is contaminated, K=radionuclide index, and q(fresh)=fresh fodder for animal type q). The soil ingested by beef cattle uses the same decay and leaching factor ( $F_{V,I,K,\text{Fresh}(\text{beef})}$ ) as the fresh fodder used by beef cattle. The soil ingested by other animals uses the same decay and leaching factor ( $F_{V,I,K,\text{Fresh}(\text{milk})}$ ) as the fresh fodder used by the other animals.
- $M_{S,q}$  = daily mass of soil ingested by animal type q in Table A32, in kg/d
- $M_{V,p,q}$  = daily mass of animal fodder type p eaten by animal type q, in kg (wet)/d. These amounts are shown in Table A32.
- p = index to the various types of animal fodder shown in Table A39
- q = index to the four types of animal products, i.e., meat, milk, poultry, and eggs
- $T_{\text{beef}}$  = consumption period for beef, 120 d (0.3288 y)
- $V_{W,q}$  = daily volume of water ingested by animal type q from Table A32, in L/d
- $\lambda_{R,K}$  = radioactive decay constant for the Kth radionuclide, per year. These are calculated as  $\ln(2)=0.6931472$  divided by the material half life (in years).

The concentration of tritium in animal products is calculated from an equilibrium model very similar to the one shown in Section 3.3. The ratio of contaminated water mass ingested per

day to total mass of water ingested per day is closer to 1.0 in the irrigation cases because the animal's drinking water is contaminated. The drinking water is the bulk of the total water ingested each day. The equation below shows the calculation of tritium concentration in animal products. The time-integration factors are the same as shown above for tritium concentration in vegetation.

$$C_{A,q,H-3} = \left( \frac{C_{W,H-3}}{\rho_W} \right) \left( \frac{8.94 \text{ kg water}}{\text{kg hydrogen}} \right) F_{H,q} \left( \frac{M_{W,C,q}}{M_{W,T,q}} \right) F_{A,H-3,q}$$

$$M_{W,C,q} = \rho_W V_{W,q} + \left( \frac{I}{P+I} \right) \left( \frac{\theta \rho_W}{\rho_{\text{Garden}}} \right) M_{S,q} F_{V,I,H-3,q(\text{fresh})}$$

$$+ \left( \frac{I}{P+I} \right) \sum_p \left( \frac{8.94 \text{ kg water}}{\text{kg hydrogen}} \right) F_{H,p} F_{V,I,H-3,p} M_{V,p,q}$$

$$M_{W,T,q} = \rho_W V_{W,q} + \left( \frac{\theta \rho_W}{\rho_{\text{Garden}}} \right) M_{S,q} + \sum_p \left( \frac{8.94 \text{ kg water}}{\text{kg hydrogen}} \right) F_{H,p} M_{V,p}$$

where,

- $C_{A,q,H-3}$  = time-integrated tritium concentration in animal product type q, in Ci/kg
- $C_{W,K}$  = concentration of the Kth radionuclide in the irrigation water, in Ci/L
- $F_{A,H-3,q}$  = factor that results from the time integral of the dose rate for tritium over the full year (A=animal calculation, H-3=tritium, and q=animal type).
- $F_{H,p}$  = mass fraction of hydrogen in animal fodder type p from Table A34, in kg hydrogen per kg plant (wet)
- $F_{H,q}$  = mass fraction of hydrogen in animal product type q from Table A34, in kg hydrogen per kg of the animal product
- $F_{V,I,H-3,p}$  = factor that results from the time integral of the dose rate for tritium over the full year (V=plant calculation, I=the irrigation water is contaminated, H-3=tritium, and p=plant type). Equations are given in the preceding pages for calculating tritium concentration in vegetation.
- $I$  = total irrigation water applied during the irrigation season, in cm. For the all pathways farmer it is 82.3 cm (32.4 inches). Nearly all of this is deposited during the 6 month period from April to September.
- $M_{S,q}$  = daily mass of soil ingested by animal type q in Table A32, in kg/d
- $M_{V,p,q}$  = daily mass of animal fodder type p eaten by animal type q, in kg (wet)/d. These amounts are shown in Table A32.
- $M_{W,C,q}$  = mass of contaminated water ingested daily by the animal, in kg/d
- $M_{W,T,q}$  = total mass of water ingested daily by the animal, in kg/d
- $P$  = total precipitation, in centimeters, during the irrigation period. Over the period 1971 to 2000, the precipitation during the 6 month irrigation season (April to September) has been 5.766 cm (PNNL-13859).
- $p$  = index to the types of animal fodder, i.e., fresh pasture grass and stored hay and grain for beef, milk, poultry, and eggs
- $q$  = index to the four types of animal products, i.e., meat, milk, poultry, and eggs

- $V_{W,q}$  = daily volume of water ingested by animal type q from Table A32, in L/d  
 $\rho_{\text{Garden}}$  = average density of the surface soil, 1.5 kg soil per liter of soil  
 $\rho_W$  = density of water, 1.0 kg water per liter of water  
 $\theta$  = volumetric water content of the surface soil, liters of water per liter of soil. A value of 0.2 is assumed.

Note that the equation for the concentration of tritium in the animal product can be rearranged to indicate an equilibrium concentration ratio for tritium in the animal product. This equation has the same form as the equation used for all the other radionuclides. The equilibrium transfer factors ( $B_{A,q,H-3}$ ) are identical to the ones shown for the rural pasture scenario in Section 3.3.

$$C_{A,q,H-3} = B_{A,q,H-3} \left( C_{S,H-3} M_{S,q} F_{V,I,H-3,q(\text{fresh})} + \sum_p C_{V,p,H-3} M_{V,p,q} + C_{W,H-3} V_{W,q} \right) F_{A,H-3,q}$$

$$B_{A,q,H-3} = \left( \frac{8.94 \text{ kg water}}{\text{kg hydrogen}} \right) \left( \frac{F_{H,q}}{M_{W,T,q}} \right)$$

The simplified model for the milk cow and chicken has them foraging throughout the year. In reality, most of the fresh forage is consumed during the irrigation season, with a heavier emphasis on stored feed and grain during the non-irrigation season. Supposing that some fraction, say 80% of the fresh forage was consumed during the irrigation season. Then the direct deposition portion of  $C_{V,p,K}$  would need to be multiplied by this fraction because the plants consumed by the animals during the non-irrigation season would not receive direct deposition. This would lower  $C_{V,p,K}$ . However, the integration factor,  $F_{V,I,K,\text{Fresh}(\text{other})}$ , would need to be adjusted to move more of the fresh fodder consumption into the first half of the year. This would lower the integration factor (except for tritium, which rapidly disappears from the soil during the non-irrigation season). Thus the simplified milk cow and chicken model tends to overestimate the resulting ingestion doses.

#### Total Dose to the All Pathways Farmer -- Well Water

The total dose to the all pathways farmer is the sum of the external (from soil), inhalation (from soil and water), and ingestion doses (from water, soil, vegetables, and animal products). With the exception of tritium (H-3), absorption of radionuclides through the skin is not a significant pathway, as discussed in Section A.3.4.1. The source of contaminated water is a well to groundwater. Scenario dose factors for the all pathways farmer who uses well water are presented in Table 12 in the "Total" column. This column shows the first year dose equivalent per pCi/L in the ground water. These unit dose factors must be multiplied by the ground water concentration to calculate the first year dose. The radiation dose to this individual is the 50 year committed effective dose equivalent from one year of exposure.

Table 12 also shows the dose from only the drinking water consumed by the all pathways farmer (545 L/y, from Table A4). The third column shows the ratio of the total dose to the drinking water dose. Large ratios indicate that most of the dose comes from pathways other than drinking water. Additional detail on the doses by pathway is provided in Appendix D. For most radionuclides, the drinking water pathway contributes the bulk of the total dose.

**Table 12. Unit Dose Factors for the All Pathway Farmer (mrem/y per pCi/L) Using Well Water.**

<b>Nuclide</b>	<b>Total</b>	<b>Drinking Water</b>	<b>Ratio</b>	<b>Nuclide</b>	<b>Total</b>	<b>Drinking Water</b>	<b>Ratio</b>
H-3	4.75E-05	3.49E-05	1.36	Gd-152	1.25E-01	8.77E-02	1.42
Be-10	3.09E-03	2.54E-03	1.22	Ho-166m	1.75E-02	4.40E-03	3.99
C-14	4.84E-03	1.14E-03	4.25	Re-187	8.48E-06	5.18E-06	1.64
Na-22	4.72E-02	6.27E-03	7.54	Tl-204	4.69E-03	1.83E-03	2.56
Al-26	2.86E-02	7.95E-03	3.60	Pb-205	1.09E-03	8.88E-04	1.23
Si-32+D	7.23E-03	6.00E-03	1.21	Pb-210+D	3.68E+00	2.93E+00	1.26
Cl-36	2.49E-02	1.65E-03	15.1	Bi-207	1.41E-02	2.99E-03	4.72
K-40	2.88E-02	1.01E-02	2.84	Po-209	2.01E+00	1.29E+00	1.55
Ca-41	1.15E-03	6.94E-04	1.66	Po-210	1.53E+00	1.04E+00	1.47
Ti-44+D	5.81E-02	1.34E-02	4.33	Ra-226+D	9.83E-01	7.25E-01	1.36
V-49	4.16E-05	3.35E-05	1.24	Ra-228+D	1.05E+00	7.85E-01	1.34
Mn-54	6.07E-03	1.51E-03	4.02	Ac-227+D	9.46E+00	8.07E+00	1.17
Fe-55	5.94E-04	3.31E-04	1.80	Th-228+D	5.39E-01	4.42E-01	1.22
Fe-60+D	1.54E-01	8.31E-02	1.85	Th-229+D	2.64E+00	2.20E+00	1.20
Co-60	3.99E-02	1.47E-02	2.72	Th-230	3.61E-01	2.99E-01	1.21
Ni-59	3.60E-04	1.14E-04	3.15	Th-232	1.79E+00	1.49E+00	1.20
Ni-63	9.89E-04	3.14E-04	3.15	Pa-231	6.77E+00	5.78E+00	1.17
Se-79	1.29E-02	4.74E-03	2.73	U-232	9.22E-01	7.14E-01	1.29
Rb-87	8.39E-03	2.68E-03	3.13	U-233	2.03E-01	1.58E-01	1.29
Sr-90+D	1.53E-01	8.34E-02	1.83	U-234	1.99E-01	1.54E-01	1.29
Zr-93	1.05E-03	9.05E-04	1.16	U-235+D	1.88E-01	1.46E-01	1.30
Nb-91	3.44E-04	2.84E-04	1.21	U-236	1.89E-01	1.47E-01	1.29
Nb-93m	3.30E-04	2.84E-04	1.16	U-238+D	1.88E-01	1.46E-01	1.29
Nb-94	1.54E-02	3.89E-03	3.96	Np-237+D	2.91E+00	2.42E+00	1.20
Mo-93	1.12E-03	7.36E-04	1.52	Pu-236	7.45E-01	6.38E-01	1.17
Tc-99	1.75E-03	7.96E-04	2.20	Pu-238	2.04E+00	1.74E+00	1.17
Ru-106+D	3.76E-02	1.49E-02	2.51	Pu-239	2.26E+00	1.93E+00	1.17
Pd-107	1.98E-04	8.12E-05	2.44	Pu-240	2.26E+00	1.93E+00	1.17
Ag-108m+D	1.67E-02	4.15E-03	4.03	Pu-241+D	4.37E-02	3.73E-02	1.17
Cd-109	9.44E-03	7.14E-03	1.32	Pu-242	2.14E+00	1.83E+00	1.17
Cd-113m	1.18E-01	8.77E-02	1.34	Pu-244+D	2.12E+00	1.81E+00	1.17
In-115	1.25E-01	8.61E-02	1.45	Am-241	2.32E+00	1.98E+00	1.17
Sn-121m+D	4.55E-03	1.23E-03	3.71	Am-242m+D	2.25E+00	1.92E+00	1.17
Sn-126+D	5.62E-02	1.14E-02	4.91	Am-243+D	2.32E+00	1.98E+00	1.17
Sb-125	4.45E-03	1.53E-03	2.91	Cm-242	7.29E-02	6.27E-02	1.16
Te-125m	2.77E-03	2.00E-03	1.38	Cm-243	1.60E+00	1.37E+00	1.17
I-129	5.25E-01	1.50E-01	3.49	Cm-244	1.29E+00	1.10E+00	1.17
Cs-134	1.51E-01	3.99E-02	3.78	Cm-245	2.39E+00	2.04E+00	1.17

**Table 12. Unit Dose Factors for the All Pathway Farmer (mrem/y per pCi/L) Using Well Water.**

Nuclide	Total	Drinking Water	Ratio	Nuclide	Total	Drinking Water	Ratio
Cs-135	1.44E-02	3.85E-03	3.74	Cm-246	2.36E+00	2.02E+00	1.17
Cs-137+D	1.06E-01	2.73E-02	3.87	Cm-247+D	2.19E+00	1.86E+00	1.17
Ba-133	4.62E-03	1.85E-03	2.49	Cm-248	8.69E+00	7.41E+00	1.17
Pm-147	7.45E-04	5.72E-04	1.30	Cm-250+D	4.96E+01	4.23E+01	1.17
Sm-147	1.36E-01	1.01E-01	1.35	Bk-247	3.00E+00	2.56E+00	1.17
Sm-151	2.80E-04	2.12E-04	1.32	Cf-248	2.35E-01	1.82E-01	1.29
Eu-150	1.45E-02	3.47E-03	4.20	Cf-249	3.42E+00	2.58E+00	1.32
Eu-152	1.22E-02	3.53E-03	3.46	Cf-250	1.53E+00	1.16E+00	1.32
Eu-154	1.51E-02	5.20E-03	2.89	Cf-251	3.49E+00	2.64E+00	1.32
Eu-155	1.31E-03	8.34E-04	1.57	Cf-252	7.71E-01	5.89E-01	1.31

## Notes:

- The radiation dose to this individual is the 50 year committed effective dose equivalent from one year of exposure.
- These scenario dose factors must be multiplied by the ground water concentration.
- The "Total" column is for the full scenario. The column "Drinking Water" shows only the drinking water dose. The "Ratio" column is the "Total" divided by the "Drinking Water" doses. Large ratios mean that drinking water is a minor contributor to the total dose.

Additional Pathways for the All Pathways Farmer Using Columbia River Water

If the all pathways farmer obtains all of his water from the Columbia River there are additional dose pathways due to the contamination of fish taken from the river, and exposure to shoreline sediments. All of the pathways discussed previously still apply. The additional pathways make the unit dose factors larger. The sediments add ingestion of trace amounts of soil (shoreline sediment), and external dose from proximity to the shoreline sediments.

The ingestion dose from fish consumption is the product of the river water concentration for a radionuclide, the bioaccumulation factor for that radionuclide in fish, the mass of fish consumed annually, and the ingestion dose factor for that radionuclide. The mass of fish eaten that come from the Columbia River is half the value shown in Table A4. The other fish are uncontaminated. The dose from fish is calculated using the equation below.

$$H_{F,K} = C_{W,K} B_{F,K} M_F D_{G,K}$$

where,

- $B_{F,K}$  = bioaccumulation factor for the Kth radionuclide in fish from Table A33, in units of Ci/kg fish per Ci/L water
- $C_{W,K}$  = concentration of the Kth radionuclide in the river water, in Ci/L
- $D_{G,K}$  = ingestion dose factor for the Kth radionuclide from Table A21, in mrem/pCi ingested
- $H_{F,K}$  = ingestion dose from eating fish for the Kth radionuclide, mrem/y
- $M_F$  = total mass of contaminated fish eaten during the year, 3.29 kg/y

The model used for shoreline sediment concentrations is described in Section A6.3. Sediment concentrations are generally larger than those for irrigated land. The ingestion dose from eating trace amounts of sediment is shown in the equation below. Also shown is the external dose from proximity to the shoreline sediment. A preliminary sediment accumulation time of 20 years is assumed. Radionuclides accumulate in the shoreline sediment for 20 years before the farmer begins to irrigate crops from the Columbia River.

$$H_{XD,K} = C_{W,K} V_S T_{D,K} D_{X,K} T_{XD}$$

$$H_{GD,K} = C_{W,K} V_S T_{D,K} D_{G,K} \frac{M_{GD}}{\rho_{GARDEN} L_{GARDEN}}$$

$$T_{D,K} = \frac{\lambda_K T_C - \text{Exp}(-\lambda_K T_A) + \text{Exp}[-\lambda_K (T_A + T_C)]}{(1 y) \lambda_K^2}$$

where,

- $C_{W,K}$  = concentration of the Kth radionuclide in the river water, in Ci/L
- $D_{G,K}$  = ingestion dose factor for the Kth radionuclide from Table A21, in mrem/pCi ingested
- $D_{X,K}$  = external dose rate factor for the Kth radionuclide to a person standing on a layer 0.15 m thick and of great extent in all directions, in mrem/h per Ci/m<sup>2</sup>. Values are listed in Table A25.
- $H_{GD,K}$  = ingestion dose to the all pathways farmer from the Kth radionuclide in shoreline sediment, mrem/y
- $H_{XD,K}$  = external dose to the all pathways farmer from the Kth radionuclide in shoreline sediment, mrem/y
- $L_{GARDEN}$  = thickness of the contaminated layer of surface soil in the garden, 0.15 m
- $M_{GD}$  = mass of shoreline sediment ingested annually from Table A8, 0.0007 kg/y
- $T_A$  = preliminary sediment accumulation time, 20 y
- $T_C$  = dose accumulation period, 1 y for the all pathways farmer
- $T_{D,K}$  = effective sediment accumulation time for the Kth radionuclide, in years. If the removal constant is very small,  $T_{D,K} = T_C (T_A + T_C) / (2 y)$ . If the removal constant is very large,  $T_{D,K} = T_C / (1 y) / \lambda_K$ .
- $T_{XD}$  = effective time of exposure to shoreline sediments each year from Table A15, 11 h/y. The estimated time of exposure (56 h/y) was reduced by the shoreline width geometry factor, 0.2.
- $V_S$  = effective river-to-sediment deposition rate, 25,300 L/m<sup>2</sup> per year
- $\lambda_K$  = total removal constant (decay plus leaching) for the Kth radionuclide, per year
- $\rho_{GARDEN}$  = average density of the soil in the garden, 1,500 kg/m<sup>3</sup>

#### Total Dose to the All Pathways Farmer -- Columbia River Water

The total dose to the all pathways farmer is the sum of the external (from soil and sediments), inhalation (from soil and water), and ingestion doses (from water, soil, sediments, vegetables, and animal products). With the exception of tritium (H-3), absorption of radionuclides through the skin is not a significant pathway, as discussed in Section A.3.4.1. The source of contaminated water is the Columbia River. Scenario dose factors for the all pathways

farmer who uses water from the Columbia River are presented in Table 13 in the “Total” column. This column shows the 50 year committed effective dose equivalent from one year of exposure per pCi/L in the Columbia River. These unit dose factors must be multiplied by the river water concentration to calculate the first year dose.

Table 13 also shows the dose from fish consumption for the all pathways farmer. The drinking water doses are the same as shown in Table 12. The third column of Table 13 shows the ratio of the total dose to the fish dose. Large ratios indicate that dose from fish is a small fraction of the total dose. For many radionuclides, the fish pathway contributes significantly to the total dose. Additional detail on the doses by pathway is shown in Appendix D.

**Table 13. Unit Dose Factors for the All Pathway Farmer (mrem/y per pCi/L) Using Columbia River Water.**

Nuclide	Total	Fish	Ratio	Nuclide	Total	Fish	Ratio
H-3	4.77E-05	2.11E-07	227	Gd-152	1.38E-01	1.32E-02	10.4
Be-10	4.63E-03	1.53E-03	3.02	Ho-166m	4.40E-02	6.64E-04	66.3
C-14	3.49E-01	3.44E-01		Re-187	1.22E-05	3.75E-06	3.26
Na-22	5.37E-02	3.03E-04	177	Tl-204	1.15E-01	1.11E-01	
Al-26	9.43E-02	2.40E-02	3.93	Pb-205	2.70E-03	1.61E-03	1.68
Si-32+D	8.00E-03	7.24E-04	11.1	Pb-210+D	8.98E+00	5.30E+00	1.70
Cl-36	2.54E-02	4.98E-04	50.9	Bi-207	3.32E-02	1.80E-04	184
K-40	9.16E-02	6.12E-02	1.50	Po-209	2.40E+00	3.90E-01	6.16
Ca-41	1.32E-03	1.68E-04	7.88	Po-210	1.84E+00	3.13E-01	5.88
Ti-44+D	1.69E-01	8.09E-02	2.08	Ra-226+D	1.23E+00	2.19E-01	5.64
V-49	8.20E-05	4.04E-05	2.03	Ra-228+D	1.31E+00	2.37E-01	5.51
Mn-54	1.05E-02	3.65E-03	2.88	Ac-227+D	1.07E+01	1.22E+00	8.79
Fe-55	9.94E-04	3.99E-04	2.49	Th-228+D	8.09E-01	2.67E-01	3.03
Fe-60+D	2.79E-01	1.00E-01	2.78	Th-229+D	3.98E+00	1.33E+00	3.00
Co-60	7.94E-02	2.66E-02	2.99	Th-230	5.42E-01	1.80E-01	3.01
Ni-59	4.30E-04	6.91E-05	6.22	Th-232	2.72E+00	8.98E-01	3.03
Ni-63	1.18E-03	1.90E-04	6.22	Pa-231	7.14E+00	3.49E-01	20.5
Se-79	1.78E-02	4.87E-03	3.66	U-232	9.78E-01	4.31E-02	22.7
Rb-87	4.08E-02	3.24E-02	1.26	U-233	2.13E-01	9.51E-03	22.4
Sr-90+D	1.83E-01	3.02E-02	6.07	U-234	2.08E-01	9.31E-03	22.4
Zr-93	2.69E-03	1.64E-03	1.64	U-235+D	1.99E-01	8.78E-03	22.6
Nb-91	8.92E-04	5.15E-04	1.73	U-236	1.98E-01	8.85E-03	22.4
Nb-93m	8.46E-04	5.15E-04	1.64	U-238+D	1.98E-01	8.82E-03	22.4
Nb-94	4.63E-02	7.05E-03	6.56	Np-237+D	3.22E+00	3.07E-01	10.5
Mo-93	1.16E-03	4.44E-05	26.2	Pu-236	8.27E-01	8.08E-02	10.2
Tc-99	1.85E-03	9.61E-05	19.2	Pu-238	2.27E+00	2.21E-01	10.3
Ru-106+D	3.87E-02	9.01E-04	42.9	Pu-239	2.51E+00	2.45E-01	10.3
Pd-107	2.03E-04	4.90E-06	41.5	Pu-240	2.51E+00	2.45E-01	10.3
Ag-108m+D	3.93E-02	1.25E-04	314	Pu-241+D	4.86E-02	4.73E-03	10.3
Cd-109	1.81E-02	8.62E-03	2.10	Pu-242	2.38E+00	2.32E-01	10.3

**Table 13. Unit Dose Factors for the All Pathway Farmer (mrem/y per pCi/L) Using Columbia River Water.**

Nuclide	Total	Fish	Ratio	Nuclide	Total	Fish	Ratio
Cd-113m	2.24E-01	1.06E-01	2.11	Pu-244+D	2.36E+00	2.29E-01	10.3
In-115	5.21E+01	5.20E+01		Am-241	2.58E+00	2.51E-01	10.3
Sn-121m+D	2.68E-02	2.22E-02	1.21	Am-242m+D	2.50E+00	2.43E-01	10.3
Sn-126+D	2.94E-01	2.07E-01	1.42	Am-243+D	2.58E+00	2.51E-01	10.3
Sb-125	6.60E-03	9.24E-04	7.14	Cm-242	8.09E-02	7.95E-03	10.2
Te-125m	7.60E-03	4.83E-03	1.57	Cm-243	1.78E+00	1.73E-01	10.3
I-129	5.62E-01	3.63E-02	15.5	Cm-244	1.43E+00	1.40E-01	10.3
Cs-134	6.37E-01	4.82E-01	1.32	Cm-245	2.66E+00	2.58E-01	10.3
Cs-135	6.10E-02	4.65E-02	1.31	Cm-246	2.63E+00	2.56E-01	10.3
Cs-137+D	4.42E-01	3.29E-01	1.34	Cm-247+D	2.43E+00	2.36E-01	10.3
Ba-133	7.43E-03	4.47E-05	166	Cm-248	9.65E+00	9.40E-01	10.3
Pm-147	8.49E-04	1.04E-04	8.20	Cm-250+D	5.51E+01	5.37E+00	10.3
Sm-147	1.52E-01	1.52E-02	9.98	Bk-247	3.40E+00	3.87E-01	8.79
Sm-151	3.12E-04	3.20E-05	9.76	Cf-248	2.63E-01	2.75E-02	9.56
Eu-150	3.41E-02	1.05E-03	32.6	Cf-249	3.82E+00	3.90E-01	9.79
Eu-152	2.39E-02	1.07E-03	22.5	Cf-250	1.71E+00	1.75E-01	9.75
Eu-154	2.59E-02	1.57E-03	16.5	Cf-251	3.90E+00	3.99E-01	9.78
Eu-155	1.73E-03	2.52E-04	6.87	Cf-252	8.60E-01	8.88E-02	9.68

## Notes:

- The radiation dose to this individual is the 50 year committed effective dose equivalent from the first year of exposure.
- These scenario dose factors must be multiplied by the Columbia River concentration.
- The "Total" column is for the full scenario. The column "Fish" shows only the dose from eating fish. The "Ratio" column is the "Total" divided by the "Fish" doses. Large ratios mean that fish is a minor contributor to the total dose. Blank cells mean the dose from fish is within 10% of the total.

Increased Cancer Risk for the All Pathways Farmer -- Radionuclides

The increase in risk of developing some type of cancer due to radioactive contaminants in either ground water or the Columbia River is calculated using the same equations presented for the radiation dose. The two differences are (1) the use of the risk coefficients from Federal Guidance Report Number 13 rather than internal and external dose factors, and (2) the calculation of the cumulative risk from 30 years of water use.

When calculating the cumulative intakes over several years of irrigation with contaminated water it is convenient to distinguish two components to the intakes. The first component is direct from the water. Examples are drinking water and inhalation of airborne water. The second is indirect from radionuclides that are adsorbed on soil particles. Examples are external exposure, soil inhalation, and soil ingestion. Plant and animal pathways are a mixture of these two components.

The intakes from the direct pathways are the same every year because the water concentration remains constant. Thus, the cumulative intake is the number of years times the

intake in one year. However, the intakes from the second component are based on the concentration in the soil. Each year this concentration increases due to the applied irrigation water. The methods used for calculating intakes from residual soil contamination are shown in the discussion of doses in the suburban garden and rural pasture scenarios (Sections 3.2 and 3.3). Thus, the cumulative intake from N years of irrigation is the sum of N years of the direct component plus the cumulative sum of (N-1) years of prior irrigation. Equations for this are described in Section A6.2. The formulas below show how the cumulative total dose (or risk) is calculated. For the shoreline sediment the dose is calculated using the equations presented above with  $T_C=30$  y.

$$D_{CUM} = ND_{DIRECT} + \frac{D_{SOIL} F_{IS}}{1 - F_{NS}} \left( N - \frac{1 - (F_{NS})^N}{1 - F_{NS}} \right)$$

$$F_{IS} = \left( \frac{1 - \text{Exp}(-\lambda T_{irr})}{\lambda T_{irr}} \right) \text{Exp}(-\lambda_R T_{no})$$

$$F_{NS} = \text{Exp}(-\lambda T_{irr}) \text{Exp}(-\lambda_R T_{no})$$

where,

- $D_{CUM}$  = cumulative total dose (or risk) from N years of irrigation, excluding doses from shoreline sediments, in mrem
- $D_{DIRECT}$  = annual dose (or risk) from direct intakes of contaminated water during one year (excludes doses from shoreline sediments), in mrem
- $D_{SOIL}$  = annual dose (or risk) from the soil contamination present at the beginning of the year (excludes doses from shoreline sediments), in mrem
- $F_{IS}$  = fraction of the total soil concentration (amount deposited per unit area during the year divided by the area density of the soil) that is present at the end of 1 year when the irrigation water is adding contaminants to the soil
- $F_{NS}$  = fraction of the initial soil concentration that is left at the end of 1 year when the irrigation water adds no contaminants (see Section A6.2)
- $N$  = number of years of irrigation
- $T_{irr}$  = irrigation period, 0.5 y
- $T_{no}$  = no irrigation period, 1 y -  $T_{irr} = 0.5$  y
- $\lambda$  = total removal constant, per year  $\lambda = \lambda_R + \lambda_S$
- $\lambda_R$  = radioactive decay or chemical decomposition constant, per year. These are calculated as  $\ln(2)=0.6931472$  divided by the material half life (in years).
- $\lambda_S$  = average soil leaching coefficient, fraction removed from the surface layer of soil, per year

The lifetime increase in the risk of developing some type of cancer from radionuclides is the sum of 30 years of exposure. Each year there is a small amount of the radioactive material in the soil from previous years. The method of calculation uses formulas for the current year of irrigation as well as those for an initial soil concentration presented for the suburban garden and rural pasture. The soil concentration at the start of the year as well as the addition from irrigation determines the intake for that year. This leads to a total risk that is greater than 30 times the first year's risk for many nuclides.

