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Exposure Scenarios and Unit Factors for the Hanford Tank Waste Performance Assessment

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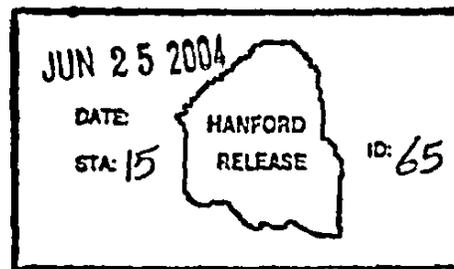
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Abstract: Unit factors have been prepared for the postulated intrusion scenarios as well as the various scenarios utilizing well water or water taken from the Columbia River. A total of 93 radionuclides and 161 chemicals are evaluated. The unit factors relate a unit concentration in the water to the various toxicity indicators (radiological dose, lifetime cancer risk, and hazard index).

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

Paul D. Rittmann PhD CHP

May 2004

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**Exposure Scenarios and Unit 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. The development of risk assessments for particular disposal options requires (1) knowledge of the waste inventory, (2) the waste characteristics that influence the release of waste from the disposal site into the air or vadose zone soil, (3) soil characteristics that influence the rate of travel away from the disposal site, and (4) potential pathways of exposure to the waste by persons living near the disposal site.

This report focuses on the exposure pathways and the dose and risk parameters employed to estimate environmental impacts from unit concentrations in selected media. The actual concentrations will be provided in the appropriate risk assessment documents based on waste inventory, waste release characteristics, and waste migration analyses. In the present document, exposure scenarios and model parameters have been selected to be acceptable to the DOE as well as local technical experts at the Hanford Site. An additional set of modeling assumptions provided in the Hanford Site Risk Assessment Methodology report (DOE/RL-91-45 Rev 3) was also used.

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 term "unit" means that a specified media (such as ground water) has a unit concentration of a contaminant. The contaminants of potential concern are identified and listed in Sections A1.0 and A2.0. The unit factors are applied to the estimated contaminant concentrations in the media of concern 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 or technically sound.

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. 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 15 ft of soil.

The intent of these exposure assumptions is to establish reasonable bounds on the potential doses resulting from the waste disposal site. Worst-case assumptions lead to exposure scenarios that are extremely unlikely to ever occur. Hence, typical parameters are chosen for the exposure scenarios. In Table 1, the onsite and offsite individuals are given average intake rates. The presence of an individual living onsite directly over a waste site is unlikely. The 200 Area Plateau is never expected to have a high population density due to its distance from the Columbia River, as well as the distance to ground water. Given a random distribution of dwellings, most of any future wells and basements will not be near the disposal site. Assuming both a perfect location (directly over the waste) and maximum consumption parameters for the intruders makes the onsite scenario unreasonable. The perfect location is retained, but the exposure scenario parameters are chosen to be typical rather than bounding.

Exposure to individuals living offsite is more likely to occur due to the inevitable migration of contaminants offsite. The contaminants are found in the ground or surface water. A variety of offsite individuals are modeled to span the possible range of impacts. The recreational and industrial scenarios are low impact cases. The residential and farming scenarios represent reasonable bounds for typical cases. The Native American scenario is a bounding case. Numerous other special groups of individuals can be studied, but the individuals selected are believed to span the range of potential exposures.

Table 1. General Features of Performance Assessment Exposure Scenarios.

Feature	Onsite Receptor	Offsite Receptor
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 fence line 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

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 presence of passive barriers to intrusion, such as durable markers and thick asphalt over the waste should increase the time delay before intrusion.

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
< inhalation of plume < ingestion (plants & animals) < external radiation exposure from plume < dermal absorption from air
Onsite Resident -- gas/vapor emanations into the basement of a residence located over the disposal site
< inhalation (higher concentrations in a dwelling) < external radiation exposure (from buried waste and air) < dermal absorption (from air)
Intruder -- individual present while a well is being drilled through the waste disposal site
< inhalation (resuspended dust & gaseous emissions) < ingestion (trace amounts of soil) < external radiation exposure < dermal absorption (contact with soil)
Post-intrusion Resident -- spreads the exhumed waste into an area that is subsequently used in some manner
< inhalation (resuspended dust & gaseous emissions) < ingestion (trace amounts of soil & garden produce or cow's milk) < external radiation exposure (working in garden) < dermal absorption (contact with soil)

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 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 15 ft 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 10 ft. Thus, at least 5 ft 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.

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 3rd and 4th 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. Based on well log data from the State of Washington from 1960 to 2003, the diameter of the well could range from 1 inch up to 30 inches, as described in Appendix A, Section A7.0. 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). A well diameter of 6.5 inches (16.51 cm) is typical of most wells drilled near the Hanford Site, and will be assumed in this report when example calculations are presented. Note that the well diameter is not part of the dose, risk, or hazard index unit factors.

The typical well diameter for domestic wells in the area surrounding the Hanford Site is six inches. The basis for this diameter is the current (i.e., December 2003) database of water well logs for the counties near Hanford, as described in more detail Section A7.0. About 70% of the water wells between 200 feet and 400 feet deep have a 6-inch diameter.

The actual diameter of the borehole is slightly larger than 6 inches due to the typical technique used to drill the well. The well is drilled with a bit that is slightly less than 6 inches. It is lowered down a steel casing with an inside diameter of 6 inches. The casing's lower edge is made of hardened steel so the casing can be driven from above to follow the bit. The actual well hole is about 6.5 inches in diameter. If the casing cannot be driven any deeper then the well may be drilled further without casing. To calculate the volume of soil removed from the borehole, it is assumed to have a diameter of 6.5 inches over its entire length.

The irrigation of the rural pasture is a small-scale operation, but requires a larger pump than normal domestic service. Hence, an increased well diameter of 10 inches (10.5 inch hole diameter) was selected for the rural pasture scenario.

A commercial irrigator typically uses a larger diameter well to extract water at a higher flow rate. Irrigation well diameters range from 6 to 30 inches. A 16-inch diameter well (16.5 inch hole diameter) is used as a representative diameter in this setting. It is the most likely large diameter well for irrigation purposes, as shown in Appendix A.

The total volume of drill tailings 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 well tailings excavated by drilling the 6.5-inch diameter hole is 2.14 m³. In addition, this volume must be adjusted for the decrease in density. Using an initial density (undisturbed) of 1.7 kg/L and a final density on the surface of 1.5 kg/L, the volume of tailings on the surface is 2.43 m³, as shown below.

$$\text{Soil Volume} = (3.14159)(0.08255 \text{ m})^2 (100 \text{ m}) \left(\frac{1.7 \text{ kg/L}}{1.5 \text{ kg/L}} \right) = 2.43 \text{ m}^3$$

The volume of waste exhumed is the product of the well cross sectional area and the waste thickness at the location of the well. 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 0.17 m³. For comparison, the Grouted Waste PA (WHC-SD-WM-EE-004) used a waste volume of 0.64 m³.

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 (WHC-SD-WM-EE-004) and the 2001 ILAW PA (DOE/ORP-2000-24) the area used was 100 m^2 . The 200 West Area Burial Ground PA (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 $(100 \text{ m}^2)(0.15 \text{ m})=15 \text{ m}^3$. 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^3 , 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. Each of these is discussed below.

The customary tilling to prepare the surface soil for planting is assumed to affect only 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. This leads to lessened doses (from all pathways) to persons using the contaminated area.

The 15 cm depth is typical for root systems of garden vegetables. Hence, the tilling depth is chosen to match the root system depth both for reasons of economy (why till to a greater depth than the plants need?) and to bound the potential doses from garden vegetables. If the tilling depth were greater than the root depth, the soil concentration is reduced unnecessarily. If the tilling depth were less than the root depth, then the plant concentrations are 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. Some garden plants have root systems that 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 are not 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.

$$\text{Resident's Dose} \sim (\text{Soil Conc})(\text{Intake or Exposure Time})$$

In general, the soil concentration is inversely proportional to the area over which the waste is spread (i.e., the spreading area). 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 2.43 m³ to a uniform depth of 5.08 cm (2 inch) would cover an area of 48 m². The largest useful thickness is the tilling depth, 15 cm (6 inch). Spreading a volume of 2.43 m³ uniformly to a depth of 15 cm would cover an area of 16 m². Note that an increase in the borehole diameter from 6.5 inches to 12 inches would increase the volume exhumed as well as the spreading areas by a factor of 3.4.

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 garden 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 m²) is mostly for production of grains (138 m²).

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 m²). Again, the grains occupy most of this area (140 m²).

From these references it will be assumed that an efficiently planned and maintained garden of 100 m² 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 m². Beyond 100 m² there is more food than the individual is likely to 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, people with gardens obtain about 25% of their vegetable diet from the garden (EPA/600/P-95/002Fa, Exposure Factors Handbook). A family of four would likely have a garden no larger than 100 m².

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 m². 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 m² for the post-intrusion suburban garden scenario will be used in this document.

The chosen garden area of 100 m² 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 m². The more realistic area of 100 m² 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 m² (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 m² 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. In this scenario the land surface area needed to grow food for the cow must be estimated. Based on reports found through internet searches using phrases such as "animal unit month" and "pasture size" for semi-arid locations, the area needed for the cow is estimated in Section A4.1 to be 5,000 m². About half this area is used for grazing during the irrigation season. The other half is used to raise hay and grain for the non-irrigation season. There is considerable variety in the size and species of cow that may be found in this pasture. The cow typically tramples 40% of the standing biomass, making it unavailable. In addition, the cow eats only half of the remaining biomass. The cow must graze in different parts of the pasture to allow time for the grass to regrow. The pasture/field areas were derived from the milk cow parameters presented in Table A32 to ensure overall consistency with the representative cow assumed in this report. Note that 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 m²). 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, the no infiltration exposure scenarios assume that people live directly over the waste sites and that specific types of waste intrusion occur. Given that the unlikely event of people living directly over the waste has occurred, the dose consequences are calculated for typical land uses and typical scenario parameters, such as well diameter, garden area, individual intakes and exposure times. The unlikely portion of the scenario is the chances of a well actually penetrating a waste site. A small fraction of the available land surface lies above the buried waste. An additional concern is that the borehole cuttings are broken rocks and sand. These materials are more likely to be placed on a driveway than a garden or pasture. The combination of typical parameters with unlikely situations gives assurance that the exposure scenarios provide reasonable bounds on the potential impacts to exposed individuals.

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, the mobile chemicals will begin to reach the ground water and can thus contribute dose to the intruder. Performance assessments required by the U.S. Department of Energy (DOE Order 435.1) use intruder analyses at times less than 1000 years. Groundwater contamination is evaluated at much longer 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. The irrigation activities by assumption are not located directly over the disposal site. Thus, water infiltration at the disposal site is at the natural rate. 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 1.7×10^7 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.

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.

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.

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 are simply the radiation dose, incremental cancer risk, or hazard index based on a unit amount in the medium of interest (eg. ground water). The unit factors are multiplied by the amount of each contaminant and summed to give the total dose or risk or hazard index for the mixture. Additional detail by pathway is provided in Appendix D.

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 are divided into two kinds. The first kind deals with the human exposures during the actual intrusion event and is represented in the Well Driller scenario. The second kind deals with how the exhumed contaminants may affect an individuals living near the well in subsequent years. The a variety of living situations are represented in the Suburban Garden, Rural Pasture, and Commercial Farm scenarios. These are referred to as the post-intrusion scenarios because they occur after the well is drilled.

For the Well Driller, the unit factors are calculated based on the average concentration of the contaminant in the borehole. The entire mass of material from the ground surface to the water table is used for the average. The exposure period is the period needed to drill the well to ground water, 1 week. For the other post-intrusion cases, the unit factors are 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. Radiation doses are calculated during the first year after the well is drilled. Lifetime cancer risks and hazard quotients cannot be calculated for the Well Driller due to the short exposure period of an adult. The toxicity parameters require lifetime exposures or perhaps short-duration exposures of a population with all ages represented.

For the post-intrusion scenarios the cancer risks and hazard quotients from a lifetime exposure could be calculated for a child growing to maturity. These calculations were not carried out due to an absence of regulatory criteria for the post-intrusion scenarios. The performance objectives for the post-intrusion scenarios are annual radiation doses, so the lifetime risk and hazard quotient calculations were not performed. Budget and time constraints also contributed to this decision.

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 effective 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.

In Table 5 the water pathways contribute nothing to the intruder scenario doses. This means the water obtained from the well is uncontaminated. In a real world intrusion scenario, this might not be the case. First of all, the intrusion could occur after mobile contaminants had reached the ground water. This would lessen the amount of the mobile contaminants that are exhumed, but would add contaminated ground water pathways. Second, the presence of a well would accelerate migration of contaminants to the ground water. For example, contaminants could migrate along the borehole. In addition, irrigation of a garden or pasture would increase the water infiltration and could result in greater contaminant release and migration rates from the waste. While contaminants would probably not be present the first year after drilling, they could show up in the groundwater several years later.

The intruder scenarios presented in this document follow the standard approach used to evaluate inadvertent intrusion presented in DOE 435.1. The contaminants are assumed to be stationary. Ground water contamination is assumed zero. This approach separates the impacts of intrusion and the impacts of contaminant migration into ground water to facilitate the design of the disposal facility. If intruder doses exceed criteria, then the inventory must be limited or intrusion barriers added. If ground water contamination exceeds criteria, then the inventory must be limited or the contaminant release and migration rates reduced. It is difficult to imagine how a facility could be designed to prevent both intrusion and migration to ground water for the indefinite future.

The next two exposure scenarios in Table 5 represent 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, the pathways used for the ground and surface water sources 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 scenarios shown in Table 5. Most of this dose is 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 and external doses to various organs are represented as weighted sums of the organ doses known as an 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). Additional information on radiation dose nomenclature is presented in Section A3.5 and A3.6.

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. The scenario factors include removal mechanisms from the surface layer of soil, i.e., leaching, volatilization, and radioactive decay. The equations describing the calculations are unique to this report. Partly this was to ensure a consistent labeling of variables, and partly to conform to the layout of the calculations used in the spreadsheets.

To simplify the presentation, the treatment of radioactive 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 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 effective 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. 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 well driller's 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 exposure rates and times 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.

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

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

where,

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

Note that the tailings concentration is independent of the well diameter. Thus, for the well driller, the well diameter has no effect on the estimated doses.

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 m^3 , then the well tailings are spread over an area of 80 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.

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

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
- $D_{X,S,K}$ = 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/m². 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
- ρ_{TAIL} = average density of the well tailings, 1,500 kg/m³

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/m³ 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 m³/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, 4.84x10⁻⁶ 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, as recommended in EPA/600/P-95/002Fa. 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. Because the radionuclides of interest are likely to be present as inorganic compounds, the dermal absorption is small. Thus, 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.

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

where,

F_{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_{DRILLER} = total effective dose equivalent received by the driller from all radionuclides in the waste at the time of intrusion, in mrem

$H_{B,K}$ = inhalation dose to the driller from the Kth radionuclide, in mrem

$H_{G,K}$ = ingestion dose to the driller from the Kth radionuclide, in mrem

$H_{X,K}$ = external dose to the driller from the Kth radionuclide, in mrem

The fraction of exhumed waste that is available for inhalation and ingestion (F_{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. The fraction of finely ground material is expected to be minimized by drilling practices, so that a reasonable estimate for F_{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 estimate for F_{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)

Nuclide	Total	External	Internal	Nuclide	Total	External	Internal
H-3	3.25E+01	0.00E+00	3.25E+01	Gd-152	1.26E+06	0.00E+00	1.26E+06
Bc-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

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

Nuclide	Total	External	Internal	Nuclide	Total	External	Internal
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
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.