The estimated lifetime increase in the risk of developing some type of cancer in the All Pathways Farmer from radioactive materials in the water are shown in Table 14. The first column of risks shows the 30-year total where all the contaminated water comes from a well. The water concentration of each nuclide is 1 pCi/L for this entire period. The second column of risks shows the 30-year total where all of the contaminated water comes from the Columbia River. Again, the water concentration is constant over the 30-year period. The third column is the ratio of the Columbia River risk factors divided by the ground water risk factors. If the two numbers are within 10%, they are not shown. Because the only difference is the addition of the fish and sediment pathways, radionuclides with large ratios indicate that the added pathways are major contributors to the total.

**Table 14. Unit Risk Factors for Radionuclides in the All Pathways Farmer Scenario (lifetime risk per pCi/L).**

Nuclide	Ground Water	River Water	Ratio	Nuclide	Ground Water	River Water	Ratio
H-3	2.66E-09	2.67E-09		Gd-152	6.87E-07	7.87E-07	1.1
Be-10	1.54E-07	2.56E-07	1.7	Ho-166m	6.15E-06	7.27E-06	1.2
C-14	1.90E-07	1.01E-05	53	Re-187	9.11E-10	1.22E-09	1.3
Na-22	2.86E-06	3.03E-06		Tl-204	3.10E-07	8.45E-06	27
Al-26	1.08E-05	1.40E-05	1.3	Pb-205	1.38E-08	3.83E-08	2.8
Si-32+D	2.92E-07	3.29E-07	1.1	Pb-210+D	2.46E-05	6.00E-05	2.4
Cl-36	4.71E-06	4.73E-06		Bi-207	4.66E-06	5.38E-06	1.2
K-40	2.64E-06	6.09E-06	2.3	Po-209	3.67E-05	5.07E-05	1.4
Ca-41	1.90E-08	2.08E-08		Po-210	2.36E-05	3.47E-05	1.5
Ti-44+D	8.85E-06	1.38E-05	1.6	Ra-226+D	1.69E-05	2.09E-05	1.2
V-49	2.71E-09	6.25E-09	2.3	Ra-228+D	2.87E-05	3.62E-05	1.3
Mn-54	2.87E-07	4.30E-07	1.5	Ac-227+D	1.09E-05	1.27E-05	1.2
Fe-55	2.94E-08	5.24E-08	1.8	Th-228+D	7.28E-06	1.16E-05	1.6
Fe-60+D	1.25E-05	1.86E-05	1.5	Th-229+D	1.21E-05	1.94E-05	1.6
Co-60	4.12E-06	5.15E-06	1.3	Th-230	1.92E-06	3.12E-06	1.6
Ni-59	1.97E-08	2.36E-08	1.2	Th-232	7.82E-06	1.07E-05	1.4
Ni-63	4.78E-08	5.73E-08	1.2	Pa-231	4.01E-06	4.41E-06	
Se-79	4.14E-07	5.77E-07	1.4	U-232	1.05E-05	1.14E-05	
Rb-87	5.74E-07	1.97E-06	3.4	U-233	1.70E-06	1.81E-06	
Sr-90+D	4.66E-06	5.24E-06	1.1	U-234	1.68E-06	1.78E-06	
Zr-93	2.22E-08	6.51E-08	2.9	U-235+D	2.02E-06	2.16E-06	
Nb-91	2.05E-08	5.60E-08	2.7	U-236	1.59E-06	1.68E-06	
Nb-93m	1.65E-08	5.12E-08	3.1	U-238+D	2.13E-06	2.26E-06	
Nb-94	5.82E-06	7.17E-06	1.2	Np-237+D	2.03E-06	2.32E-06	1.1
Mo-93	1.40E-07	1.44E-07		Pu-236	1.65E-06	1.87E-06	1.1
Tc-99	6.97E-07	7.05E-07		Pu-238	2.68E-06	3.05E-06	1.1
Ru-106+D	2.22E-06	2.28E-06		Pu-239	2.76E-06	3.15E-06	1.1
Pd-107	1.41E-08	1.45E-08		Pu-240	2.76E-06	3.15E-06	1.1

**Table 14. Unit Risk Factors for Radionuclides in the All Pathways Farmer Scenario (lifetime risk per pCi/L).**

Nuclide	Ground Water	River Water	Ratio	Nuclide	Ground Water	River Water	Ratio
Ag-108m+D	5.44E-06	6.33E-06	1.2	Pu-241+D	3.63E-08	4.16E-08	1.1
Cd-109	1.20E-07	2.52E-07	2.1	Pu-242	2.62E-06	2.98E-06	1.1
Cd-113m	7.63E-07	1.48E-06	1.9	Pu-244+D	4.14E-06	4.78E-06	1.2
In-115	8.91E-07	4.28E-04	481	Am-241	2.16E-06	2.46E-06	1.1
Sn-121m+D	3.01E-07	1.82E-06	6.0	Am-242m+D	1.54E-06	1.75E-06	1.1
Sn-126+D	9.26E-06	2.22E-05	2.4	Am-243+D	2.72E-06	3.13E-06	1.1
Sb-125	4.15E-07	5.06E-07	1.2	Cm-242	7.87E-07	9.00E-07	1.1
Te-125m	8.39E-08	2.69E-07	3.2	Cm-243	2.21E-06	2.51E-06	1.1
I-129	1.33E-05	1.41E-05		Cm-244	1.72E-06	1.95E-06	1.1
Cs-134	3.96E-06	1.42E-05	3.6	Cm-245	2.33E-06	2.66E-06	1.1
Cs-135	4.54E-07	1.62E-06	3.6	Cm-246	2.10E-06	2.39E-06	1.1
Cs-137+D	4.34E-06	1.20E-05	2.8	Cm-247+D	3.13E-06	3.63E-06	1.2
Ba-133	7.81E-07	8.61E-07		Cm-248	7.68E-06	8.74E-06	1.1
Pm-147	3.99E-08	4.73E-08	1.2	Cm-250+D	4.50E-05	5.13E-05	1.1
Sm-147	8.87E-07	1.01E-06	1.1	Bk-247	2.79E-06	3.25E-06	1.2
Sm-151	1.35E-08	1.56E-08	1.2	Cf-248	1.04E-06	1.19E-06	1.1
Eu-150	4.33E-06	5.04E-06	1.2	Cf-249	4.11E-06	4.72E-06	1.1
Eu-152	2.77E-06	3.16E-06	1.1	Cf-250	2.06E-06	2.34E-06	1.1
Eu-154	2.59E-06	2.95E-06	1.1	Cf-251	3.47E-06	3.96E-06	1.1
Eu-155	7.91E-08	9.63E-08	1.2	Cf-252	1.13E-06	1.29E-06	1.1

Notes:

- The increase in risk of the All Pathways Farmer developing some type of cancer is calculated using intakes from 30 consecutive years, representing a lifetime. The soil concentration is zero at the start of the exposure.
- These scenario risk factors must be multiplied by the water concentration.
- The "Ground Water" column assumes all of the contaminated water comes from a well. The "River Water" column assumes all of the contaminated water comes from the Columbia River. The "Ratio" column is the "River Water" divided by the "Ground Water" risks. Blank entries indicate the two risks are within 10 percent of each other.

Chemicals in the Water Used by the All Pathways Farmer

The hazard index and cancer risk from chemicals are calculated using reference doses and cancer induction slope factors presented in Section A3.8. The same consumption parameters are used for both radionuclides and chemicals. The contaminant concentration in well or river water is expressed in mg/L. Dermal absorption during showering is included, as is dermal contact with soil and sediment. Decomposition of the chemicals in the environment is not included, although for some organics this is a significant omission. Solubility limits are presented in Table A3, although these limits are not used in the calculation of unit hazard index and unit risk factors.

When calculating the average daily dose, the cumulative intake over some exposure period is divided by the number of days in the averaging period. In the All Pathways Farmer scenario, the exposure period is 30 years. The averaging periods depend on whether the cancer

risk or the non-carcinogenic hazard index is to be calculated. For calculating the increase in the risk of cancer, the daily dose is averaged over 70 years. When calculating the hazard index, the averaging time is the same as the exposure time (30 years).

The hazard index and cancer induction risk for a chemical are calculated using the formulas below. Separate calculations are made for inhalation, ingestion, and dermal intakes.

$$(\text{Hazard Index})_K = \frac{W_K T_{\text{EXP}}}{T_{\text{AVE,HI}} R_{\text{HI,K}}} \quad \text{and} \quad (\text{Cancer Risk})_K = \frac{W_K T_{\text{EXP}} R_{\text{IC,K}}}{T_{\text{AVE,IC}}}$$

where,

- $R_{\text{HI,K}}$  = reference dose for the Kth chemical from Table A31, in mg/kg per day
- $R_{\text{IC,K}}$  = cancer induction slope factor for the Kth chemical from Table A31, in risk per (mg/kg per day)
- $T_{\text{AVE,HI}}$  = averaging period for calculating hazard index. This is always the same as the exposure duration, in years, i.e.,  $T_{\text{AVE,HI}} = T_{\text{EXP}}$ .
- $T_{\text{AVE,IC}}$  = averaging period for calculating cancer risk, 70 years
- $T_{\text{EXP}}$  = exposure duration, i.e., the number of years the individual receives the average daily dose
- $W_K$  = average daily dose of the Kth chemical, in mg/kg per day

As part of this calculation, the concentration of the contaminants in soil is increased each year. The effect of leaching from the surface layer is included using the leaching coefficients shown in Table A38. The effect of volatilization removal from the surface layer is included using the emanation constants shown in Table A41.

The degradation of chemicals into other chemicals due to biotic and abiotic action in the environment is not included in the calculations. Some of the chemicals evaluated (eg Xylenes) are known to degrade with half lives less than 1 year. Moreover, the chemicals produced by degradation processes (eg Cr+6) may be more toxic than the original chemical (eg Cr+3). The omission of degradation is conventional in risk assessments due in part to the dearth of experimental data on this subject for most of the chemicals of interest.

The tables of hazard index and cancer risks per unit concentration in the water include the effects of leaching and volatilization from the surface layer of soil. The scenario calculations use decay and leaching factors very similar to the ones for radionuclides. During the irrigation season, the decay and leaching terms are replaced with volatilization and leaching terms. During the non-irrigation season, the decay terms are replaced with volatilization terms. Thus, the same formulas are used with the redefinition of the  $\lambda_K$  and  $\lambda_{R,K}$  terms shown below.

$$\lambda_K = \lambda_{\text{VIR,K}} + \lambda_{\text{S,K}} \quad \text{and} \quad \lambda_{R,K} = \lambda_{\text{Vno,K}}$$

where,

- $\lambda_K$  = total removal coefficient for the Kth chemical during the irrigation season, fraction removed from the surface layer of soil, per year
- $\lambda_{R,K}$  = total removal coefficient for the Kth chemical during the non-irrigation season, fraction removed from the surface layer of soil, per year

- $\lambda_{S,K}$  = average soil leaching coefficient for the Kth chemical, fraction removed from the surface layer of soil, per year (see Table A38)  
 $\lambda_{V,irr,K}$  = average soil emanation constant for the Kth chemical during the irrigation season (see Table A41)  
 $\lambda_{V,no,K}$  = average soil emanation constant for the Kth chemical during the non-irrigation season (see Table A41)

The factors that represent the average soil concentration during the period of interest are shown below. These factors are used in the equations for average daily intake (W) that follow. The  $F_{M,K}$  term represents continuous intakes, namely, soil ingestion, soil inhalation, and the portion of the milk, poultry, and egg intakes that come from soil ingested by the animal. The  $F_{V,K}$  term represents the intakes that occur following a harvest of garden produce, and animal fodder. It gives the portion of the intake due to indirect ingestion of contaminated soil. The cumulative factor ( $F_{CUM,K}$ ) is the same factor shown earlier for the calculation of lifetime cancer risks from radionuclides. It has been restated to show the more general form that allows calculation of cumulative intakes for any start and ending times ( $N_1$  and  $N_2$ ).

$$\begin{aligned}
 F_{M,K} &= F_{X,I,K} + F_{B,N,K} F_{CUM,K}(N_1, N_2) \\
 F_{V,K} &= F_{C,N,K} [1 + F_{CUM,K}(N_1, N_2)] \\
 F_{C,N,K} &= \frac{1 - \text{Exp}(-\lambda_K T_{irr})}{\lambda_K T_{irr}} \quad \text{and} \quad F_{no,K} = \frac{1 - \text{Exp}(-\lambda_{R,K} T_{no})}{\lambda_{R,K} T_{no}} \\
 F_{X,I,K} &= \frac{\lambda_K T_{irr} - 1 + \text{Exp}(-\lambda_K T_{irr})}{(1 y) \lambda_K^2 T_{irr}} + \left( \frac{T_{no}}{1 y} \right) F_{C,N,K} F_{no,K} \\
 F_{B,N,K} &= \left( \frac{T_{irr}}{1 y} \right) F_{C,N,K} + \left( \frac{T_{no}}{1 y} \right) \text{Exp}(-\lambda_K T_{irr}) F_{no,K} \\
 F_{IS,K} &= \frac{1 - \text{Exp}(-\lambda_K T_{irr})}{\lambda_K T_{irr}} \text{Exp}(-\lambda_{R,K} T_{no}) \quad \text{and} \quad F_{NS,K} = \text{Exp}(-\lambda_K T_{irr}) \text{Exp}(-\lambda_{R,K} T_{no}) \\
 F_{CUM,K}(N_1, N_2) &= \frac{F_{IS,K}}{1 - F_{NS,K}} \left[ 1 - \frac{(F_{NS,K})^{N_2} - (F_{NS,K})^{N_1}}{(N_2 - N_1)(1 - F_{NS,K})} \right]
 \end{aligned}$$

where,

- $F_{B,N,K}$  = factor that results from the time integral of the soil intake rate for the Kth chemical present in the soil at the start of the year (B=inhalation calculation, N=irrigation water is not contaminated, K=chemical index). The first portion is the sum during the irrigation season, while the second portion is the intake during the no-irrigation season. This is the same formula used earlier for the inhalation dose from radionuclides in soil.  
 $F_{C,N,K}$  = factor that represents the soil concentration of the Kth chemical at the end of the irrigation season, or, equivalently, the accumulated soil intake of the Kth chemical during the irrigation season from soil contamination present at the beginning of the year (C=chemical, N=irrigation water is not contaminated, K=chemical index)

- $F_{CUM,K}$  = cumulative average soil intake factor from residual soil contamination due to irrigation in prior years for the Kth chemical. The intake begins at the end of year  $N_1$  and concludes at the end of year  $N_2$ .
- $F_{IS,K}$  = fraction of the soil concentration added by irrigation during one year that is present at the end of that year
- $F_{M,K}$  = factor that results from the time integral of the soil intake rate for ingestion, inhalation, and dermal contact for the Kth chemical over the years  $N_1$  to  $N_2$ . The intake begins at the end of year  $N_1$  and concludes at the end of year  $N_2$ . Irrigation has been taking place since year zero. The irrigation water concentration is constant. Note that this factor is the average per year.
- $F_{no,K}$  = factor that results from the time integral of the soil intake rate for the Kth chemical during the non-irrigation period
- $F_{NS,K}$  = fraction of the soil concentration present at the beginning of a year that is present at the end of that year
- $F_{V,K}$  = factor that results from the time integral of the indirect intake of soil during consumption of vegetation and animal products for the Kth chemical over the years  $N_1$  to  $N_2$ . The intake begins at the end of year  $N_1$  and concludes at the end of year  $N_2$ . Irrigation has been taking place since year zero. The irrigation water concentration is constant. The plants are harvested at the end of the irrigation season. Note that this factor is the average per year.
- $F_{X,I,K}$  = factor that results from the time integral of the soil intake rate for the Kth chemical over the full year (X=external dose, I=irrigation water is contaminated, K=chemical index). The first portion is the sum during the irrigation season, while the second portion is the intake during the no-irrigation season. This is the same formula used earlier for the external dose from radionuclides in soil.
- $N_1, N_2$  = integers that indicate the start year and end year for the cumulative average soil concentration calculations. The first year of irrigation is specified using  $(N_1, N_2)=(0, 1)$ . The childhood years in certain HSRAM scenarios are specified using  $(N_1, N_2)=(0, 6)$ . The adult years are specified using  $(N_1, N_2)=(7, 30)$ .
- $T_{irr}$  = irrigation period (the 1<sup>st</sup> half of the year), 0.5 y
- $T_{no}$  = no irrigation period (the 2<sup>nd</sup> half of the year),  $T_{irr} + T_{no} = 1$  y
- $\lambda_K$  = total removal coefficient for the Kth chemical during the irrigation season, fraction removed from the surface layer of soil, per year
- $\lambda_{R,K}$  = total removal coefficient for the Kth chemical during the non-irrigation season, fraction removed from the surface layer of soil, per year

#### Inhalation Dose from Chemicals for the All Pathways Farmer

The average daily dose via inhalation is calculated from the sum of resuspended soil and volatilized water. The soil is contaminated by irrigation with contaminated water. Each year the soil concentration is greater than the year before. The water becomes volatilized during the shower. The annual intakes via inhalation are presented in Appendix A, Section A3.2. The formula used to calculate the average daily dose of the Kth chemical from inhalation is shown below.

$$W_{B,K} = \frac{C_{S,K} M_B F_{M,K} + C_{W,K} V_{AIR} \text{MIN}\left[0.5 \text{ L/m}^3, F_{SAT} (1000 \text{ L/m}^3) K_{UNITLESS,K}\right]}{(365 \text{ d/y}) M_{ADULT}}$$

where,

- $C_{S,K}$  = concentration of the Kth chemical in the surface soil, in mg/kg. This concentration includes the accumulation from prior years. The surface soil concentration is calculated from the water concentration as shown at the beginning of Section 3.3.
- $C_{W,K}$  = concentration of the Kth chemical in the water, in mg/L
- $F_{M,K}$  = factor that results from the time integral of the soil intake rate for inhalation for the Kth chemical from the start of irrigation to the end of the exposure duration, 30 y for the all pathways farmer [(N<sub>1</sub>,N<sub>2</sub>)=(0,30)]. The irrigation water concentration is assumed constant. Note that this factor is the average per year.
- $F_{SAT}$  = fraction of the upper limit concentration given by Henry's Law that is likely to be present on the average, 50% is assumed
- $K_{UNITLESS,K}$  = unitless Henry's Law constant for the Kth chemical. Values are listed in Table A3. Application to volatile chemicals is described in Section A3.2.
- $M_{ADULT}$  = mass of an adult, 70 kg
- $M_B$  = mass of soil inhaled during the year,  $5.39 \times 10^{-4}$  kg/y from Table A10
- MIN = function that returns the smaller of the two values. In this case, the air concentration has an upper limit of  $0.5 \text{ L/m}^3$ .
- $V_{AIR}$  = volume of air with volatilized chemicals inhaled in a year,  $8,094 \text{ m}^3/\text{y}$  from Table A14
- $W_{B,K}$  = average daily dose of the Kth chemical from inhalation, in mg/kg per day
- $0.5 \text{ L/m}^3$  = volatile chemical concentration in the air from the HSRAM, in liters of solution per cubic meter of air

### Ingestion Dose from Chemicals for the All Pathways Farmer

The average daily dose via ingestion is calculated from the sum of the contaminated soil ingested, the contaminated plant and animal produce ingested, and the contaminated water. The soil is contaminated by irrigation with contaminated water. Each year the soil concentration is greater than the year before. The intake from soil ingestion depends on the age of the individual. The adult soil ingestion rate ( $0.0365 \text{ kg/y}$ ) is used for the all pathways farmer the entire 30 years he is exposed. The garden produce is contaminated by root uptake, rain splash and direct deposition from the overhead irrigation. For chemicals there is only one plant type used as food for both people and animals. This crop is harvested at the end of the irrigation season. The total consumed by the all pathways farmer is 25% of  $190 \text{ kg/y}$ , or  $47.5 \text{ kg/y}$ . This excludes grains, which are not irrigated with contaminated water. The animal products (meat, milk, poultry, and eggs) are contaminated by the animal consuming contaminated soil, plants, and drinking water. The animal fodder uses the same model as the garden vegetables. The formula used to calculate the average daily dose of the Kth chemical from ingestion is shown below. The contribution from fish only applies when the Columbia River is the source of contaminated water.

$$W_{G,K} = \frac{C_{S,K} M_G + C_{V,K} M_V + \sum_q C_{A,q,K} M_{A,q} + C_{W,K} (V_G + B_{F,K} M_F)}{(365 \text{ d/y}) M_{ADULT}}$$

where,

- $B_{F,K}$  = transfer factor for the Kth chemical from water to fish from Table A35
- $C_{A,q,K}$  = concentration of the Kth chemical in animal product type q, in mg/kg
- $C_{S,K}$  = concentration of the Kth chemical in the surface soil, in mg/kg. This concentration includes the accumulation from prior years.
- $C_{V,K}$  = concentration of the Kth chemical in the plants consumed by both people and animals, in mg/kg wet weight
- $C_{W,K}$  = concentration of the Kth chemical in the water, in mg/L
- $M_{ADULT}$  = mass of an adult, 70 kg
- $M_{A,q}$  = mass of animal product type q eaten during the year, in kg/y. These amounts are 50% of the values shown in Table A4 under the heading "USDA".
- $M_F$  = total mass of contaminated fish eaten during the year, 3.29 kg/y. Half of the USDA average from Table A4 is used for the All Pathways Farmer when the contaminated water comes from the Columbia River.
- $M_G$  = mass of contaminated soil ingested during the year, 0.0365 kg/y from Table A8
- $M_V$  = mass of contaminated vegetables ingested during the year, 47.5 kg/y.
- q = index to the four types of animal products, i.e., meat, milk, poultry, and eggs
- $V_G$  = volume of contaminated drinking water consumed in a year, 545 L/y from Table A4
- $W_{G,K}$  = average daily dose of the Kth chemical from ingestion, in mg/kg per day

The concentration of the chemical in the plants is calculated using a simplified version of the model for radionuclides. One plant type represents all garden produce as well as the plants consumed by the animals. The root uptake factors are listed in Table A38. The dry-to-wet ratio is 0.2. For the rain splash calculation, the interception fraction is 50% and the transfer from plant surfaces to edible portions of the plant is 100%. The standing biomass is 2 kg/m<sup>2</sup> and the effective exposure time is calculated using a 60-day growing period. The formula used is shown below.

$$C_{V,K} = F_{V,K} C_{S,K} \left( F_{DRY} B_{V,K} + \frac{J_{SPLASH} F_{INT} F_{TRANS} T_W}{Y_V} \right) + \frac{0.25 ID_K F_{TRANS} T_W}{Y_V}$$

where,

- $B_{V,K}$  = soil-to-plant transfer factor for the Kth chemical from Table A38
- $C_{S,K}$  = concentration of the Kth chemical in irrigated soil at the end of the year with no decay or leaching, in mg/kg
- $C_{V,K}$  = chemical concentration in plants, in mg/kg wet weight
- $F_{DRY}$  = dry-to-wet ratio for plants, 0.2
- $F_{INT}$  = interception fraction for airborne soil on exposed surfaces of plants, 0.5
- $F_{TRANS}$  = translocation factor from exposed surfaces to the edible portion of plants, 1.0

- $F_{V,K}$  = factor that results from the time integral of the indirect intake of soil during consumption of vegetation for the Kth chemical from the start of irrigation to the end of the exposure duration, 30 y for the all pathways farmer. The irrigation water concentration is constant. The plants are harvested at the end of the irrigation season. Note that this factor is the average per year.  
 $ID_K$  = irrigation deposition rate for the Kth chemical during the irrigation season,  $\text{mg/m}^2$  per year (1 y = 365 d)  
 $J_{\text{SPLASH}}$  = average soil deposition rate due to rain splash (see Section A5.2),  $2.7 \times 10^{-4} \text{ kg/m}^2$  per day  
 $T_W$  = effective exposure time for contaminants deposited on the exposed surfaces of plants, 19.16 days. This is based on a growing period of 60 days and a weathering half time of 14 days.  
 $Y_V$  = standing biomass of the plants,  $2 \text{ kg(wet)/m}^2$

The concentration of a chemical in animal products is calculated a formula similar to that used for radionuclides. The transfer factors for chemicals into animal products are listed in Table A35.

$$C_{A,q,K} = B_{A,q,K} (C_{S,K} M_{S,q} F_{A,q,K} + C_{V,K} M_{V,q} + C_{W,K} V_{W,q})$$

where,

- $B_{A,q,K}$  = animal transfer factor for the Kth chemical into animal product type q from Table A35, in day/kg  
 $C_{A,q,K}$  = concentration of the Kth chemical in animal product type q, in mg/kg  
 $C_{S,K}$  = concentration of the Kth chemical in irrigated soil at the end of the year with no decay or leaching, in mg/kg  
 $C_{V,K}$  = chemical concentration in plants eaten by the animals, in mg/kg wet weight  
 $C_{W,K}$  = concentration of the Kth chemical in the irrigation water, in mg/L  
 $F_{A,q,K}$  = factor that results from the time integral of the indirect intake of soil during consumption of animal product q for the Kth chemical from the start of irrigation to the end of the exposure duration, 30 y for the all pathways farmer. The factor  $F_{V,K}$  is used for beef (slaughtered at the end of the irrigation season). The factor  $F_{M,K}$  is used for milk, poultry, and eggs (collected and eaten continuously during the year).  
 $M_{S,q}$  = daily mass of soil ingested by animal type q in Table A32, in kg/d  
 $M_{V,q}$  = daily mass of animal fodder eaten by animal type q, in kg (wet)/d. These amounts are shown in Table A32.  
q = index to the four types of animal products, i.e., meat, milk, poultry, and eggs  
 $V_{W,q}$  = daily volume of water ingested by animal type q from Table A32, in L/d

#### Dermal Absorption of Chemicals for the All Pathways Farmer

The average daily dose via dermal absorption is calculated from the estimated contact with soil and water presented in Section A3.4.2. There are no reference doses or slope factors for dermal absorption, so the ingestion values are used in their place. Because the ingestion factors deal with unit amounts entering the mouth, and the dermal absorption intakes estimate the amounts entering body fluids, the dermal intakes are divided by the GI absorption factor (f1). The formula used to calculate the average daily dose of the Kth chemical from dermal absorption

is shown below. Note that the permeability coefficient is usually represented with the symbol  $K_p$ . A different symbol ( $U_D$ ) is used here to avoid confusion with the chemical index  $K$ .

$$W_{D,K} = \frac{C_{S,K} M_D F_{D,K} F_{M,K} + C_{W,K} V_D U_{D,K}}{(365 \text{ d/y}) M_{ADULT} (f1)_K}$$

where,

- $C_{S,K}$  = concentration of the Kth chemical in the surface soil, in mg/kg. This concentration includes the accumulation from prior years.
- $C_{W,K}$  = concentration of the Kth chemical in the water, in mg/L
- $(f1)_K$  = GI absorption factor, the fraction of the material ingested that is absorbed into body fluids (see Table A20)
- $F_{D,K}$  = dermal absorption factors from Table A20 for contact with soil
- $F_{M,K}$  = factor that results from the time integral of the soil intake rate for dermal contact for the Kth chemical from the start of irrigation to the end of the exposure duration, 30 y for the all pathways farmer. Note that this factor is the average per year.
- $M_{ADULT}$  = mass of an adult, 70 kg
- $M_D$  = mass of contaminated absorbed through the skin during the year, 0.225 kg/y from Table A18
- $U_{D,K}$  = permeability coefficient for dermal absorption of the Kth chemical in water solution in contact with the skin, in cm/h. Values are listed in Table A20.
- $V_D$  = volume of contaminated drinking water absorbed through the skin in a year, 1,825 L/y per cm/h from Table A19
- $W_{D,K}$  = average daily dose of the Kth chemical from dermal absorption, in mg/kg per day. These are adjusted by the GI absorption factors  $(f1)_K$  so they can be used with the ingestion reference dose and cancer slope factors.