Contaminant Concentration in Garden Soil

The garden area is 100 m² 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 m³. The density of the garden soil is assumed to be 1,500 kg/m³. 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 m³. 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_{GARDEN} = cultivated area of a garden, 100 m²
- A_{SITE} = horizontal area occupied by the disposal site, in m²
- A_{WELL} = cross-sectional area of the well, in m²
- C_{GARDEN} = initial concentration of a radionuclide in the garden, in Ci/kg
- C_{WASTE} = concentration of a radionuclide in the disposal site, in Ci/kg
- L_{GARDEN} = thickness of the contaminated layer of surface soil in the garden, 0.15 m
- L_{WASTE} = thickness of the waste in the well, in m
- Q_{EXHUMED} = activity of a radionuclide brought to the surface by the well-drilling, in Ci
- Q_{SITE} = total activity of a radionuclide in the disposal site, in Ci
- ρ_{GARDEN} = average density of the soil in the garden, 1,500 kg/m³
- ρ_{WASTE} = average density of the waste, in kg/m³

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.

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

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

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_{irr} = irrigation period (the 1st half of the year), 0.5 y
- λ_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 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 (1.405×10^{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.

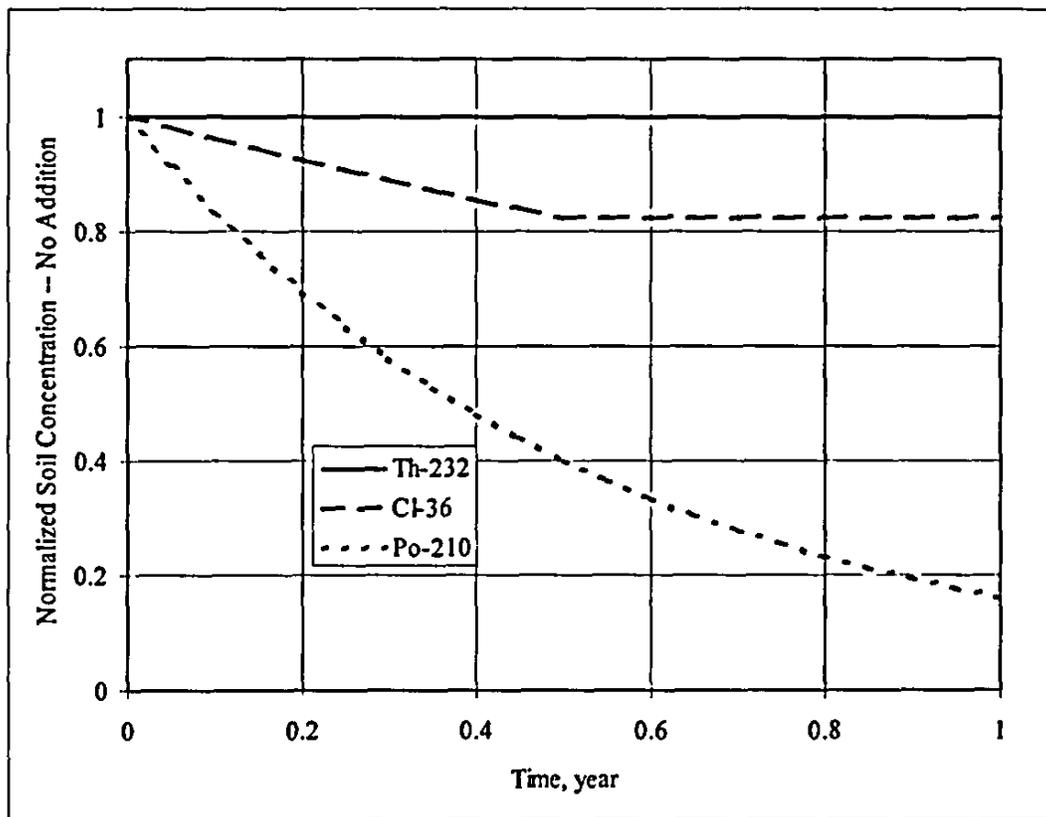


Figure 1. Fraction of Garden Soil Concentration Remaining During the Year.

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,

- $C_{\text{GARDEN},K}$ = initial average concentration of the Kth radionuclide in the garden soil, in Ci/kg
- L_{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/m². Values from EPA Federal Guidance Report Number 12 for a 15 cm thickness are listed in Table A25.
- 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_{irr} = irrigation period, 0.5 y (the first half of the year)
- λ_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)
- ρ_{GARDEN} = average density of the garden soil, 1,500 kg/m³

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,

- $C_{\text{GARDEN},K}$ = initial 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, 8.7×10^{-5} kg/y
- T_{irr} = irrigation period (the 1st half of the year), 0.5 y
- T_{no} = no irrigation period (the 2nd half of the year), $T_{\text{irr}} + T_{\text{no}} = 1 \text{ y}$
- λ_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.

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

where,

- $C_{\text{GARDEN},K}$ = 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
- $C_{GARDEN,K}$ = 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
- $F_{DRY,p}$ = 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), 2.7×10^{-4} kg/m² 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
- $T_{harvest}$ = time at which harvest occurs, 0.25 y (midway through the irrigation season)
- T_{irr} = irrigation period (the 1st half of the year), 0.5 y
- T_{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)/m²
- λ_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)
- λ_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.

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

where,

- $C_{GARDEN,H-3}$ = 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
 ρ_{GARDEN} = average density of the garden soil, 1.5 kg soil per liter of soil
 ρ_{W} = density of water, 1.0 kg water per liter of water
 θ = 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.

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

where,

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

$H_{X,K}$ = 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
Sc-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

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

Nuclide	Total	External	Internal	Nuclide	Total	External	Internal
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
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.

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

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

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

where,

A_{GARDEN}	=	cultivated area of a garden, 100 m^2
A_{WELL}	=	cross-sectional area of the well, in m^2
$C_{\text{GARDEN,K}}$	=	initial 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
$D_{\text{X,K}}$	=	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^2 . Values from EPA Federal Guidance Report Number 12 for a 15 cm thickness are listed in Table A25.
$D_{\text{X,5,K}}$	=	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^2 . 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
ρ_{GARDEN}	=	average density of the soil in the garden, $1,500 \text{ kg/m}^3$
ρ_{WELL}	=	average density of the soil in the well, $1,700 \text{ kg/m}^3$

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 dose ratios are essentially independent of the radionuclide. Partly because the dose from garden vegetables is not included. 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^2 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 0.165 m (6.5 in.), and the compacted soil density in the well is $1,700 \text{ kg/m}^3$, then the soil concentration ratio (gardener/driller) is 0.162. 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 0.165 m (6.5 in.). The general conclusion

is that wells shallower than about 90 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.

For other post-intrusion scenarios, the well diameters are larger. This increases the dose to the post-intrusion resident but has no effect on the well driller dose. However, the increased amount exhumed is offset by the larger area of the pasture and farm. Thus for the other post-intrusion cases, the ratio with the driller dose is smaller, and the well depths to have equal doses are greater.

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	5.8	17 m
Soil Inhalation	2.9	35 m
External Exposure	1.1	92 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 1,700 kg/m³.
- Ingestion of garden vegetables is not included in this comparison because the well driller does not consume any.
- The internal dose is the 50 year committed effective dose equivalent from intakes during the first year of exposure. The external dose is the effective dose equivalent accumulated during the year of exposure.
- The assumed well is 0.165 m diameter and 100 m deep.
- The minimum well depths shown in the last column assume a 0.165 m diameter well, in addition to an in situ density of 1,700 kg/m³.

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 m². 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 m².

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 m³. Since the density of the surface soil is assumed to be 1,500 kg/m³, 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. From recent USDA estimates of per capita food consumption (Putnam and Allshouse, 1999), the total milk equivalent is 263 kg/y. Deducting cheeses and other milk products unlikely to be produced at home leaves 116 kg/y. The owner of the cow is assumed to consume 58 L of milk during the year, which is 22% of the total milk equivalent and 50% of the home milk consumption. These fractions are derived from the EPA exposure factors handbook (EPA/600-P-95/002Fa), which shows 20% to 25% for all dairy products in Table 13-71 under "Questionnaire Response". 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
- $C_{\text{Pasture},K}$ = initial 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_{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.

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

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

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

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

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

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

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

- $C_{\text{Pasture},K}$ = initial 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_{SPLASH} = average soil deposition rate due to rain splash (see Section A5.2), 2.7×10^{-4} kg/m² 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 1st 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)/m²
 λ_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.

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

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

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

where,

- $C_{A,q,H-3}$ = time-integrated tritium concentration in animal product type q, in Ci/kg
- $C_{\text{Pasture},K}$ = initial 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
- ρ_{Pasture} = average density of the soil in the pasture and hay field, 1.5 kg soil per liter of soil
- ρ_w = density of water, 1.0 kg water per liter of water
- θ = 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.

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

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

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

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
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

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

Nuclide	Total	External	Internal	Nuclide	Total	External	Internal
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 m². 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 m³. Since the density of the surface soil is assumed to be 1,500 kg/m³, 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.

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

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 $F_{\text{AVAIL}}=1$ 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
- $H_{\text{B},K}$ = inhalation dose to the commercial farm scenario from the Kth radionuclide, in mrem/y
- $H_{\text{G},K}$ = ingestion dose to the commercial farm scenario from the Kth radionuclide, in mrem/y
- $H_{\text{X},K}$ = 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. Unit factors 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
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

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

Nuclide	Total	External	Internal	Nuclide	Total	External	Internal
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. In effect, the individual drills the well, uses it for one year, and then moves to another location. Alternate strategies for estimating dose allow contaminants to accumulate in the soil. The two leading methods are to calculate the doses after some period of accumulation, or to calculate the average annual dose during some period of accumulation. Neither of these alternate methods is employed when calculating radiation dose factors. A comparison of the alternate method dose factors with the first year dose factors is shown in Appendix G.

The number of equations presented in this section is very large. It includes the pathways used for the post-intrusion residents. The intrusion 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

ρ_{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).

ρ_{Garden} = average density of the surface soil, 1.5 kg soil per liter of soil

θ = 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.

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

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

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
- $C_{\text{Soil},K}(t)$ = 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_{irr} = irrigation period (the 1st half of the year), 0.5 y
- λ_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 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 ($C_{S,K}$). The first isotope (Th-232) illustrates the case with little decay and little leaching. Th-232 has a very long half life (1.405×10^{10} years) and a very large retardation in the surface soil ($K_d=600,000$ ml/g). Note that radioactive decay half lives are listed in Table A1, while the soil distribution coefficients are listed in Table A40. 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.

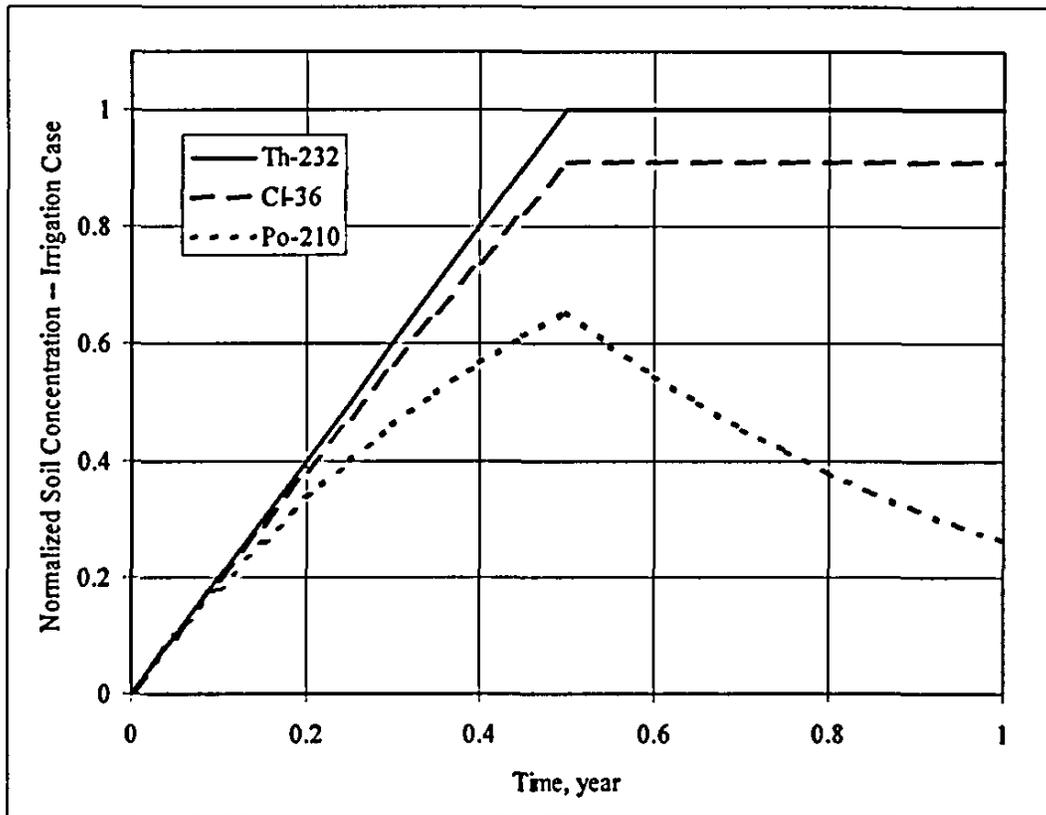


Figure 2. Fraction of Irrigation-Deposited Contamination Present in Surface Soil.

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.

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

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

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/m². 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 λ_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_{GARDEN} = thickness of the contaminated layer of surface soil in the garden, 0.15 m
 T_{irr} = irrigation period (the 1st half of the year), 0.5 y
 T_{no} = no irrigation period (the 2nd half of the year), $T_{irr} + T_{no} = 1$ y
 T_X = time of exposure each year from Table A15, 4,120 h/y
 λ_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)
 ρ_{GARDEN} = average density of the garden, 1,500 kg/m³

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 (0.0011 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 λ_K is very small, $F_{X,I,K}=0.75$.
 $H_{B,K}$ = inhalation dose to the all pathways farmer from the Kth radionuclide, mrem/y
 M_B = total mass of soil inhaled during the year from Table A10, 5.39×10^{-4} kg/y
 V_B = total volume of water inhaled during the year from Table A13, 0.0011 L/y

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 λ_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.

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

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

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

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

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

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

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

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/m² per year (1 y = 365 d)
 J_{SPLASH} = average soil deposition rate due to rain splash (see Section A5.2), 2.7×10^{-4} kg/m² 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 1st half of the year), 0.5 y
 T_{no} = no irrigation period (the 2nd 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)/m²
 λ_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)
 λ_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.

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

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

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

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

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

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

$F_{II,p}$ = 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 2nd 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.

ρ_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_{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_{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
 ρ_{Garden} = average density of the surface soil, 1.5 kg soil per liter of soil
 ρ_w = density of water, 1.0 kg water per liter of water
 θ = 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 effective 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.