#### Hazard Index and Increased Cancer Risk for the All Pathways Farmer -- Chemicals

The calculated hazard index and cancer risk per unit concentration in the well or the Columbia River for the All Pathways Farmer are shown in Table 15. These factors are calculated from the sums of the inhalation, ingestion, and dermal absorption intakes, as shown in the equation below. The factors must be multiplied by the estimated water concentration in the contaminated water, in mg per L.

$$W_K = W_{B,K} + W_{G,K} + W_{D,K}$$

**Table 15. Unit Factors for Hazard Index and Cancer Risk for Chemicals in 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	6.97E-01 d	na	4.93E+00 d
53-70-3	Dibenz[a,h]anthracene	na	1.61E+00	na	1.43E+01
56-23-5	Carbon tetrachloride	3.95E+01 b	5.10E-03	4.51E+01 b	5.32E-03
57-12-5	Cyanide, free	4.69E+02 b	na	4.69E+02 b	na

**Table 15. Unit Factors for Hazard Index and Cancer Risk for Chemicals in 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
57-14-7	1,1-Dimethylhydrazine	na	4.58E+00	na	4.58E+00
57-55-6	Propylene glycol (1,2-Propanediol)	5.72E-02 b	na	5.73E-02 b	na
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)	1.92E+02 b	3.20E-02 d	2.57E+02 b	4.29E-02 d
60-34-4	Methylhydrazine	na	3.43E+00	na	3.43E+00
60-57-1	Dieldrin	8.66E+02 b	7.43E-01	8.29E+03 b	3.29E+00
62-75-9	N-Nitrosodimethylamine	na	3.69E+01	na	3.69E+01
64-18-6	Formic acid	4.82E-01 b	na	4.82E-01 b	na
67-56-1	Methanol (Methyl alcohol)	1.23E+00 b	na	1.23E+00 b	na
67-64-1	Acetone (2-Propanone)	1.98E+00 b	na	1.99E+00 b	na
67-66-3	Chloroform	3.11E+00 b	5.48E-03	3.19E+00 b	5.48E-03
71-36-3	n-Butyl alcohol (n-Butanol)	1.05E+00 b	na	1.05E+00 b	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)	3.91E-01	na	4.02E-01	na
72-20-8	Endrin	3.99E+02 b	na	1.32E+03 b	na
74-83-9	Bromomethane	1.36E+02	na	1.36E+02	na
74-87-3	Methyl chloride (Chloromethane)	6.16E+00 a	na	6.16E+00 a	na
75-00-3	Ethyl Chloride	5.54E-02 a	na	5.54E-02 a	na
75-01-4	Vinyl chloride (Chloroethene)	1.58E+01	2.06E-02	1.60E+01	2.08E-02
75-05-8	Acetonitrile	9.26E+00 a	na	9.26E+00 a	na
75-07-0	Acetaldehyde	6.16E+01 a	5.23E-04 c	6.16E+01 a	5.23E-04 c
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	1.11E-02 a	na	1.11E-02 a	na
75-68-3	Chloro-1,1-difluoroethane, 1-	1.11E-02 a	na	1.11E-02 a	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	1.43E+02 b	4.46E-01	2.70E+03 b	2.91E+00
78-87-5	1,2-Dichloropropane	1.39E+02 a	na	1.39E+02 a	na
78-93-3	Methyl ethyl ketone (2-Butanone)	7.65E-01	na	7.66E-01	na
79-00-5	1,1,2-Trichloroethane	9.16E+00 b	4.70E-03	9.34E+00 b	4.71E-03
79-01-6	Trichloroethylene	5.22E+00 b	5.51E-04	5.53E+00 b	5.60E-04
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)	na	1.69E-02	na	1.71E-02
82-68-8	Pentachloronitrobenzene (PCNB)	1.18E+01 b	3.93E-03 d	4.39E+01 b	1.47E-02 d
83-32-9	Acenaphthene	8.48E-01 b	na	1.30E+00 b	na

**Table 15. Unit Factors for Hazard Index and Cancer Risk for Chemicals in 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
84-66-2	Diethyl phthalate	1.14E-01 b	na	1.17E-01 b	na
84-74-2	Dibutyl phthalate	3.73E-01 b	na	1.13E+00 b	na
85-68-7	Butyl benzyl phthalate	2.13E-01 b	na	7.85E-01 b	na
87-68-3	Hexachlorobutadiene	1.74E+02 b	6.39E-03	7.89E+02 b	1.05E-02
87-86-5	Pentachlorophenol	1.42E+00 b	2.19E-03 d	4.44E+00 b	6.84E-03 d
88-06-2	2,4,6-Trichlorophenol	na	3.32E-04	na	3.68E-04
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)	9.72E+01 b	na	1.16E+02 b	na
91-20-3	Naphthalene	1.87E+02	na	1.87E+02	na
92-52-4	1,1'-Biphenyl	8.79E-01 b	na	1.48E+00 b	na
95-50-1	1,2-Dichlorobenzene (ortho-)	3.42E-01 b	na	4.67E-01 b	na
95-63-6	1,2,4-Trimethylbenzene	9.33E+01	na	9.36E+01	na
98-86-2	Acetophenone	1.12E+00 b	na	1.12E+00 b	na
98-95-3	Nitrobenzene	4.73E+02	na	4.75E+02	na
100-25-4	1,4-Dinitrobenzene (para-)	2.25E+03 b	na	2.26E+03 b	na
100-41-4	Ethyl benzene	8.53E-01	na	9.21E-01	na
100-42-5	Styrene	7.13E-01	na	7.38E-01	na
100-51-6	Benzyl alcohol	6.09E-01 b	na	6.09E-01 b	na
106-46-7	1,4-Dichlorobenzene (para-)	6.92E-01 a	3.10E-04 d	6.92E-01 a	4.28E-04 d
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	2.77E+03 a	1.59E+00	2.77E+03 a	1.62E+00
106-99-0	1,3-Butadiene	2.77E+02 a	7.13E-03 c	2.77E+02 a	7.13E-03 c
107-02-8	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)	na	7.64E-03	na	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)	1.85E-01 a	na	1.85E-01 a	na
108-67-8	1,3,5-Trimethylbenzene	9.33E+01	na	9.35E+01	na
108-87-2	Methyl cyclohexane	1.85E-01 a	na	1.85E-01 a	na
108-88-3	Toluene (Methyl benzene)	1.54E+00	na	1.55E+00	na
108-90-7	Chlorobenzene	2.94E+01	na	2.96E+01	na
108-94-1	Cyclohexanone	3.59E-02 b	na	3.60E-02 b	na
108-95-2	Phenol (Carbolic acid)	1.02E+00 b	na	1.02E+00 b	na
110-00-9	Furan (Oxacyclopentadiene)	3.65E+01 b	na	3.68E+01 b	na
110-54-3	n-Hexane	3.45E+00	na	3.88E+00	na
110-86-1	Pyridine	2.60E+02 b	na	2.60E+02 b	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)	3.70E-01 b	na	3.70E-01 b	na
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)	9.22E+01 b	1.11E-02 d	9.45E+01 b	1.13E-02 d
117-84-0	Di-n-octylphthalate	2.38E+02 b	na	2.39E+02 b	na
118-74-1	Hexachlorobenzene	7.53E+01 b	1.51E-01	9.05E+02 b	6.06E-01

**Table 15. Unit Factors for Hazard Index and Cancer Risk for Chemicals in 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
120-82-1	1,2,4-Trichlorobenzene	5.94E+00	na	9.14E+00	na
121-44-8	Triethylamine	7.92E+01 a	na	7.92E+01 a	na
122-39-4	Diphenylamine	4.16E+00 b	na	4.84E+00 b	na
123-91-1	1,4-Dioxane (Diethylene oxide)	na	1.44E-03 d	na	1.44E-03 d
126-73-8	Tributyl Phosphate	3.36E-01 b	1.55E-04 d	3.83E-01 b	1.75E-04 d
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)	1.51E+03	na	1.51E+03	na
127-18-4	1,1,2,2-Tetrachloroethylene	3.69E+00	7.54E-04	4.76E+00	9.92E-04
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	8.01E-02 b	na	8.05E-02 b	na
156-59-2	cis-1,2-Dichloroethylene	3.11E+00 b	na	3.18E+00 b	na
206-44-0	Fluoranthene (1,2-Benzacenaphthene)	2.44E+00 b	na	8.56E+00 b	na
309-00-2	Aldrin	5.57E+03 b	2.38E+00	9.23E+04 b	2.13E+01
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	na	3.54E-01	na	4.14E-01
319-85-7	beta-Benzene hexachloride (beta-Lindane)	na	4.65E-02	na	6.33E-02
621-64-7	N-Nitrosodi-N-propylamine	na	1.03E+00 d	na	1.04E+00 d
1314-62-1	Vanadium pentoxide	3.77E+00 b	na	7.04E+00 b	na
1330-20-7	Xylenes (mixtures)	5.69E+00	na	5.72E+00	na
1336-36-3	Polychlorinated Biphenyls (high risk)	na	9.23E-02 d	na	6.49E+00 d
1336-36-3	Polychlorinated Biphenyls (low risk)	na	1.85E-02 d	na	1.30E+00 d
1336-36-3	Polychlorinated Biphenyls (lowest risk)	na	3.23E-03 d	na	2.27E-01 d
6533-73-9	Thallium carbonate	6.44E+02 b	na	1.68E+04 b	na
7429-90-5	Aluminum	1.11E+02	na	1.11E+02	na
7439-96-5	Manganese	1.11E+04 e	na	1.11E+04 e	na
7439-98-7	Molybdenum	3.85E+01 b	na	3.90E+01 b	na
7440-02-0	Nickel (soluble salts)	4.15E+00 b	na	4.97E+00 b	na
7440-22-4	Silver	7.36E+00 b	na	8.17E+00 b	na
7440-24-6	Strontium, Stable	3.53E-01 b	na	3.72E-01 b	na
7440-31-5	Tin	1.23E-01 b	na	7.73E-01 b	na
7440-36-0	Antimony	8.28E+01 b	na	1.34E+02 b	na
7440-38-2	Arsenic (inorganic)	1.13E+02 b	1.05E+00	2.29E+02 b	1.07E+00
7440-39-3	Barium	1.11E+03	na	1.11E+03	na
7440-41-7	Beryllium and compounds	2.78E+04	5.70E-01 c	2.78E+04	5.70E-01 c
7440-42-8	Boron and borates only	3.14E+01	na	3.14E+01	na
7440-43-9	Cadmium	1.15E+02 bf	4.28E-01 c	3.02E+02 bf	4.28E-01 c
7440-48-4	Cobalt	2.77E+04	6.65E-01 c	2.77E+04	6.65E-01 c
7440-66-6	Zinc and compounds	6.81E+01 b	na	6.82E+01 b	na
7487-94-7	Mercuric chloride	1.32E+03 b	na	1.76E+03 b	na
7664-41-7	Ammonia	7.81E-01 a	na	7.81E-01 a	na
7723-14-0	Phosphorus, white	1.10E+05 b	na	1.20E+05 b	na
7782-41-4	Fluorine (soluble fluoride)	1.84E+00 b	na	1.91E+00 b	na
7782-49-2	Selenium and compounds	1.31E+01 b	na	1.76E+01 b	na

**Table 15. Unit Factors for Hazard Index and Cancer Risk for Chemicals in 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
8001-35-2	Toxaphene	na	4.61E-02	na	3.89E-01
14797-55-8	Nitrate	1.35E-02 b	na	1.39E-02 b	na
14797-65-0	Nitrite	2.16E-01 b	na	2.22E-01 b	na
16065-83-1	Chromium (III) (insoluble salts)	2.81E-02 b	na	5.76E-02 b	na
18540-29-9	Chromium (VI) (soluble salts)	1.11E+01 g	8.89E-05 c	1.98E+01 g	8.89E-05 c
none	Uranium (soluble salts)	5.49E+01 b	na	5.92E+01 b	na

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.
- Results using route-to-route extrapolations are shown in Table C3. Results with notes (a, b, c, d, e, f, or g) have the following qualifiers:
  - (a) -- The RfD for ingestion was not available.
  - (b) -- The RfD for inhalation was not available.
  - (c) -- The Slope Factor for ingestion was not available.
  - (d) -- The Slope Factor for inhalation was not available.
  - (e) -- For manganese (7439-96-5) the drinking water has a lower RfD.
  - (f) -- For cadmium (7440-43-9) the food has a larger RfD.
  - (g) -- For chromium VI (18540-29-9) the airborne particulate has a larger RfD.

As noted in Table 15, the missing toxicity parameters were not used in the calculation. Appendix C contains unit factors calculated if the missing parameters are estimated from the given parameter (eg, estimating the inhalation reference dose from the ingestion reference dose). In some cases, the increase in hazard quotient or cancer risk is appreciable.

### 3.6 NATIVE AMERICAN

This scenario assumes that some of the waste materials have migrated into the ground water or may be present in the Columbia River. A Native American uses contaminated water from either a well (ground water only case) or the Columbia River to raise various foods. The consumption parameters are increased to represent a bounding individual. In place of showering, the Native American spends time in a sweat lodge in which contaminated water is poured onto hot rocks and flashes to steam. If the Columbia River is the source of contaminated water, then consumption of fish, deer, waterfowl, and waterfowl eggs, exposure to shoreline sediments, and dermal contact during swimming are additional sources of exposure. The present scenario is patterned closely after the Native American Subsistent Resident (NASR) scenario presented in the Columbia River Comprehensive Impact Assessment (CRCIA) (DOE/RL-96-16 Section 5.1.4.1). An alternate representation of the NASR is found in a paper by Harris and Harper (1997). The two scenarios have the same drinking water and fish intakes. Since these are the largest component of the risk, the relatively minor differences in the other scenario parameters

have little effect on the total dose. The NASR scenario parameters presented in the CRCIA will be used in this section.

The same equations used for the All Pathways Farmer also apply to the Native American. The difference is the parameter values for the various intakes. The tables in Appendix A list the annual intakes and times for each exposure scenario. The calculation of the first year radiological dose will be presented first. Then the lifetime increase in the risk of acquiring some type of cancer from either radioactive materials or chemical toxins will be presented.

The Native American food consumption rates are shown in Table A4. In the ground water case, the Native American has a well and uses ground water for drinking and to irrigate garden and pastures. All of this individual's diet is grown using the contaminated ground water. The soil ingestion rate is summarized in Table A8. The inhalation rates for soil and water are summarized in Tables A10 and A13. The external exposure times are given in Table A15.

When the Columbia River is the contaminated water source, there are additional pathways not discussed in the All Pathways Scenario, namely, deer and waterfowl. The deer and waterfowl drink from the Columbia River and thus ingest some contamination. Most of the solid food they consume is uncontaminated. Thus, the concentration in the deer or waterfowl is the product of the water concentration, the water intake rate, and the equilibrium transfer factor. Deer are assumed to drink 25% the daily volume of a milk cow, or 15 L/d. Waterfowl are assumed to drink at the same rate as a chicken, or 0.3 L/d. The transfer factors for beef shown in Table A33 and A35 are used to estimate the concentration in deer meat. The transfer factors for poultry and eggs are used to estimate the concentration in waterfowl and waterfowl eggs. It should be noted that these are minor contributors to the total dose. Thus efforts spent to fine-tune the assumed values will have little effect on the resulting dose or risk or hazard index.

Scenario dose factors for the Native American cases are presented in Table 16 as the dose equivalent in mrem per pCi/L in the water. These unit dose factors must be multiplied by the water concentration to calculate the actual dose. The radiation dose to the Native American is the 50 year committed effective dose equivalent from one year of exposure. The first column shows the dose factors for the inland well case. The second column of dose factors includes the fish and deer based on contamination in the Columbia River. The column labeled "Ratio" is the dose factor for the Columbia River case divided by the dose factor for the inland well case. Large ratios mean the additional pathways for the river are major contributors to the total. In most cases this is a result of the dose from fish intake. Additional detail on the doses by pathway is shown in Appendix D.

**Table 16. Unit Dose Factors for the Native American (mrem/y per pCi/L).**

Nuclide	Ground Water	Columbia River	Ratio	Nuclide	Ground Water	Columbia River	Ratio
H-3	1.04E-04	1.19E-04	1.1	Gd-152	1.13E+01	1.21E+01	
Be-10	2.28E-02	1.15E-01	5.1	Ho-166m	6.73E-02	1.63E+00	24.2
C-14	1.10E-02	2.06E+01	1,875	Re-187	2.15E-05	2.47E-04	11.5
Na-22	9.99E-02	4.79E-01	4.8	Tl-204	8.80E-03	6.63E+00	753
Al-26	5.42E-02	3.95E+00	72.8	Pb-205	2.60E-03	9.92E-02	38.1

**Table 16. Unit Dose Factors for the Native American (mrem/y per pCi/L).**

Nuclide	Ground Water	Columbia River	Ratio	Nuclide	Ground Water	Columbia River	Ratio
Si-32+D	6.28E-02	1.09E-01	1.7	Pb-210+D	8.77E+00	3.27E+02	37.3
Cl-36	8.00E-02	1.10E-01	1.4	Bi-207	2.70E-02	1.15E+00	42.6
K-40	7.13E-02	3.83E+00	53.8	Po-209	4.52E+00	2.82E+01	6.2
Ca-41	3.03E-03	1.32E-02	4.3	Po-210	3.46E+00	2.23E+01	6.4
Ti-44+D	1.54E-01	6.74E+00	43.8	Ra-226+D	2.73E+00	1.78E+01	6.5
V-49	1.05E-04	2.52E-03	24.1	Ra-228+D	2.72E+00	1.78E+01	6.5
Mn-54	1.16E-02	2.76E-01	23.9	Ac-227+D	1.00E+02	1.75E+02	1.7
Fe-55	1.15E-03	2.51E-02	21.9	Th-228+D	1.67E+01	3.29E+01	2.0
Fe-60+D	2.91E-01	7.78E+00	26.7	Th-229+D	8.50E+01	1.65E+02	1.9
Co-60	7.59E-02	2.43E+00	32.0	Th-230	1.27E+01	2.36E+01	1.9
Ni-59	1.18E-03	5.34E-03	4.5	Th-232	5.63E+01	1.12E+02	2.0
Ni-63	3.22E-03	1.47E-02	4.6	Pa-231	7.33E+01	9.61E+01	1.3
Se-79	2.68E-02	3.20E-01	11.9	U-232	2.72E+00	6.13E+00	2.3
Rb-87	2.39E-02	1.96E+00	82.0	U-233	8.12E-01	1.41E+00	1.7
Sr-90+D	3.78E-01	2.20E+00	5.8	U-234	7.98E-01	1.38E+00	1.7
Zr-93	6.13E-03	1.04E-01	17.1	U-235+D	7.48E-01	1.37E+00	1.8
Nb-91	9.04E-04	3.37E-02	37.3	U-236	7.56E-01	1.31E+00	1.7
Nb-93m	8.79E-04	3.18E-02	36.2	U-238+D	7.37E-01	1.30E+00	1.8
Nb-94	3.02E-02	1.85E+00	61.4	Np-237+D	3.09E+01	4.99E+01	1.6
Mo-93	3.98E-03	6.83E-03	1.7	Pu-236	8.25E+00	1.31E+01	1.6
Tc-99	4.23E-03	1.01E-02	2.4	Pu-238	2.24E+01	3.60E+01	1.6
Ru-106+D	6.69E-02	1.36E-01	2.0	Pu-239	2.45E+01	3.96E+01	1.6
Pd-107	1.17E-03	1.48E-03	1.3	Pu-240	2.45E+01	3.96E+01	1.6
Ag-108m+D	3.17E-02	1.36E+00	43.0	Pu-241+D	4.72E-01	7.67E-01	1.6
Cd-109	2.70E-02	5.44E-01	20.1	Pu-242	2.35E+01	3.78E+01	1.6
Cd-113m	3.43E-01	6.70E+00	19.5	Pu-244+D	2.30E+01	3.75E+01	1.6
In-115	4.22E-01	3.11E+03	7,373	Am-241	2.54E+01	4.09E+01	1.6
Sn-121m+D	7.58E-03	1.34E+00	177	Am-242m+D	2.44E+01	3.94E+01	1.6
Sn-126+D	9.35E-02	1.43E+01	153	Am-243+D	2.52E+01	4.08E+01	1.6
Sb-125	9.06E-03	1.37E-01	15.1	Cm-242	9.48E-01	1.43E+00	1.5
Te-125m	6.01E-03	2.95E-01	49.1	Cm-243	1.75E+01	2.82E+01	1.6
I-129	1.23E+00	3.44E+00	2.8	Cm-244	1.41E+01	2.27E+01	1.6
Cs-134	3.23E-01	2.94E+01	91.0	Cm-245	2.60E+01	4.20E+01	1.6
Cs-135	3.12E-02	2.82E+00	90.4	Cm-246	2.58E+01	4.15E+01	1.6
Cs-137+D	2.26E-01	2.03E+01	89.9	Cm-247+D	2.37E+01	3.86E+01	1.6
Ba-133	9.52E-03	1.75E-01	18.4	Cm-248	9.44E+01	1.52E+02	1.6
Pm-147	3.35E-03	9.58E-03	2.9	Cm-250+D	5.38E+02	8.69E+02	1.6
Sm-147	3.68E+00	4.62E+00	1.3	Bk-247	3.28E+01	5.66E+01	1.7
Sm-151	1.95E-03	3.91E-03	2.0	Cf-248	2.52E+00	4.17E+00	1.7
Eu-150	3.87E-02	1.19E+00	30.8	Cf-249	3.34E+01	5.76E+01	1.7
Eu-152	3.27E-02	7.24E-01	22.1	Cf-250	1.51E+01	2.58E+01	1.7
Eu-154	4.13E-02	6.82E-01	16.5	Cf-251	3.41E+01	5.86E+01	1.7
Eu-155	4.55E-03	2.94E-02	6.5	Cf-252	7.85E+00	1.32E+01	1.7

**Table 16. Unit Dose Factors for the Native American (mrem/y per pCi/L).**

Nuclide	Ground Water	Columbia River	Ratio	Nuclide	Ground Water	Columbia River	Ratio
Notes:							
<ul style="list-style-type: none"> <li>The radiation dose to this individual is the 50 year committed effective dose equivalent from one year of exposure.</li> <li>These scenario dose factors must be multiplied by the appropriate water concentration. The "Ground Water" column assumes all the contaminated water comes from the well. The "Columbia River" column assumes all the contaminated water comes from the Columbia River.</li> <li>The "Ratio" column is the "Columbia River" divided by the "Ground Water" factors.</li> </ul>							

The increase in cancer risk from lifetime exposure to radionuclides for the Native American is calculated using the same equations presented for the all pathways farmer. The difference is the calculation of the cumulative cancer risk from 70 years of contamination. No adjustment is made for the different intake rates and body mass of children and adults. The adult consumption parameters are used for the entire 70 years. Two reasons for omitting the child portion of the exposure are (1) absence of Native American child intake rates, and (2) the cancer risk coefficients from Federal Guidance Report Number 13 (EPA-402-R-99-001) already include consideration of the higher sensitivity of children.

The estimated increased risk for radioactive materials in the Native American scenarios is shown in Table 17. The first column of risks shows the inland resident, who obtains the radionuclides from ground water. The second column of risks shows the Columbia River case, in which the radionuclides are in the surface water. The third column is the ratio of the Columbia River to the inland resident risk factors. If the two risk factors are within 10%, they are not shown. Large ratios mean the additional pathways for the river are major contributors to the total. In most cases this is a result of the dose from fish intake.

**Table 17. Unit Risk Factors for Radionuclides in the Native American Scenarios (lifetime risk per pCi/L).**

Nuclide	Inland Well	Columbia River	Ratio	Nuclide	Inland Well	Columbia River	Ratio
H-3	1.38E-08	1.61E-08	1.2	Gd-152	3.26E-05	4.73E-05	1.5
Be-10	1.12E-06	1.57E-05	14.0	Ho-166m	5.56E-05	2.89E-04	5.2
C-14	1.31E-06	1.38E-03	1,054	Re-187	8.34E-09	5.17E-08	6.2
Na-22	1.34E-05	3.71E-05	2.8	Tl-204	1.33E-06	1.14E-03	854
Al-26	9.80E-05	6.93E-04	7.1	Pb-205	7.76E-08	3.52E-06	45.4
Si-32+D	2.80E-06	8.25E-06	3.0	Pb-210+D	1.40E-04	5.09E-03	36.4
Cl-36	3.97E-05	4.28E-05		Bi-207	3.34E-05	1.60E-04	4.8
K-40	2.15E-05	5.04E-04	23.5	Po-209	2.23E-04	2.19E-03	9.8
Ca-41	1.90E-07	4.36E-07	2.3	Po-210	1.46E-04	1.70E-03	11.7
Ti-44+D	6.59E-05	8.14E-04	12.4	Ra-226+D	1.67E-04	8.32E-04	5.0
V-49	1.43E-08	5.08E-07	35.6	Ra-228+D	1.80E-04	1.24E-03	6.9
Mn-54	1.24E-06	2.12E-05	17.1	Ac-227+D	5.06E-04	7.64E-04	1.5
Fe-55	1.26E-07	3.33E-06	26.4	Th-228+D	4.93E-04	1.09E-03	2.2
Fe-60+D	9.97E-05	1.09E-03	11.0	Th-229+D	7.73E-04	1.83E-03	2.4
Co-60	1.93E-05	1.63E-04	8.5	Th-230	1.02E-04	2.75E-04	2.7
Ni-59	1.70E-07	7.24E-07	4.3	Th-232	2.28E-04	7.99E-04	3.5

**Table 17. Unit Risk Factors for Radionuclides in the Native American Scenarios (lifetime risk per pCi/L).**

Nuclide	Inland Well	Columbia River	Ratio	Nuclide	Inland Well	Columbia River	Ratio
Ni-63	4.06E-07	1.75E-06	4.3	Pa-231	1.56E-04	2.41E-04	1.5
Se-79	1.99E-06	2.48E-05	12.5	U-232	1.24E-04	2.45E-04	2.0
Rb-87	6.41E-06	2.02E-04	31.5	U-233	4.61E-05	6.06E-05	1.3
Sr-90+D	4.10E-05	1.22E-04	3.0	U-234	4.53E-05	5.96E-05	1.3
Zr-93	1.46E-07	6.19E-06	42.3	U-235+D	4.34E-05	6.28E-05	1.4
Nb-91	1.35E-07	5.17E-06	38.3	U-236	4.19E-05	5.54E-05	1.3
Nb-93m	9.65E-08	4.96E-06	51.4	U-238+D	4.13E-05	6.03E-05	1.5
Nb-94	5.20E-05	3.13E-04	6.0	Np-237+D	6.91E-05	1.13E-04	1.6
Mo-93	1.20E-06	1.83E-06	1.5	Pu-236	8.17E-05	1.13E-04	1.4
Tc-99	4.67E-06	5.79E-06	1.2	Pu-238	1.21E-04	1.75E-04	1.4
Ru-106+D	8.53E-06	1.79E-05	2.1	Pu-239	1.21E-04	1.78E-04	1.5
Pd-107	1.24E-07	1.88E-07	1.5	Pu-240	1.21E-04	1.78E-04	1.5
Ag-108m+D	4.46E-05	2.16E-04	4.8	Pu-241+D	1.27E-06	2.08E-06	1.6
Cd-109	7.17E-07	1.92E-05	26.8	Pu-242	1.14E-04	1.68E-04	1.5
Cd-113m	5.20E-06	1.06E-04	20.4	Pu-244+D	1.20E-04	2.31E-04	1.9
In-115	5.57E-06	5.97E-02	10,720	Am-241	1.01E-04	1.46E-04	1.4
Sn-121m+D	1.15E-06	2.13E-04	185	Am-242m+D	5.86E-05	9.14E-05	1.6
Sn-126+D	7.24E-05	1.97E-03	27.3	Am-243+D	1.03E-04	1.69E-04	1.6
Sb-125	1.93E-06	1.46E-05	7.6	Cm-242	5.23E-05	6.82E-05	1.3
Te-125m	4.41E-07	2.64E-05	59.9	Cm-243	9.79E-05	1.43E-04	1.5
I-129	8.68E-05	1.97E-04	2.3	Cm-244	8.97E-05	1.23E-04	1.4
Cs-134	1.93E-05	1.45E-03	75.2	Cm-245	1.02E-04	1.53E-04	1.5
Cs-135	3.14E-06	1.65E-04	52.7	Cm-246	9.96E-05	1.42E-04	1.4
Cs-137+D	2.79E-05	1.10E-03	39.6	Cm-247+D	1.01E-04	1.87E-04	1.9
Ba-133	4.29E-06	1.58E-05	3.7	Cm-248	3.57E-04	5.14E-04	1.4
Pm-147	2.50E-07	1.28E-06	5.1	Cm-250+D	2.01E-03	2.96E-03	1.5
Sm-147	2.64E-05	4.45E-05	1.7	Bk-247	1.20E-04	1.90E-04	1.6
Sm-151	8.36E-08	3.90E-07	4.7	Cf-248	6.28E-05	8.44E-05	1.3
Eu-150	3.19E-05	1.57E-04	4.9	Cf-249	1.33E-04	2.35E-04	1.8
Eu-152	1.63E-05	7.56E-05	4.6	Cf-250	9.50E-05	1.35E-04	1.4
Eu-154	1.38E-05	6.45E-05	4.7	Cf-251	1.27E-04	2.03E-04	1.6
Eu-155	4.27E-07	2.84E-06	6.6	Cf-252	5.53E-05	7.72E-05	1.4

**Notes:**

- The excess cancer 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 risk factors must be multiplied by the appropriate water concentration. The “Ground Water” column assumes all the contaminated water comes from the well. The “Columbia River” column assumes all the contaminated water comes from the Columbia River.
- The “Ratio” column is the “Columbia River” divided by the “Ground Water” factors. Blank entries indicate the two risk factors are within 10 percent of each other.

For chemicals, the dermal absorption pathways are included. The Native American spends a total of 182 hours swimming in the Columbia River during the year in addition to 365 h/y in

the sweat lodge. Dermal contact with shoreline sediments (270 d/y) and dermal contact with irrigated farmland (365 d/y) is also included. Section A3.4 discusses dermal absorption.

The hazard index and cancer risk from chemicals are calculated using the consumption parameters discussed in Appendix A for the Native American. The contaminant concentration in well or river water is expressed in mg/L. The chemical dose is normalized to the average adult body mass, 70 kg. To calculate the average daily dose over a lifetime, the total dose from 70 consecutive years is calculated and then divided by (70 y)(365 d/y). Because the exposure period is the same as the lifetime averaging period for the Native American (70 y), the average daily dose used in the hazard quotient calculation is the same as the lifetime average daily dose used in the cancer risk calculation. As part of this calculation, the concentration of the contaminants in soil is increased each year. The effect of leaching from the surface layer is included using the leaching coefficients shown in Table A38.

The hazard quotients and increased in cancer risk for the Native American are calculated using the same equations presented for the all pathways farmer. The difference is the calculation of the cumulative cancer risk from 70 years of contamination. No adjustment is made for the different intake rates and body mass of children and adults. The adult consumption parameters are used for the entire 70 years. Two reasons for omitting the child portion of the exposure are (1) absence of Native American child intake rates, and (2) the reference doses and cancer slope factors already include consideration of the higher sensitivity of children.

The calculated hazard index and cancer risk per unit concentration in the well or the Columbia River for the Native American are shown in Table 18. The factors must be multiplied by the estimated water concentration in the contaminated water, in mg per L. As noted in the notes to Table 18, the missing toxicity parameters were ignored in the calculation. Appendix C contains unit factors using a simple estimation of the missing parameters, as well as a comparison of the unit factors using the two approaches.

**Table 18. Unit Factors for Hazard Index and Cancer Risk for Chemicals in 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 d	na	6.14E+02 d
53-70-3	Dibenz[a,h]anthracene	na	2.26E+01	na	1.81E+03
56-23-5	Carbon tetrachloride	1.01E+02 b	2.09E-02	4.41E+02 b	5.19E-02
57-12-5	Cyanide, free	2.99E+03 b	na	3.06E+03 b	na
57-14-7	1,1-Dimethylhydrazine	na	3.85E+01	na	3.86E+01
57-55-6	Propylene glycol (1,2-Propanediol)	2.04E-01 b	na	2.06E-01 b	na
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)	6.86E+02 b	2.67E-01 d	5.06E+03 b	1.93E+00 d
60-34-4	Methylhydrazine	na	2.88E+01	na	2.89E+01
60-57-1	Dieldrin	2.88E+03 b	3.75E+00	4.55E+05 b	3.64E+02
62-75-9	N-Nitrosodimethylamine	na	3.09E+02	na	3.10E+02
64-18-6	Formic acid	1.72E+00 b	na	1.73E+00 b	na
67-56-1	Methanol (Methyl alcohol)	4.34E+00 b	na	4.40E+00 b	na

**Table 18. Unit Factors for Hazard Index and Cancer Risk for Chemicals in 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
67-64-1	Acetone (2-Propanone)	6.78E+00 b	na	7.04E+00 b	na
67-66-3	Chloroform	8.49E+00 b	1.81E-02	1.44E+01 b	1.81E-02
71-36-3	n-Butyl alcohol (n-Butanol)	3.43E+00 b	na	3.72E+00 b	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)	7.00E-01	na	1.35E+00	na
72-20-8	Endrin	2.64E+03 b	na	7.71E+04 b	na
74-83-9	Bromomethane	2.24E+02	na	2.34E+02	na
74-87-3	Methyl chloride (Chloromethane)	8.69E+00 a	na	8.69E+00 a	na
75-00-3	Ethyl Chloride	7.80E-02 a	na	7.80E-02 a	na
75-01-4	Vinyl chloride (Chloroethene)	3.40E+01	1.17E-01	4.38E+01	1.58E-01
75-05-8	Acetonitrile	1.31E+01 a	na	1.31E+01 a	na
75-07-0	Acetaldehyde	8.69E+01 a	1.72E-03 c	8.69E+01 a	1.72E-03 c
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	1.56E-02 a	na	1.56E-02 a	na
75-68-3	Chloro-1,1-difluoroethane, 1-	1.56E-02 a	na	1.56E-02 a	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	4.70E+02 b	2.07E+00	1.54E+05 b	3.48E+02
78-87-5	1,2-Dichloropropane	1.96E+02 a	na	1.96E+02 a	na
78-93-3	Methyl ethyl ketone (2-Butanone)	1.48E+00	na	1.53E+00	na
79-00-5	1,1,2-Trichloroethane	2.47E+01 b	1.81E-02	3.64E+01 b	2.08E-02
79-01-6	Trichloroethylene	1.59E+01 b	2.38E-03	3.74E+01 b	3.79E-03
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)	na	6.52E-02	na	8.75E-02
82-68-8	Pentachloronitrobenzene (PCNB)	3.51E+01 b	2.73E-02 d	1.99E+03 b	1.55E+00 d
83-32-9	Acenaphthene	3.64E+00 b	na	3.28E+01 b	na
84-66-2	Diethyl phthalate	3.80E-01 b	na	5.70E-01 b	na
84-74-2	Dibutyl phthalate	1.13E+00 b	na	4.73E+01 b	na
85-68-7	Butyl benzyl phthalate	7.79E-01 b	na	3.70E+01 b	na
87-68-3	Hexachlorobutadiene	6.44E+02 b	2.72E-02	3.77E+04 b	6.06E-01
87-86-5	Pentachlorophenol	5.11E+00 b	1.84E-02 d	1.93E+02 b	6.89E-01 d
88-06-2	2,4,6-Trichlorophenol	na	2.33E-03	na	8.34E-03
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)	6.25E+02 b	na	3.17E+03 b	na
91-20-3	Naphthalene	2.66E+02	na	2.94E+02	na

**Table 18. Unit Factors for Hazard Index and Cancer Risk for Chemicals in 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
92-52-4	1,1'-Biphenyl	3.42E+00 b	na	4.10E+01 b	na
95-50-1	1,2-Dichlorobenzene (ortho-)	9.95E-01 b	na	8.64E+00 b	na
95-63-6	1,2,4-Trimethylbenzene	1.33E+02	na	1.52E+02	na
98-86-2	Acetophenone	3.70E+00 b	na	3.86E+00 b	na
98-95-3	Nitrobenzene	1.05E+03	na	1.16E+03	na
100-25-4	1,4-Dinitrobenzene (para-)	1.29E+04 b	na	1.42E+04 b	na
100-41-4	Ethyl benzene	1.64E+00	na	5.86E+00	na
100-42-5	Styrene	1.24E+00	na	2.74E+00	na
100-51-6	Benzyl alcohol	2.08E+00 b	na	2.14E+00 b	na
106-46-7	1,4-Dichlorobenzene (para-)	9.75E-01 a	2.07E-03 d	9.75E-01 a	1.88E-02 d
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	3.91E+03 a	1.02E+01	3.91E+03 a	1.47E+01
106-99-0	1,3-Butadiene	3.91E+02 a	2.34E-02 c	3.91E+02 a	2.34E-02 c
107-02-8	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)	na	2.95E-02	na	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)	2.60E-01 a	na	2.60E-01 a	na
108-67-8	1,3,5-Trimethylbenzene	1.32E+02	na	1.46E+02	na
108-87-2	Methyl cyclohexane	2.60E-01 a	na	2.60E-01 a	na
108-88-3	Toluene (Methyl benzene)	2.37E+00	na	3.39E+00	na
108-90-7	Chlorobenzene	4.44E+01	na	5.73E+01	na
108-94-1	Cyclohexanone	1.22E-01 b	na	1.29E-01 b	na
108-95-2	Phenol (Carbolic acid)	3.72E+00 b	na	3.96E+00 b	na
110-00-9	Furan (Oxacyclopentadiene)	9.86E+01 b	na	1.17E+02 b	na
110-54-3	n-Hexane	6.86E+00	na	3.37E+01	na
110-86-1	Pyridine	9.03E+02 b	na	9.39E+02 b	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)	1.31E+00 b	na	1.33E+00 b	na
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)	4.14E+02 b	1.16E-01 d	8.80E+02 b	2.32E-01 d
117-84-0	Di-n-octylphthalate	8.93E+02 b	na	1.48E+03 b	na
118-74-1	Hexachlorobenzene	3.81E+02 b	8.47E-01	5.03E+04 b	6.47E+01
120-82-1	1,2,4-Trichlorobenzene	1.36E+01	na	2.08E+02	na
121-44-8	Triethylamine	1.12E+02 a	na	1.12E+02 a	na
122-39-4	Diphenylamine	2.66E+01 b	na	1.19E+02 b	na
123-91-1	1,4-Dioxane (Diethylene oxide)	na	1.17E-02 d	na	1.19E-02 d
126-73-8	Tributyl Phosphate	1.89E+00 b	2.03E-03 d	1.11E+01 b	9.62E-03 d
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)	3.34E+03	na	3.61E+03	na
127-18-4	1,1,2,2-Tetrachloroethylene	8.62E+00	4.26E-03	7.32E+01	3.78E-02
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	2.50E-01 b	na	2.80E-01 b	na

**Table 18. Unit Factors for Hazard Index and Cancer Risk for Chemicals in 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
156-59-2	cis-1,2-Dichloroethylene	7.93E+00 b	na	1.23E+01 b	na
206-44-0	Fluoranthene (1,2-Benzacenaphthene)	1.50E+01 b	na	4.08E+02 b	na
309-00-2	Aldrin	2.24E+04 b	1.52E+01	5.25E+06 b	2.68E+03
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	na	1.82E+00	na	1.08E+01
319-85-7	beta-Benzene hexachloride (beta-Lindane)	na	3.86E-01	na	2.96E+00
621-64-7	N-Nitrosodi-N-propylamine	na	8.85E+00 d	na	9.42E+00 d
1314-62-1	Vanadium pentoxide	1.16E+01 b	na	3.13E+02 b	na
1330-20-7	Xylenes (mixtures)	8.24E+00	na	1.02E+01	na
1336-36-3	Polychlorinated Biphenyls (high risk)	na	9.22E-01 d	na	8.96E+02 d
1336-36-3	Polychlorinated Biphenyls (low risk)	na	1.84E-01 d	na	1.79E+02 d
1336-36-3	Polychlorinated Biphenyls (lowest risk)	na	3.23E-02 d	na	3.14E+01 d
6533-73-9	Thallium carbonate	1.72E+03 b	na	9.89E+05 b	na
7429-90-5	Aluminum	1.56E+02	na	1.61E+02	na
7439-96-5	Manganese	1.56E+04 e	na	1.57E+04 e	na
7439-98-7	Molybdenum	2.01E+02 b	na	2.82E+02 b	na
7440-02-0	Nickel (soluble salts)	2.48E+01 b	na	1.18E+02 b	na
7440-22-4	Silver	1.80E+01 b	na	2.40E+02 b	na
7440-24-6	Strontium, Stable	2.36E+00 b	na	4.94E+00 b	na
7440-31-5	Tin	3.18E-01 b	na	4.12E+01 b	na
7440-36-0	Antimony	3.05E+02 b	na	1.08E+04 b	na
7440-38-2	Arsenic (inorganic)	3.05E+02 b	3.51E+00	9.88E+03 b	7.73E+00
7440-39-3	Barium	1.56E+03	na	1.58E+03	na
7440-41-7	Beryllium and compounds	3.92E+04	1.88E+00 c	4.23E+04	1.88E+00 c
7440-42-8	Boron and borates only	5.55E+01	na	5.75E+01	na
7440-43-9	Cadmium	8.20E+02 bf	1.41E+00 c	8.68E+04 bf	1.41E+00 c
7440-48-4	Cobalt	3.91E+04	2.19E+00 c	3.93E+04	2.19E+00 c
7440-66-6	Zinc and compounds	3.36E+02 b	na	3.47E+02 b	na
7487-94-7	Mercuric chloride	3.20E+03 b	na	3.09E+04 b	na
7664-41-7	Ammonia	1.10E+00 a	na	1.10E+00 a	na
7723-14-0	Phosphorus, white	5.35E+05 b	na	1.14E+06 b	na
7782-41-4	Fluorine (soluble fluoride)	4.37E+00 b	na	2.07E+01 b	na
7782-49-2	Selenium and compounds	2.67E+01 b	na	3.58E+02 b	na
8001-35-2	Toxaphene	na	2.93E-01	na	4.90E+01
14797-55-8	Nitrate	2.75E-02 b	na	6.45E-02 b	na
14797-65-0	Nitrite	4.39E-01 b	na	1.03E+00 b	na
16065-83-1	Chromium (III) (insoluble salts)	1.15E-01 b	na	7.15E+00 b	na
18540-29-9	Chromium (VI) (soluble salts)	8.06E+02 g	7.53E-02 c	1.36E+03 g	7.53E-02 c
none	Uranium (soluble salts)	1.35E+02 b	na	7.54E+02 b	na

**Table 18. Unit Factors for Hazard Index and Cancer Risk for Chemicals in 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
Notes:					
<ul style="list-style-type: none"> <li>• CASRN = Chemical Abstract Service Reference Number</li> <li>• 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.</li> <li>• 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.</li> <li>• Results using route-to-route extrapolations are shown in Table C5. Results with notes (a, b, c, d, e, f, or g) have the following qualifiers:               <ul style="list-style-type: none"> <li>(a) -- The RfD for ingestion was not available.</li> <li>(b) -- The RfD for inhalation was not available.</li> <li>(c) -- The Slope Factor for ingestion was not available.</li> <li>(d) -- The Slope Factor for inhalation was not available.</li> <li>(e) -- For manganese (7439-96-5) the drinking water has a lower RfD.</li> <li>(f) -- For cadmium (7440-43-9) the food has a larger RfD.</li> <li>(g) -- For chromium VI (18540-29-9) the airborne particulate has a larger RfD.</li> </ul> </li> </ul>					

### 3.7 POPULATION ALONG THE COLUMBIA RIVER

The unit exposure factors for the estimated 5 million people living along the Columbia River is calculated using consumption rates discussed in Appendix A. The contaminants are initially located in the Columbia River. As time goes on, some contaminants accumulate in the soil due to irrigation from the river. The soil leaching rates are presented in Section A6.0. The affected population has 50% of its garden produce and animal products contaminated. Average drinking water and food consumption rates apply to the population. The average fish consumption is based on the total harvested from the Columbia River each year. All of the pathways used for the All Pathways Farmer are used for the population. The game and waterfowl consumption of the Native American is not included. The dermal exposures are given in Section A3.4. There are minor differences with the All Pathways Farmer in the average intakes from various pathways. Three significant differences are (1) the lower average irrigation rate (63.5 cm/y rather than 82.3 cm/y), (2) much smaller fish consumption rates, and (3) scaling by 5 million. The lower irrigation rates reflects increased precipitation near the ocean. The smaller fish consumption rate is based on estimates of the annual harvest of fish from the Columbia River averaged over the large population.

Scenario dose factors for the Columbia River Population are presented in Table 19 as the collective, or total, dose equivalent in person-rem per pCi/L in the water. These unit dose factors must be multiplied by the water concentration to calculate the actual dose. The radiation dose to this population is the 50 year committed effective dose equivalent from one year of exposure. The dose from drinking water is the main contributor to the total for most radionuclides. The average dose per individual can be calculated by dividing the doses in Table 19 by the population, 5,000,000 people.

**Table 19. Unit Dose Factors for the Columbia River Population (person-rem/y per pCi/L).**

Nuclide	Total Population	Drinking Water	Ratio	Nuclide	Total Population	Drinking Water	Ratio
H-3	2.48E-01	1.74E-01	1.42	Gd-152	6.32E+02	4.39E+02	1.44
Be-10	1.64E+01	1.27E+01	1.29	Ho-166m	1.37E+02	2.20E+01	6.23
C-14	2.27E+01	5.70E+00	3.99	Re-187	4.25E-02	2.59E-02	1.64
Na-22	2.13E+02	3.13E+01	6.80	Tl-204	2.20E+01	9.16E+00	2.41
Al-26	2.24E+02	3.97E+01	5.63	Pb-205	5.79E+00	4.44E+00	1.30
Si-32+D	3.86E+01	3.00E+01	1.29	Pb-210+D	1.94E+04	1.46E+04	1.33
Cl-36	1.25E+02	8.26E+00	15.1	Bi-207	1.05E+02	1.49E+01	7.04
K-40	1.35E+02	5.07E+01	2.67	Po-209	1.01E+04	6.46E+03	1.56
Ca-41	5.75E+00	3.47E+00	1.66	Po-210	7.69E+03	5.18E+03	1.49
Ti-44+D	3.21E+02	6.70E+01	4.78	Ra-226+D	5.16E+03	3.62E+03	1.42
V-49	2.19E-01	1.67E-01	1.31	Ra-228+D	5.49E+03	3.92E+03	1.40
Mn-54	2.89E+01	7.55E+00	3.83	Ac-227+D	5.06E+04	4.03E+04	1.26
Fe-55	2.89E+00	1.65E+00	1.75	Th-228+D	2.85E+03	2.21E+03	1.29
Fe-60+D	8.02E+02	4.15E+02	1.93	Th-229+D	1.40E+04	1.10E+04	1.28
Co-60	2.14E+02	7.33E+01	2.92	Th-230	1.91E+03	1.49E+03	1.28
Ni-59	1.61E+00	5.72E-01	2.81	Th-232	9.58E+03	7.44E+03	1.29
Ni-63	4.42E+00	1.57E+00	2.81	Pa-231	3.63E+04	2.89E+04	1.26
Se-79	5.92E+01	2.37E+01	2.50	U-232	4.86E+03	3.57E+03	1.36
Rb-87	3.82E+01	1.34E+01	2.85	U-233	1.06E+03	7.88E+02	1.35
Sr-90+D	7.50E+02	4.17E+02	1.80	U-234	1.04E+03	7.71E+02	1.35
Zr-93	5.66E+00	4.52E+00	1.25	U-235+D	9.88E+02	7.28E+02	1.36
Nb-91	1.91E+00	1.42E+00	1.34	U-236	9.89E+02	7.33E+02	1.35
Nb-93m	1.78E+00	1.42E+00	1.25	U-238+D	9.86E+02	7.30E+02	1.35
Nb-94	1.23E+02	1.95E+01	6.32	Np-237+D	1.55E+04	1.21E+04	1.28
Mo-93	5.76E+00	3.68E+00	1.57	Pu-236	3.99E+03	3.19E+03	1.25
Tc-99	9.08E+00	3.98E+00	2.28	Pu-238	1.09E+04	8.72E+03	1.25
Ru-106+D	1.73E+02	7.47E+01	2.32	Pu-239	1.21E+04	9.65E+03	1.25
Pd-107	9.15E-01	4.06E-01	2.25	Pu-240	1.21E+04	9.65E+03	1.25
Ag-108m+D	1.26E+02	2.08E+01	6.06	Pu-241+D	2.34E+02	1.87E+02	1.26
Cd-109	4.92E+01	3.57E+01	1.38	Pu-242	1.15E+04	9.16E+03	1.25
Cd-113m	6.12E+02	4.39E+02	1.40	Pu-244+D	1.14E+04	9.05E+03	1.26
In-115	8.71E+02	4.31E+02	2.02	Am-241	1.25E+04	9.92E+03	1.26
Sn-121m+D	2.01E+01	6.13E+00	3.28	Am-242m+D	1.20E+04	9.59E+03	1.26
Sn-126+D	3.13E+02	5.72E+01	5.47	Am-243+D	1.24E+04	9.89E+03	1.26
Sb-125	2.33E+01	7.66E+00	3.04	Cm-242	3.88E+02	3.13E+02	1.24
Te-125m	1.41E+01	1.00E+01	1.41	Cm-243	8.59E+03	6.84E+03	1.26
I-129	2.32E+03	7.52E+02	3.09	Cm-244	6.91E+03	5.50E+03	1.25
Cs-134	6.74E+02	2.00E+02	3.38	Cm-245	1.28E+04	1.02E+04	1.26
Cs-135	6.36E+01	1.93E+01	3.30	Cm-246	1.27E+04	1.01E+04	1.26
Cs-137+D	4.80E+02	1.36E+02	3.52	Cm-247+D	1.17E+04	9.32E+03	1.26
Ba-133	2.79E+01	9.27E+00	3.01	Cm-248	4.65E+04	3.71E+04	1.26
Pm-147	3.88E+00	2.86E+00	1.36	Cm-250+D	2.66E+05	2.12E+05	1.26
Sm-147	7.04E+02	5.04E+02	1.40	Bk-247	1.61E+04	1.28E+04	1.26

**Table 19. Unit Dose Factors for the Columbia River Population (person-rem/y per pCi/L).**

Nuclide	Total Population	Drinking Water	Ratio	Nuclide	Total Population	Drinking Water	Ratio
Sm-151	1.45E+00	1.06E+00	1.37	Cf-248	1.22E+03	9.10E+02	1.34
Eu-150	1.07E+02	1.73E+01	6.16	Cf-249	1.78E+04	1.29E+04	1.38
Eu-152	7.95E+01	1.77E+01	4.50	Cf-250	7.96E+03	5.80E+03	1.37
Eu-154	9.03E+01	2.60E+01	3.47	Cf-251	1.82E+04	1.32E+04	1.37
Eu-155	6.96E+00	4.17E+00	1.67	Cf-252	4.01E+03	2.94E+03	1.36

Notes:

- The unit dose factors for the Columbia River Population are the total 50 year committed effective dose equivalent from one year of exposure to 5 million people. The average per person can be obtained by dividing the values on this table by 5,000,000.
- These scenario dose factors must be multiplied by the water concentration.
- The "Total population" column includes the full scenario. The column "Drinking Water" shows just the drinking water dose. The "Ratio" column is the "Total Population" divided by the "Drinking Water" doses.

The increase in cancer risk due to radioactive contaminants entering the Columbia River is calculated using the same equations presented for the radiation dose previously. The two differences are (1) the use of the risk coefficients from Federal Guidance Report Number 13 (Tables A29 and A30) rather than radiation dose factors, and (2) the calculation of the cumulative risk from 70 years of contamination. The lifetime exposure is at the adult consumption rates.

The lifetime increase in the risk of developing some type of cancer from the radionuclides is the sum of 70 years of exposure. Each year there is a small amount of the radioactive material in the soil from previous years. This leads to a total risk that is greater than 70 times the first year's risk for many nuclides. The estimated risks from radioactive materials in the Columbia River are shown in Table 20. The first column of risks shows the 70-year total. The second column shows the risk from the first year multiplied by 70. The third column is the ratio of the 70-year total to the 70-times-first-year risk. If the two numbers are within 10%, they are not shown. Radionuclides with large ratios generally indicate that the isotopes accumulate in the soil and that the soil pathways (soil ingestion and inhalation, plants, and animals) are significant compared to the drinking water pathway. The average lifetime risk per individual can be calculated by dividing the collective risk in Table 20 by the population, 5,000,000 people.

**Table 20. Unit Risk Factors for Radionuclides in the Columbia River Population Scenario (total risk per pCi/L).**

Nuclide	70-year Total	70 Times First Year	Ratio	Nuclide	70-year Total	70 Times First Year	Ratio
H-3	3.28E-02	3.28E-02		Gd-152	8.71E+00	8.23E+00	
Be-10	2.01E+00	1.90E+00		Ho-166m	1.41E+02	8.61E+00	16.3
C-14	2.59E+00	1.44E+00	1.8	Re-187	1.70E-02	6.54E-03	2.6
Na-22	2.99E+01	1.47E+01	2.0	Tl-204	3.37E+00	3.33E+00	
Al-26	2.52E+02	1.59E+01	15.9	Pb-205	1.79E-01	1.69E-01	
Si-32+D	4.35E+00	3.30E+00	1.3	Pb-210+D	3.17E+02	2.71E+02	1.2
Cl-36	6.22E+01	1.26E+01	4.9	Bi-207	8.51E+01	6.80E+00	12.5
K-40	4.06E+01	1.51E+01	2.7	Po-209	4.65E+02	3.90E+02	1.2

**Table 20. Unit Risk Factors for Radionuclides in the Columbia River Population Scenario (total risk per pCi/L).**

Nuclide	70-year Total	70 Times First Year	Ratio	Nuclide	70-year Total	70 Times First Year	Ratio
Ca-41	3.04E-01	1.22E-01	2.5	Po-210	2.81E+02	2.80E+02	
Ti-44+D	1.57E+02	2.67E+01	5.9	Ra-226+D	3.13E+02	1.19E+02	2.6
V-49	3.38E-02	3.38E-02		Ra-228+D	3.52E+02	3.06E+02	1.1
Mn-54	3.05E+00	1.77E+00	1.7	Ac-227+D	1.43E+02	1.27E+02	1.1
Fe-55	3.33E-01	3.30E-01		Th-228+D	8.97E+01	8.18E+01	
Fe-60+D	2.61E+02	7.41E+01	3.5	Th-229+D	1.66E+02	1.39E+02	1.2
Co-60	4.85E+01	1.18E+01	4.1	Th-230	2.62E+01	2.34E+01	1.1
Ni-59	2.28E-01	1.87E-01	1.2	Th-232	2.21E+02	3.16E+01	7.0
Ni-63	5.42E-01	4.56E-01	1.2	Pa-231	6.39E+01	4.47E+01	1.4
Se-79	4.42E+00	4.16E+00		U-232	1.49E+02	8.42E+01	1.8
Rb-87	1.03E+01	3.49E+00	3.0	U-233	2.14E+01	2.03E+01	
Sr-90+D	7.37E+01	2.86E+01	2.6	U-234	2.10E+01	2.00E+01	
Zr-93	2.97E-01	2.80E-01		U-235+D	2.67E+01	2.07E+01	1.3
Nb-91	3.16E-01	2.13E-01	1.5	U-236	1.99E+01	1.89E+01	
Nb-93m	2.17E-01	2.09E-01		U-238+D	2.70E+01	2.48E+01	
Nb-94	1.33E+02	7.97E+00	16.7	Np-237+D	3.10E+01	1.84E+01	1.7
Mo-93	2.48E+00	1.09E+00	2.3	Pu-236	2.18E+01	1.92E+01	1.1
Tc-99	1.06E+01	1.50E+00	7.0	Pu-238	3.44E+01	3.34E+01	
Ru-106+D	2.36E+01	2.30E+01		Pu-239	3.56E+01	3.44E+01	
Pd-107	1.69E-01	1.35E-01	1.3	Pu-240	3.56E+01	3.44E+01	
Ag-108m+D	1.14E+02	8.07E+00	14.1	Pu-241+D	4.82E-01	4.49E-01	
Cd-109	1.48E+00	1.44E+00		Pu-242	3.37E+01	3.26E+01	
Cd-113m	1.03E+01	8.22E+00	1.2	Pu-244+D	6.64E+01	3.81E+01	1.7
In-115	1.55E+01	1.49E+01		Am-241	2.80E+01	2.66E+01	
Sn-121m+D	3.21E+00	2.89E+00	1.1	Am-242m+D	2.06E+01	1.86E+01	1.1
Sn-126+D	1.89E+02	2.96E+01	6.4	Am-243+D	4.05E+01	2.82E+01	1.4
Sb-125	4.67E+00	1.92E+00	2.4	Cm-242	9.92E+00	9.91E+00	
Te-125m	9.98E-01	9.98E-01		Cm-243	2.95E+01	2.46E+01	1.2
I-129	1.41E+02	1.25E+02	1.1	Cm-244	2.17E+01	2.14E+01	
Cs-134	4.11E+01	3.18E+01	1.3	Cm-245	3.20E+01	2.68E+01	1.2
Cs-135	6.26E+00	3.49E+00	1.8	Cm-246	2.70E+01	2.61E+01	
Cs-137+D	6.22E+01	2.40E+01	2.6	Cm-247+D	5.20E+01	2.68E+01	1.9
Ba-133	1.06E+01	2.72E+00	3.9	Cm-248	9.88E+01	9.55E+01	
Pm-147	4.92E-01	4.90E-01		Cm-250+D	5.92E+02	5.47E+02	
Sm-147	1.11E+01	1.06E+01		Bk-247	3.85E+01	3.19E+01	1.2
Sm-151	1.70E-01	1.63E-01		Cf-248	1.27E+01	1.27E+01	
Eu-150	8.08E+01	6.09E+00	13.3	Cf-249	6.28E+01	3.72E+01	1.7
Eu-152	4.07E+01	5.18E+00	7.9	Cf-250	2.53E+01	2.46E+01	
Eu-154	3.40E+01	6.40E+00	5.3	Cf-251	4.71E+01	3.78E+01	1.2
Eu-155	9.50E-01	6.14E-01	1.5	Cf-252	1.38E+01	1.37E+01	

**Table 20. Unit Risk Factors for Radionuclides in the Columbia River Population Scenario (total risk per pCi/L).**

Nuclide	70-year Total	70 Times First Year	Ratio	Nuclide	70-year Total	70 Times First Year	Ratio
Notes:							
<ul style="list-style-type: none"> <li>The total risk to the population along the Columbia River is calculated using intakes from 70 consecutive years. The soil concentration is zero at the start of the exposure.</li> <li>These scenario risk factors must be multiplied by the water concentration.</li> <li>The "70-year Total" column gives the Columbia River Population scenario risk factors. The column "70 Times First Year" shows the first year risk multiplied by 70. The "Ratio" column is the "70-year Total" divided by the "70 Times First Year" risks. Blank entries indicate the two risks are within 10 percent of each other.</li> </ul>							

The hazard index and cancer risk from chemicals are calculated using the same consumption parameters discussed in Appendix A for the population. The contaminant concentration in river water is expressed in mg/L. The chemical dose is normalized to the average adult body mass, 70 kg. The hazard quotient is based on the annual average daily dose (averaged over the period of exposure). The increased cancer risk is based on the lifetime average daily dose. To calculate the average daily dose over a lifetime, the dose from 70 consecutive years is calculated and then divided by (70 y)(365 d/y) to obtain the daily average. As part of this calculation, the concentration of the contaminants in soil is increased each year. The effect of leaching from the surface layer is included using the leaching coefficients shown in Table A38. Dermal absorption during showering and swimming is included.