Nuclide	Total	Drinking Water	Ratio	Nuclide	Total	Drinking Water	Ratio
H-3	4.75E-05	3.49E-05	1.36	Gd-152	1.12E-01	8.77E-02	1.27
Be-10	3.07E-03	2.54E-03	1.21	Ho-166m	1.75E-02	4.40E-03	3.98
C-14	4.84E-03	1.14E-03	4.25	Re-187	8.47E-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	7.18E-03	6.00E-03	1.20	Pb-210+D	3.67E+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	1.52E+00	1.04E+00	1.47
Ti-44+D	5.81E-02	1.34E-02	4.33	Ra-226+D	9.82E-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	9.37E+00	8.07E+00	1.16
Fe-55	5.94E-04	3.31E-04	1.80	Th-228+D	5.21E-01	4.42E-01	1.18
Fe-60+D	1.54E-01	8.31E-02	1.85	Th-229+D	2.55E+00	2.20E+00	1.16
Co-60	3.99E-02	1.47E-02	2.72	Th-230	3.47E-01	2.99E-01	1.16
Ni-59	3.60E-04	1.14E-04	3.15	Th-232	1.73E+00	1.49E+00	1.16
Ni-63	9.89E-04	3.14E-04	3.15	Pa-231	6.70E+00	5.78E+00	1.16
Se-79	1.29E-02	4.74E-03	2.73	U-232	9.21E-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	1.98E-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	1.29
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	2.88E+00	2.42E+00	1.19
Mo-93	1.11E-03	7.36E-04	1.51	Pu-236	7.38E-01	6.38E-01	1.16
Tc-99	1.75E-03	7.96E-04	2.20	Pu-238	2.02E+00	1.74E+00	1.16
Ru-106+D	3.75E-02	1.49E-02	2.51	Pu-239	2.24E+00	1.93E+00	1.16
Pd-107	1.98E-04	8.12E-05	2.43	Pu-240	2.24E+00	1.93E+00	1.16
Ag-108m+D	1.67E-02	4.15E-03	4.03	Pu-241+D	4.33E-02	3.73E-02	1.16
Cd-109	9.44E-03	7.14E-03	1.32	Pu-242	2.12E+00	1.83E+00	1.16
Cd-113m	1.17E-01	8.77E-02	1.34	Pu-244+D	2.10E+00	1.81E+00	1.16
In-115	1.24E-01	8.61E-02	1.44	Am-241	2.30E+00	1.98E+00	1.16
Sn-121m+D	4.55E-03	1.23E-03	3.71	Am-242m+D	2.23E+00	1.92E+00	1.16
Sn-126+D	5.62E-02	1.14E-02	4.91	Am-243+D	2.30E+00	1.98E+00	1.16

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
Sb-125	4.45E-03	1.53E-03	2.90	Cm-242	7.20E-02	6.27E-02	1.15
Te-125m	2.77E-03	2.00E-03	1.38	Cm-243	1.59E+00	1.37E+00	1.16
I-129	5.25E-01	1.50E-01	3.49	Cm-244	1.28E+00	1.10E+00	1.16
Cs-134	1.51E-01	3.99E-02	3.78	Cm-245	2.37E+00	2.04E+00	1.16
Cs-135	1.44E-02	3.85E-03	3.74	Cm-246	2.34E+00	2.02E+00	1.16
Cs-137+D	1.06E-01	2.73E-02	3.87	Cm-247+D	2.17E+00	1.86E+00	1.16
Ba-133	4.62E-03	1.85E-03	2.49	Cm-248	8.60E+00	7.41E+00	1.16
Pm-147	7.43E-04	5.72E-04	1.30	Cm-250+D	4.91E+01	4.23E+01	1.16
Sm-147	1.32E-01	1.01E-01	1.31	Bk-247	2.97E+00	2.56E+00	1.16
Sm-151	2.78E-04	2.12E-04	1.31	Cf-248	2.33E-01	1.82E-01	1.28
Eu-150	1.45E-02	3.47E-03	4.19	Cf-249	3.39E+00	2.58E+00	1.31
Eu-152	1.22E-02	3.53E-03	3.46	Cf-250	1.52E+00	1.16E+00	1.31
Eu-154	1.50E-02	5.20E-03	2.89	Cf-251	3.46E+00	2.64E+00	1.31
Eu-155	1.31E-03	8.34E-04	1.57	Cf-252	7.63E-01	5.89E-01	1.30

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/m². 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/m² per year
 λ_K = total removal constant (decay plus leaching) for the Kth radionuclide, per year
 ρ_{GARDEN} = average density of the soil in the garden, 1,500 kg/m³

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	1.25E-01	1.32E-02	9.5
Be-10	4.61E-03	1.53E-03	3.01	Ho-166m	4.40E-02	6.64E-04	66.3
C-14	3.49E-01	3.44E-01	0.00	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	0.00
Al-26	9.43E-02	2.40E-02	3.93	Pb-205	2.70E-03	1.61E-03	1.68
Si-32+D	7.95E-03	7.24E-04	11.0	Pb-210+D	8.98E+00	5.30E+00	1.69
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	1.68E-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	1.30E+00	2.37E-01	5.51
Mn-54	1.05E-02	3.65E-03	2.88	Ac-227+D	1.06E+01	1.22E+00	8.71
Fe-55	9.94E-04	3.99E-04	2.49	Th-228+D	7.91E-01	2.67E-01	2.96
Fe-60+D	2.79E-01	1.00E-01	2.78	Th-229+D	3.89E+00	1.33E+00	2.93
Co-60	7.94E-02	2.66E-02	2.99	Th-230	5.28E-01	1.80E-01	2.93
Ni-59	4.30E-04	6.91E-05	6.22	Th-232	2.66E+00	8.98E-01	2.96
Ni-63	1.18E-03	1.90E-04	6.22	Pa-231	7.07E+00	3.49E-01	20.3
Se-79	1.78E-02	4.87E-03	3.66	U-232	9.77E-01	4.31E-02	22.7
Rb-87	4.08E-02	3.24E-02	1.26	U-233	2.12E-01	9.51E-03	22.3
Sr-90+D	1.83E-01	3.02E-02	6.07	U-234	2.08E-01	9.31E-03	22.3
Zr-93	2.69E-03	1.64E-03	1.64	U-235+D	1.98E-01	8.78E-03	22.6
Nb-91	8.92E-04	5.15E-04	1.73	U-236	1.98E-01	8.85E-03	22.3
Nb-93m	8.46E-04	5.15E-04	1.64	U-238+D	1.97E-01	8.82E-03	22.4
Nb-94	4.63E-02	7.05E-03	6.56	Np-237+D	3.20E+00	3.07E-01	10.4

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
Mo-93	1.16E-03	4.44E-05	26.1	Pu-236	8.19E-01	8.08E-02	10.1
Tc-99	1.85E-03	9.61E-05	19.2	Pu-238	2.25E+00	2.21E-01	10.2
Ru-106+D	3.87E-02	9.01E-04	42.9	Pu-239	2.49E+00	2.45E-01	10.2
Pd-107	2.03E-04	4.90E-06	41.3	Pu-240	2.49E+00	2.45E-01	10.2
Ag-108m+D	3.93E-02	1.25E-04	314	Pu-241+D	4.81E-02	4.73E-03	10.2
Cd-109	1.81E-02	8.62E-03	2.10	Pu-242	2.36E+00	2.32E-01	10.2
Cd-113m	2.24E-01	1.06E-01	2.11	Pu-244+D	2.34E+00	2.29E-01	10.2
In-115	5.21E+01	5.20E+01	0.00	Am-241	2.56E+00	2.51E-01	10.2
Sn-121m+D	2.68E-02	2.22E-02	1.21	Am-242m+D	2.47E+00	2.43E-01	10.2
Sn-126+D	2.94E-01	2.07E-01	1.42	Am-243+D	2.55E+00	2.51E-01	10.2
Sb-125	6.60E-03	9.24E-04	7.14	Cm-242	8.00E-02	7.95E-03	10.1
Te-125m	7.60E-03	4.83E-03	1.57	Cm-243	1.77E+00	1.73E-01	10.2
I-129	5.62E-01	3.63E-02	15.5	Cm-244	1.42E+00	1.40E-01	10.2
Cs-134	6.37E-01	4.82E-01	1.32	Cm-245	2.63E+00	2.58E-01	10.2
Cs-135	6.10E-02	4.65E-02	1.31	Cm-246	2.60E+00	2.56E-01	10.2
Cs-137+D	4.42E-01	3.29E-01	1.34	Cm-247+D	2.41E+00	2.36E-01	10.2
Ba-133	7.43E-03	4.47E-05	166	Cm-248	9.56E+00	9.40E-01	10.2
Pm-147	8.47E-04	1.04E-04	8.18	Cm-250+D	5.46E+01	5.37E+00	10.2
Sm-147	1.48E-01	1.52E-02	9.72	Bk-247	3.37E+00	3.87E-01	8.71
Sm-151	3.11E-04	3.20E-05	9.71	Cf-248	2.60E-01	2.75E-02	9.47
Eu-150	3.41E-02	1.05E-03	32.6	Cf-249	3.79E+00	3.90E-01	9.72
Eu-152	2.39E-02	1.07E-03	22.5	Cf-250	1.69E+00	1.75E-01	9.67
Eu-154	2.59E-02	1.57E-03	16.5	Cf-251	3.87E+00	3.99E-01	9.70
Eu-155	1.73E-03	2.52E-04	6.86	Cf-252	8.53E-01	8.88E-02	9.60

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.

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

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

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

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 - $T_{\text{irr}} = 0.5$ y
- λ = total removal constant, per year $\lambda = \lambda_{\text{R}} + \lambda_{\text{S}}$
- λ_{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).
- λ_{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	6.73E-07	7.73E-07	1.1
Be-10	1.53E-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	2.08E-05	1.2
V-49	2.71E-09	6.25E-09	2.3	Ra-228+D	2.86E-05	3.62E-05	1.3
Mn-54	2.87E-07	4.30E-07	1.5	Ac-227+D	1.07E-05	1.25E-05	1.2
Fe-55	2.94E-08	5.24E-08	1.8	Th-228+D	7.05E-06	1.13E-05	1.6
Fe-60+D	1.25E-05	1.86E-05	1.5	Th-229+D	1.17E-05	1.90E-05	1.6
Co-60	4.12E-06	5.15E-06	1.3	Th-230	1.87E-06	3.07E-06	1.6
Ni-59	1.97E-08	2.36E-08	1.2	Th-232	7.75E-06	1.06E-05	1.4
Ni-63	4.78E-08	5.73E-08	1.2	Pa-231	3.95E-06	4.35E-06	
Se-79	4.14E-07	5.77E-07	1.4	U-232	1.05E-05	1.13E-05	
Rb-87	5.74E-07	1.97E-06	3.4	U-233	1.69E-06	1.79E-06	
Sr-90+D	4.66E-06	5.24E-06	1.1	U-234	1.66E-06	1.76E-06	
Zr-93	2.22E-08	6.51E-08	2.9	U-235+D	2.01E-06	2.14E-06	

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
Nb-91	2.05E-08	5.60E-08	2.7	U-236	1.57E-06	1.67E-06	
Nb-93m	1.65E-08	5.12E-08	3.1	U-238+D	2.12E-06	2.25E-06	
Nb-94	5.82E-06	7.17E-06	1.2	Np-237+D	2.00E-06	2.29E-06	1.1
Mo-93	1.40E-07	1.44E-07		Pu-236	1.61E-06	1.83E-06	1.1
Tc-99	6.97E-07	7.05E-07		Pu-238	2.63E-06	3.00E-06	1.1
Ru-106+D	2.22E-06	2.28E-06		Pu-239	2.71E-06	3.09E-06	1.1
Pd-107	1.41E-08	1.45E-08		Pu-240	2.71E-06	3.09E-06	1.1
Ag-108m+D	5.44E-06	6.33E-06	1.2	Pu-241+D	3.58E-08	4.10E-08	1.1
Cd-109	1.20E-07	2.52E-07	2.1	Pu-242	2.57E-06	2.93E-06	1.1
Cd-113m	7.63E-07	1.48E-06	1.9	Pu-244+D	4.09E-06	4.74E-06	1.2
In-115	8.90E-07	4.28E-04	481	Am-241	2.11E-06	2.41E-06	1.1
Sn-121m+D	3.01E-07	1.82E-06	6.0	Am-242m+D	1.51E-06	1.73E-06	1.1
Sn-126+D	9.26E-06	2.22E-05	2.4	Am-243+D	2.68E-06	3.08E-06	1.2
Sb-125	4.15E-07	5.06E-07	1.2	Cm-242	7.63E-07	8.77E-07	1.1
Te-125m	8.39E-08	2.69E-07	3.2	Cm-243	2.16E-06	2.47E-06	1.1
I-129	1.33E-05	1.41E-05		Cm-244	1.68E-06	1.91E-06	1.1
Cs-134	3.96E-06	1.42E-05	3.6	Cm-245	2.28E-06	2.62E-06	1.1
Cs-135	4.54E-07	1.62E-06	3.6	Cm-246	2.05E-06	2.34E-06	1.1
Cs-137+D	4.34E-06	1.20E-05	2.8	Cm-247+D	3.09E-06	3.59E-06	1.2
Ba-133	7.81E-07	8.61E-07		Cm-248	7.52E-06	8.58E-06	1.1
Pm-147	3.99E-08	4.73E-08	1.2	Cm-250+D	4.42E-05	5.04E-05	1.1
Sm-147	8.77E-07	1.00E-06	1.1	Bk-247	2.74E-06	3.20E-06	1.2
Sm-151	1.34E-08	1.55E-08	1.2	Cf-248	1.01E-06	1.17E-06	1.2
Eu-150	4.33E-06	5.04E-06	1.2	Cf-249	4.05E-06	4.67E-06	1.2
Eu-152	2.77E-06	3.16E-06	1.1	Cf-250	2.02E-06	2.30E-06	1.1
Eu-154	2.59E-06	2.95E-06	1.1	Cf-251	3.41E-06	3.91E-06	1.1
Eu-155	7.91E-08	9.63E-08	1.2	Cf-252	1.11E-06	1.26E-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_{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 λ_K and $\lambda_{R,K}$ terms shown below.

$$\lambda_K = \lambda_{V_{irr,K}} + \lambda_{S,K} \quad \text{and} \quad \lambda_{R,K} = \lambda_{V_{no,K}}$$

where,

- λ_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).

$$F_{M,K} = F_{X,I,K} + F_{B,N,K} F_{CUM,K}(N_1, N_2)$$

$$F_{V,K} = F_{C,N,K} \left[1 + F_{CUM,K}(N_1, N_2) \right]$$

$$F_{C,N,K} = \frac{1 - \text{Exp}(-\lambda_K T_{irr})}{\lambda_K T_{irr}} \quad \text{and} \quad F_{no,K} = \frac{1 - \text{Exp}(-\lambda_{R,K} T_{no})}{\lambda_{R,K} T_{no}}$$

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

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

$$F_{IS,K} = \frac{1 - \text{Exp}(-\lambda_K T_{irr})}{\lambda_K T_{irr}} \text{Exp}(-\lambda_{R,K} T_{no}) \quad \text{and} \quad F_{NS,K} = \text{Exp}(-\lambda_K T_{irr}) \text{Exp}(-\lambda_{R,K} T_{no})$$

$$F_{CUM,K}(N_1, N_2) = \frac{F_{IS,K}}{1 - F_{NS,K}} \left[1 - \frac{(F_{NS,K})^{N_2} - (F_{NS,K})^{N_1}}{(N_2 - N_1)(1 - F_{NS,K})} \right]$$

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 1st half of the year), 0.5 y
- T_{no} = no irrigation period (the 2nd half of the year), $T_{irr} + T_{no} = 1$ y
- λ_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 [(N₁,N₂)=(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, 5.39×10^{-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 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 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 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 kg/y, or 47.5 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/m² 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, mg/m² per year (1 y = 365 d)
 J_{SPLASH} = average soil deposition rate due to rain splash (see Section A5.2), 2.7x10⁻⁴ kg/m² 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 kg(wet)/m²

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 (f_1). 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.

$$W_{D,K} = \frac{C_{S,K} M_D F_{D,K} F_{M,K} + C_{W,K} V_D U_{D,K}}{(365 \text{ d/y}) M_{ADULT} (f_1)_K}$$

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
 $(f_1)_K$ = 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 $(f_1)_K$ 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. Additional detail on the contributions from each pathway are shown in Appendix D.