The calculated hazard index and cancer risk per unit concentration in the Columbia River for a population of 5 million are shown in Table 21. The factors must be multiplied by the estimated water concentration in the Columbia River, in mg per L.

**Table 21. Unit Factors for Hazard Index and Cancer Risk for Chemicals in the Columbia River Population Scenario.**

CASRN	Chemical Name	Hazard Index per mg/L	Increased Cancer Risk per mg/L
50-32-8	Benzo[a]pyrene	na	1.00E+07 d
53-70-3	Dibenz[a,h]anthracene	na	2.44E+07
56-23-5	Carbon tetrachloride	2.18E+08 b	6.14E+04
57-12-5	Cyanide, free	6.48E+09 b	na
57-14-7	1,1-Dimethylhydrazine	na	8.35E+07
57-55-6	Propylene glycol (1,2-Propanediol)	4.43E+05 b	na
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)	1.53E+09 b	5.94E+05 d
60-34-4	Methylhydrazine	na	6.24E+07
60-57-1	Dieldrin	5.56E+09 b	9.58E+06
62-75-9	N-Nitrosodimethylamine	na	6.71E+08
64-18-6	Formic acid	3.73E+06 b	na
67-56-1	Methanol (Methyl alcohol)	9.44E+06 b	na
67-64-1	Acetone (2-Propanone)	1.48E+07 b	na
67-66-3	Chloroform	1.79E+07 b	6.39E+04
71-36-3	n-Butyl alcohol (n-Butanol)	7.55E+06 b	na
71-43-2	Benzene	1.37E+08	3.15E+04

**Table 21. Unit Factors for Hazard Index and Cancer Risk for Chemicals in the Columbia River Population Scenario.**

CASRN	Chemical Name	Hazard Index per mg/L	Increased Cancer Risk per mg/L
71-55-6	1,1,1-Trichloroethane (Methyl chloroform)	2.04E+06	na
72-20-8	Endrin	2.70E+09 b	na
74-83-9	Bromomethane	7.09E+08	na
74-87-3	Methyl chloride (Chloromethane)	3.08E+07 a	na
75-00-3	Ethyl Chloride	2.77E+05 a	na
75-01-4	Vinyl chloride (Chloroethene)	8.74E+07	2.75E+05
75-05-8	Acetonitrile	4.63E+07 a	na
75-07-0	Acetaldehyde	3.08E+08 a	6.10E+03 c
75-09-2	Dichloromethane (Methylene chloride)	4.59E+06	2.96E+03
75-15-0	Carbon disulfide	5.62E+06	na
75-21-8	Ethylene Oxide (Oxirane)	na	1.33E+06
75-34-3	1,1-Dichloroethane (Ethylidene chloride)	7.34E+06	na
75-35-4	1,1-Dichloroethylene	1.71E+07	na
75-45-6	Chlorodifluoromethane	5.54E+04 a	na
75-68-3	Chloro-1,1-difluoroethane, 1-	5.54E+04 a	na
75-69-4	Trichlorofluoromethane	4.50E+06	na
75-71-8	Dichlorodifluoromethane	1.47E+07	na
76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane (CFC-113)	9.74E+04	na
76-44-8	Heptachlor	7.76E+08 b	5.34E+06
78-87-5	1,2-Dichloropropane	6.95E+08 a	na
78-93-3	Methyl ethyl ketone (2-Butanone)	4.31E+06	na
79-00-5	1,1,2-Trichloroethane	5.62E+07 b	5.72E+04
79-01-6	Trichloroethylene	2.92E+07 b	6.64E+03
79-10-7	2-Propenoic acid (Acrylic acid)	4.53E+07	na
79-34-5	1,1,2,2-Tetrachloroethane (Acetylene tetrachloride)	na	2.06E+05
82-68-8	Pentachloronitrobenzene (PCNB)	7.08E+07 b	5.50E+04 d
83-32-9	Acenaphthene	5.07E+06 b	na
84-66-2	Diethyl phthalate	8.39E+05 b	na
84-74-2	Dibutyl phthalate	2.37E+06 b	na
85-68-7	Butyl benzyl phthalate	1.62E+06 b	na
87-68-3	Hexachlorobutadiene	9.44E+08 b	7.57E+04
87-86-5	Pentachlorophenol	8.87E+06 b	3.17E+04 d
88-06-2	2,4,6-Trichlorophenol	na	5.11E+03
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)	1.40E+09 b	na
91-20-3	Naphthalene	9.36E+08	na
92-52-4	1,1'-Biphenyl	5.20E+06 b	na
95-50-1	1,2-Dichlorobenzene (ortho-)	1.92E+06 b	na
95-63-6	1,2,4-Trimethylbenzene	4.67E+08	na
98-86-2	Acetophenone	8.13E+06 b	na
98-95-3	Nitrobenzene	2.82E+09	na
100-25-4	1,4-Dinitrobenzene (para-)	2.81E+10 b	na
100-41-4	Ethyl benzene	4.44E+06	na

**Table 21. Unit Factors for Hazard Index and Cancer Risk for Chemicals in the Columbia River Population Scenario.**

CASRN	Chemical Name	Hazard Index per mg/L	Increased Cancer Risk per mg/L
100-42-5	Styrene	3.68E+06	na
100-51-6	Benzyl alcohol	4.56E+06 b	na
106-46-7	1,4-Dichlorobenzene (para-)	3.46E+06 a	4.05E+03 d
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	1.39E+10 a	2.34E+07
106-99-0	1,3-Butadiene	1.39E+09 a	8.32E+04 c
107-02-8	Acrolein	1.40E+11	na
107-05-1	3-Chloropropene (Allyl chloride)	2.77E+09	na
107-06-2	1,2-Dichloroethane (Ethylene chloride)	na	9.31E+04
107-13-1	Acrylonitrile	2.12E+09	5.86E+05
108-10-1	Methyl isobutyl ketone (4-Methyl-2-pentanone)	9.24E+05 a	na
108-67-8	1,3,5-Trimethylbenzene	4.67E+08	na
108-87-2	Methyl cyclohexane	9.24E+05 a	na
108-88-3	Toluene (Methyl benzene)	7.78E+06	na
108-90-7	Chlorobenzene	1.48E+08	na
108-94-1	Cyclohexanone	2.68E+05 b	na
108-95-2	Phenol (Carbolic acid)	8.10E+06 b	na
110-00-9	Furan (Oxacyclopentadiene)	2.24E+08 b	na
110-54-3	n-Hexane	1.75E+07	na
110-86-1	Pyridine	1.97E+09 b	na
111-76-2	2-Butoxyethanol (Ethylene Glycol Monobutyl Ether)	1.89E+06	na
111-90-0	2-(2-Ethoxyethoxy)-ethanol (Diethylene Glycol Monoethyl Ether)	2.85E+06 b	na
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)	6.35E+08 b	1.77E+05 d
117-84-0	Di-n-octylphthalate	1.70E+09 b	na
118-74-1	Hexachlorobenzene	4.03E+08 b	1.79E+06
120-82-1	1,2,4-Trichlorobenzene	3.16E+07	na
121-44-8	Triethylamine	3.96E+08 a	na
122-39-4	Diphenylamine	5.80E+07 b	na
123-91-1	1,4-Dioxane (Diethylene oxide)	na	2.54E+04 d
126-73-8	Tributyl Phosphate	4.23E+06 b	4.49E+03 d
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)	8.92E+09	na
127-18-4	1,1,2,2-Tetrachloroethylene	1.98E+07	9.49E+03
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	5.57E+05 b	na
156-59-2	cis-1,2-Dichloroethylene	1.81E+07 b	na
206-44-0	Fluoranthene (1,2-Benzacenaphthene)	1.55E+07 b	na
309-00-2	Aldrin	3.45E+10 b	3.11E+07
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	na	4.97E+06
319-85-7	beta-Benzene hexachloride (beta-Lindane)	na	8.68E+05
621-64-7	N-Nitrosodi-N-propylamine	na	1.93E+07 d
1314-62-1	Vanadium pentoxide	2.83E+07 b	na
1330-20-7	Xylenes (mixtures)	2.85E+07	na
1336-36-3	Polychlorinated Biphenyls (high risk)	na	5.84E+05 dh
1336-36-3	Polychlorinated Biphenyls (low risk)	na	1.75E+05 dh

**Table 21. Unit Factors for Hazard Index and Cancer Risk for Chemicals in the Columbia River Population Scenario.**

CASRN	Chemical Name	Hazard Index per mg/L	Increased Cancer Risk per mg/L
1336-36-3	Polychlorinated Biphenyls (lowest risk)	na	2.33E+04 dh
6533-73-9	Thallium carbonate	5.10E+09 b	na
7429-90-5	Aluminum	5.54E+08	na
7439-96-5	Manganese	5.54E+10 e	na
7439-98-7	Molybdenum	4.18E+08 b	na
7440-02-0	Nickel (soluble salts)	3.85E+07 b	na
7440-22-4	Silver	5.52E+07 b	na
7440-24-6	Strontium, Stable	4.81E+06 b	na
7440-31-5	Tin	9.59E+05 b	na
7440-36-0	Antimony	8.12E+08 b	na
7440-38-2	Arsenic (inorganic)	8.92E+08 b	1.24E+07
7440-39-3	Barium	5.54E+09	na
7440-41-7	Beryllium and compounds	1.39E+11	6.65E+06 c
7440-42-8	Boron and borates only	1.73E+08	na
7440-43-9	Cadmium	2.66E+09 bf	4.99E+06 c
7440-48-4	Cobalt	1.39E+11	7.76E+06 c
7440-66-6	Zinc and compounds	7.30E+08 b	na
7487-94-7	Mercuric chloride	9.73E+09 b	na
7664-41-7	Ammonia	3.91E+06 a	na
7723-14-0	Phosphorus, white	9.49E+11 b	na
7782-41-4	Fluorine (soluble fluoride)	1.40E+07 b	na
7782-49-2	Selenium and compounds	6.86E+07 b	na
8001-35-2	Toxaphene	na	6.73E+05
14797-55-8	Nitrate	6.84E+04 b	na
14797-65-0	Nitrite	1.09E+06 b	na
16065-83-1	Chromium (III) (insoluble salts)	2.93E+05 b	na
18540-29-9	Chromium (VI) (soluble salts)	5.83E+07 g	6.91E+02 c
none	Uranium (soluble salts)	3.47E+08 b	na

## Notes:

- 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.
- These scenario risk factors must be multiplied by the water concentration.
- Results using route-to-route extrapolations are shown in Table C7. Results with notes (a, b, c, d, e, f, g, or h) have the following qualifiers:
  - (a) -- The RfD for ingestion was not available.
  - (b) -- The RfD for inhalation was not available.
  - (c) -- The Slope Factor for ingestion was not available.
  - (d) -- The Slope Factor for inhalation was not available.
  - (e) -- For manganese (7439-96-5) the drinking water has a lower RfD.
  - (f) -- For cadmium (7440-43-9) the food has a larger RfD.
  - (g) -- For chromium VI (18540-29-9) the airborne particulate has a larger RfD.
  - (h) -- PCBs (1336-36-3) use the central estimate slope factors from IRIS for a population.

### 3.8 HSRAM INDUSTRIAL SCENARIO

The default commercial/industrial exposure scenario presented in the HSRAM is used to represent an occupationally exposed individual. The worker is primarily located indoors. Outdoor activities may include building and grounds maintenance. The principle avenue for the contaminants to get into the worker is through the drinking water. Soil is contaminated by irrigation of grass and other plants. This leads to dermal absorption of chemicals and external exposure from radionuclides. A small amount becomes airborne and is inhaled. The contaminated water comes from a well or is drawn from the Columbia River. The intakes from either source (assuming the same water concentration) are the same because there are no additional pathways associated with the Columbia River. The intakes continue for 20 years, and then the worker retires, or finds a different work location.

The worker consumes water at the rate of 1 L/d for 250 days during the year. The total drinking water intake is 250 L/y. The individual has a 10-minute shower at work and inhales the equivalent of 0.021 L/y (Table A13). Volatile materials are inhaled in much greater quantities (Tables A13 and A14). Chemicals are absorbed through the skin during the shower as described in Section A3.4.2.

The soil becomes contaminated just as in the All Pathways Farmer scenario. The soil is irrigated with 82.3 cm water during a 6-month growing season. The actual soil concentration depends on the leaching coefficient for the material from the surface layer of soil. The worker ingests 7.3 g/y (Table A8) and inhales 0.25 g/y (Table A10). The worker's skin comes in contact with the soil. For chemicals, the effective dermal intake is 146 g/y (Table A18) times the dermal absorption factor for the chemical. For radionuclides, there is an effective external exposure time of 934 h/y (Table A15).

The lifetime increase in the worker's risk of developing some type of cancer from the radionuclides is the sum of 20 years of exposure. Each year there is a small amount of the radioactive material in the soil from previous years. This leads to a total risk that is greater than 20 times the first year's risk. The estimated risks from radioactive materials are shown in Table 22. The first column of risks shows the 20-year total. The second column shows the risk from the first year multiplied by 20. The third column is the ratio of the 20-year total to the 20-times-first-year risk. If the two numbers are within 10%, they are not shown.

Note that the risk coefficients in Federal Guidance Report Number 13 (Tables A29 and A30) have been used in the industrial scenario although they were not intended for this application. Adults receive the exposures during their working years. There are no exposures during childhood. The risk coefficients were developed for a population containing all ages. They can be applied to an individual only if there is a lifetime of exposure. The increased cancer risk factors shown in Table 22 may either overestimate or underestimate the worker risk depending on whether the increased risk coefficient for children is offset by the reduced consumption rates during childhood.

**Table 22. Unit Risk Factors for Radionuclides in the Industrial Scenario (risk per pCi/L).**

Nuclide	20-year Total	20 Times First Year	Ratio	Nuclide	20-year Total	20 Times First Year	Ratio
H-3	6.75E-10	6.75E-10		Gd-152	1.55E-07	1.53E-07	
Be-10	3.54E-08	3.52E-08		Ho-166m	6.49E-07	8.53E-08	7.6
C-14	7.77E-09	7.75E-09		Re-187	8.98E-11	8.95E-11	
Na-22	2.96E-07	1.02E-07	2.9	Tl-204	2.94E-08	2.93E-08	
Al-26	1.15E-06	1.64E-07	7.0	Pb-205	3.17E-09	3.17E-09	
Si-32+D	6.31E-08	6.22E-08		Pb-210+D	4.47E-06	4.45E-06	
Cl-36	1.66E-08	1.65E-08		Bi-207	5.20E-07	6.94E-08	7.5
K-40	1.79E-07	1.28E-07	1.4	Po-209	2.37E-06	2.36E-06	
Ca-41	1.77E-09	1.77E-09		Po-210	1.89E-06	1.89E-06	
Ti-44+D	8.76E-07	1.95E-07	4.5	Ra-226+D	2.62E-06	1.99E-06	1.3
V-49	6.10E-10	6.10E-10		Ra-228+D	5.67E-06	5.23E-06	
Mn-54	4.70E-08	2.83E-08	1.7	Ac-227+D	2.63E-06	2.52E-06	
Fe-55	4.31E-09	4.31E-09		Th-228+D	1.73E-06	1.62E-06	
Fe-60+D	1.40E-06	9.04E-07	1.6	Th-229+D	2.90E-06	2.77E-06	
Co-60	5.55E-07	1.47E-07	3.8	Th-230	4.78E-07	4.70E-07	
Ni-59	1.37E-09	1.37E-09		Th-232	9.48E-07	5.30E-07	1.8
Ni-63	3.36E-09	3.35E-09		Pa-231	9.35E-07	8.88E-07	
Se-79	3.65E-08	3.65E-08		U-232	1.87E-06	1.48E-06	1.3
Rb-87	2.62E-08	2.61E-08		U-233	3.68E-07	3.65E-07	
Sr-90+D	3.72E-07	3.70E-07		U-234	3.62E-07	3.60E-07	
Zr-93	5.57E-09	5.55E-09		U-235+D	4.02E-07	3.68E-07	
Nb-91	4.43E-09	4.05E-09		U-236	3.43E-07	3.41E-07	
Nb-93m	4.03E-09	4.02E-09		U-238+D	4.49E-07	4.41E-07	
Nb-94	6.16E-07	8.15E-08	7.6	Np-237+D	4.10E-07	3.51E-07	1.2
Mo-93	1.68E-08	1.68E-08		Pu-236	3.98E-07	3.86E-07	
Tc-99	1.38E-08	1.38E-08		Pu-238	6.80E-07	6.73E-07	
Ru-106+D	2.22E-07	2.15E-07		Pu-239	7.00E-07	6.93E-07	
Pd-107	1.26E-09	1.25E-09		Pu-240	7.00E-07	6.93E-07	
Ag-108m+D	5.86E-07	8.26E-08	7.1	Pu-241+D	9.11E-09	8.98E-09	
Cd-109	2.51E-08	2.51E-08		Pu-242	6.64E-07	6.57E-07	
Cd-113m	1.44E-07	1.44E-07		Pu-244+D	8.64E-07	7.45E-07	1.2
In-115	1.70E-07	1.69E-07		Am-241	5.43E-07	5.35E-07	
Sn-121m+D	1.76E-08	1.75E-08		Am-242m+D	3.81E-07	3.71E-07	
Sn-126+D	8.41E-07	1.88E-07	4.5	Am-243+D	6.11E-07	5.58E-07	
Sb-125	6.73E-08	3.15E-08	2.1	Cm-242	2.01E-07	2.00E-07	
Te-125m	1.67E-08	1.67E-08		Cm-243	5.21E-07	4.90E-07	
I-129	7.42E-07	7.40E-07		Cm-244	4.36E-07	4.32E-07	
Cs-134	3.53E-07	2.48E-07	1.4	Cm-245	5.60E-07	5.36E-07	
Cs-135	2.37E-08	2.37E-08		Cm-246	5.31E-07	5.25E-07	
Cs-137+D	3.27E-07	1.67E-07	2.0	Cm-247+D	6.28E-07	5.21E-07	1.2
Ba-133	1.10E-07	4.23E-08	2.6	Cm-248	1.94E-06	1.92E-06	
Pm-147	8.47E-09	8.46E-09		Cm-250+D	1.12E-05	1.10E-05	
Sm-147	1.92E-07	1.91E-07		Bk-247	6.69E-07	6.39E-07	
Sm-151	2.79E-09	2.78E-09		Cf-248	2.32E-07	2.32E-07	

**Table 22. Unit Risk Factors for Radionuclides in the Industrial Scenario (risk per pCi/L).**

Nuclide	20-year Total	20 Times First Year	Ratio	Nuclide	20-year Total	20 Times First Year	Ratio
Eu-150	4.78E-07	5.94E-08	8.0	Cf-249	7.68E-07	6.61E-07	1.2
Eu-152	3.37E-07	6.08E-08	5.5	Cf-250	4.49E-07	4.45E-07	
Eu-154	3.41E-07	8.46E-08	4.0	Cf-251	7.15E-07	6.80E-07	
Eu-155	1.40E-08	1.02E-08	1.4	Cf-252	2.52E-07	2.51E-07	

Notes:

- The radiation risk to this individual is calculated using intakes from 20 consecutive years. The soil concentration is zero at the start of the exposure.
- These scenario risk factors must be multiplied by the water concentration.
- The "20-year Total" column gives the industrial scenario risk factors. The column "20 Times First Year" shows the first year risk multiplied by 20. The "Ratio" column is the "20-year Total" divided by the "20 Times First Year" factors. Blank entries indicate the two risk factors are within 10 percent of each other.

The hazard index and cancer risk from chemicals are calculated using the same consumption parameters discussed in Appendix A for the HSRAM Industrial scenario. The same intakes occur regardless of whether the water comes from a well or from the Columbia River because there are no additional pathways for water coming from the river. In addition, the dilution that occurs when ground water reaches the river does not enter into the calculation of unit factors, i.e., factors that are normalized to a unit water concentration.

The contaminant concentration in the water is expressed in mg/L. The chemical dose is normalized to the average adult body mass, 70 kg. The hazard index is calculated from the average annual daily dose. The increased cancer risk is calculated from the lifetime average daily dose. To calculate these average daily doses, the dose from 20 consecutive years is calculated and then divided by (20 y)(365 d/y) for the hazard index and (70 y)(365 d/y) for the cancer risk. As part of this calculation, the concentration of the contaminants in soil is increased each year. The effect of leaching from the surface layer is included using the leaching coefficients shown in Table A38. Dermal absorption during showering is included.

The calculated hazard index and cancer risk per unit concentration in the water for the HSRAM industrial scenario are shown in Table 23. The factors must be multiplied by the estimated water concentration, in mg per L.

**Table 23. Unit Factors for Hazard Index and Cancer Risk for Chemicals in the HSRAM Industrial Scenario.**

CASRN	Chemical Name	Hazard Index per mg/L	Increased Cancer Risk per mg/L
50-32-8	Benzo[a]pyrene	na	2.93E-01 d
53-70-3	Dibenz[a,h]anthracene	na	5.42E-01
56-23-5	Carbon tetrachloride	1.56E+01 b	1.89E-03
57-12-5	Cyanide, free	5.08E-01 b	na
57-14-7	1,1-Dimethylhydrazine	na	9.79E-03
57-55-6	Propylene glycol (1,2-Propanediol)	4.90E-04 b	na
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)	3.45E+01 b	3.84E-03 d
60-34-4	Methylhydrazine	na	9.04E-03

**Table 23. Unit Factors for Hazard Index and Cancer Risk for Chemicals in the HSRAM Industrial Scenario.**

CASRN	Chemical Name	Hazard Index per mg/L	Increased Cancer Risk per mg/L
60-57-1	Dieldrin	2.79E+02 b	2.49E-01
62-75-9	N-Nitrosodimethylamine	na	2.46E-01
64-18-6	Formic acid	4.91E-03 b	na
67-56-1	Methanol (Methyl alcohol)	1.96E-02 b	na
67-64-1	Acetone (2-Propanone)	9.81E-02 b	na
67-66-3	Chloroform	1.12E+00 b	2.28E-03
71-36-3	n-Butyl alcohol (n-Butanol)	9.97E-02 b	na
71-43-2	Benzene	1.42E+01	9.35E-04
71-55-6	1,1,1-Trichloroethane (Methyl chloroform)	2.09E-01	na
72-20-8	Endrin	2.78E+02 b	na
74-83-9	Bromomethane	7.62E+01	na
74-87-3	Methyl chloride (Chloromethane)	3.84E+00 a	na
75-00-3	Ethyl Chloride	3.45E-02 a	na
75-01-4	Vinyl chloride (Chloroethene)	6.84E+00	2.47E-03 h
75-05-8	Acetonitrile	5.78E+00 a	na
75-07-0	Acetaldehyde	3.84E+01 a	2.17E-04 c
75-09-2	Dichloromethane (Methylene chloride)	2.81E-01	6.79E-05
75-15-0	Carbon disulfide	6.00E-01	na
75-21-8	Ethylene Oxide (Oxirane)	na	1.27E-02
75-34-3	1,1-Dichloroethane (Ethylidene chloride)	7.92E-01	na
75-35-4	1,1-Dichloroethylene	1.94E+00	na
75-45-6	Chlorodifluoromethane	6.91E-03 a	na
75-68-3	Chloro-1,1-difluoroethane, 1-	6.91E-03 a	na
75-69-4	Trichlorofluoromethane	5.35E-01	na
75-71-8	Dichlorodifluoromethane	1.79E+00	na
76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane (CFC-113)	1.19E-02	na
76-44-8	Heptachlor	3.93E+01 b	1.54E-01
78-87-5	1,2-Dichloropropane	8.67E+01 a	na
78-93-3	Methyl ethyl ketone (2-Butanone)	3.62E-01	na
79-00-5	1,1,2-Trichloroethane	2.51E+00 b	1.74E-03
79-01-6	Trichloroethylene	2.20E+00 b	2.10E-04
79-10-7	2-Propenoic acid (Acrylic acid)	5.25E+00	na
79-34-5	1,1,2,2-Tetrachloroethane (Acetylene tetrachloride)	na	6.31E-03
82-68-8	Pentachloronitrobenzene (PCNB)	4.09E+00 b	9.11E-04 d
83-32-9	Acenaphthene	3.97E-01 b	na
84-66-2	Diethyl phthalate	1.25E-02 b	na
84-74-2	Dibutyl phthalate	1.18E-01 b	na
85-68-7	Butyl benzyl phthalate	6.40E-02 b	na
87-68-3	Hexachlorobutadiene	8.85E+01 b	2.57E-03
87-86-5	Pentachlorophenol	5.42E-01 b	5.57E-04 d
88-06-2	2,4,6-Trichlorophenol	na	7.39E-05
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)	1.14E+01 b	na

**Table 23. Unit Factors for Hazard Index and Cancer Risk for Chemicals in the HSRAM Industrial Scenario.**

CASRN	Chemical Name	Hazard Index per mg/L	Increased Cancer Risk per mg/L
91-20-3	Naphthalene	1.16E+02	na
92-52-4	1,1'-Biphenyl	3.88E-01 b	na
95-50-1	1,2-Dichlorobenzene (ortho-)	1.39E-01 b	na
95-63-6	1,2,4-Trimethylbenzene	5.81E+01	na
98-86-2	Acetophenone	9.99E-02 b	na
98-95-3	Nitrobenzene	1.90E+02	na
100-25-4	1,4-Dinitrobenzene (para-)	2.51E+01 b	na
100-41-4	Ethyl benzene	4.68E-01	na
100-42-5	Styrene	4.06E-01	na
100-51-6	Benzyl alcohol	3.31E-02 b	na
106-46-7	1,4-Dichlorobenzene (para-)	4.31E-01 a	8.38E-05 d
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	1.73E+03 a	2.63E-01
106-99-0	1,3-Butadiene	1.73E+02 a	2.96E-03 c
107-02-8	Acrolein	1.73E+04	na
107-05-1	3-Chloropropene (Allyl chloride)	3.46E+02	na
107-06-2	1,2-Dichloroethane (Ethylene chloride)	na	2.83E-03
107-13-1	Acrylonitrile	1.83E+02	8.24E-03
108-10-1	Methyl isobutyl ketone (4-Methyl-2-pentanone)	1.15E-01 a	na
108-67-8	1,3,5-Trimethylbenzene	5.81E+01	na
108-87-2	Methyl cyclohexane	1.15E-01 a	na
108-88-3	Toluene (Methyl benzene)	9.25E-01	na
108-90-7	Chlorobenzene	1.80E+01	na
108-94-1	Cyclohexanone	1.97E-03 b	na
108-95-2	Phenol (Carbolic acid)	3.34E-02 b	na
110-00-9	Furan (Oxacyclopentadiene)	1.01E+01 b	na
110-54-3	n-Hexane	2.12E+00	na
110-86-1	Pyridine	9.91E+00 b	na
111-76-2	2-Butoxyethanol (Ethylene Glycol Monobutyl Ether)	2.15E-02	na
111-90-0	2-(2-Ethoxyethoxy)-ethanol (Diethylene Glycol Monoethyl Ether)	4.90E-03 b	na
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)	1.74E+01 b	1.39E-03 d
117-84-0	Di-n-octylphthalate	8.58E+00 b	na
118-74-1	Hexachlorobenzene	4.56E+01 b	6.21E-02
120-82-1	1,2,4-Trichlorobenzene	3.07E+00	na
121-44-8	Triethylamine	4.94E+01 a	na
122-39-4	Diphenylamine	5.39E-01 b	na
123-91-1	1,4-Dioxane (Diethylene oxide)	na	3.08E-05 d
126-73-8	Tributyl Phosphate	5.99E-02 b	1.85E-05 d
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)	5.93E+02	na
127-18-4	1,1,2,2-Tetrachloroethylene	1.71E+00	2.26E-04
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	1.10E-02 b	na
156-59-2	cis-1,2-Dichloroethylene	1.01E+00 b	na
206-44-0	Fluoranthene (1,2-Benzacenaphthene)	1.60E+00 b	na