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

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	7.01E-01	na	4.93E+00
53-70-3	Dibenz[a,h]anthracene	na	1.37E+00	na	1.40E+01
56-23-5	Carbon tetrachloride	3.95E+01	5.07E-03	4.51E+01	5.29E-03
57-12-5	Cyanide, free	3.13E+01	na	3.13E+01	na
57-14-7	1,1-Dimethylhydrazine	na	4.58E+00	na	4.58E+00
57-55-6	Propylene glycol (1,2-Propanediol)	2.29E+00	na	2.29E+00	na
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)	1.93E+02	3.23E-02	2.59E+02	4.32E-02
60-29-7	Ethyl ether (Diethyl ether)	2.11E-01	na	2.13E-01	na
60-34-4	Methylhydrazine	na	3.43E+00	na	3.43E+00
60-57-1	Dieldrin	8.41E+02	7.32E-01	8.27E+03	3.28E+00
62-75-9	N-Nitrosodimethylamine	2.10E+05	3.69E+01	2.10E+05	3.69E+01
64-18-6	Formic acid	4.82E-01	na	4.82E-01	na
67-56-1	Methanol (Methyl alcohol)	1.23E+00	na	1.23E+00	na
67-64-1	Acetone (2-Propanone)	2.20E-01	na	2.21E-01	na
67-66-3	Chloroform	1.87E+02	5.47E-03	1.87E+02	5.47E-03
67-72-1	Hexachloroethane	3.19E+01	1.14E-03	7.16E+01	1.38E-03
71-36-3	n-Butyl alcohol (n-Butanol)	2.30E+01	na	2.30E+01	na
71-43-2	Benzene	2.62E+01	2.58E-03	2.65E+01	2.61E-03
71-55-6	1,1,1-Trichloroethane (Methyl chloroform)	3.51E-01	na	3.59E-01	na
72-20-8	Endrin	3.99E+02	na	1.32E+03	na
74-83-9	Bromomethane	1.36E+02	na	1.36E+02	na
74-87-3	Methyl chloride (Chloromethane)	6.16E+00	6.45E-04	6.16E+00	6.47E-04
75-00-3	Ethyl Chloride	1.36E-01	4.00E-05	1.37E-01	4.04E-05
75-01-4	Vinyl chloride (Chloroethene)	1.58E+01	2.06E-02	1.60E+01	2.08E-02
75-05-8	Acetonitrile	9.26E+00	na	9.26E+00	na
75-07-0	Acetaldehyde	6.16E+01	5.23E-04	6.16E+01	5.23E-04
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	na	1.11E-02	na
75-68-3	Chloro-1,1-difluoroethane, 1-	1.11E-02	na	1.11E-02	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
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	4.43E-01	2.70E+03	2.91E+00
78-83-1	Isobutanol	3.70E-01	na	3.71E-01	na
78-87-5	1,2-Dichloropropane	1.39E+02	9.19E-04	1.39E+02	9.44E-04
78-93-3	Methyl ethyl ketone (2-Butanone)	3.22E-01	na	3.23E-01	na
79-00-5	1,1,2-Trichloroethane	9.16E+00	4.76E-03	9.34E+00	4.78E-03
79-01-6	Trichloroethylene	1.18E+02	3.25E-02	1.24E+02	3.28E-02
79-10-7	2-Propenoic acid (Acrylic acid)	8.83E+00	na	8.83E+00	na
79-34-5	1,1,2,2-Tetrachloroethane (Acetylene tetrachloride)	6.09E-01	1.67E-02	6.39E-01	1.69E-02
79-46-9	2-Nitropropane	2.77E+01	6.38E-01	2.77E+01	6.38E-01
82-68-8	Pentachloronitrobenzene (PCNB)	1.18E+01	3.93E-03	4.39E+01	1.47E-02
83-32-9	Acenaphthene	8.48E-01	na	1.30E+00	na
84-66-2	Diethyl phthalate	1.14E-01	na	1.17E-01	na
84-74-2	Dibutyl phthalate	3.73E-01	na	1.13E+00	na
85-68-7	Butyl benzyl phthalate	2.13E-01	na	7.85E-01	na
87-68-3	Hexachlorobutadiene	1.16E+02	6.46E-03	5.26E+02	1.06E-02
87-86-5	Pentachlorophenol	1.42E+00	2.19E-03	4.44E+00	6.84E-03
88-06-2	2,4,6-Trichlorophenol	5.38E+02	3.33E-04	6.15E+02	3.69E-04
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)	6.99E+01	na	8.53E+01	na
91-20-3	Naphthalene	1.87E+02	na	1.87E+02	na
92-52-4	1,1'-Biphenyl	8.78E-01	na	1.48E+00	na
95-47-6	o-Xylene	5.69E+00	na	5.72E+00	na
95-48-7	2-Methylphenol (o-Cresol)	3.85E+00	na	3.87E+00	na
95-50-1	1,2-Dichlorobenzene (ortho-)	3.12E+00	na	3.24E+00	na
95-57-8	2-Chlorophenol	2.36E+01	na	2.39E+01	na
95-63-6	1,2,4-Trimethylbenzene	9.33E+01	na	9.36E+01	na
95-95-4	2,4,5-Trichlorophenol	5.36E-01	na	6.17E-01	na
98-86-2	Acetophenone	1.12E+00	na	1.12E+00	na
98-95-3	Nitrobenzene	4.73E+02	na	4.75E+02	na
100-25-4	1,4-Dinitrobenzene (para-)	3.00E+03	na	3.00E+03	na
100-41-4	Ethyl benzene	8.53E-01	2.61E-04	9.21E-01	2.61E-04
100-42-5	Styrene	7.13E-01	na	7.38E-01	na
100-51-6	Benzyl alcohol	6.09E-01	na	6.09E-01	na
106-42-3	p-Xylene	5.69E+00	na	5.72E+00	na
106-44-5	4-Methylphenol (p-Cresol)	3.77E+01	na	3.79E+01	na
106-46-7	1,4-Dichlorobenzene (para-)	1.70E+00	1.80E-03	2.08E+00	1.92E-03
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	2.77E+03	1.59E+00	2.77E+03	1.62E+00

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
106-99-0	1,3-Butadiene	2.77E+02	7.13E-03	2.77E+02	7.13E-03
107-02-8	2-Propenal (Acrolein)	2.80E+04	na	2.80E+04	na
107-05-1	3-Chloropropene (Allyl chloride)	5.54E+02	na	5.54E+02	na
107-06-2	1,2-Dichloroethane (Ethylene chloride)	1.14E+02	7.64E-03	1.14E+02	7.65E-03
107-13-1	Acrylonitrile	3.80E+02	3.98E-02	3.80E+02	3.99E-02
108-10-1	Methyl isobutyl ketone (4-Methyl-2-pentanone)	8.24E-01	na	8.28E-01	na
108-38-3	m-Xylene	5.69E+00	na	5.73E+00	na
108-39-4	3-Methylphenol (m-Cresol)	3.72E+00	na	3.75E+00	na
108-67-8	1,3,5-Trimethylbenzene	9.33E+01	na	9.35E+01	na
108-87-2	Methyl cyclohexane	1.85E-01	na	1.85E-01	na
108-88-3	Toluene (Methyl benzene)	1.54E+00	na	1.55E+00	na
108-90-7	Chlorobenzene	1.10E+01	na	1.12E+01	na
108-94-1	Cyclohexanone	3.59E-02	na	3.60E-02	na
108-95-2	Phenol (Carbolic acid)	1.02E+00	na	1.02E+00	na
109-99-9	Tetrahydrofuran	2.31E+00	7.75E-04	2.31E+00	7.77E-04
110-00-9	Furan (Oxacyclopentadiene)	3.65E+01	na	3.68E+01	na
110-54-3	n-Hexane	3.45E+00	na	3.88E+00	na
110-80-5	2-Ethoxyethanol	1.33E+00	na	1.33E+00	na
110-82-7	Cyclohexane	9.26E-02	na	9.26E-02	na
110-86-1	Pyridine	2.60E+02	na	2.60E+02	na
111-76-2	2-Butoxyethanol (Ethylene Glycol Monobutyl Ether)	2.59E-01	na	2.60E-01	na
111-90-0	2-(2-Ethoxyethoxy)-ethanol (Diethylene Glycol Monoethyl Ether)	1.23E+01	na	1.23E+01	na
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)	9.22E+01	1.11E-02	9.45E+01	1.13E-02
117-84-0	Di-n-octylphthalate	1.19E+02	na	1.19E+02	na
118-74-1	Hexachlorobenzene	7.52E+01	1.50E-01	9.05E+02	6.05E-01
120-82-1	1,2,4-Trichlorobenzene	1.42E+02	na	1.45E+02	na
121-14-2	2,4-Dinitrotoluene	9.87E+01	na	9.93E+01	na
121-44-8	Triethylamine	7.92E+01	na	7.92E+01	na
122-39-4	Diphenylamine	2.47E+00	na	3.00E+00	na
123-91-1	1,4-Dioxane (Diethylene oxide)	na	1.44E-03	na	1.44E-03
126-73-8	Tributyl Phosphate	2.47E-01	1.14E-04	2.78E-01	1.28E-04
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)	1.51E+03	na	1.51E+03	na
127-18-4	Tetrachloroethylene	3.70E+00	7.54E-04	4.77E+00	9.92E-04
129-00-0	Pyrene	2.55E+00	na	7.55E+00	na
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	8.01E-02	na	8.05E-02	na
156-59-2	cis-1,2-Dichloroethylene	3.12E+00	na	3.19E+00	na
206-44-0	Fluoranthene (1,2-Benzacenaphthene)	2.44E+00	na	8.56E+00	na
309-00-2	Aldrin	5.57E+03	2.37E+00	9.23E+04	2.13E+01
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	1.05E+02	3.55E-01	1.50E+02	4.16E-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
319-85-7	beta-Benzene hexachloride (beta-Lindane)	2.89E+02	4.68E-02	3.98E+02	6.36E-02
541-73-1	1,3-Dichlorobenzene	3.42E+01	na	4.91E+01	na
542-75-6	1,3-Dichloropropene (cis & trans)	2.88E+01	2.31E-03	2.88E+01	2.35E-03
621-64-7	N-Nitrosodi-N-propylamine	na	1.03E+00	na	1.04E+00
1314-62-1	Vanadium pentoxide	3.77E+00	na	7.04E+00	na
1330-20-7	Xylenes (mixtures)	5.69E+00	na	5.72E+00	na
1336-36-3	Polychlorinated Biphenyls	na	8.01E-02	na	6.48E+00
1336-36-3	Polychlorinated Biphenyls (lowest risk)	na	7.20E-02	na	6.47E+00
6533-73-9	Thallium carbonate	6.44E+02	na	1.68E+04	na
7429-90-5	Aluminum	3.93E-02	na	1.08E-01	na
7439-89-6	Iron	1.44E-01	na	2.42E-01	na
7439-93-2	Lithium	3.73E+00	na	3.90E+00	na
7439-96-5	Manganese	1.78E+00	na	2.27E+00	na
7439-97-6	Mercury metal vapor	3.91E-02	na	3.91E-02	na
7439-98-7	Molybdenum	3.85E+01	na	3.90E+01	na
7440-02-0	Nickel (soluble salts)	4.15E+00	na	4.97E+00	na
7440-22-4	Silver	7.36E+00	na	8.17E+00	na
7440-24-6	Strontium, Stable	3.53E-01	na	3.72E-01	na
7440-28-0	Thallium metal	7.79E+02	na	2.03E+04	na
7440-31-5	Tin	1.23E-01	na	7.73E-01	na
7440-36-0	Antimony	8.28E+01	na	1.34E+02	na
7440-38-2	Arsenic (inorganic)	1.13E+02	2.19E-02	2.29E+02	4.42E-02
7440-39-3	Barium	6.06E-01	na	6.70E-01	na
7440-41-7	Beryllium and compounds	1.82E+01	4.21E-05	3.05E+01	4.21E-05
7440-42-8	Boron and borates only	3.64E+00	na	3.65E+00	na
7440-43-9	Cadmium	9.70E+01	3.10E-05	1.60E+02	3.10E-05
7440-45-1	Cerium (Ceric oxide 1306-38-3)	2.07E-01	na	2.07E-01	na
7440-48-4	Cobalt	4.73E+00	4.79E-05	6.81E+00	4.79E-05
7440-50-8	Copper	6.23E+00	na	6.95E+00	na
7440-62-2	Vanadium metal	5.20E+00	na	1.06E+01	na
7440-66-6	Zinc and compounds	6.81E+01	na	6.82E+01	na
7487-94-7	Mercuric chloride	1.32E+03	na	1.76E+03	na
7664-41-7	Ammonia	7.81E-01	na	7.81E-01	na
7723-14-0	Phosphorus, white	1.10E+05	na	1.20E+05	na
7782-41-4	Fluorine (soluble fluoride)	1.84E+00	na	1.91E+00	na
7782-49-2	Selenium and compounds	1.31E+01	na	1.76E+01	na
8001-35-2	Toxaphene	na	4.58E-02	na	3.89E-01
11096-82-5	Aroclor 1260	na	4.67E+00	na	5.21E+00
11097-69-1	Aroclor 1254	1.18E+04	1.81E-01	9.18E+05	1.57E+01
11104-28-2	Aroclor 1221	na	4.07E-02	na	1.09E-01
11141-16-5	Aroclor 1232	na	4.07E-02	na	1.09E-01
12672-29-6	Aroclor 1248	na	7.84E-02	na	7.07E+00

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
12674-11-2	Aroclor 1016	8.22E+02	4.25E-02	3.34E+04	1.99E+00
14797-55-8	Nitrate	1.35E-02	na	1.39E-02	na
14797-65-0	Nitrite	2.16E-01	na	2.22E-01	na
16065-83-1	Chromium (III) (insoluble salts)	2.81E-02	na	5.76E-02	na
16984-48-8	Fluorine anion	1.84E+00	na	1.91E+00	na
18540-29-9	Chromium (VI) (soluble salts)	1.02E+01	5.19E-05	1.89E+01	5.19E-05
53469-21-9	Aroclor 1242	na	7.87E-02	na	6.48E+00
na	Uranium (soluble salts)	5.49E+01	na	5.92E+01	na
na	Total Chromium (1:6 ratio CrVI:Cr III)	1.48E+00	7.41E-06	2.75E+00	7.41E-06

Notes:

- CASRN = Chemical Abstract Service Reference Number
- The total risk to the All Pathways Farmer is calculated using intakes from 30 consecutive years. The soil concentration is zero at the start of the exposure.
- These scenario factors must be multiplied by the appropriate water concentration. The "Well Water Only" columns assume all the contaminated water comes from a well. The "Columbia River" columns assume all the contaminated water comes from the Columbia River.
- Results using route-to-route extrapolations are shown in Table C4.

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 effective 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.

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.

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	753.2
Al-26	5.42E-02	3.95E+00	72.8	Pb-205	2.60E-03	9.92E-02	38.1
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

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
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

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 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.

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
Ni-63	4.06E-07	1.75E-06	4.3	Pa-231	1.56E-04	2.41E-04	1.5
Sc-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

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
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. Additional detail on the contributions from each pathway are shown in Appendix D.

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	na	6.14E+02
53-70-3	Dibenz[a,h]anthracene	na	1.80E+01	na	1.81E+03
56-23-5	Carbon tetrachloride	1.01E+02	2.08E-02	4.41E+02	5.17E-02
57-12-5	Cyanide, free	1.11E+02	na	1.13E+02	na
57-14-7	1,1-Dimethylhydrazine	na	3.85E+01	na	3.86E+01
57-55-6	Propylene glycol (1,2-Propanediol)	1.02E+01	na	1.03E+01	na
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)	6.99E+02	2.72E-01	5.08E+03	1.93E+00
60-29-7	Ethyl ether (Diethyl ether)	5.92E-01	na	7.20E-01	na
60-34-4	Methylhydrazine	na	2.88E+01	na	2.89E+01
60-57-1	Dieldrin	2.68E+03	3.59E+00	4.55E+05	3.63E+02
62-75-9	N-Nitrosodimethylamine	7.54E+05	3.09E+02	7.59E+05	3.10E+02
64-18-6	Formic acid	1.72E+00	na	1.73E+00	na
67-56-1	Methanol (Methyl alcohol)	4.34E+00	na	4.40E+00	na
67-64-1	Acetone (2-Propanone)	7.53E-01	na	7.82E-01	na
67-66-3	Chloroform	2.68E+02	1.80E-02	2.74E+02	1.80E-02
67-72-1	Hexachloroethane	9.95E+01	4.52E-03	2.50E+03	3.81E-02
71-36-3	n-Butyl alcohol (n-Butanol)	3.43E+01	na	3.46E+01	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
71-43-2	Benzene	4.62E+01	1.05E-02	6.40E+01	1.44E-02
71-55-6	1,1,1-Trichloroethane (Methyl chloroform)	6.01E-01	na	1.07E+00	na
72-20-8	Endrin	2.64E+03	na	7.71E+04	na
74-83-9	Bromomethane	2.24E+02	na	2.34E+02	na
74-87-3	Methyl chloride (Chloromethane)	8.69E+00	2.79E-03	8.69E+00	3.13E-03
75-00-3	Ethyl Chloride	2.86E-01	2.41E-04	3.40E-01	3.03E-04
75-01-4	Vinyl chloride (Chloroethene)	3.40E+01	1.17E-01	4.38E+01	1.58E-01
75-05-8	Acetonitrile	1.31E+01	na	1.31E+01	na
75-07-0	Acetaldehyde	8.69E+01	1.72E-03	8.69E+01	1.72E-03
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	na	1.56E-02	na
75-68-3	Chloro-1,1-difluoroethane, 1-	1.56E-02	na	1.56E-02	na
75-69-4	Trichlorofluoromethane	1.40E+00	na	1.89E+00	na
75-71-8	Dichlorodifluoromethane	4.31E+00	na	4.71E+00	na
76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane (CFC-113)	2.83E-02	na	4.24E-02	na
76-44-8	Heptachlor	4.70E+02	2.06E+00	1.54E+05	3.48E+02
78-83-1	Isobutanol	1.22E+00	na	1.31E+00	na
78-87-5	1,2-Dichloropropane	1.96E+02	5.54E-03	1.96E+02	9.23E-03
78-93-3	Methyl ethyl ketone (2-Butanone)	8.58E-01	na	9.02E-01	na
79-00-5	1,1,2-Trichloroethane	2.47E+01	1.84E-02	3.64E+01	2.10E-02
79-01-6	Trichloroethylene	3.37E+02	1.27E-01	7.68E+02	1.79E-01
79-10-7	2-Propenoic acid (Acrylic acid)	1.34E+01	na	1.34E+01	na
79-34-5	1,1,2,2-Tetrachloroethane (Acetylene tetrachloride)	1.66E+00	6.45E-02	3.53E+00	8.68E-02
79-46-9	2-Nitropropane	3.91E+01	2.10E+00	3.91E+01	2.10E+00
82-68-8	Pentachloronitrobenzene (PCNB)	3.51E+01	2.73E-02	1.99E+03	1.55E+00
83-32-9	Acenaphthene	3.65E+00	na	3.28E+01	na
84-66-2	Diethyl phthalate	3.80E-01	na	5.70E-01	na
84-74-2	Dibutyl phthalate	1.13E+00	na	4.73E+01	na
85-68-7	Butyl benzyl phthalate	7.79E-01	na	3.70E+01	na
87-68-3	Hexachlorobutadiene	4.29E+02	2.74E-02	2.51E+04	6.06E-01
87-86-5	Pentachlorophenol	5.11E+00	1.84E-02	1.93E+02	6.89E-01
88-06-2	2,4,6-Trichlorophenol	1.88E+03	2.33E-03	7.77E+03	8.34E-03
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)	2.78E+02	na	1.44E+03	na
91-20-3	Naphthalene	2.66E+02	na	2.94E+02	na
92-52-4	1,1'-Biphenyl	3.42E+00	na	4.10E+01	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
95-47-6	<i>o</i> -Xylene	8.25E+00	na	1.03E+01	na
95-48-7	2-Methylphenol (<i>o</i> -Cresol)	1.40E+01	na	1.67E+01	na
95-50-1	1,2-Dichlorobenzene (<i>ortho</i> -)	4.90E+00	na	1.26E+01	na
95-57-8	2-Chlorophenol	8.12E+01	na	1.06E+02	na
95-63-6	1,2,4-Trimethylbenzene	1.33E+02	na	1.52E+02	na
95-95-4	2,4,5-Trichlorophenol	1.89E+00	na	8.06E+00	na
98-86-2	Acetophenone	3.70E+00	na	3.86E+00	na
98-95-3	Nitrobenzene	1.05E+03	na	1.16E+03	na
100-25-4	1,4-Dinitrobenzene (<i>para</i> -)	1.09E+04	na	1.18E+04	na
100-41-4	Ethyl benzene	1.64E+00	8.59E-04	5.86E+00	8.59E-04
100-42-5	Styrene	1.24E+00	na	2.74E+00	na
100-51-6	Benzyl alcohol	2.08E+00	na	2.14E+00	na
106-42-3	<i>p</i> -Xylene	8.25E+00	na	1.04E+01	na
106-44-5	4-Methylphenol (<i>p</i> -Cresol)	1.37E+02	na	1.60E+02	na
106-46-7	1,4-Dichlorobenzene (<i>para</i> -)	3.85E+00	6.98E-03	2.71E+01	2.37E-02
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	3.91E+03	1.02E+01	3.91E+03	1.47E+01
106-99-0	1,3-Butadiene	3.91E+02	2.34E-02	3.91E+02	2.34E-02
107-02-8	2-Propenal (Acrolein)	3.99E+04	na	3.99E+04	na
107-05-1	3-Chloropropene (Allyl chloride)	7.82E+02	na	7.83E+02	na
107-06-2	1,2-Dichloroethane (Ethylene chloride)	1.63E+02	2.95E-02	1.64E+02	3.16E-02
107-13-1	Acrylonitrile	7.24E+02	2.33E-01	7.50E+02	2.47E-01
108-10-1	Methyl isobutyl ketone (4-Methyl-2-pentanone)	2.14E+00	na	2.37E+00	na
108-38-3	<i>m</i> -Xylene	8.26E+00	na	1.06E+01	na
108-39-4	3-Methylphenol (<i>m</i> -Cresol)	1.35E+01	na	1.61E+01	na
108-67-8	1,3,5-Trimethylbenzene	1.32E+02	na	1.46E+02	na
108-87-2	Methyl cyclohexane	2.60E-01	na	2.60E-01	na
108-88-3	Toluene (Methyl benzene)	2.37E+00	na	3.39E+00	na
108-90-7	Chlorobenzene	1.84E+01	na	3.14E+01	na
108-94-1	Cyclohexanone	1.22E-01	na	1.29E-01	na
108-95-2	Phenol (Carbolic acid)	3.72E+00	na	3.96E+00	na
109-99-9	Tetrahydrofuran	4.09E+00	3.89E-03	4.22E+00	4.09E-03
110-00-9	Furan (Oxacyclopentadiene)	9.86E+01	na	1.17E+02	na
110-54-3	<i>n</i> -Hexane	6.87E+00	na	3.37E+01	na
110-80-5	2-Ethoxyethanol	4.59E+00	na	4.67E+00	na
110-82-7	Cyclohexane	1.31E-01	na	1.31E-01	na
110-86-1	Pyridine	9.03E+02	na	9.39E+02	na
111-76-2	2-Butoxyethanol (Ethylene Glycol Monobutyl Ether)	8.59E-01	na	9.20E-01	na
111-90-0	2-(2-Ethoxyethoxy)-ethanol (Diethylene Glycol Monoethyl Ether)	4.58E+01	na	4.64E+01	na
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)	4.14E+02	1.16E-01	8.81E+02	2.33E-01

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
117-84-0	Di-n-octylphthalate	4.46E+02	na	7.38E+02	na
118-74-1	Hexachlorobenzene	3.81E+02	8.44E-01	5.03E+04	6.47E+01
120-82-1	1,2,4-Trichlorobenzene	2.06E+02	na	3.99E+02	na
121-14-2	2,4-Dinitrotoluene	3.62E+02	na	4.23E+02	na
121-44-8	Triethylamine	1.12E+02	na	1.12E+02	na
122-39-4	Diphenylamine	8.91E+00	na	4.62E+01	na
123-91-1	1,4-Dioxane (Diethylene oxide)	na	1.17E-02	na	1.19E-02
126-73-8	Tributyl Phosphate	8.70E-01	9.36E-04	3.64E+00	3.57E-03
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)	3.34E+03	na	3.61E+03	na
127-18-4	Tetrachloroethylene	8.62E+00	4.26E-03	7.32E+01	3.78E-02
129-00-0	Pyrene	1.45E+01	na	3.44E+02	na
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	2.50E-01	na	2.80E-01	na
156-59-2	cis-1,2-Dichloroethylene	8.06E+00	na	1.25E+01	na
206-44-0	Fluoranthene (1,2-Benzacenaphthene)	1.50E+01	na	4.08E+02	na
309-00-2	Aldrin	2.24E+04	1.52E+01	5.25E+06	2.68E+03
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	3.62E+02	1.84E+00	3.28E+03	1.08E+01
319-85-7	beta-Benzene hexachloride (beta-Lindane)	1.07E+03	3.93E-01	8.45E+03	2.97E+00
541-73-1	1,3-Dichlorobenzene	1.02E+02	na	1.01E+03	na
542-75-6	1,3-Dichloropropene (cis & trans)	4.19E+01	1.15E-02	4.39E+01	1.75E-02
621-64-7	N-Nitrosodi-N-propylamine	na	8.85E+00	na	9.42E+00
1314-62-1	Vanadium pentoxide	1.17E+01	na	3.13E+02	na
1330-20-7	Xylenes (mixtures)	8.24E+00	na	1.02E+01	na
1336-36-3	Polychlorinated Biphenyls	na	4.74E-01	na	8.95E+02
1336-36-3	Polychlorinated Biphenyls (lowest risk)	na	3.64E-01	na	8.95E+02
6533-73-9	Thallium carbonate	1.72E+03	na	9.89E+05	na
7429-90-5	Aluminum	1.37E+00	na	6.64E+00	na
7439-89-6	Iron	3.57E-01	na	9.74E+00	na
7439-93-2	Lithium	1.71E+01	na	6.70E+01	na
7439-96-5	Manganese	1.34E+02	na	2.02E+02	na
7439-97-6	Mercury metal vapor	2.09E+01	na	2.09E+01	na
7439-98-7	Molybdenum	2.01E+02	na	2.82E+02	na
7440-02-0	Nickel (soluble salts)	2.48E+01	na	1.18E+02	na
7440-22-4	Silver	1.80E+01	na	2.40E+02	na
7440-24-6	Strontium, Stable	2.36E+00	na	4.94E+00	na
7440-28-0	Thallium metal	2.05E+03	na	1.19E+06	na
7440-31-5	Tin	3.18E-01	na	4.12E+01	na
7440-36-0	Antimony	3.05E+02	na	1.08E+04	na
7440-38-2	Arsenic (inorganic)	3.05E+02	1.65E-01	9.88E+03	4.38E+00
7440-39-3	Barium	1.48E+01	na	3.41E+01	na
7440-41-7	Beryllium and compounds	3.77E+02	1.55E-02	3.57E+03	1.55E-02

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
7440-42-8	Boron and borates only	1.67E+01	na	1.87E+01	na
7440-43-9	Cadmium	5.06E+02	1.16E-02	2.03E+04	1.16E-02
7440-45-1	Cerium (Ceric oxide 1306-38-3)	3.22E+01	na	3.22E+01	na
7440-48-4	Cobalt	3.31E+02	1.80E-02	4.88E+02	1.80E-02
7440-50-8	Copper	3.83E+01	na	9.60E+01	na
7440-62-2	Vanadium metal	1.93E+01	na	1.08E+03	na
7440-66-6	Zinc and compounds	3.36E+02	na	3.47E+02	na
7487-94-7	Mercuric chloride	3.20E+03	na	3.09E+04	na
7664-41-7	Ammonia	1.10E+00	na	1.10E+00	na
7723-14-0	Phosphorus, white	5.35E+05	na	1.14E+06	na
7782-41-4	Fluorine (soluble fluoride)	4.37E+00	na	2.07E+01	na
7782-49-2	Selenium and compounds	2.67E+01	na	3.58E+02	na
8001-35-2	Toxaphene	na	2.92E-01	na	4.90E+01
11096-82-5	Aroclor 1260	na	3.00E+01	na	1.35E+02
11097-69-1	Aroclor 1254	4.36E+04	1.10E+00	5.44E+07	2.17E+03
11104-28-2	Aroclor 1221	na	2.05E-01	na	9.86E+00
11141-16-5	Aroclor 1232	na	2.05E-01	na	9.86E+00
12672-29-6	Aroclor 1248	na	4.61E-01	na	9.78E+02
12674-11-2	Aroclor 1016	3.59E+03	2.00E-01	1.96E+06	2.73E+02
14797-55-8	Nitrate	2.75E-02	na	6.45E-02	na
14797-65-0	Nitrite	4.39E-01	na	1.03E+00	na
16065-83-1	Chromium (III) (insoluble salts)	1.15E-01	na	7.15E+00	na
16984-48-8	Fluorine anion	4.37E+00	na	2.07E+01	na
18540-29-9	Chromium (VI) (soluble salts)	8.06E+02	7.53E-02	1.36E+03	7.53E-02
53469-21-9	Aroclor 1242	na	4.64E-01	na	8.95E+02
na	Uranium (soluble salts)	1.35E+02	na	7.54E+02	na
na	Total Chromium (1:6 ratio CrVI:Cr III)	1.15E+02	1.08E-02	2.01E+02	1.08E-02

Notes:

- CASRN = Chemical Abstract Service Reference Number
- The total risk to the Native American is calculated using intakes from 70 consecutive years. The soil concentration is zero at the start of the exposure.
- These scenario factors must be multiplied by the appropriate water concentration. The "Well Water" columns assume all the contaminated water comes from the well. The "Columbia River" columns assume all contaminated water comes from the Columbia River.
- Results using route-to-route extrapolations are shown in Table C6.

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	5.86E+02	4.39E+02	1.34
Be-10	1.64E+01	1.27E+01	1.29	Ho-166m	1.37E+02	2.20E+01	6.22
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	5.78E+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	5.15E+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	5.03E+04	4.03E+04	1.25
Fe-55	2.89E+00	1.65E+00	1.75	Th-228+D	2.79E+03	2.21E+03	1.26
Fe-60+D	8.02E+02	4.15E+02	1.93	Th-229+D	1.37E+04	1.10E+04	1.25
Co-60	2.14E+02	7.33E+01	2.92	Th-230	1.86E+03	1.49E+03	1.25
Ni-59	1.61E+00	5.72E-01	2.81	Th-232	9.36E+03	7.44E+03	1.26
Ni-63	4.42E+00	1.57E+00	2.81	Pa-231	3.60E+04	2.89E+04	1.25
Se-79	5.92E+01	2.37E+01	2.50	U-232	4.85E+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	9.87E+02	7.28E+02	1.36
Nb-91	1.91E+00	1.42E+00	1.34	U-236	9.88E+02	7.33E+02	1.35
Nb-93m	1.78E+00	1.42E+00	1.25	U-238+D	9.85E+02	7.30E+02	1.35

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
Nb-94	1.23E+02	1.95E+01	6.32	Np-237+D	1.54E+04	1.21E+04	1.27
Mo-93	5.76E+00	3.68E+00	1.57	Pu-236	3.96E+03	3.19E+03	1.24
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	1.20E+04	9.65E+03	1.25
Pd-107	9.15E-01	4.06E-01	2.25	Pu-240	1.20E+04	9.65E+03	1.25
Ag-108m+D	1.26E+02	2.08E+01	6.06	Pu-241+D	2.33E+02	1.87E+02	1.25
Cd-109	4.92E+01	3.57E+01	1.38	Pu-242	1.14E+04	9.16E+03	1.25
Cd-113m	6.12E+02	4.39E+02	1.40	Pu-244+D	1.13E+04	9.05E+03	1.25
In-115	8.71E+02	4.31E+02	2.02	Am-241	1.24E+04	9.92E+03	1.25
Sn-121m+D	2.01E+01	6.13E+00	3.28	Am-242m+D	1.20E+04	9.59E+03	1.25
Sn-126+D	3.13E+02	5.72E+01	5.47	Am-243+D	1.23E+04	9.89E+03	1.25
Sb-125	2.33E+01	7.66E+00	3.04	Cm-242	3.85E+02	3.13E+02	1.23
Te-125m	1.41E+01	1.00E+01	1.41	Cm-243	8.53E+03	6.84E+03	1.25
I-129	2.32E+03	7.52E+02	3.09	Cm-244	6.86E+03	5.50E+03	1.25
Cs-134	6.74E+02	2.00E+02	3.38	Cm-245	1.27E+04	1.02E+04	1.25
Cs-135	6.36E+01	1.93E+01	3.30	Cm-246	1.26E+04	1.01E+04	1.25
Cs-137+D	4.80E+02	1.36E+02	3.52	Cm-247+D	1.16E+04	9.32E+03	1.25
Ba-133	2.79E+01	9.27E+00	3.01	Cm-248	4.62E+04	3.71E+04	1.25
Pm-147	3.88E+00	2.86E+00	1.36	Cm-250+D	2.64E+05	2.12E+05	1.25
Sm-147	7.04E+02	5.04E+02	1.40	Bk-247	1.60E+04	1.28E+04	1.25
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	1.77E+04	1.29E+04	1.37
Eu-152	7.95E+01	1.77E+01	4.50	Cf-250	7.91E+03	5.80E+03	1.36
Eu-154	9.03E+01	2.60E+01	3.47	Cf-251	1.81E+04	1.32E+04	1.37
Eu-155	6.96E+00	4.17E+00	1.67	Cf-252	3.98E+03	2.94E+03	1.35