**Table 23. Unit Factors for Hazard Index and Cancer Risk for Chemicals in the HSRAM Industrial Scenario.**

CASRN	Chemical Name	Hazard Index per mg/L	Increased Cancer Risk per mg/L
309-00-2	Aldrin	1.35E+03 b	6.82E-01
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	na	1.07E-01
319-85-7	beta-Benzene hexachloride (beta-Lindane)	na	6.31E-03
621-64-7	N-Nitrosodi-N-propylamine	na	2.04E-02 d
1314-62-1	Vanadium pentoxide	1.45E+00 b	na
1330-20-7	Xylenes (mixtures)	3.52E+00	na
1336-36-3	Polychlorinated Biphenyls (high risk)	na	2.48E-02 d
1336-36-3	Polychlorinated Biphenyls (low risk)	na	4.96E-03 d
1336-36-3	Polychlorinated Biphenyls (lowest risk)	na	8.68E-04 d
6533-73-9	Thallium carbonate	1.24E+02 b	na
7429-90-5	Aluminum	6.91E+01	na
7439-96-5	Manganese	6.91E+03 e	na
7439-98-7	Molybdenum	1.99E+00 b	na
7440-02-0	Nickel (soluble salts)	4.97E-01 b	na
7440-22-4	Silver	2.00E+00 b	na
7440-24-6	Strontium, Stable	1.67E-02 b	na
7440-31-5	Tin	1.81E-02 b	na
7440-36-0	Antimony	2.94E+01 b	na
7440-38-2	Arsenic (inorganic)	3.35E+01 b	4.31E-01
7440-39-3	Barium	6.91E+02	na
7440-41-7	Beryllium and compounds	1.73E+04	2.37E-01 c
7440-42-8	Boron and borates only	1.74E+01	na
7440-43-9	Cadmium	2.62E+01 bf	1.78E-01 c
7440-48-4	Cobalt	1.73E+04	2.77E-01 c
7440-66-6	Zinc and compounds	3.32E-02 b	na
7487-94-7	Mercuric chloride	3.31E+01 b	na
7664-41-7	Ammonia	4.87E-01 a	na
7723-14-0	Phosphorus, white	5.01E+02 b	na
7782-41-4	Fluorine (soluble fluoride)	1.66E-01 b	na
7782-49-2	Selenium and compounds	1.98E+00 b	na
8001-35-2	Toxaphene	na	1.24E-02
14797-55-8	Nitrate	6.18E-03 b	na
14797-65-0	Nitrite	9.89E-02 b	na
16065-83-1	Chromium (III) (insoluble salts)	1.12E-02 b	na
18540-29-9	Chromium (VI) (soluble salts)	4.32E+00 g	2.70E-05 c
none	Uranium (soluble salts)	1.65E+01 b	na

**Table 23. Unit Factors for Hazard Index and Cancer Risk for Chemicals in the HSRAM Industrial Scenario.**

CASRN	Chemical Name	Hazard Index per mg/L	Increased Cancer Risk per mg/L
Notes: <ul style="list-style-type: none"> <li>• CASRN = Chemical Abstract Service Reference Number</li> <li>• 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.</li> <li>• These scenario factors must be multiplied by the water concentration.</li> <li>• Results using route-to-route extrapolations are shown in Table C7. Results with notes (a, b, c, d, e, f, g, or h) have the following qualifiers:               <ul style="list-style-type: none"> <li>(a) -- The RfD for ingestion was not available.</li> <li>(b) -- The RfD for inhalation was not available.</li> <li>(c) -- The Slope Factor for ingestion was not available.</li> <li>(d) -- The Slope Factor for inhalation was not available.</li> <li>(e) -- For manganese (7439-96-5) the drinking water has a lower RfD.</li> <li>(f) -- For cadmium (7440-43-9) the food has a larger RfD.</li> <li>(g) -- For chromium VI (18540-29-9) the airborne particulate has a larger RfD.</li> <li>(h) -- Vinyl chloride (75-01-4) uses slope factors from IRIS for adulthood only exposures.</li> </ul> </li> </ul>			

### 3.9 HSRAM RECREATIONAL SCENARIO

The default recreational exposure scenario presented in the HSRAM is used to represent a visitor engaging in various forms of recreational activity. The most likely location is near the Columbia River. The HSRAM presents additional parameters to cover possible future recreational activities some distance from the river.

The hazard quotient for chemicals is calculated using the drinking, breathing and soil ingestion rates for children. HSRAM uses the higher normalized intake rates for the child to maximize the average daily intake. The incremental cancer risk is calculated using adult drinking and breathing rates, and an average soil ingestion rate that includes 6 years at the child's higher rate. Thus, the calculation of the 30-year intakes depends on the location of the contaminant.

The principle avenue for the contaminants to get into the visitors is through drinking water and game fish. However, if a well to ground water is the source of contaminated water then the fish are not contaminated. Hence, for the recreational scenario there are two cases. The first is for a well to groundwater. This water is used to irrigate a recreational area some distance from the Columbia River. The individual drinks from the well and enjoys the park facilities. Soil is contaminated by irrigation of grass and other plants. This leads to dermal absorption of chemicals and external exposure from radionuclides. A small amount becomes airborne and is inhaled. The intakes continue 7 days each year for 30 years.

The second case is for contamination in the Columbia River. In this case the visitor consumes 9.9 kg game fish (Table A4) every year for 30 years. There is an additional small amount of deer mentioned in the HSRAM. This is calculated to be 0.19 deer per year with a mass of 45 kg, with half eaten by one person. The average game intake is 4.2 kg/y. The deer is

contaminated by drinking from the river. The daily water intake is 25% of a milk cow's. The transfer factors for beef are used to represent the deer meat concentration. The other pathways are regarded as the same as the inland park simply because there may be a park along the river. Dermal contact during swimming is also part of the second case.

The lifetime increase in the visitor's risk of developing some type of cancer from the radionuclides is the sum of 30 years of exposure. The first 6 years are at the child's soil ingestion rate (1.4 g/y), while the last 24 are at the adult's soil ingestion rate (0.7 g/y). Both of these are shown in Table A8. The other intakes are all at the adult rate. Drinking water consumption is 14 L/y. Soil inhalation is 0.007 g/y (Table A10). External exposure is 45 h/y (Table A15). The estimated risks from radioactive materials in the recreation scenarios are shown in Table 24. The first column of risks shows the inland park case in which the radionuclides are from ground water. The second column of risks shows the Columbia River case, in which the radionuclides are in the surface water. The third column is the ratio of the Columbia River to the inland park risk. For most radionuclides, the fish contributes the majority of the dose. In a few cases, the external dose from shoreline sediments dominates. If the contaminants are from well water, the water gives the majority of the dose.

**Table 24. Unit Risk Factors for Radionuclides in the Recreational Scenarios (risk per pCi/L).**

Nuclide	Inland Park	Columbia River	Ratio	Nuclide	Inland Park	Columbia River	Ratio
H-3	4.73E-11	9.81E-11	2.1	Gd-152	1.28E-08	3.05E-07	23.8
Be-10	2.99E-09	3.08E-07	103	Ho-166m	6.85E-08	1.25E-06	18.2
C-14	6.54E-10	2.97E-05	45,429	Re-187	7.58E-12	9.24E-10	122
Na-22	2.32E-08	2.16E-07	9.3	Tl-204	2.47E-09	2.45E-05	9,922
Al-26	1.21E-07	5.78E-06	47.6	Pb-205	2.67E-10	7.39E-08	276
Si-32+D	5.33E-09	1.11E-07	21	Pb-210+D	3.76E-07	1.07E-04	283
Cl-36	1.39E-09	6.76E-08	48.5	Bi-207	5.18E-08	7.97E-07	15.4
K-40	1.60E-08	1.03E-05	642	Po-209	1.99E-07	4.20E-05	211
Ca-41	1.49E-10	5.37E-09	36.1	Po-210	1.59E-07	3.36E-05	212
Ti-44+D	8.74E-08	1.27E-05	146	Ra-226+D	2.36E-07	9.27E-06	39.2
V-49	5.13E-11	1.07E-08	208	Ra-228+D	4.78E-07	2.22E-05	46.4
Mn-54	3.57E-09	3.93E-07	110	Ac-227+D	2.18E-07	5.27E-06	24.1
Fe-55	3.63E-10	6.93E-08	191	Th-228+D	1.40E-07	1.28E-05	91.5
Fe-60+D	1.41E-07	1.58E-05	112	Th-229+D	2.39E-07	2.18E-05	91.1
Co-60	4.62E-08	2.41E-06	52.1	Th-230	3.96E-08	3.60E-06	91.1
Ni-59	1.16E-10	1.17E-08	101	Th-232	1.02E-07	5.60E-06	54.8
Ni-63	2.83E-10	2.87E-08	101	Pa-231	7.94E-08	9.37E-07	11.8
Se-79	3.07E-09	4.93E-07	160	U-232	1.65E-07	1.76E-06	10.7
Rb-87	2.21E-09	4.20E-06	1,904	U-233	3.06E-08	3.25E-07	10.6
Sr-90+D	3.14E-08	1.74E-06	55.5	U-234	3.01E-08	3.20E-07	10.6
Zr-93	4.70E-10	1.29E-07	275	U-235+D	3.40E-08	3.62E-07	10.6
Nb-91	3.83E-10	1.06E-07	276	U-236	2.85E-08	3.03E-07	10.6
Nb-93m	3.39E-10	1.05E-07	308	U-238+D	3.76E-08	4.11E-07	10.9
Nb-94	6.51E-08	2.08E-06	32.0	Np-237+D	3.52E-08	7.01E-07	19.9
Mo-93	1.41E-09	1.41E-08	10.0	Pu-236	3.32E-08	6.72E-07	20.2

**Table 24. Unit Risk Factors for Radionuclides in the Recreational Scenarios (risk per pCi/L).**

Nuclide	Inland Park	Columbia River	Ratio	Nuclide	Inland Park	Columbia River	Ratio
Tc-99	1.16E-09	2.50E-08	21.6	Pu-238	5.62E-08	1.13E-06	20.1
Ru-106+D	1.85E-08	2.12E-07	11.4	Pu-239	5.79E-08	1.17E-06	20.2
Pd-107	1.06E-10	1.26E-09	11.9	Pu-240	5.79E-08	1.17E-06	20.2
Ag-108m+D	6.06E-08	9.64E-07	15.9	Pu-241+D	7.59E-10	1.55E-08	20.5
Cd-109	2.11E-09	4.00E-07	190	Pu-242	5.49E-08	1.11E-06	20.2
Cd-113m	1.21E-08	2.18E-06	180	Pu-244+D	7.47E-08	1.51E-06	20.3
In-115	1.43E-08	1.29E-03	90,054	Am-241	4.49E-08	9.04E-07	20.1
Sn-121m+D	1.49E-09	4.57E-06	3,066	Am-242m+D	3.17E-08	6.22E-07	19.6
Sn-126+D	8.72E-08	3.63E-05	416	Am-243+D	5.18E-08	1.05E-06	20.3
Sb-125	5.37E-09	2.18E-07	40.6	Cm-242	1.64E-08	3.59E-07	21.8
Te-125m	1.40E-09	5.60E-07	400	Cm-243	4.35E-08	8.64E-07	19.9
I-129	6.25E-08	2.39E-06	38.2	Cm-244	3.59E-08	7.19E-07	20.0
Cs-134	2.86E-08	3.07E-05	1,073	Cm-245	4.68E-08	9.44E-07	20.2
Cs-135	2.00E-09	3.50E-06	1,748	Cm-246	4.39E-08	8.81E-07	20.1
Cs-137+D	3.03E-08	2.25E-05	742	Cm-247+D	5.47E-08	1.09E-06	20.0
Ba-133	9.72E-09	9.69E-08	10.0	Cm-248	1.61E-07	3.23E-06	20.1
Pm-147	7.12E-10	2.29E-08	32.2	Cm-250+D	9.32E-07	1.87E-05	20.1
Sm-147	1.60E-08	3.77E-07	23.6	Bk-247	5.59E-08	1.31E-06	23.5
Sm-151	2.35E-10	6.36E-09	27.1	Cf-248	1.90E-08	4.82E-07	25.4
Eu-150	4.80E-08	8.20E-07	17.1	Cf-249	6.61E-08	1.49E-06	22.6
Eu-152	3.12E-08	5.13E-07	16.4	Cf-250	3.70E-08	8.78E-07	23.7
Eu-154	3.00E-08	5.34E-07	17.8	Cf-251	5.99E-08	1.40E-06	23.4
Eu-155	1.17E-09	4.59E-08	39.2	Cf-252	2.07E-08	4.90E-07	23.7

**Notes:**

- The radiation risk to this individual is calculated using intakes from 30 consecutive years. The soil concentration is zero at the start of the exposure.
- These scenario risk factors must be multiplied by the water concentration.
- The "Inland Park" column gives the recreational scenario risk factors from ground water. The column "Columbia River" shows the risk factors for surface water. The "Ratio" column is the "Columbia River" divided by the "Inland Park" risk factors.

The hazard index and cancer risk from chemicals are calculated using the same consumption parameters discussed in Appendix A for the HSRAM Recreational scenario. The contaminant concentration in well or river water is expressed in mg/L. The chemical dose is normalized to the average adult body mass, 70 kg. To calculate the average daily dose over a lifetime, the total dose from 30 consecutive years is calculated and then divided by (30 y)(365 d/y) for the hazard index and (70 y)(365 d/y) for the cancer risk. As part of this calculation, the concentration of the contaminants in soil is increased each year. The effect of leaching from the surface layer is included using the leaching coefficients shown in Table A38. Dermal absorption during showering is included.

The calculated hazard index and cancer risk per unit concentration in the well or the Columbia River for the HSRAM Recreational scenario are shown in Table 25. The factors must be multiplied by the estimated water concentration, in mg per L.

**Table 25. Unit Factors for Hazard Index and Cancer Risk for Chemicals in 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 d	na	1.29E+01 d
53-70-3	Dibenz[a,h]anthracene	na	2.37E-02	na	3.85E+01
56-23-5	Carbon tetrachloride	1.76E+00 b	3.29E-05	1.91E+01 b	7.11E-04
57-12-5	Cyanide, free	6.19E-02 b	na	2.78E-01 b	na
57-14-7	1,1-Dimethylhydrazine	na	7.09E-04	na	2.35E-03
57-55-6	Propylene glycol (1,2-Propanediol)	6.01E-05 b	na	1.23E-04 b	na
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)	4.13E+00 b	3.20E-04 d	1.97E+02 b	3.23E-02 d
60-34-4	Methylhydrazine	na	7.08E-04	na	2.34E-03
60-57-1	Dieldrin	2.68E+01 b	4.73E-03	2.23E+04 b	7.65E+00
62-75-9	N-Nitrosodimethylamine	na	1.21E-02	na	4.02E-02
64-18-6	Formic acid	6.02E-04 b	na	1.24E-03 b	na
67-56-1	Methanol (Methyl alcohol)	2.40E-03 b	na	4.90E-03 b	na
67-64-1	Acetone (2-Propanone)	1.20E-02 b	na	2.45E-02 b	na
67-66-3	Chloroform	1.24E-01 b	1.18E-06	4.42E-01 b	2.55E-06
71-36-3	n-Butyl alcohol (n-Butanol)	1.21E-02 b	na	2.53E-02 b	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)	6.18E-03	na	3.95E-02	na
72-20-8	Endrin	1.11E+01 b	na	2.74E+03 b	na
74-83-9	Bromomethane	9.01E-01	na	1.40E+00	na
74-87-3	Methyl chloride (Chloromethane)	2.30E-03 a	na	2.30E-03 a	na
75-00-3	Ethyl Chloride	2.06E-05 a	na	2.06E-05 a	na
75-01-4	Vinyl chloride (Chloroethene)	4.05E-01	3.35E-04	9.15E-01	1.25E-03
75-05-8	Acetonitrile	3.45E-03 a	na	3.45E-03 a	na
75-07-0	Acetaldehyde	2.30E-02 a	8.91E-08 c	2.30E-02 a	8.91E-08 c
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	4.13E-06 a	na	4.13E-06 a	na
75-68-3	Chloro-1,1-difluoroethane, 1-	4.13E-06 a	na	4.13E-06 a	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	3.00E+00 b	1.67E-03	7.71E+03 b	7.43E+00
78-87-5	1,2-Dichloropropane	5.18E-02 a	na	5.18E-02 a	na
78-93-3	Methyl ethyl ketone (2-Butanone)	2.21E-03	na	4.30E-03	na
79-00-5	1,1,2-Trichloroethane	3.02E-01 b	1.42E-05	8.84E-01 b	7.10E-05

**Table 25. Unit Factors for Hazard Index and Cancer Risk for Chemicals in 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	2.16E-01 b	3.11E-06	1.41E+00 b	3.68E-05
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)	na	5.04E-05	na	5.26E-04
82-68-8	Pentachloronitrobenzene (PCNB)	4.30E-01 b	6.97E-05 d	9.73E+01 b	3.24E-02 d
83-32-9	Acenaphthene	2.68E-02 b	na	1.48E+00 b	na
84-66-2	Diethyl phthalate	1.53E-03 b	na	8.98E-03 b	na
84-74-2	Dibutyl phthalate	1.28E-02 b	na	2.28E+00 b	na
85-68-7	Butyl benzyl phthalate	6.54E-03 b	na	1.72E+00 b	na
87-68-3	Hexachlorobutadiene	7.11E+00 b	2.66E-05	1.88E+03 b	1.25E-02
87-86-5	Pentachlorophenol	4.68E-02 b	3.81E-05 d	9.17E+00 b	1.41E-02 d
88-06-2	2,4,6-Trichlorophenol	na	3.08E-06	na	1.13E-04
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)	1.27E+00 b	na	4.85E+01 b	na
91-20-3	Naphthalene	1.33E-01	na	1.54E+00	na
92-52-4	1,1'-Biphenyl	2.97E-02 b	na	1.91E+00 b	na
95-50-1	1,2-Dichlorobenzene (ortho-)	1.42E-02 b	na	4.03E-01 b	na
95-63-6	1,2,4-Trimethylbenzene	6.16E-02	na	1.07E+00	na
98-86-2	Acetophenone	1.21E-02 b	na	1.55E-02 b	na
98-95-3	Nitrobenzene	2.53E+00	na	7.05E+00	na
100-25-4	1,4-Dinitrobenzene (para-)	3.08E+00 b	na	1.10E+01 b	na
100-41-4	Ethyl benzene	1.29E-02	na	2.30E-01	na
100-42-5	Styrene	6.52E-03	na	8.37E-02	na
100-51-6	Benzyl alcohol	4.03E-03 b	na	4.85E-03 b	na
106-46-7	1,4-Dichlorobenzene (para-)	2.58E-04 a	6.34E-06 d	2.58E-04 a	3.72E-04 d
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	1.03E+00 a	2.01E-02	1.03E+00 a	1.14E-01
106-99-0	1,3-Butadiene	1.03E-01 a	1.21E-06 c	1.03E-01 a	1.21E-06 c
107-02-8	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)	na	2.26E-05	na	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)	6.89E-05 a	na	6.89E-05 a	na
108-67-8	1,3,5-Trimethylbenzene	6.07E-02	na	7.59E-01	na
108-87-2	Methyl cyclohexane	6.89E-05 a	na	6.89E-05 a	na
108-88-3	Toluene (Methyl benzene)	6.78E-03	na	5.97E-02	na
108-90-7	Chlorobenzene	7.64E-02	na	7.65E-01	na
108-94-1	Cyclohexanone	2.41E-04 b	na	5.01E-04 b	na
108-95-2	Phenol (Carbolic acid)	4.08E-03 b	na	8.86E-03 b	na
110-00-9	Furan (Oxacyclopentadiene)	1.21E+00 b	na	2.16E+00 b	na
110-54-3	n-Hexane	2.74E-02	na	1.42E+00	na
110-86-1	Pyridine	1.21E+00 b	na	2.54E+00 b	na

**Table 25. Unit Factors for Hazard Index and Cancer Risk for Chemicals in 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
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)	6.01E-04 b	na	1.23E-03 b	na
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)	5.35E-01 b	6.03E-05 d	1.41E+01 b	1.68E-03 d
117-84-0	Di-n-octylphthalate	2.88E-01 b	na	5.22E+00 b	na
118-74-1	Hexachlorobenzene	2.44E+00 b	9.09E-04	2.51E+03 b	1.38E+00
120-82-1	1,2,4-Trichlorobenzene	1.31E-01	na	9.92E+00	na
121-44-8	Triethylamine	2.95E-02 a	na	2.95E-02 a	na
122-39-4	Diphenylamine	5.32E-02 b	na	1.80E+00 b	na
123-91-1	1,4-Dioxane (Diethylene oxide)	na	2.59E-06 d	na	8.44E-06 d
126-73-8	Tributyl Phosphate	6.44E-03 b	1.45E-06 d	1.07E-01 b	4.62E-05 d
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)	1.23E+01	na	2.51E+01	na
127-18-4	1,1,2,2-Tetrachloroethylene	1.25E-01	1.32E-05	3.40E+00	7.44E-04
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	1.34E-03 b	na	2.74E-03 b	na
156-59-2	cis-1,2-Dichloroethylene	1.21E-01 b	na	3.45E-01 b	na
206-44-0	Fluoranthene (1,2-Benzacenaphthene)	6.86E-02 b	na	1.89E+01 b	na
309-00-2	Aldrin	6.94E+01 b	1.06E-02	2.61E+05 b	5.71E+01
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	na	1.59E-03	na	1.80E-01
319-85-7	beta-Benzene hexachloride (beta-Lindane)	na	4.46E-04	na	4.98E-02
621-64-7	N-Nitrosodi-N-propylamine	na	1.70E-03 d	na	5.44E-03 d
1314-62-1	Vanadium pentoxide	1.46E-01 b	na	9.33E+00 b	na
1330-20-7	Xylenes (mixtures)	8.41E-03	na	1.12E-01	na
1336-36-3	Polychlorinated Biphenyls (high risk)	na	1.29E-03 d	na	1.93E+01 d
1336-36-3	Polychlorinated Biphenyls (low risk)	na	2.57E-04 d	na	3.85E+00 d
1336-36-3	Polychlorinated Biphenyls (lowest risk)	na	4.50E-05 d	na	6.75E-01 d
6533-73-9	Thallium carbonate	1.54E+01 b	na	4.85E+04 b	na
7429-90-5	Aluminum	4.26E-02	na	2.41E-01	na
7439-96-5	Manganese	4.16E+00 e	na	5.30E+00 e	na
7439-98-7	Molybdenum	2.46E-01 b	na	1.44E+00 b	na
7440-02-0	Nickel (soluble salts)	6.14E-02 b	na	2.19E+00 b	na
7440-22-4	Silver	2.46E-01 b	na	1.37E+00 b	na
7440-24-6	Strontium, Stable	2.05E-03 b	na	4.71E-02 b	na
7440-31-5	Tin	2.09E-03 b	na	1.95E+00 b	na
7440-36-0	Antimony	3.21E+00 b	na	1.14E+02 b	na
7440-38-2	Arsenic (inorganic)	4.11E+00 b	5.44E-04	3.32E+02 b	6.33E-02
7440-39-3	Barium	4.31E-01	na	5.07E-01	na
7440-41-7	Beryllium and compounds	1.10E+01	9.77E-05 c	3.38E+01	9.77E-05 c
7440-42-8	Boron and borates only	2.40E-02	na	5.81E-02	na
7440-43-9	Cadmium	2.80E+00 bf	7.33E-05 c	1.28E+02 bf	7.33E-05 c
7440-48-4	Cobalt	1.04E+01	1.14E-04 c	1.64E+01	1.14E-04 c

**Table 25. Unit Factors for Hazard Index and Cancer Risk for Chemicals in 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
7440-66-6	Zinc and compounds	4.10E-03 b	na	3.42E-01 b	na
7487-94-7	Mercuric chloride	4.09E+00 b	na	1.30E+03 b	na
7664-41-7	Ammonia	2.92E-04 a	na	2.92E-04 a	na
7723-14-0	Phosphorus, white	6.15E+01 b	na	2.92E+04 b	na
7782-41-4	Fluorine (soluble fluoride)	2.05E-02 b	na	1.46E-01 b	na
7782-49-2	Selenium and compounds	2.45E-01 b	na	1.36E+01 b	na
8001-35-2	Toxaphene	na	3.34E-04	na	1.03E+00
14797-55-8	Nitrate	7.62E-04 b	na	1.74E-03 b	na
14797-65-0	Nitrite	1.22E-02 b	na	2.78E-02 b	na
16065-83-1	Chromium (III) (insoluble salts)	9.61E-04 b	na	5.97E-02 b	na
18540-29-9	Chromium (VI) (soluble salts)	4.45E-01 g	1.07E-06 c	2.66E+01 g	1.07E-06 c
none	Uranium (soluble salts)	2.04E+00 b	na	1.18E+01 b	na

## 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.
- Results using route-to-route extrapolations are shown in Table C9. Results with notes (a, b, c, d, e, f, or g) have the following qualifiers:
  - (a) -- The RfD for ingestion was not available.
  - (b) -- The RfD for inhalation was not available.
  - (c) -- The Slope Factor for ingestion was not available.
  - (d) -- The Slope Factor for inhalation was not available.
  - (e) -- For manganese (7439-96-5) the drinking water has a lower RfD.
  - (f) -- For cadmium (7440-43-9) the food has a larger RfD.
  - (g) -- For chromium VI (18540-29-9) the airborne particulate has a larger RfD.

**3.10 HSRAM RESIDENTIAL SCENARIO**

The default residential exposure scenario presented in the HSRAM is similar to the all pathways farmer discussed earlier. The difference is that deer and fish are the only animal products included, and the other intake rates are different. For food and water, these are shown in Table A4.

The hazard quotient for chemicals is calculated using the drinking, breathing and soil ingestion rates for children. The incremental cancer risk is calculated using adult drinking and breathing rates, and an average soil ingestion rate that includes 6 years at the child’s higher rate. Thus, the calculation of the 30-year intakes depends on the location of the contaminant.

The principle avenues for the contaminants to get into the resident are drinking water and game fish. However, if a well to ground water is the source of contaminated water then the fish are not contaminated. Hence, for the residential scenario there are two cases. The first is for a well to groundwater. The second is when the water supply is taken directly from the Columbia River. The second case adds fish, sediment exposure, and dermal contact with water during swimming to the first case. The added pathways use the same annual intakes as the recreational scenario along the Columbia River.

The lifetime increase in the resident's risk of developing some type of cancer from the radionuclides is the sum of 30 years of exposure. The first 6 years are at the child's intake rates for some pathways, while the last 24 are at the adult's rate. Both of these are shown in Table A8. The other intakes are all at the adult rate. Drinking water consumption is 730 L/y (Table A4). The individual has a 10-minute shower every day and inhales the equivalent of 0.031 L/y (Table A13). Soil inhalation is 0.365 g/y (Table A10). External exposure is 7,008 h/y (Table A15). The estimated risks from radioactive materials in the residential scenarios are shown in Table 26. The first column of risks shows the inland resident, who obtains the radionuclides from ground water. The second column of risks shows the Columbia River case, in which the radionuclides are in the surface water. The third column is the ratio of the Columbia River to the inland resident risk factors.