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	8.58E+00	8.23E+00	
Be-10	2.00E+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	4.34E+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
Ca-41	3.04E-01	1.22E-01	2.5	Po-210	2.80E+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	1.41E+02	1.27E+02	
Fe-55	3.33E-01	3.30E-01		Th-228+D	8.78E+01	8.18E+01	
Fe-60+D	2.61E+02	7.41E+01	3.5	Th-229+D	1.63E+02	1.39E+02	1.2
Co-60	4.85E+01	1.18E+01	4.1	Th-230	2.58E+01	2.34E+01	
Ni-59	2.28E-01	1.87E-01	1.2	Th-232	2.20E+02	3.16E+01	7.0
Ni-63	5.42E-01	4.56E-01	1.2	Pa-231	6.33E+01	4.47E+01	1.4
Se-79	4.41E+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	2.12E+01	2.03E+01	
Sr-90+D	7.37E+01	2.86E+01	2.6	U-234	2.08E+01	2.00E+01	
Zr-93	2.97E-01	2.80E-01		U-235+D	2.65E+01	2.07E+01	1.3
Nb-91	3.16E-01	2.13E-01	1.5	U-236	1.97E+01	1.89E+01	
Nb-93m	2.17E-01	2.09E-01		U-238+D	2.69E+01	2.48E+01	
Nb-94	1.33E+02	7.97E+00	16.7	Np-237+D	3.08E+01	1.84E+01	1.7
Mo-93	2.48E+00	1.09E+00	2.3	Pu-236	2.15E+01	1.92E+01	1.1
Tc-99	1.06E+01	1.50E+00	7.0	Pu-238	3.39E+01	3.34E+01	
Ru-106+D	2.36E+01	2.30E+01		Pu-239	3.51E+01	3.44E+01	
Pd-107	1.69E-01	1.35E-01	1.3	Pu-240	3.51E+01	3.44E+01	
Ag-108m+D	1.14E+02	8.07E+00	14.1	Pu-241+D	4.78E-01	4.49E-01	
Cd-109	1.48E+00	1.44E+00		Pu-242	3.33E+01	3.26E+01	
Cd-113m	1.03E+01	8.22E+00	1.2	Pu-244+D	6.60E+01	3.81E+01	1.7
In-115	1.55E+01	1.49E+01		Am-241	2.76E+01	2.66E+01	
Sn-121m+D	3.21E+00	2.89E+00		Am-242m+D	2.04E+01	1.86E+01	
Sn-126+D	1.89E+02	2.96E+01	6.4	Am-243+D	4.01E+01	2.82E+01	1.4
Sb-125	4.67E+00	1.92E+00	2.4	Cm-242	9.72E+00	9.91E+00	
Te-125m	9.98E-01	9.98E-01		Cm-243	2.91E+01	2.46E+01	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
I-129	1.41E+02	1.25E+02	1.1	Cm-244	2.14E+01	2.14E+01	
Cs-134	4.11E+01	3.18E+01	1.3	Cm-245	3.16E+01	2.68E+01	1.2
Cs-135	6.26E+00	3.49E+00	1.8	Cm-246	2.66E+01	2.61E+01	
Cs-137+D	6.22E+01	2.40E+01	2.6	Cm-247+D	5.17E+01	2.68E+01	1.9
Ba-133	1.06E+01	2.72E+00	3.9	Cm-248	9.75E+01	9.55E+01	
Pm-147	4.92E-01	4.90E-01		Cm-250+D	5.85E+02	5.47E+02	
Sm-147	1.10E+01	1.06E+01		Bk-247	3.80E+01	3.19E+01	1.2
Sm-151	1.70E-01	1.63E-01		Cf-248	1.25E+01	1.27E+01	
Eu-150	8.08E+01	6.09E+00	13.3	Cf-249	6.23E+01	3.72E+01	1.7
Eu-152	4.07E+01	5.18E+00	7.9	Cf-250	2.49E+01	2.46E+01	
Eu-154	3.40E+01	6.40E+00	5.3	Cf-251	4.66E+01	3.78E+01	1.2
Eu-155	9.49E-01	6.14E-01	1.5	Cf-252	1.36E+01	1.37E+01	

Notes:

- 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.
- These scenario risk factors must be multiplied by the water concentration.
- 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.

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	1.01E+07
53-70-3	Dibenz[a,h]anthracene	na	2.14E+07
56-23-5	Carbon tetrachloride	2.18E+08	6.10E+04
57-12-5	Cyanide, free	2.41E+08	na
57-14-7	1,1-Dimethylhydrazine	na	8.35E+07

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
57-55-6	Propylene glycol (1,2-Propanediol)	1.77E+07	na
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)	1.54E+09	5.98E+05
60-29-7	Ethyl ether (Diethyl ether)	1.35E+06	na
60-34-4	Methylhydrazine	na	6.24E+07
60-57-1	Dieldrin	5.43E+09	9.45E+06
62-75-9	N-Nitrosodimethylamine	1.64E+12	6.71E+08
64-18-6	Formic acid	3.73E+06	na
67-56-1	Methanol (Methyl alcohol)	9.44E+06	na
67-64-1	Acetone (2-Propanone)	1.65E+06	na
67-66-3	Chloroform	9.39E+08	6.38E+04
67-72-1	Hexachloroethane	1.78E+08	1.36E+04
71-36-3	n-Butyl alcohol (n-Butanol)	1.17E+08	na
71-43-2	Benzene	1.37E+08	3.15E+04
71-55-6	1,1,1-Trichloroethane (Methyl chloroform)	1.81E+06	na
72-20-8	Endrin	2.70E+09	na
74-83-9	Bromomethane	7.09E+08	na
74-87-3	Methyl chloride (Chloromethane)	3.08E+07	8.15E+03
75-00-3	Ethyl Chloride	7.52E+05	5.51E+02
75-01-4	Vinyl chloride (Chloroethene)	8.74E+07	2.75E+05
75-05-8	Acetonitrile	4.63E+07	na
75-07-0	Acetaldehyde	3.08E+08	6.10E+03
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	na
75-68-3	Chloro-1,1-difluoroethane, 1-	5.54E+04	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	5.30E+06
78-83-1	Isobutanol	2.68E+06	na
78-87-5	1,2-Dichloropropane	6.95E+08	1.26E+04
78-93-3	Methyl ethyl ketone (2-Butanone)	2.10E+06	na
79-00-5	1,1,2-Trichloroethane	5.62E+07	5.80E+04
79-01-6	Trichloroethylene	6.53E+08	3.87E+05
79-10-7	2-Propenoic acid (Acrylic acid)	4.53E+07	na
79-34-5	1,1,2,2-Tetrachloroethane (Acetylene tetrachloride)	3.73E+06	2.03E+05
79-46-9	2-Nitropropane	1.39E+08	7.44E+06

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
82-68-8	Pentachloronitrobenzene (PCNB)	7.08E+07	5.50E+04
83-32-9	Acenaphthene	5.07E+06	na
84-66-2	Diethyl phthalate	8.39E+05	na
84-74-2	Dibutyl phthalate	2.37E+06	na
85-68-7	Butyl benzyl phthalate	1.62E+06	na
87-68-3	Hexachlorobutadiene	6.29E+08	7.65E+04
87-86-5	Pentachlorophenol	8.87E+06	3.17E+04
88-06-2	2,4,6-Trichlorophenol	3.83E+09	5.12E+03
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)	6.05E+08	na
91-20-3	Naphthalene	9.36E+08	na
92-52-4	1,1'-Biphenyl	5.19E+06	na
95-47-6	o-Xylene	2.85E+07	na
95-48-7	2-Methylphenol (o-Cresol)	3.05E+07	na
95-50-1	1,2-Dichlorobenzene (ortho-)	1.58E+07	na
95-57-8	2-Chlorophenol	1.77E+08	na
95-63-6	1,2,4-Trimethylbenzene	4.67E+08	na
95-95-4	2,4,5-Trichlorophenol	3.81E+06	na
98-86-2	Acetophenone	8.13E+06	na
98-95-3	Nitrobenzene	2.82E+09	na
100-25-4	1,4-Dinitrobenzene (para-)	2.38E+10	na
100-41-4	Ethyl benzene	4.44E+06	3.05E+03
100-42-5	Styrene	3.68E+06	na
100-51-6	Benzyl alcohol	4.56E+06	na
106-42-3	p-Xylene	2.85E+07	na
106-44-5	4-Methylphenol (p-Cresol)	2.98E+08	na
106-46-7	1,4-Dichlorobenzene (para-)	9.08E+06	2.15E+04
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	1.39E+10	2.34E+07
106-99-0	1,3-Butadiene	1.39E+09	8.32E+04
107-02-8	2-Propenal (Acrolein)	1.40E+11	na
107-05-1	3-Chloropropene (Allyl chloride)	2.77E+09	na
107-06-2	1,2-Dichloroethane (Ethylene chloride)	5.73E+08	9.31E+04
107-13-1	Acrylonitrile	2.12E+09	5.86E+05
108-10-1	Methyl isobutyl ketone (4-Methyl-2-pentanone)	5.15E+06	na
108-38-3	m-Xylene	2.85E+07	na
108-39-4	3-Methylphenol (m-Cresol)	2.94E+07	na
108-67-8	1,3,5-Trimethylbenzene	4.67E+08	na
108-87-2	Methyl cyclohexane	9.24E+05	na
108-88-3	Toluene (Methyl benzene)	7.78E+06	na
108-90-7	Chlorobenzene	5.60E+07	na
108-94-1	Cyclohexanone	2.68E+05	na
108-95-2	Phenol (Carbolic acid)	8.10E+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
109-99-9	Tetrahydrofuran	1.25E+07	1.06E+04
110-00-9	Furan (Oxacyclopentadiene)	2.24E+08	na
110-54-3	n-Hexane	1.75E+07	na
110-80-5	2-Ethoxyethanol	1.01E+07	na
110-82-7	Cyclohexane	4.63E+05	na
110-86-1	Pyridine	1.97E+09	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)	9.51E+07	na
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)	6.35E+08	1.77E+05
117-84-0	Di-n-octylphthalate	8.51E+08	na
118-74-1	Hexachlorobenzene	4.02E+08	1.78E+06
120-82-1	1,2,4-Trichlorobenzene	7.12E+08	na
121-14-2	2,4-Dinitrotoluene	7.92E+08	na
121-44-8	Triethylamine	3.96E+08	na
122-39-4	Diphenylamine	1.81E+07	na
123-91-1	1,4-Dioxane (Diethylene oxide)	na	2.54E+04
126-73-8	Tributyl Phosphate	1.84E+06	1.98E+03
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)	8.92E+09	na
127-18-4	Tetrachloroethylene	1.98E+07	9.49E+03
129-00-0	Pyrene	1.74E+07	na
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	5.57E+05	na
156-59-2	cis-1,2-Dichloroethylene	1.82E+07	na
206-44-0	Fluoranthene (1,2-Benzacenaphthene)	1.55E+07	na
309-00-2	Aldrin	3.45E+10	3.09E+07
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	7.96E+08	4.99E+06
319-85-7	beta-Benzene hexachloride (beta-Lindane)	2.36E+09	8.71E+05
541-73-1	1,3-Dichlorobenzene	1.91E+08	na
542-75-6	1,3-Dichloropropene (cis & trans)	1.45E+08	2.97E+04
621-64-7	N-Nitrosodi-N-propylamine	na	1.93E+07
1314-62-1	Vanadium pentoxide	2.83E+07	na
1330-20-7	Xylenes (mixtures)	2.85E+07	na
1336-36-3	Polychlorinated Biphenyls	na	6.11E+05
1336-36-3	Polychlorinated Biphenyls (lowest risk)	na	5.33E+05
6533-73-9	Thallium carbonate	5.10E+09	na
7429-90-5	Aluminum	2.94E+05	na
7439-89-6	Iron	1.13E+06	na
7439-93-2	Lithium	2.86E+07	na
7439-96-5	Manganese	1.71E+07	na
7439-97-6	Mercury metal vapor	1.24E+05	na
7439-98-7	Molybdenum	4.18E+08	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
7440-02-0	Nickel (soluble salts)	3.85E+07	na
7440-22-4	Silver	5.52E+07	na
7440-24-6	Strontium, Stable	4.81E+06	na
7440-28-0	Thallium metal	5.99E+09	na
7440-31-5	Tin	9.59E+05	na
7440-36-0	Antimony	8.12E+08	na
7440-38-2	Arsenic (inorganic)	8.92E+08	3.99E+05
7440-39-3	Barium	5.38E+06	na
7440-41-7	Beryllium and compounds	1.74E+08	6.50E+02
7440-42-8	Boron and borates only	3.39E+07	na
7440-43-9	Cadmium	1.34E+09	4.65E+02
7440-45-1	Cerium (Ceric oxide 1306-38-3)	1.38E+06	na
7440-48-4	Cobalt	3.83E+07	7.13E+02
7440-50-8	Copper	8.23E+07	na
7440-62-2	Vanadium metal	5.08E+07	na
7440-66-6	Zinc and compounds	7.30E+08	na
7487-94-7	Mercuric chloride	9.73E+09	na
7664-41-7	Ammonia	3.90E+06	na
7723-14-0	Phosphorus, white	9.49E+11	na
7782-41-4	Fluorine (soluble fluoride)	1.40E+07	na
7782-49-2	Selenium and compounds	6.86E+07	na
8001-35-2	Toxaphene	na	6.69E+05
11096-82-5	Aroclor 1260	na	2.98E+07
11097-69-1	Aroclor 1254	6.48E+10	1.26E+06
11104-28-2	Aroclor 1221	na	3.59E+05
11141-16-5	Aroclor 1232	na	3.59E+05
12672-29-6	Aroclor 1248	na	5.95E+05
12674-11-2	Aroclor 1016	4.69E+09	4.36E+05
14797-55-8	Nitrate	6.84E+04	na
14797-65-0	Nitrite	1.09E+06	na
16065-83-1	Chromium (III) (insoluble salts)	2.93E+05	na
16984-48-8	Fluorine anion	1.40E+07	na
18540-29-9	Chromium (VI) (soluble salts)	5.51E+07	3.79E+02
53469-21-9	Aroclor 1242	na	6.00E+05
na	Uranium (soluble salts)	3.47E+08	na
na	Total Chromium (1:6 ratio CrVI:Cr III)	8.12E+06	5.41E+01

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 C8.

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 0.49 mL/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: 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	1.51E-07	1.49E-07	
Be-10	3.53E-08	3.52E-08		Ho-166m	6.49E-07	8.51E-08	7.6
C-14	7.76E-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	6.29E-08	6.21E-08		Pb-210+D	4.46E-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	2.36E-06	2.35E-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	2.61E-06	1.98E-06	1.3
V-49	6.10E-10	6.10E-10		Ra-228+D	5.66E-06	5.23E-06	
Mn-54	4.70E-08	2.83E-08	1.7	Ac-227+D	2.56E-06	2.45E-06	
Fe-55	4.31E-09	4.31E-09		Th-228+D	1.66E-06	1.55E-06	
Fe-60+D	1.40E-06	9.04E-07	1.6	Th-229+D	2.78E-06	2.65E-06	
Co-60	5.55E-07	1.47E-07	3.8	Th-230	4.64E-07	4.56E-07	
Ni-59	1.37E-09	1.37E-09		Th-232	9.26E-07	5.08E-07	1.8
Ni-63	3.36E-09	3.35E-09		Pa-231	9.14E-07	8.67E-07	
Sc-79	3.65E-08	3.65E-08		U-232	1.86E-06	1.47E-06	1.3
Rb-87	2.62E-08	2.61E-08		U-233	3.62E-07	3.59E-07	
Sr-90+D	3.72E-07	3.70E-07		U-234	3.56E-07	3.54E-07	
Zr-93	5.57E-09	5.55E-09		U-235+D	3.97E-07	3.62E-07	
Nb-91	4.43E-09	4.05E-09		U-236	3.37E-07	3.35E-07	
Nb-93m	4.03E-09	4.02E-09		U-238+D	4.44E-07	4.36E-07	
Nb-94	6.16E-07	8.15E-08	7.6	Np-237+D	4.01E-07	3.42E-07	1.2
Mo-93	1.68E-08	1.68E-08		Pu-236	3.87E-07	3.74E-07	
Tc-99	1.38E-08	1.38E-08		Pu-238	6.63E-07	6.56E-07	
Ru-106+D	2.21E-07	2.15E-07		Pu-239	6.83E-07	6.76E-07	
Pd-107	1.25E-09	1.25E-09		Pu-240	6.83E-07	6.76E-07	
Ag-108m+D	5.86E-07	8.26E-08	7.1	Pu-241+D	8.94E-09	8.81E-09	
Cd-109	2.51E-08	2.50E-08		Pu-242	6.48E-07	6.41E-07	
Cd-113m	1.44E-07	1.44E-07		Pu-244+D	8.49E-07	7.30E-07	1.2
In-115	1.69E-07	1.69E-07		Am-241	5.29E-07	5.21E-07	
Sn-121m+D	1.76E-08	1.75E-08		Am-242m+D	3.73E-07	3.63E-07	
Sn-126+D	8.41E-07	1.88E-07	4.5	Am-243+D	5.97E-07	5.44E-07	
Sb-125	6.73E-08	3.15E-08	2.1	Cm-242	1.93E-07	1.93E-07	
Te-125m	1.67E-08	1.67E-08		Cm-243	5.08E-07	4.77E-07	
I-129	7.42E-07	7.40E-07		Cm-244	4.23E-07	4.19E-07	
Cs-134	3.53E-07	2.48E-07	1.4	Cm-245	5.46E-07	5.22E-07	
Cs-135	2.37E-08	2.37E-08		Cm-246	5.17E-07	5.11E-07	
Cs-137+D	3.27E-07	1.67E-07	2.0	Cm-247+D	6.16E-07	5.09E-07	1.2
Ba-133	1.10E-07	4.23E-08	2.6	Cm-248	1.89E-06	1.87E-06	
Pm-147	8.46E-09	8.45E-09		Cm-250+D	1.09E-05	1.07E-05	
Sm-147	1.89E-07	1.87E-07		Bk-247	6.52E-07	6.23E-07	
Sm-151	2.78E-09	2.78E-09		Cf-248	2.23E-07	2.22E-07	

Table 22. Unit Risk Factors for Radionuclides: 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	5.93E-08	8.1	Cf-249	7.51E-07	6.44E-07	1.2
Eu-152	3.37E-07	6.07E-08	5.5	Cf-250	4.36E-07	4.32E-07	
Eu-154	3.41E-07	8.46E-08	4.0	Cf-251	6.98E-07	6.63E-07	
Eu-155	1.40E-08	1.02E-08	1.4	Cf-252	2.44E-07	2.43E-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. Additional detail on the contributions from each pathway are shown in Appendix D.

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	2.95E-01
53-70-3	Dibenz[a,h]anthracene	na	3.91E-01
56-23-5	Carbon tetrachloride	1.56E+01	1.87E-03
57-12-5	Cyanide, free	4.98E-01	na
57-14-7	1,1-Dimethylhydrazine	na	9.79E-03
57-55-6	Propylene glycol (1,2-Propanediol)	2.04E-02	na
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)	3.60E+01	4.01E-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
60-29-7	Ethyl ether (Diethyl ether)	4.95E-02	na
60-34-4	Methylhydrazine	na	9.04E-03
60-57-1	Dieldrin	2.56E+02	2.43E-01
62-75-9	N-Nitrosodimethylamine	1.23E+03	2.50E-01
64-18-6	Formic acid	4.91E-03	na
67-56-1	Methanol (Methyl alcohol)	1.96E-02	na
67-64-1	Acetone (2-Propanone)	1.09E-02	na
67-66-3	Chloroform	1.16E+02	2.27E-03
67-72-1	Hexachloroethane	1.37E+01	4.50E-04
71-36-3	n-Butyl alcohol (n-Butanol)	1.38E+01	na
71-43-2	Benzene	1.42E+01	9.35E-04
71-55-6	1,1,1-Trichloroethane (Methyl chloroform)	1.94E-01	na
72-20-8	Endrin	2.78E+02	na
74-83-9	Bromomethane	7.62E+01	na
74-87-3	Methyl chloride (Chloromethane)	3.84E+00	2.15E-04
75-00-3	Ethyl Chloride	5.98E-02	8.38E-06
75-01-4	Vinyl chloride (Chloroethene)	6.84E+00	2.52E-03
75-05-8	Acetonitrile	5.78E+00	na
75-07-0	Acetaldehyde	3.84E+01	2.17E-04
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	na
75-68-3	Chloro-1,1-difluoroethane, 1-	6.91E-03	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	3.94E+01	1.52E-01
78-83-1	Isobutanol	3.29E-02	na
78-87-5	1,2-Dichloropropane	8.67E+01	1.99E-04
78-93-3	Methyl ethyl ketone (2-Butanone)	8.55E-02	na
79-00-5	1,1,2-Trichloroethane	2.51E+00	1.77E-03
79-01-6	Trichloroethylene	5.27E+01	1.28E-02
79-10-7	2-Propenoic acid (Acrylic acid)	5.25E+00	na
79-34-5	1,1,2,2-Tetrachloroethane (Acetylene tetrachloride)	1.70E-01	6.23E-03
79-46-9	2-Nitropropane	1.73E+01	2.65E-01
82-68-8	Pentachloronitrobenzene (PCNB)	4.09E+00	9.11E-04
83-32-9	Acenaphthene	3.98E-01	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
84-66-2	Diethyl phthalate	1.25E-02	na
84-74-2	Dibutyl phthalate	1.18E-01	na
85-68-7	Butyl benzyl phthalate	6.40E-02	na
87-68-3	Hexachlorobutadiene	5.90E+01	2.60E-03
87-86-5	Pentachlorophenol	5.42E-01	5.57E-04
88-06-2	2,4,6-Trichlorophenol	1.31E+02	7.42E-05
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)	1.13E+01	na
91-20-3	Naphthalene	1.16E+02	na
92-52-4	1,1'-Biphenyl	3.87E-01	na
95-47-6	o-Xylene	3.52E+00	na
95-48-7	2-Methylphenol (o-Cresol)	2.10E-01	na
95-50-1	1,2-Dichlorobenzene (ortho-)	1.87E+00	na
95-57-8	2-Chlorophenol	2.10E+00	na
95-63-6	1,2,4-Trimethylbenzene	5.81E+01	na
95-95-4	2,4,5-Trichlorophenol	1.33E-01	na
98-86-2	Acetophenone	9.99E-02	na
98-95-3	Nitrobenzene	1.90E+02	na
100-25-4	1,4-Dinitrobenzene (para-)	9.96E+01	na
100-41-4	Ethyl benzene	4.68E-01	1.09E-04
100-42-5	Styrene	4.06E-01	na
100-51-6	Benzyl alcohol	3.31E-02	na
106-42-3	p-Xylene	3.52E+00	na
106-44-5	4-Methylphenol (p-Cresol)	2.07E+00	na
106-46-7	1,4-Dichlorobenzene (para-)	8.39E-01	7.05E-04
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	1.73E+03	2.63E-01
106-99-0	1,3-Butadiene	1.73E+02	2.96E-03
107-02-8	2-Propenal (Acrolein)	1.73E+04	na
107-05-1	3-Chloropropene (Allyl chloride)	3.46E+02	na
107-06-2	1,2-Dichloroethane (Ethylene chloride)	7.09E+01	2.83E-03
107-13-1	Acrylonitrile	1.83E+02	8.24E-03
108-10-1	Methyl isobutyl ketone (4-Methyl-2-pentanone)	2.40E-01	na
108-38-3	m-Xylene	3.52E+00	na
108-39-4	3-Methylphenol (m-Cresol)	2.10E-01	na
108-67-8	1,3,5-Trimethylbenzene	5.81E+01	na
108-87-2	Methyl cyclohexane	1.15E-01	na
108-88-3	Toluene (Methyl benzene)	9.25E-01	na
108-90-7	Chlorobenzene	6.52E+00	na
108-94-1	Cyclohexanone	1.97E-03	na
108-95-2	Phenol (Carbolic acid)	3.34E-02	na
109-99-9	Tetrahydrofuran	1.20E+00	2.13E-04
110-00-9	Furan (Oxacyclopentadiene)	1.01E+01	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
110-54-3	n-Hexane	2.12E+00	na
110-80-5	2-Ethoxyethanol	5.78E-02	na
110-82-7	Cyclohexane	5.78E-02	na
110-86-1	Pyridine	9.91E+00	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)	1.64E-01	na
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)	1.74E+01	1.40E-03
117-84-0	Di-n-octylphthalate	4.29E+00	na
118-74-1	Hexachlorobenzene	4.56E+01	6.18E-02
120-82-1	1,2,4-Trichlorobenzene	8.80E+01	na
121-14-2	2,4-Dinitrotoluene	4.99E+00	na
121-44-8	Triethylamine	4.94E+01	na
122-39-4	Diphenylamine	5.36E-01	na
123-91-1	1,4-Dioxane (Diethylene oxide)	na	3.08E-05
126-73-8	Tributyl Phosphate	5.96E-02	1.84E-05
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)	5.93E+02	na
127-18-4	Tetrachloroethylene	1.72E+00	2.26E-04
129-00-0	Pyrene	1.47E+00	na
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	1.10E-02	na
156-59-2	cis-1,2-Dichloroethylene	1.03E+00	na
206-44-0	Fluoranthene (1,2-Benzacenaphthene)	1.60E+00	na
309-00-2	Aldrin	1.35E+03	6.76E-01
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	2.16E+01	1.08E-01
319-85-7	beta-Benzene hexachloride (beta-Lindane)	5.44E+01	6.51E-03
541-73-1	1,3-Dichlorobenzene	1.44E+01	na
542-75-6	1,3-Dichloropropene (cis & trans)	1.77E+01	6.94E-04
621-64-7	N-Nitrosodi-N-propylamine	na	2.04E-02
1314-62-1	Vanadium pentoxide	1.45E+00	na
1330-20-7	Xylenes (mixtures)	3.52E+00	na
1336-36-3	Polychlorinated Biphenyls	na	1.63E-02
1336-36-3	Polychlorinated Biphenyls (lowest risk)	na	1.22E-02
6533-73-9	Thallium carbonate	1.24E+02	na
7429-90-5	Aluminum	1.32E-02	na
7439-89-6	Iron	3.32E-02	na
7439-93-2	Lithium	4.96E-01	na
7439-96-5	Manganese	4.93E-01	na
7439-97-6	Mercury metal vapor	1.67E-02	na
7439-98-7	Molybdenum	1.99E+00	na
7440-02-0	Nickel (soluble salts)	4.97E-01	na
7440-22-4	Silver	2.00E+00	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
7440-24-6	Strontium, Stable	1.67E-02	na
7440-28-0	Thallium metal	1.51E+02	na
7440-31-5	Tin	1.81E-02	na
7440-36-0	Antimony	2.95E+01	na
7440-38-2	Arsenic (inorganic)	3.35E+01	4.32E-03
7440-39-3	Barium	1.70E-01	na
7440-41-7	Beryllium and compounds	6.77E+00	8.80E-06
7440-42-8	Boron and borates only	1.11E-01	na
7440-43-9	Cadmium	2.11E+01	6.52E-06
7440-45-1	Cerium (Ceric oxide 1306-38-3)	6.45E-02	na
7440-48-4	Cobalt	1.13E+00	1.01E-05
7440-50-8	Copper	2.48E-01	na
7440-62-2	Vanadium metal	2.07E+00	na
7440-66-6	Zinc and compounds	3.32E-02	na
7487-94-7	Mercuric chloride	3.31E+01	na
7664-41-7	Ammonia	4.87E-01	na
7723-14-0	Phosphorus, white	5.01E+02	na
7782-41-4	Fluorine (soluble fluoride)	1.66E-01	na
7782-49-2	Selenium and compounds	1.98E+00	na
8001-35-2	Toxaphene	na	1.22E-02
11096-82-5	Aroclor 1260	na	3.53E-02
11097-69-1	Aroclor 1254	2.84E+03	1.79E-02
11104-28-2	Aroclor 1221	na	1.34E-02
11141-16-5	Aroclor 1232	na	1.34E-02
12672-29-6	Aroclor 1248	na	1.66E-02
12674-11-2	Aroclor 1016	4.01E+02	1.19E-02
14797-55-8	Nitrate	6.18E-03	na
14797-65-0	Nitrite	9.89E-02	na
16065-83-1	Chromium (III) (insoluble salts)	1.12E-02	na
16984-48-8	Fluorine anion	1.66E-01	na
18540-29-9	Chromium (VI) (soluble salts)	3.88E+00	1.50E-05
53469-21-9	Aroclor 1242	na	1.63E-02
na	Uranium (soluble salts)	1.65E+01	na
na	Total Chromium (1:6 ratio CrVI:Cr III)	5.64E-01	2.14E-06

Notes:

- CASRN = Chemical Abstract Service Reference Number
- The total risk to the worker is calculated using intakes from 20 consecutive years. The soil concentration is zero at the start of the exposure.
- These scenario factors must be multiplied by the water concentration.
- Results using route-to-route extrapolations are shown in Table C8.