**Table 26. Unit Risk Factors for Radionuclides in the Residential Scenarios (risk per pCi/L).**

Nuclide	Inland Resident	Columbia River	Ratio	Nuclide	Inland Resident	Columbia River	Ratio
H-3	2.81E-09	2.85E-09		Gd-152	7.77E-07	1.37E-06	1.8
Be-10	1.84E-07	5.83E-07	3.2	Ho-166m	1.03E-05	1.16E-05	1.1
C-14	5.61E-08	2.98E-05	530	Re-187	6.23E-10	1.75E-09	2.8
Na-22	3.23E-06	3.44E-06		Tl-204	1.52E-07	2.47E-05	163
Al-26	1.82E-05	2.41E-05	1.3	Pb-205	1.63E-08	9.59E-08	5.9
Si-32+D	3.53E-07	5.77E-07	1.6	Pb-210+D	2.36E-05	1.38E-04	5.8
Cl-36	1.55E-06	1.62E-06		Bi-207	7.85E-06	8.64E-06	
K-40	1.75E-06	1.22E-05	6.9	Po-209	1.82E-05	6.42E-05	3.5
Ca-41	1.17E-08	1.82E-08	1.6	Po-210	1.38E-05	4.73E-05	3.4
Ti-44+D	1.25E-05	2.54E-05	2.0	Ra-226+D	2.14E-05	3.86E-05	1.8
V-49	3.14E-09	1.38E-08	4.4	Ra-228+D	3.29E-05	5.82E-05	1.8
Mn-54	4.66E-07	8.57E-07	1.8	Ac-227+D	1.42E-05	2.26E-05	1.6
Fe-55	2.20E-08	9.21E-08	4.2	Th-228+D	9.62E-06	2.26E-05	2.4
Fe-60+D	1.48E-05	3.22E-05	2.2	Th-229+D	1.55E-05	4.32E-05	2.8
Co-60	6.58E-06	8.98E-06	1.4	Th-230	2.43E-06	7.01E-06	2.9
Ni-59	7.47E-09	2.26E-08	3.0	Th-232	1.16E-05	2.90E-05	2.5
Ni-63	1.82E-08	5.42E-08	3.0	Pa-231	5.23E-06	1.01E-05	1.9
Se-79	1.88E-07	6.89E-07	3.7	U-232	1.38E-05	1.78E-05	1.3
Rb-87	2.31E-07	4.48E-06	19.4	U-233	1.87E-06	2.49E-06	1.3
Sr-90+D	2.61E-06	4.77E-06	1.8	U-234	1.84E-06	2.45E-06	1.3
Zr-93	2.85E-08	1.72E-07	6.0	U-235+D	2.41E-06	3.07E-06	1.3
Nb-91	2.78E-08	1.43E-07	5.1	U-236	1.74E-06	2.31E-06	1.3
Nb-93m	2.11E-08	1.31E-07	6.2	U-238+D	2.37E-06	3.16E-06	1.3

**Table 26. Unit Risk Factors for Radionuclides in the Residential Scenarios (risk per pCi/L).**

Nuclide	Inland Resident	Columbia River	Ratio	Nuclide	Inland Resident	Columbia River	Ratio
Nb-94	9.83E-06	1.19E-05	1.2	Np-237+D	2.76E-06	4.00E-06	1.5
Mo-93	1.26E-07	1.52E-07	1.2	Pu-236	2.13E-06	2.97E-06	1.4
Tc-99	3.36E-07	3.65E-07		Pu-238	3.40E-06	5.61E-06	1.7
Ru-106+D	1.21E-06	1.42E-06	1.2	Pu-239	3.50E-06	5.93E-06	1.7
Pd-107	6.77E-09	1.09E-08	1.6	Pu-240	3.50E-06	5.93E-06	1.7
Ag-108m+D	9.11E-06	1.01E-05	1.1	Pu-241+D	4.62E-08	8.58E-08	1.9
Cd-109	1.31E-07	5.32E-07	4.1	Pu-242	3.32E-06	5.63E-06	1.7
Cd-113m	7.91E-07	3.06E-06	3.9	Pu-244+D	5.77E-06	8.71E-06	1.5
In-115	8.63E-07	1.29E-03	1,492	Am-241	2.74E-06	4.60E-06	1.7
Sn-121m+D	9.27E-08	4.69E-06	51	Am-242m+D	1.95E-06	3.62E-06	1.9
Sn-126+D	1.25E-05	4.91E-05	3.9	Am-243+D	3.66E-06	5.76E-06	1.6
Sb-125	6.62E-07	8.83E-07	1.3	Cm-242	9.97E-07	1.35E-06	1.4
Te-125m	8.36E-08	6.42E-07	7.7	Cm-243	2.90E-06	4.38E-06	1.5
I-129	3.84E-06	6.96E-06	1.8	Cm-244	2.17E-06	3.33E-06	1.5
Cs-134	2.77E-06	3.34E-05	12.1	Cm-245	3.02E-06	4.98E-06	1.6
Cs-135	1.36E-07	3.66E-06	26.9	Cm-246	2.65E-06	4.49E-06	1.7
Cs-137+D	3.58E-06	2.62E-05	7.3	Cm-247+D	4.43E-06	6.48E-06	1.5
Ba-133	1.25E-06	1.36E-06		Cm-248	9.71E-06	1.65E-05	1.7
Pm-147	4.37E-08	6.85E-08	1.6	Cm-250+D	5.75E-05	9.64E-05	1.7
Sm-147	9.68E-07	1.68E-06	1.7	Bk-247	3.63E-06	6.06E-06	1.7
Sm-151	1.45E-08	2.71E-08	1.9	Cf-248	1.16E-06	1.67E-06	1.4
Eu-150	7.30E-06	8.11E-06	1.1	Cf-249	5.11E-06	7.69E-06	1.5
Eu-152	4.62E-06	5.14E-06	1.1	Cf-250	2.25E-06	3.49E-06	1.6
Eu-154	4.26E-06	4.81E-06	1.1	Cf-251	3.95E-06	6.53E-06	1.7
Eu-155	1.07E-07	1.57E-07	1.5	Cf-252	1.25E-06	1.78E-06	1.4

## Notes:

- The radiation risk to this individual is calculated using intakes from 30 consecutive years. The soil concentration is zero at the start of the exposure.
- These scenario risk factors must be multiplied by the water concentration.
- The "Inland Resident" column gives the residential scenario risk factors from ground water. The column "Columbia River" shows the risk factors for surface water. The "Ratio" column is the "Columbia River" divided by the "Inland Resident" risk factors.

The hazard index and cancer risk from chemicals are calculated using the same consumption parameters discussed in Appendix A for the HSRAM Residential scenario. The contaminant concentration in well or river water is expressed in mg/L. The chemical dose is normalized to the average adult body mass, 70 kg. To calculate the average daily dose over a lifetime, the total dose from 30 consecutive years is calculated and then divided by (30 y)(365 d/y) for the hazard index and (70 y)(365 d/y) for the cancer risk. As part of this calculation, the concentration of the contaminants in soil is increased each year. The effect of leaching from the surface layer is included using the leaching coefficients shown in Table A38. Dermal absorption during showering is included.

The calculated hazard index and cancer risk per unit concentration in the well or the Columbia River for the HSRAM Residential scenario are shown in Table 27. The factors must be multiplied by the estimated water concentration, in mg per L.

**Table 27. Unit Factors for Hazard Index and Cancer Risk for Chemicals in 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	7.09E-01 d	na	1.36E+01 d
53-70-3	Dibenz[a,h]anthracene	na	1.25E+00	na	3.97E+01
56-23-5	Carbon tetrachloride	9.85E+01 b	4.39E-03	1.16E+02 b	5.07E-03
57-12-5	Cyanide, free	4.41E+02 b	na	4.42E+02 b	na
57-14-7	1,1-Dimethylhydrazine	na	4.30E+00	na	4.30E+00
57-55-6	Propylene glycol (1,2-Propanediol)	5.58E-02 b	na	5.58E-02 b	na
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)	3.24E+02 b	3.49E-02 d	5.17E+02 b	6.69E-02 d
60-34-4	Methylhydrazine	na	3.22E+00	na	3.22E+00
60-57-1	Dieldrin	1.55E+03 b	6.02E-01	2.39E+04 b	8.25E+00
62-75-9	N-Nitrosodimethylamine	na	3.47E+01	na	3.47E+01
64-18-6	Formic acid	4.73E-01 b	na	4.74E-01 b	na
67-56-1	Methanol (Methyl alcohol)	1.24E+00 b	na	1.24E+00 b	na
67-64-1	Acetone (2-Propanone)	2.28E+00 b	na	2.29E+00 b	na
67-66-3	Chloroform	7.23E+00 b	3.76E-03	7.55E+00 b	3.76E-03
71-36-3	n-Butyl alcohol (n-Butanol)	1.41E+00 b	na	1.42E+00 b	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)	5.17E-01	na	5.50E-01	na
72-20-8	Endrin	6.02E+02 b	na	3.33E+03 b	na
74-83-9	Bromomethane	1.30E+02	na	1.31E+02	na
74-87-3	Methyl chloride (Chloromethane)	4.22E+00 a	na	4.22E+00 a	na
75-00-3	Ethyl Chloride	3.80E-02 a	na	3.80E-02 a	na
75-01-4	Vinyl chloride (Chloroethene)	2.76E+01	2.40E-02	2.82E+01	2.49E-02
75-05-8	Acetonitrile	6.35E+00 a	na	6.35E+00 a	na
75-07-0	Acetaldehyde	4.22E+01 a	3.58E-04 c	4.22E+01 a	3.58E-04 c
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	7.59E-03 a	na	7.59E-03 a	na
75-68-3	Chloro-1,1-difluoroethane, 1-	7.59E-03 a	na	7.59E-03 a	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	1.67E+02 b	3.06E-01	7.87E+03 b	7.74E+00

**Table 27. Unit Factors for Hazard Index and Cancer Risk for Chemicals in 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
78-87-5	1,2-Dichloropropane	9.52E+01 a	na	9.52E+01 a	na
78-93-3	Methyl ethyl ketone (2-Butanone)	6.48E-01	na	6.50E-01	na
79-00-5	1,1,2-Trichloroethane	1.93E+01 b	3.66E-03	1.98E+01 b	3.71E-03
79-01-6	Trichloroethylene	1.22E+01 b	4.63E-04	1.34E+01 b	4.96E-04
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)	na	1.31E-02	na	1.36E-02
82-68-8	Pentachloronitrobenzene (PCNB)	2.55E+01 b	4.66E-03 d	1.22E+02 b	3.70E-02 d
83-32-9	Acenaphthene	1.62E+00 b	na	3.07E+00 b	na
84-66-2	Diethyl phthalate	1.61E-01 b	na	1.69E-01 b	na
84-74-2	Dibutyl phthalate	7.83E-01 b	na	3.05E+00 b	na
85-68-7	Butyl benzyl phthalate	4.11E-01 b	na	2.12E+00 b	na
87-68-3	Hexachlorobutadiene	3.91E+02 b	5.06E-03	2.26E+03 b	1.76E-02
87-86-5	Pentachlorophenol	2.74E+00 b	2.44E-03 d	1.19E+01 b	1.65E-02 d
88-06-2	2,4,6-Trichlorophenol	na	3.39E-04	na	4.48E-04
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)	1.34E+02 b	na	1.82E+02 b	na
91-20-3	Naphthalene	1.31E+02	na	1.32E+02	na
92-52-4	1,1'-Biphenyl	1.77E+00 b	na	3.65E+00 b	na
95-50-1	1,2-Dichlorobenzene (ortho-)	8.07E-01 b	na	1.20E+00 b	na
95-63-6	1,2,4-Trimethylbenzene	6.50E+01	na	6.60E+01	na
98-86-2	Acetophenone	1.48E+00 b	na	1.48E+00 b	na
98-95-3	Nitrobenzene	4.61E+02	na	4.66E+02	na
100-25-4	1,4-Dinitrobenzene (para-)	2.22E+03 b	na	2.23E+03 b	na
100-41-4	Ethyl benzene	1.10E+00	na	1.31E+00	na
100-42-5	Styrene	7.47E-01	na	8.24E-01	na
100-51-6	Benzyl alcohol	7.13E-01 b	na	7.14E-01 b	na
106-46-7	1,4-Dichlorobenzene (para-)	4.74E-01 a	3.90E-04 d	4.74E-01 a	7.55E-04 d
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	1.90E+03 a	1.79E+00	1.90E+03 a	1.88E+00
106-99-0	1,3-Butadiene	1.90E+02 a	4.88E-03 c	1.90E+02 a	4.88E-03 c
107-02-8	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)	na	5.94E-03	na	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)	1.27E-01 a	na	1.27E-01 a	na
108-67-8	1,3,5-Trimethylbenzene	6.49E+01	na	6.56E+01	na
108-87-2	Methyl cyclohexane	1.27E-01 a	na	1.27E-01 a	na
108-88-3	Toluene (Methyl benzene)	1.31E+00	na	1.36E+00	na
108-90-7	Chlorobenzene	2.28E+01	na	2.35E+01	na
108-94-1	Cyclohexanone	4.22E-02 b	na	4.24E-02 b	na
108-95-2	Phenol (Carbolic acid)	1.10E+00 b	na	1.10E+00 b	na

**Table 27. Unit Factors for Hazard Index and Cancer Risk for Chemicals in 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
110-00-9	Furan (Oxacyclopentadiene)	7.69E+01 b	na	7.78E+01 b	na
110-54-3	n-Hexane	3.34E+00	na	4.74E+00	na
110-86-1	Pyridine	2.86E+02 b	na	2.88E+02 b	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)	3.68E-01 b	na	3.69E-01 b	na
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)	2.81E+01 b	3.17E-03 d	4.16E+01 b	4.79E-03 d
117-84-0	Di-n-octylphthalate	1.52E+01 b	na	2.01E+01 b	na
118-74-1	Hexachlorobenzene	1.32E+02 b	1.24E-01	2.64E+03 b	1.50E+00
120-82-1	1,2,4-Trichlorobenzene	9.29E+00	na	1.91E+01	na
121-44-8	Triethylamine	5.43E+01 a	na	5.43E+01 a	na
122-39-4	Diphenylamine	5.67E+00 b	na	7.41E+00 b	na
123-91-1	1,4-Dioxane (Diethylene oxide)	na	1.39E-03 d	na	1.39E-03 d
126-73-8	Tributyl Phosphate	5.31E-01 b	1.66E-04 d	6.32E-01 b	2.11E-04 d
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)	1.64E+03	na	1.65E+03	na
127-18-4	1,1,2,2-Tetrachloroethylene	7.55E+00	8.79E-04	1.08E+01	1.61E-03
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	1.22E-01 b	na	1.24E-01 b	na
156-59-2	cis-1,2-Dichloroethylene	7.18E+00 b	na	7.40E+00 b	na
206-44-0	Fluoranthene (1,2-Benzacenaphthene)	3.83E+00 b	na	2.27E+01 b	na
309-00-2	Aldrin	3.78E+03 b	1.38E+00	2.65E+05 b	5.85E+01
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	na	3.02E-01	na	4.80E-01
319-85-7	beta-Benzene hexachloride (beta-Lindane)	na	4.97E-02	na	9.90E-02
621-64-7	N-Nitrosodi-N-propylamine	na	9.95E-01 d	na	9.99E-01 d
1314-62-1	Vanadium pentoxide	8.13E+00 b	na	1.73E+01 b	na
1330-20-7	Xylenes (mixtures)	4.15E+00	na	4.26E+00	na
1336-36-3	Polychlorinated Biphenyls (high risk)	na	7.10E-02 d	na	1.93E+01 d
1336-36-3	Polychlorinated Biphenyls (low risk)	na	1.42E-02 d	na	3.87E+00 d
1336-36-3	Polychlorinated Biphenyls (lowest risk)	na	2.49E-03 d	na	6.77E-01 d
6533-73-9	Thallium carbonate	8.52E+02 b	na	4.93E+04 b	na
7429-90-5	Aluminum	7.60E+01	na	7.62E+01	na
7439-96-5	Manganese	7.59E+03 e	na	7.59E+03 e	na
7439-98-7	Molybdenum	3.82E+01 b	na	3.94E+01 b	na
7440-02-0	Nickel (soluble salts)	4.00E+00 b	na	6.12E+00 b	na
7440-22-4	Silver	1.37E+01 b	na	1.48E+01 b	na
7440-24-6	Strontium, Stable	3.10E-01 b	na	3.55E-01 b	na
7440-31-5	Tin	1.18E-01 b	na	2.06E+00 b	na
7440-36-0	Antimony	1.86E+02 b	na	2.98E+02 b	na
7440-38-2	Arsenic (inorganic)	2.32E+02 b	7.25E-01	5.60E+02 b	7.88E-01
7440-39-3	Barium	7.60E+02	na	7.60E+02	na
7440-41-7	Beryllium and compounds	1.90E+04	3.91E-01 c	1.91E+04	3.91E-01 c

**Table 27. Unit Factors for Hazard Index and Cancer Risk for Chemicals in 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
7440-42-8	Boron and borates only	2.24E+01	na	2.25E+01	na
7440-43-9	Cadmium	1.74E+02 bf	2.93E-01 c	3.00E+02 bf	2.93E-01 c
7440-48-4	Cobalt	1.90E+04	4.56E-01 c	1.90E+04	4.56E-01 c
7440-66-6	Zinc and compounds	1.50E+01 b	na	1.53E+01 b	na
7487-94-7	Mercuric chloride	3.54E+02 b	na	1.65E+03 b	na
7664-41-7	Ammonia	5.35E-01 a	na	5.35E-01 a	na
7723-14-0	Phosphorus, white	3.14E+04 b	na	6.06E+04 b	na
7782-41-4	Fluorine (soluble fluoride)	1.16E+00 b	na	1.29E+00 b	na
7782-49-2	Selenium and compounds	1.40E+01 b	na	2.74E+01 b	na
8001-35-2	Toxaphene	na	3.33E-02	na	1.06E+00
14797-55-8	Nitrate	3.98E-02 b	na	4.07E-02 b	na
14797-65-0	Nitrite	6.36E-01 b	na	6.52E-01 b	na
16065-83-1	Chromium (III) (insoluble salts)	5.23E-02 b	na	1.11E-01 b	na
18540-29-9	Chromium (VI) (soluble salts)	2.40E+01 g	6.00E-05 c	5.02E+01 g	6.00E-05 c
none	Uranium (soluble salts)	1.16E+02 b	na	1.25E+02 b	na

## 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.
- Results using route-to-route extrapolations are shown in Table C11. Results with notes (a, b, c, d, e, f, or g) have the following qualifiers:
  - (a) -- The RfD for ingestion was not available.
  - (b) -- The RfD for inhalation was not available.
  - (c) -- The Slope Factor for ingestion was not available.
  - (d) -- The Slope Factor for inhalation was not available.
  - (e) -- For manganese (7439-96-5) the drinking water has a lower RfD.
  - (f) -- For cadmium (7440-43-9) the food has a larger RfD.
  - (g) -- For chromium VI (18540-29-9) the airborne particulate has a larger RfD.

**3.11 HSRAM AGRICULTURAL SCENARIO**

The agricultural exposure scenario presented in the HSRAM is similar to the all pathways farmer discussed earlier. The difference is that the HSRAM includes deer and the other intake rates are different. For food and water, these are shown in Table A4. The HSRAM residential and agricultural scenarios differ only in the addition of beef, milk, and the deer.

The usual two versions of the agricultural scenario are calculated. The first places the farm inland so that the contaminants come from ground water. The second case adds game animal products, shoreline sediments, and dermal contact during swimming to the first case.

The lifetime increase in the resident's risk of developing some type of cancer from the radionuclides is the sum of 30 years of exposure. The first 6 years are at the child's soil ingestion rate (73 g/y), while the last 24 are at the adult's soil ingestion rate (36.5 g/y). Both of these are shown in Table A8. The other intakes are all at the adult rate. Drinking water consumption is 730 L/y (Table A4). The individual has a 10-minute shower every day and inhales the equivalent of 0.031 L/y (Table A13). Soil inhalation is 0.365 g/y (Table A10). External exposure is 7,008 h/y (Table A15). The estimated risks from radioactive materials in the residential scenarios are shown in Table 28. The first column of risks shows the inland resident, who obtains the radionuclides from ground water. The second column of risks shows the Columbia River case, in which the radionuclides are in the surface water. The third column is the ratio of the Columbia River to the inland resident risk factors.

**Table 28. Unit Risk Factors for Radionuclides in the Agricultural Scenarios (risk per pCi/L).**

Nuclide	Inland Resident	Columbia River	Ratio	Nuclide	Inland Resident	Columbia River	Ratio
H-3	3.31E-09	3.36E-09		Gd-152	8.56E-07	1.45E-06	1.7
Be-10	1.90E-07	5.89E-07	3.1	Ho-166m	1.04E-05	1.17E-05	1.1
C-14	2.39E-07	2.99E-05	125	Re-187	1.16E-09	2.28E-09	2.0
Na-22	4.49E-06	4.70E-06		Tl-204	3.80E-07	2.49E-05	65
Al-26	1.83E-05	2.42E-05	1.3	Pb-205	1.72E-08	9.69E-08	5.6
Si-32+D	3.55E-07	5.79E-07	2	Pb-210+D	2.82E-05	1.42E-04	5.0
Cl-36	6.72E-06	6.79E-06		Bi-207	7.86E-06	8.66E-06	
K-40	3.82E-06	1.42E-05	3.7	Po-209	2.96E-05	7.57E-05	2.6
Ca-41	2.77E-08	3.43E-08	1.2	Po-210	1.96E-05	5.31E-05	2.7
Ti-44+D	1.46E-05	2.75E-05	1.9	Ra-226+D	2.44E-05	4.16E-05	1.7
V-49	3.35E-09	1.41E-08	4.2	Ra-228+D	4.03E-05	6.56E-05	1.6
Mn-54	4.67E-07	8.58E-07	1.8	Ac-227+D	1.42E-05	2.26E-05	1.6
Fe-55	3.39E-08	1.04E-07	3.1	Th-228+D	9.63E-06	2.26E-05	2.4
Fe-60+D	1.76E-05	3.50E-05	2.0	Th-229+D	1.55E-05	4.32E-05	2.8
Co-60	6.73E-06	9.13E-06	1.4	Th-230	2.43E-06	7.02E-06	2.9
Ni-59	3.27E-08	4.78E-08	1.5	Th-232	1.21E-05	2.96E-05	2.4
Ni-63	7.94E-08	1.15E-07	1.5	Pa-231	5.24E-06	1.01E-05	1.9
Se-79	4.10E-07	9.11E-07	2.2	U-232	1.44E-05	1.84E-05	1.3
Rb-87	8.05E-07	5.06E-06	6.3	U-233	2.03E-06	2.65E-06	1.3
Sr-90+D	6.43E-06	8.59E-06	1.3	U-234	2.00E-06	2.60E-06	1.3
Zr-93	2.86E-08	1.72E-07	6.0	U-235+D	2.57E-06	3.23E-06	1.3
Nb-91	2.78E-08	1.43E-07	5.1	U-236	1.89E-06	2.46E-06	1.3
Nb-93m	2.11E-08	1.31E-07	6.2	U-238+D	2.57E-06	3.36E-06	1.3
Nb-94	9.83E-06	1.19E-05	1.2	Np-237+D	2.81E-06	4.05E-06	1.4
Mo-93	1.66E-07	1.93E-07	1.2	Pu-236	2.14E-06	2.97E-06	1.4
Tc-99	4.72E-07	5.01E-07		Pu-238	3.40E-06	5.61E-06	1.6
Ru-106+D	2.61E-06	2.83E-06		Pu-239	3.50E-06	5.93E-06	1.7

**Table 28. Unit Risk Factors for Radionuclides in the Agricultural Scenarios (risk per pCi/L).**

Nuclide	Inland Resident	Columbia River	Ratio	Nuclide	Inland Resident	Columbia River	Ratio
Pd-107	2.27E-08	2.68E-08	1.2	Pu-240	3.50E-06	5.94E-06	1.7
Ag-108m+D	9.13E-06	1.01E-05	1.1	Pu-241+D	4.62E-08	8.58E-08	1.9
Cd-109	1.55E-07	5.56E-07	3.6	Pu-242	3.32E-06	5.63E-06	1.7
Cd-113m	9.66E-07	3.24E-06	3.4	Pu-244+D	5.77E-06	8.72E-06	1.5
In-115	1.08E-06	1.29E-03	1,197	Am-241	2.74E-06	4.60E-06	1.7
Sn-121m+D	3.47E-07	4.95E-06	14	Am-242m+D	1.96E-06	3.63E-06	1.9
Sn-126+D	1.45E-05	5.11E-05	3.5	Am-243+D	3.66E-06	5.77E-06	1.6
Sb-125	6.66E-07	8.87E-07	1.3	Cm-242	1.00E-06	1.36E-06	1.4
Te-125m	9.45E-08	6.53E-07	6.9	Cm-243	2.91E-06	4.39E-06	1.5
I-129	1.96E-05	2.27E-05	1.2	Cm-244	2.18E-06	3.34E-06	1.5
Cs-134	5.58E-06	3.62E-05	6.5	Cm-245	3.03E-06	4.99E-06	1.6
Cs-135	5.88E-07	4.12E-06	7.0	Cm-246	2.66E-06	4.50E-06	1.7
Cs-137+D	6.28E-06	2.89E-05	4.6	Cm-247+D	4.44E-06	6.49E-06	1.5
Ba-133	1.26E-06	1.38E-06		Cm-248	9.75E-06	1.65E-05	1.7
Pm-147	5.02E-08	7.50E-08	1.5	Cm-250+D	5.77E-05	9.67E-05	1.7
Sm-147	1.11E-06	1.82E-06	1.6	Bk-247	3.64E-06	6.07E-06	1.7
Sm-151	1.68E-08	2.94E-08	1.7	Cf-248	1.29E-06	1.80E-06	1.4
Eu-150	7.32E-06	8.13E-06	1.1	Cf-249	5.58E-06	8.16E-06	1.5
Eu-152	4.65E-06	5.16E-06	1.1	Cf-250	2.56E-06	3.80E-06	1.5
Eu-154	4.30E-06	4.85E-06	1.1	Cf-251	4.43E-06	7.02E-06	1.6
Eu-155	1.14E-07	1.64E-07	1.4	Cf-252	1.41E-06	1.94E-06	1.4

## Notes:

- The radiation risk to this individual is calculated using intakes from 30 consecutive years. The soil concentration is zero at the start of the exposure.
- These scenario risk factors must be multiplied by the water concentration.
- The "Inland Resident" column gives the agricultural scenario risk factors from ground water. The column "Columbia River" shows the risk factors for surface water. The "Ratio" column is the "Columbia River" divided by the "Inland Resident" risk factors.

The hazard index and cancer risk from chemicals are calculated using the same consumption parameters discussed in Appendix A for the HSRAM Agricultural scenario. The contaminant concentration in well or river water is expressed in mg/L. The chemical dose is normalized to the average adult body mass, 70 kg. To calculate the average daily dose over a lifetime, the total dose from 30 consecutive years is calculated and then divided by (30 y)(365 d/y) for the hazard index and (70 y)(365 d/y) for the cancer risk. As part of this calculation, the concentration of the contaminants in soil is increased each year. The effect of leaching from the surface layer is included using the leaching coefficients shown in Table A38. Dermal absorption during showering is included.

The calculated hazard index and cancer risk per unit concentration in the well or the Columbia River for the HSRAM Agricultural scenario are shown in Table 29. The factors must be multiplied by the estimated water concentration, in mg per L.

**Table 29. Unit Factors for Hazard Index and Cancer Risk for Chemicals in 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	8.69E-01 d	na	1.38E+01 d
53-70-3	Dibenz[a,h]anthracene	na	1.89E+00	na	4.04E+01
56-23-5	Carbon tetrachloride	9.85E+01 b	4.39E-03	1.16E+02 b	5.07E-03
57-12-5	Cyanide, free	4.41E+02 b	na	4.42E+02 b	na
57-14-7	1,1-Dimethylhydrazine	na	4.30E+00	na	4.30E+00
57-55-6	Propylene glycol (1,2-Propanediol)	5.58E-02 b	na	5.58E-02 b	na
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)	3.25E+02 b	3.51E-02 d	5.18E+02 b	6.71E-02 d
60-34-4	Methylhydrazine	na	3.22E+00	na	3.22E+00
60-57-1	Dieldrin	1.73E+03 b	6.62E-01	2.40E+04 b	8.31E+00
62-75-9	N-Nitrosodimethylamine	na	3.47E+01	na	3.47E+01
64-18-6	Formic acid	4.73E-01 b	na	4.74E-01 b	na
67-56-1	Methanol (Methyl alcohol)	1.24E+00 b	na	1.24E+00 b	na
67-64-1	Acetone (2-Propanone)	2.28E+00 b	na	2.29E+00 b	na
67-66-3	Chloroform	7.23E+00 b	3.76E-03	7.55E+00 b	3.76E-03
71-36-3	n-Butyl alcohol (n-Butanol)	1.41E+00 b	na	1.42E+00 b	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)	5.17E-01	na	5.50E-01	na
72-20-8	Endrin	6.23E+02 b	na	3.35E+03 b	na
74-83-9	Bromomethane	1.30E+02	na	1.31E+02	na
74-87-3	Methyl chloride (Chloromethane)	4.22E+00 a	na	4.22E+00 a	na
75-00-3	Ethyl Chloride	3.80E-02 a	na	3.80E-02 a	na
75-01-4	Vinyl chloride (Chloroethene)	2.76E+01	2.40E-02	2.82E+01	2.49E-02
75-05-8	Acetonitrile	6.35E+00 a	na	6.35E+00 a	na
75-07-0	Acetaldehyde	4.22E+01 a	3.58E-04 c	4.22E+01 a	3.58E-04 c
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	7.59E-03 a	na	7.59E-03 a	na
75-68-3	Chloro-1,1-difluoroethane, 1-	7.59E-03 a	na	7.59E-03 a	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	2.34E+02 b	3.70E-01	7.94E+03 b	7.80E+00

**Table 29. Unit Factors for Hazard Index and Cancer Risk for Chemicals in 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
78-87-5	1,2-Dichloropropane	9.52E+01 a	na	9.52E+01 a	na
78-93-3	Methyl ethyl ketone (2-Butanone)	6.48E-01	na	6.50E-01	na
79-00-5	1,1,2-Trichloroethane	1.93E+01 b	3.66E-03	1.98E+01 b	3.71E-03
79-01-6	Trichloroethylene	1.22E+01 b	4.63E-04	1.34E+01 b	4.96E-04
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)	na	1.31E-02	na	1.36E-02
82-68-8	Pentachloronitrobenzene (PCNB)	2.59E+01 b	4.81E-03 d	1.23E+02 b	3.72E-02 d
83-32-9	Acenaphthene	1.62E+00 b	na	3.07E+00 b	na
84-66-2	Diethyl phthalate	1.61E-01 b	na	1.69E-01 b	na
84-74-2	Dibutyl phthalate	7.95E-01 b	na	3.07E+00 b	na
85-68-7	Butyl benzyl phthalate	4.24E-01 b	na	2.14E+00 b	na
87-68-3	Hexachlorobutadiene	3.94E+02 b	5.08E-03	2.26E+03 b	1.76E-02
87-86-5	Pentachlorophenol	2.89E+00 b	2.68E-03 d	1.20E+01 b	1.67E-02 d
88-06-2	2,4,6-Trichlorophenol	na	3.40E-04	na	4.50E-04
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)	1.35E+02 b	na	1.82E+02 b	na
91-20-3	Naphthalene	1.31E+02	na	1.32E+02	na
92-52-4	1,1'-Biphenyl	1.77E+00 b	na	3.66E+00 b	na
95-50-1	1,2-Dichlorobenzene (ortho-)	8.07E-01 b	na	1.20E+00 b	na
95-63-6	1,2,4-Trimethylbenzene	6.50E+01	na	6.60E+01	na
98-86-2	Acetophenone	1.48E+00 b	na	1.48E+00 b	na
98-95-3	Nitrobenzene	4.61E+02	na	4.66E+02	na
100-25-4	1,4-Dinitrobenzene (para-)	2.22E+03 b	na	2.23E+03 b	na
100-41-4	Ethyl benzene	1.10E+00	na	1.31E+00	na
100-42-5	Styrene	7.47E-01	na	8.24E-01	na
100-51-6	Benzyl alcohol	7.13E-01 b	na	7.14E-01 b	na
106-46-7	1,4-Dichlorobenzene (para-)	4.74E-01 a	3.90E-04 d	4.74E-01 a	7.56E-04 d
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	1.90E+03 a	1.79E+00	1.90E+03 a	1.88E+00
106-99-0	1,3-Butadiene	1.90E+02 a	4.88E-03 c	1.90E+02 a	4.88E-03 c
107-02-8	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)	na	5.94E-03	na	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)	1.27E-01 a	na	1.27E-01 a	na
108-67-8	1,3,5-Trimethylbenzene	6.49E+01	na	6.56E+01	na
108-87-2	Methyl cyclohexane	1.27E-01 a	na	1.27E-01 a	na
108-88-3	Toluene (Methyl benzene)	1.31E+00	na	1.36E+00	na
108-90-7	Chlorobenzene	2.28E+01	na	2.35E+01	na
108-94-1	Cyclohexanone	4.22E-02 b	na	4.24E-02 b	na
108-95-2	Phenol (Carbolic acid)	1.10E+00 b	na	1.10E+00 b	na

**Table 29. Unit Factors for Hazard Index and Cancer Risk for Chemicals in 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
110-00-9	Furan (Oxacyclopentadiene)	7.69E+01 b	na	7.78E+01 b	na
110-54-3	n-Hexane	3.34E+00	na	4.74E+00	na
110-86-1	Pyridine	2.86E+02 b	na	2.88E+02 b	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)	3.68E-01 b	na	3.69E-01 b	na
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)	9.62E+01 b	1.13E-02 d	1.10E+02 b	1.30E-02 d
117-84-0	Di-n-octylphthalate	2.29E+02 b	na	2.34E+02 b	na
118-74-1	Hexachlorobenzene	1.41E+02 b	1.29E-01	2.65E+03 b	1.51E+00
120-82-1	1,2,4-Trichlorobenzene	9.31E+00	na	1.91E+01	na
121-44-8	Triethylamine	5.43E+01 a	na	5.43E+01 a	na
122-39-4	Diphenylamine	5.69E+00 b	na	7.44E+00 b	na
123-91-1	1,4-Dioxane (Diethylene oxide)	na	1.39E-03 d	na	1.39E-03 d
126-73-8	Tributyl Phosphate	5.36E-01 b	1.68E-04 d	6.37E-01 b	2.13E-04 d
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)	1.64E+03	na	1.65E+03	na
127-18-4	1,1,2,2-Tetrachloroethylene	7.55E+00	8.80E-04	1.08E+01	1.61E-03
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	1.22E-01 b	na	1.24E-01 b	na
156-59-2	cis-1,2-Dichloroethylene	7.18E+00 b	na	7.40E+00 b	na
206-44-0	Fluoranthene (1,2-Benzacenaphthene)	3.99E+00 b	na	2.28E+01 b	na
309-00-2	Aldrin	7.22E+03 b	2.13E+00	2.68E+05 b	5.92E+01
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	na	3.03E-01	na	4.81E-01
319-85-7	beta-Benzene hexachloride (beta-Lindane)	na	5.01E-02	na	9.94E-02
621-64-7	N-Nitrosodi-N-propylamine	na	9.95E-01 d	na	9.99E-01 d
1314-62-1	Vanadium pentoxide	8.29E+00 b	na	1.75E+01 b	na
1330-20-7	Xylenes (mixtures)	4.15E+00	na	4.26E+00	na
1336-36-3	Polychlorinated Biphenyls (high risk)	na	1.10E-01 d	na	1.94E+01 d
1336-36-3	Polychlorinated Biphenyls (low risk)	na	2.20E-02 d	na	3.88E+00 d
1336-36-3	Polychlorinated Biphenyls (lowest risk)	na	3.85E-03 d	na	6.78E-01 d
6533-73-9	Thallium carbonate	1.18E+03 b	na	4.97E+04 b	na
7429-90-5	Aluminum	7.60E+01	na	7.62E+01	na
7439-96-5	Manganese	7.59E+03 e	na	7.59E+03 e	na
7439-98-7	Molybdenum	4.64E+01 b	na	4.76E+01 b	na
7440-02-0	Nickel (soluble salts)	7.98E+00 b	na	1.01E+01 b	na
7440-22-4	Silver	1.40E+01 b	na	1.51E+01 b	na
7440-24-6	Strontium, Stable	4.58E-01 b	na	5.04E-01 b	na
7440-31-5	Tin	1.97E-01 b	na	2.14E+00 b	na
7440-36-0	Antimony	1.87E+02 b	na	2.98E+02 b	na
7440-38-2	Arsenic (inorganic)	2.37E+02 b	7.26E-01	5.64E+02 b	7.89E-01
7440-39-3	Barium	7.60E+02	na	7.60E+02	na
7440-41-7	Beryllium and compounds	1.90E+04	3.91E-01 c	1.91E+04	3.91E-01 c

**Table 29. Unit Factors for Hazard Index and Cancer Risk for Chemicals in 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
7440-42-8	Boron and borates only	2.32E+01	na	2.32E+01	na
7440-43-9	Cadmium	1.83E+02 bf	2.93E-01 c	3.08E+02 bf	2.93E-01 c
7440-48-4	Cobalt	1.90E+04	4.56E-01 c	1.90E+04	4.56E-01 c
7440-66-6	Zinc and compounds	7.62E+01 b	na	7.65E+01 b	na
7487-94-7	Mercuric chloride	1.55E+03 b	na	2.85E+03 b	na
7664-41-7	Ammonia	5.35E-01 a	na	5.35E-01 a	na
7723-14-0	Phosphorus, white	1.42E+05 b	na	1.71E+05 b	na
7782-41-4	Fluorine (soluble fluoride)	2.61E+00 b	na	2.73E+00 b	na
7782-49-2	Selenium and compounds	1.69E+01 b	na	3.02E+01 b	na
8001-35-2	Toxaphene	na	4.42E-02	na	1.07E+00
14797-55-8	Nitrate	3.98E-02 b	na	4.07E-02 b	na
14797-65-0	Nitrite	6.36E-01 b	na	6.52E-01 b	na
16065-83-1	Chromium (III) (insoluble salts)	5.54E-02 b	na	1.14E-01 b	na
18540-29-9	Chromium (VI) (soluble salts)	2.47E+01 g	6.00E-05 c	5.09E+01 g	6.00E-05 c
none	Uranium (soluble salts)	1.18E+02 b	na	1.27E+02 b	na

## 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.
- Results using route-to-route extrapolations are shown in Table C13. Results with notes (a, b, c, d, e, f, or g) have the following qualifiers:
  - (a) -- The RfD for ingestion was not available.
  - (b) -- The RfD for inhalation was not available.
  - (c) -- The Slope Factor for ingestion was not available.
  - (d) -- The Slope Factor for inhalation was not available.
  - (e) -- For manganese (7439-96-5) the drinking water has a lower RfD.
  - (f) -- For cadmium (7440-43-9) the food has a larger RfD.
  - (g) -- For chromium VI (18540-29-9) the airborne particulate has a larger RfD.

**3.12 MODEL TOXICS CONTROL ACT SCENARIOS**

The Model Toxics Control Act (MTCA) Cleanup Regulation, Chapter 173-340 WAC describes various exposure scenarios (methods) that may be used to establish compliance. Method A reiterates national standards. Method B considers residential exposure. Method C considers occupational exposure. The only pathway considered for ground water is drinking water. For surface water the consequences of fish intake are compared with drinking water and the most limiting is chosen.

For the Method B (Residential) exposure to non-carcinogenic chemicals, the child's body mass (16 kg) and water consumption rate (1 L/d) applies. All other cases use the adult body mass (70 kg) and water consumption rate (2 L/d). Fish is consumed at the rate of 54 g/d. For the Method B (Residential) case, 50% of the fish intake is contaminated. For the Method C (Occupational) case, 20% of the fish intake is contaminated. The reference doses and slope factors are from Table A31. For carcinogenic chemicals the exposure duration is 30 years while the averaging time is 75 years.

The calculated hazard index and cancer risk per unit concentration for the groundwater scenarios are shown in Table 30. Also shown in Table 30 is the inhalation correction factor. This factor doubles the intake for those chemicals that are considered volatile. The calculated hazard index and cancer risk per unit concentration for surface water are shown in Table 31. The factors on these tables must be multiplied by the estimated water concentration, in mg per L.

**Table 30. Unit Factors for Hazard Index and Cancer Risk for Chemicals Under the MTCA for Ground Water.**

CASRN	Chemical	Method B (Residential) per mg/L		Inhale Factor	Method C (Occupational) per mg/L	
		Hazard Index	Increased Cancer Risk		Hazard Index	Increased Cancer Risk
50-32-8	Benzo[a]pyrene	na	8.34E-02	1	na	8.34E-02
53-70-3	Dibenz[a,h]anthracene	na	8.34E-02	1	na	8.34E-02
56-23-5	Carbon tetrachloride	1.79E+02	2.97E-03	2	8.16E+01	2.97E-03
57-12-5	Cyanide, free	3.13E+00	na	1	1.43E+00	na
57-14-7	1,1-Dimethylhydrazine	na	3.43E-02	1	na	3.43E-02
57-55-6	Propylene glycol (1,2-Propanediol)	3.13E-03	na	1	1.43E-03	na
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)	2.08E+02	1.49E-02	1	9.52E+01	1.49E-02
60-34-4	Methylhydrazine	na	3.43E-02	1	na	3.43E-02
60-57-1	Dieldrin	1.25E+03	1.83E-01	1	5.71E+02	1.83E-01
62-75-9	N-Nitrosodimethylamine	na	5.83E-01	1	na	5.83E-01
64-18-6	Formic acid	3.13E-02	na	1	1.43E-02	na
67-56-1	Methanol (Methyl alcohol)	2.50E-01	na	2	1.14E-01	na
67-64-1	Acetone (2-Propanone)	1.25E+00	na	2	5.71E-01	na
67-66-3	Chloroform	1.25E+01	2.29E-05	2	5.71E+00	2.29E-05
71-36-3	n-Butyl alcohol (n-Butanol)	6.25E-01	na	1	2.86E-01	na
71-43-2	Benzene	3.13E+01	1.26E-03	2	1.43E+01	1.26E-03
71-55-6	1,1,1-Trichloroethane (Methyl chloroform)	6.25E-01	na	2	2.86E-01	na
72-20-8	Endrin	2.08E+02	na	1	9.52E+01	na
74-83-9	Bromomethane	8.93E+01	na	2	4.08E+01	na
74-87-3	Methyl chloride (Chloromethane)	na	na	2	na	na
75-00-3	Ethyl Chloride	na	na	1	na	na
75-01-4	Vinyl chloride (Chloroethene)	4.17E+01	3.20E-02	2	1.90E+01	1.60E-02
75-05-8	Acetonitrile	na	na	2	na	na
75-07-0	Acetaldehyde	na	na	2	na	na

**Table 30. Unit Factors for Hazard Index and Cancer Risk for Chemicals Under the MTCA for Ground Water.**

CASRN	Chemical	Method B (Residential) per mg/L		Inhale Factor	Method C (Occupational) 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	2	9.52E-01	1.71E-04
75-15-0	Carbon disulfide	1.25E+00	na	2	5.71E-01	na
75-21-8	Ethylene Oxide (Oxirane)	na	2.33E-02	2	na	2.33E-02
75-34-3	1,1-Dichloroethane (Ethylidene chloride)	1.25E+00	na	2	5.71E-01	na
75-35-4	1,1-Dichloroethylene	2.50E+00	na	2	1.14E+00	na
75-45-6	Chlorodifluoromethane	na	na	2	na	na
75-68-3	Chloro-1,1-difluoroethane, 1-	na	na	2	na	na
75-69-4	Trichlorofluoromethane	4.17E-01	na	2	1.90E-01	na
75-71-8	Dichlorodifluoromethane	6.25E-01	na	2	2.86E-01	na
76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane (CFC-113)	2.08E-03	na	1	9.52E-04	na
76-44-8	Heptachlor	1.25E+02	5.14E-02	1	5.71E+01	5.14E-02
78-87-5	1,2-Dichloropropane	na	na	2	na	na
78-93-3	Methyl ethyl ketone (2-Butanone)	2.08E-01	na	2	9.52E-02	na
79-00-5	1,1,2-Trichloroethane	3.13E+01	1.30E-03	2	1.43E+01	1.30E-03
79-01-6	Trichloroethylene	2.08E+01	2.51E-04	2	9.52E+00	2.51E-04
79-10-7	2-Propenoic acid (Acrylic acid)	1.25E-01	na	1	5.71E-02	na
79-34-5	1,1,2,2-Tetrachloroethane (Acetylene tetrachloride)	na	4.57E-03	2	na	4.57E-03
82-68-8	Pentachloronitrobenzene (PCNB)	2.08E+01	2.97E-03	1	9.52E+00	2.97E-03
83-32-9	Acenaphthene	1.04E+00	na	1	4.76E-01	na
84-66-2	Diethyl phthalate	7.81E-02	na	1	3.57E-02	na
84-74-2	Dibutyl phthalate	6.25E-01	na	1	2.86E-01	na
85-68-7	Butyl benzyl phthalate	3.13E-01	na	1	1.43E-01	na
87-68-3	Hexachlorobutadiene	6.25E+02	1.78E-03	2	2.86E+02	1.78E-03
87-86-5	Pentachlorophenol	2.08E+00	1.37E-03	1	9.52E-01	1.37E-03
88-06-2	2,4,6-Trichlorophenol	na	1.26E-04	1	na	1.26E-04
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)	6.25E+01	na	1	2.86E+01	na
91-20-3	Naphthalene	6.25E+00	na	2	2.86E+00	na
92-52-4	1,1'-Biphenyl	1.25E+00	na	1	5.71E-01	na
95-50-1	1,2-Dichlorobenzene (ortho-)	1.39E+00	na	2	6.35E-01	na
95-63-6	1,2,4-Trimethylbenzene	2.50E+00	na	2	1.14E+00	na
98-86-2	Acetophenone	6.25E-01	na	1	2.86E-01	na
98-95-3	Nitrobenzene	1.25E+02	na	1	5.71E+01	na
100-25-4	1,4-Dinitrobenzene (para-)	1.56E+02	na	1	7.14E+01	na
100-41-4	Ethyl benzene	1.25E+00	na	2	5.71E-01	na
100-42-5	Styrene	6.25E-01	na	2	2.86E-01	na
100-51-6	Benzyl alcohol	2.08E-01	na	1	9.52E-02	na
106-46-7	1,4-Dichlorobenzene (para-)	na	5.49E-04	2	na	5.49E-04
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	na	1.94E+00	2	na	1.94E+00
106-99-0	1,3-Butadiene	na	na	1	na	na

**Table 30. Unit Factors for Hazard Index and Cancer Risk for Chemicals Under the MTCA for Ground Water.**

CASRN	Chemical	Method B (Residential) per mg/L		Inhale Factor	Method C (Occupational) per mg/L	
		Hazard Index	Increased Cancer Risk		Hazard Index	Increased Cancer Risk
107-02-8	Acrolein	2.50E+02	na	2	1.14E+02	na
107-05-1	3-Chloropropene (Allyl chloride)	1.25E+00	na	1	5.71E-01	na
107-06-2	1,2-Dichloroethane (Ethylene chloride)	na	2.08E-03	2	na	2.08E-03
107-13-1	Acrylonitrile	1.25E+02	1.23E-02	2	5.71E+01	1.23E-02
108-10-1	Methyl isobutyl ketone (4-Methyl-2-pentanone)	na	na	2	na	na
108-67-8	1,3,5-Trimethylbenzene	2.50E+00	na	2	1.14E+00	na
108-87-2	Methyl cyclohexane	na	na	2	na	na
108-88-3	Toluene (Methyl benzene)	6.25E-01	na	2	2.86E-01	na
108-90-7	Chlorobenzene	6.25E+00	na	2	2.86E+00	na
108-94-1	Cyclohexanone	1.25E-02	na	1	5.71E-03	na
108-95-2	Phenol (Carbolic acid)	2.08E-01	na	1	9.52E-02	na
110-00-9	Furan (Oxacyclopentadiene)	6.25E+01	na	1	2.86E+01	na
110-54-3	n-Hexane	2.08E+00	na	2	9.52E-01	na
110-86-1	Pyridine	6.25E+01	na	1	2.86E+01	na
111-76-2	2-Butoxyethanol (Ethylene Glycol Monobutyl Ether)	2.50E-01	na	2	1.14E-01	na
111-90-0	2-(2-Ethoxyethoxy)-ethanol (Diethylene Glycol Monoethyl Ether)	6.25E-02	na	2	2.86E-02	na
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)	3.13E+00	1.60E-04	1	1.43E+00	1.60E-04
117-84-0	Di-n-octylphthalate	3.13E+00	na	1	1.43E+00	na
118-74-1	Hexachlorobenzene	7.81E+01	1.83E-02	1	3.57E+01	1.83E-02
120-82-1	1,2,4-Trichlorobenzene	1.25E+01	na	2	5.71E+00	na
121-44-8	Triethylamine	na	na	1	na	na
122-39-4	Diphenylamine	2.50E+00	na	1	1.14E+00	na
123-91-1	1,4-Dioxane (Diethylene oxide)	na	1.26E-04	1	na	1.26E-04
126-73-8	Tributyl Phosphate	3.13E-01	6.17E-05	1	1.43E-01	6.17E-05
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)	6.25E+02	na	1	2.86E+02	na
127-18-4	1,1,2,2-Tetrachloroethylene	1.25E+01	1.19E-03	2	5.71E+00	1.19E-03
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	6.94E-02	na	1	3.17E-02	na
156-59-2	cis-1,2-Dichloroethylene	1.25E+01	na	2	5.71E+00	na
206-44-0	Fluoranthene (1,2-Benzacenaphthene)	1.56E+00	na	1	7.14E-01	na
309-00-2	Aldrin	2.08E+03	1.94E-01	1	9.52E+02	1.94E-01
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	na	7.20E-02	1	na	7.20E-02
319-85-7	beta-Benzene hexachloride (beta-Lindane)	na	2.06E-02	1	na	2.06E-02
621-64-7	N-Nitrosodi-N-propylamine	na	8.00E-02	1	na	8.00E-02
1314-62-1	Vanadium pentoxide	6.94E+00	na	1	3.17E+00	na
1330-20-7	Xylenes (mixtures)	6.25E-01	na	2	2.86E-01	na
1336-36-3	Polychlorinated Biphenyls (high risk)	na	2.29E-02	1	na	2.29E-02

**Table 30. Unit Factors for Hazard Index and Cancer Risk for Chemicals Under the MTCA for Ground Water.**

CASRN	Chemical	Method B (Residential) per mg/L		Inhale Factor	Method C (Occupational) per mg/L	
		Hazard Index	Increased Cancer Risk		Hazard Index	Increased Cancer Risk
1336-36-3	Polychlorinated Biphenyls (low risk)	na	4.57E-03	1	na	4.57E-03
1336-36-3	Polychlorinated Biphenyls (lowest risk)	na	8.00E-04	1	na	8.00E-04
6533-73-9	Thallium carbonate	7.81E+02	na	1	3.57E+02	na
7429-90-5	Aluminum	6.25E-02	na	1	2.86E-02	na
7439-96-5	Manganese	1.34E+00	na	1	6.12E-01	na
7439-98-7	Molybdenum	1.25E+01	na	1	5.71E+00	na
7440-02-0	Nickel (soluble salts)	3.13E+00	na	1	1.43E+00	na
7440-22-4	Silver	1.25E+01	na	1	5.71E+00	na
7440-24-6	Strontium, Stable	1.04E-01	na	1	4.76E-02	na
7440-31-5	Tin	1.04E-01	na	1	4.76E-02	na
7440-36-0	Antimony	1.56E+02	na	1	7.14E+01	na
7440-38-2	Arsenic (inorganic)	2.08E+02	1.71E-02	1	9.52E+01	1.71E-02
7440-39-3	Barium	8.93E-01	na	1	4.08E-01	na
7440-41-7	Beryllium and compounds	3.13E+01	na	1	1.43E+01	na
7440-42-8	Boron and borates only	6.94E-01	na	1	3.17E-01	na
7440-43-9	Cadmium	1.25E+02	na	1	5.71E+01	na
7440-48-4	Cobalt	3.13E+00	na	1	1.43E+00	na
7440-66-6	Zinc and compounds	2.08E-01	na	1	9.52E-02	na
7487-94-7	Mercuric chloride	2.08E+02	na	1	9.52E+01	na
7664-41-7	Ammonia	na	na	2	na	na
7723-14-0	Phosphorus, white	3.13E+03	na	1	1.43E+03	na
7782-41-4	Fluorine (soluble fluoride)	1.04E+00	na	1	4.76E-01	na
7782-49-2	Selenium and compounds	1.25E+01	na	1	5.71E+00	na
8001-35-2	Toxaphene	na	1.26E-02	1	na	1.26E-02
14797-55-8	Nitrate	3.91E-02	na	1	1.79E-02	na
14797-65-0	Nitrite	6.25E-01	na	1	2.86E-01	na
16065-83-1	Chromium (III) (insoluble salts)	4.17E-02	na	1	1.90E-02	na
18540-29-9	Chromium (VI) (soluble salts)	2.08E+01	na	1	9.52E+00	na
none	Uranium (soluble salts)	1.04E+02	na	1	4.76E+01	na

## Notes:

- 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 A31.
- The "Inhale Factor" 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". Results using route-to-route extrapolations are shown in Table C15.

**Table 31. Unit Factors for Hazard Index and Cancer Risk for Chemicals Under the MTCA 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)	3.13E-03	na	1.43E-03	na
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)	2.08E+02	2.93E-02	9.52E+01	1.49E-02
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	na	5.83E-01	na	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)	1.25E+00	na	5.71E-01	na
67-66-3	Chloroform	1.25E+01	2.29E-05	5.71E+00	2.29E-05
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)	6.25E-01	na	2.86E-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)	na	na	na	na
75-00-3	Ethyl Chloride	na	na	na	na
75-01-4	Vinyl chloride (Chloroethene)	4.17E+01	3.20E-02	1.90E+01	1.60E-02
75-05-8	Acetonitrile	na	na	na	na
75-07-0	Acetaldehyde	na	na	na	na
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	na	na	na	na
75-68-3	Chloro-1,1-difluoroethane, 1-	na	na	na	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
78-87-5	1,2-Dichloropropane	na	na	na	na
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

**Table 31. Unit Factors for Hazard Index and Cancer Risk for Chemicals Under the MTCA 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
79-01-6	Trichloroethylene	2.08E+01	2.51E-04	9.52E+00	2.51E-04
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)	na	4.57E-03	na	4.57E-03
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	3.69E+03	2.30E-02	1.48E+03	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	na	1.26E-04	na	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
95-50-1	1,2-Dichlorobenzene (ortho-)	1.39E+00	na	6.35E-01	na
95-63-6	1,2,4-Trimethylbenzene	2.50E+00	na	1.14E+00	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-)	1.56E+02	na	7.14E+01	na
100-41-4	Ethyl benzene	1.25E+00	na	5.71E-01	na
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
106-46-7	1,4-Dichlorobenzene (para-)	na	6.58E-04	na	5.49E-04
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	na	1.94E+00	na	1.94E+00
106-99-0	1,3-Butadiene	na	na	na	na
107-02-8	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)	na	2.08E-03	na	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)	na	na	na	na
108-67-8	1,3,5-Trimethylbenzene	2.50E+00	na	1.14E+00	na
108-87-2	Methyl cyclohexane	na	na	na	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
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
110-86-1	Pyridine	6.25E+01	na	2.86E+01	na

**Table 31. Unit Factors for Hazard Index and Cancer Risk for Chemicals Under the MTCA 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
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)	6.25E-02	na	2.86E-02	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	3.13E+00	na	1.43E+00	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
121-44-8	Triethylamine	na	na	na	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	1,1,2,2-Tetrachloroethylene	1.25E+01	1.33E-03	5.71E+00	1.19E-03
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-Benzaceneaphthene)	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)	na	1.64E-01	na	7.20E-02
319-85-7	beta-Benzene hexachloride (beta-Lindane)	na	4.51E-02	na	2.06E-02
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 (high risk)	na	1.79E+01	na	7.16E+00
1336-36-3	Polychlorinated Biphenyls (low risk)	na	3.58E+00	na	1.43E+00
1336-36-3	Polychlorinated Biphenyls (lowest risk)	na	6.26E-01	na	2.50E-01
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
7439-96-5	Manganese	1.34E+00	na	6.12E-01	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
7440-31-5	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	na	1.43E+01	na
7440-42-8	Boron and borates only	6.94E-01	na	3.17E-01	na
7440-43-9	Cadmium	1.25E+02	na	5.71E+01	na

**Table 31. Unit Factors for Hazard Index and Cancer Risk for Chemicals Under the MTCA 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
7440-48-4	Cobalt	5.79E+00	na	2.31E+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	na	na	na	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
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
18540-29-9	Chromium (VI) (soluble salts)	2.57E+01	na	1.03E+01	na
none	Uranium (soluble salts)	1.04E+02	na	4.76E+01	na

Notes:

- CASRN = Chemical Abstract Service Reference Number
- The fish bioaccumulation factor are from Table A35. The reference doses and slope factors for ingestion are shown in Table A31. This table shows the larger of the drinking water and fish results.
- 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”. Results using route-to-route extrapolations are shown in Table C16.

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