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: 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	2.07	Gd-152	1.27E-08	3.05E-07	24.1
Be-10	2.98E-09	3.08E-07	103	Ho-166m	6.85E-08	1.25E-06	18.2
C-14	6.54E-10	2.97E-05	45,436	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	5.32E-09	1.11E-07	20.9	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	1.58E-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	2.16E-07	5.27E-06	24.4
Fe-55	3.63E-10	6.93E-08	191	Th-228+D	1.38E-07	1.28E-05	92.9
Fe-60+D	1.41E-07	1.58E-05	112	Th-229+D	2.36E-07	2.18E-05	92.4
Co-60	4.62E-08	2.41E-06	52.1	Th-230	3.91E-08	3.60E-06	92.1
Ni-59	1.16E-10	1.17E-08	101	Th-232	1.02E-07	5.60E-06	55.1
Ni-63	2.83E-10	2.87E-08	101	Pa-231	7.88E-08	9.37E-07	11.9
Se-79	3.07E-09	4.93E-07	160	U-232	1.64E-07	1.76E-06	10.7
Rb-87	2.21E-09	4.20E-06	1,904	U-233	3.04E-08	3.25E-07	10.7
Sr-90+D	3.14E-08	1.74E-06	55.5	U-234	2.99E-08	3.20E-07	10.7
Zr-93	4.70E-10	1.29E-07	275	U-235+D	3.39E-08	3.62E-07	10.7
Nb-91	3.83E-10	1.06E-07	276	U-236	2.84E-08	3.02E-07	10.7
Nb-93m	3.39E-10	1.05E-07	308	U-238+D	3.75E-08	4.11E-07	11.0
Nb-94	6.51E-08	2.08E-06	32.0	Np-237+D	3.50E-08	7.01E-07	20.0
Mo-93	1.41E-09	1.41E-08	10.0	Pu-236	3.28E-08	6.71E-07	20.4
Tc-99	1.16E-09	2.50E-08	21.6	Pu-238	5.57E-08	1.13E-06	20.3
Ru-106+D	1.85E-08	2.12E-07	11.4	Pu-239	5.74E-08	1.17E-06	20.3
Pd-107	1.06E-10	1.26E-09	11.9	Pu-240	5.74E-08	1.17E-06	20.3
Ag-108m+D	6.06E-08	9.64E-07	15.9	Pu-241+D	7.54E-10	1.55E-08	20.6
Cd-109	2.11E-09	4.00E-07	190	Pu-242	5.45E-08	1.11E-06	20.3
Cd-113m	1.21E-08	2.18E-06	180	Pu-244+D	7.43E-08	1.51E-06	20.4
In-115	1.43E-08	1.29E-03	90,093	Am-241	4.45E-08	9.04E-07	20.3
Sn-121m+D	1.49E-09	4.57E-06	3,067	Am-242m+D	3.14E-08	6.22E-07	19.8
Sn-126+D	8.72E-08	3.63E-05	416	Am-243+D	5.14E-08	1.05E-06	20.5
Sb-125	5.37E-09	2.18E-07	40.6	Cm-242	1.62E-08	3.58E-07	22.1
Te-125m	1.40E-09	5.60E-07	400	Cm-243	4.31E-08	8.64E-07	20.1
I-129	6.25E-08	2.39E-06	38.2	Cm-244	3.55E-08	7.18E-07	20.2
Cs-134	2.86E-08	3.07E-05	1,073	Cm-245	4.63E-08	9.44E-07	20.4
Cs-135	2.00E-09	3.50E-06	1,748	Cm-246	4.34E-08	8.80E-07	20.3
Cs-137+D	3.03E-08	2.25E-05	742	Cm-247+D	5.43E-08	1.09E-06	20.1
Ba-133	9.72E-09	9.69E-08	10.0	Cm-248	1.59E-07	3.23E-06	20.3
Pm-147	7.11E-10	2.29E-08	32.2	Cm-250+D	9.23E-07	1.87E-05	20.3
Sm-147	1.59E-08	3.77E-07	23.8	Bk-247	5.54E-08	1.31E-06	23.7
Sm-151	2.35E-10	6.36E-09	27.1	Cf-248	1.87E-08	4.82E-07	25.8

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

Nuclide	Inland Park	Columbia River	Ratio	Nuclide	Inland Park	Columbia River	Ratio
Eu-150	4.80E-08	8.20E-07	17.1	Cf-249	6.55E-08	1.49E-06	22.8
Eu-152	3.12E-08	5.13E-07	16.4	Cf-250	3.66E-08	8.77E-07	24.0
Eu-154	3.00E-08	5.34E-07	17.8	Cf-251	5.94E-08	1.40E-06	23.6
Eu-155	1.17E-09	4.59E-08	39.2	Cf-252	2.04E-08	4.90E-07	24.0

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. Additional detail on the contributions from each pathway are shown in Appendix D.

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	na	1.29E+01
53-70-3	Dibenz[a,h]anthracene	na	1.73E-02	na	3.84E+01
56-23-5	Carbon tetrachloride	1.76E+00	3.29E-05	1.91E+01	7.11E-04
57-12-5	Cyanide, free	6.04E-02	na	1.28E-01	na
57-14-7	1,1-Dimethylhydrazine	na	7.09E-04	na	2.35E-03
57-55-6	Propylene glycol (1,2-Propanediol)	2.42E-03	na	4.93E-03	na
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)	4.17E+00	3.27E-04	1.98E+02	3.25E-02
60-29-7	Ethyl ether (Diethyl ether)	6.01E-03	na	1.24E-02	na
60-34-4	Methylhydrazine	na	7.08E-04	na	2.34E-03
60-57-1	Dieldrin	2.62E+01	4.51E-03	2.23E+04	7.65E+00
62-75-9	N-Nitrosodimethylamine	1.51E+02	1.21E-02	3.16E+02	4.02E-02
64-18-6	Formic acid	6.02E-04	na	1.24E-03	na

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
67-56-1	Methanol (Methyl alcohol)	2.40E-03	na	4.90E-03	na
67-64-1	Acetone (2-Propanone)	1.33E-03	na	2.72E-03	na
67-66-3	Chloroform	1.93E-01	9.89E-07	5.11E-01	1.30E-06
67-72-1	Hexachloroethane	1.31E+00	4.12E-06	1.22E+02	7.29E-04
71-36-3	n-Butyl alcohol (n-Butanol)	2.02E-02	na	3.35E-02	na
71-43-2	Benzene	3.12E-01	1.37E-05	1.23E+00	1.01E-04
71-55-6	1,1,1-Trichloroethane (Methyl chloroform)	4.44E-03	na	2.82E-02	na
72-20-8	Endrin	1.11E+01	na	2.74E+03	na
74-83-9	Bromomethane	9.01E-01	na	1.40E+00	na
74-87-3	Methyl chloride (Chloromethane)	2.30E-03	3.15E-06	2.30E-03	1.04E-05
75-00-3	Ethyl Chloride	3.04E-03	6.93E-07	5.84E-03	2.08E-06
75-01-4	Vinyl chloride (Chloroethene)	4.05E-01	3.35E-04	9.16E-01	1.25E-03
75-05-8	Acetonitrile	3.45E-03	na	3.45E-03	na
75-07-0	Acetaldehyde	2.30E-02	8.91E-08	2.30E-02	8.91E-08
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	na	4.13E-06	na
75-68-3	Chloro-1,1-difluoroethane, 1-	4.13E-06	na	4.13E-06	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	1.67E-03	7.71E+03	7.43E+00
78-83-1	Isobutanol	4.01E-03	na	8.30E-03	na
78-87-5	1,2-Dichloropropane	5.18E-02	1.63E-05	5.18E-02	9.74E-05
78-93-3	Methyl ethyl ketone (2-Butanone)	2.04E-03	na	4.14E-03	na
79-00-5	1,1,2-Trichloroethane	3.02E-01	1.42E-05	8.84E-01	7.10E-05
79-01-6	Trichloroethylene	4.32E+00	1.15E-04	2.81E+01	1.34E-03
79-10-7	2-Propenoic acid (Acrylic acid)	5.56E-03	na	8.14E-03	na
79-34-5	1,1,2,2-Tetrachloroethane (Acetylene tetrachloride)	2.02E-02	5.04E-05	1.13E-01	5.26E-04
79-46-9	2-Nitropropane	1.03E-02	1.09E-04	1.03E-02	1.09E-04
82-68-8	Pentachloronitrobenzene (PCNB)	4.30E-01	6.97E-05	9.73E+01	3.24E-02
83-32-9	Acenaphthene	2.68E-02	na	1.48E+00	na
84-66-2	Diethyl phthalate	1.53E-03	na	8.98E-03	na
84-74-2	Dibutyl phthalate	1.28E-02	na	2.28E+00	na
85-68-7	Butyl benzyl phthalate	6.54E-03	na	1.72E+00	na
87-68-3	Hexachlorobutadiene	4.74E+00	2.66E-05	1.25E+03	1.25E-02

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
87-86-5	Pentachlorophenol	4.68E-02	3.81E-05	9.17E+00	1.41E-02
88-06-2	2,4,6-Trichlorophenol	1.31E+01	3.08E-06	2.48E+02	1.13E-04
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)	1.27E+00	na	4.59E+01	na
91-20-3	Naphthalene	1.33E-01	na	1.54E+00	na
92-52-4	1,1'-Biphenyl	2.97E-02	na	1.91E+00	na
95-47-6	o-Xylene	8.47E-03	na	1.12E-01	na
95-48-7	2-Methylphenol (o-Cresol)	2.48E-02	na	8.76E-02	na
95-50-1	1,2-Dichlorobenzene (ortho-)	1.52E-02	na	4.04E-01	na
95-57-8	2-Chlorophenol	2.47E-01	na	1.06E+00	na
95-63-6	1,2,4-Trimethylbenzene	6.16E-02	na	1.07E+00	na
95-95-4	2,4,5-Trichlorophenol	1.32E-02	na	2.61E-01	na
98-86-2	Acetophenone	1.21E-02	na	1.55E-02	na
98-95-3	Nitrobenzene	2.53E+00	na	7.05E+00	na
100-25-4	1,4-Dinitrobenzene (para-)	1.22E+01	na	2.63E+01	na
100-41-4	Ethyl benzene	1.29E-02	4.45E-08	2.30E-01	4.45E-08
100-42-5	Styrene	6.52E-03	na	8.37E-02	na
100-51-6	Benzyl alcohol	4.03E-03	na	4.85E-03	na
106-42-3	p-Xylene	8.49E-03	na	1.18E-01	na
106-44-5	4-Methylphenol (p-Cresol)	2.47E-01	na	8.47E-01	na
106-46-7	1,4-Dichlorobenzene (para-)	4.26E-02	6.60E-06	1.23E+00	3.72E-04
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	1.03E+00	2.01E-02	1.03E+00	1.14E-01
106-99-0	1,3-Butadiene	1.03E-01	1.21E-06	1.03E-01	1.21E-06
107-02-8	2-Propenal (Acrolein)	1.27E+01	na	1.52E+01	na
107-05-1	3-Chloropropene (Allyl chloride)	2.31E-01	na	2.84E-01	na
107-06-2	1,2-Dichloroethane (Ethylene chloride)	8.23E-02	2.26E-05	1.21E-01	6.73E-05
107-13-1	Acrylonitrile	1.30E+00	1.30E-04	2.56E+00	4.20E-04
108-10-1	Methyl isobutyl ketone (4-Methyl-2-pentanone)	1.51E-02	na	2.60E-02	na
108-38-3	m-Xylene	8.52E-03	na	1.28E-01	na
108-39-4	3-Methylphenol (m-Cresol)	2.48E-02	na	8.83E-02	na
108-67-8	1,3,5-Trimethylbenzene	6.07E-02	na	7.59E-01	na
108-87-2	Methyl cyclohexane	6.89E-05	na	6.89E-05	na
108-88-3	Toluene (Methyl benzene)	6.77E-03	na	5.97E-02	na
108-90-7	Chlorobenzene	6.95E-02	na	7.58E-01	na
108-94-1	Cyclohexanone	2.41E-04	na	5.01E-04	na
108-95-2	Phenol (Carbolic acid)	4.08E-03	na	8.86E-03	na
109-99-9	Tetrahydrofuran	6.42E-03	1.87E-06	1.25E-02	6.02E-06
110-00-9	Furan (Oxacyclopentadiene)	1.21E+00	na	2.16E+00	na
110-54-3	n-Hexane	2.74E-02	na	1.42E+00	na
110-80-5	2-Ethoxyethanol	3.03E-03	na	6.18E-03	na
110-82-7	Cyclohexane	3.45E-05	na	3.45E-05	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
110-86-1	Pyridine	1.21E+00	na	2.54E+00	na
111-76-2	2-Butoxyethanol (Ethylene Glycol Monobutyl Ether)	2.41E-03	na	5.00E-03	na
111-90-0	2-(2-Ethoxyethoxy)-ethanol (Diethylene Glycol Monoethyl Ether)	2.01E-02	na	4.10E-02	na
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)	5.36E-01	6.04E-05	1.41E+01	1.68E-03
117-84-0	Di-n-octylphthalate	1.44E-01	na	2.61E+00	na
118-74-1	Hexachlorobenzene	2.44E+00	9.08E-04	2.51E+03	1.38E+00
120-82-1	1,2,4-Trichlorobenzene	1.82E-01	na	9.97E+00	na
121-14-2	2,4-Dinitrotoluene	6.12E-01	na	2.15E+00	na
121-44-8	Triethylamine	2.95E-02	na	2.95E-02	na
122-39-4	Diphenylamine	5.29E-02	na	1.68E+00	na
123-91-1	1,4-Dioxane (Diethylene oxide)	na	2.59E-06	na	8.44E-06
126-73-8	Tributyl Phosphate	6.41E-03	1.43E-06	9.38E-02	4.08E-05
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)	1.23E+01	na	2.51E+01	na
127-18-4	Tetrachloroethylene	1.25E-01	1.32E-05	3.40E+00	7.43E-04
129-00-0	Pyrene	7.29E-02	na	1.54E+01	na
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	1.34E-03	na	2.74E-03	na
156-59-2	cis-1,2-Dichloroethylene	1.21E-01	na	3.52E-01	na
206-44-0	Fluoranthene (1,2-Benzacenaphthene)	6.86E-02	na	1.89E+01	na
309-00-2	Aldrin	6.94E+01	1.06E-02	2.61E+05	5.71E+01
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	2.50E+00	1.62E-03	1.36E+02	1.80E-01
319-85-7	beta-Benzene hexachloride (beta-Lindane)	6.27E+00	4.56E-04	3.30E+02	4.99E-02
541-73-1	1,3-Dichlorobenzene	1.43E+00	na	4.79E+01	na
542-75-6	1,3-Dichloropropene (cis & trans)	5.09E-02	2.44E-05	1.55E-01	1.58E-04
621-64-7	N-Nitrosodi-N-propylamine	na	1.70E-03	na	5.44E-03
1314-62-1	Vanadium pentoxide	1.46E-01	na	9.33E+00	na
1330-20-7	Xylenes (mixtures)	8.41E-03	na	1.12E-01	na
1336-36-3	Polychlorinated Biphenyls	na	2.73E-04	na	1.93E+01
1336-36-3	Polychlorinated Biphenyls (lowest risk)	na	6.31E-05	na	1.93E+01
6533-73-9	Thallium carbonate	1.54E+01	na	4.85E+04	na
7429-90-5	Aluminum	1.30E-03	na	1.99E-01	na
7439-89-6	Iron	4.10E-03	na	2.75E-01	na
7439-93-2	Lithium	6.14E-02	na	2.66E-01	na
7439-96-5	Manganese	3.21E-02	na	1.24E+00	na
7439-97-6	Mercury metal vapor	6.13E-04	na	6.13E-04	na
7439-98-7	Molybdenum	2.46E-01	na	1.44E+00	na
7440-02-0	Nickel (soluble salts)	6.14E-02	na	2.19E+00	na
7440-22-4	Silver	2.46E-01	na	1.37E+00	na
7440-24-6	Strontium, Stable	2.05E-03	na	4.71E-02	na
7440-28-0	Thallium metal	1.86E+01	na	5.88E+04	na

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
7440-31-5	Tin	2.09E-03	na	1.95E+00	na
7440-36-0	Antimony	3.21E+00	na	1.14E+02	na
7440-38-2	Arsenic (inorganic)	4.11E+00	3.69E-04	3.32E+02	6.31E-02
7440-39-3	Barium	1.81E-02	na	9.46E-02	na
7440-41-7	Beryllium and compounds	6.64E-01	5.47E-07	2.35E+01	5.47E-07
7440-42-8	Boron and borates only	1.36E-02	na	4.78E-02	na
7440-43-9	Cadmium	2.53E+00	4.02E-07	9.59E+01	4.02E-07
7440-45-1	Cerium (Ceric oxide 1306-38-3)	1.27E-03	na	1.27E-03	na
7440-48-4	Cobalt	7.40E-02	6.22E-07	6.06E+00	6.22E-07
7440-50-8	Copper	3.07E-02	na	2.05E+00	na
7440-62-2	Vanadium metal	1.95E-01	na	1.24E+01	na
7440-66-6	Zinc and compounds	4.10E-03	na	3.42E-01	na
7487-94-7	Mercuric chloride	4.09E+00	na	1.30E+03	na
7664-41-7	Ammonia	2.91E-04	na	2.91E-04	na
7723-14-0	Phosphorus, white	6.15E+01	na	2.92E+04	na
7782-41-4	Fluorine (soluble fluoride)	2.05E-02	na	1.46E-01	na
7782-49-2	Selenium and compounds	2.45E-01	na	1.36E+01	na
8001-35-2	Toxaphene	na	3.34E-04	na	1.03E+00
11096-82-5	Aroclor 1260	na	1.07E-03	na	1.64E+00
11097-69-1	Aroclor 1254	1.27E+02	3.40E-04	2.73E+06	4.67E+01
11104-28-2	Aroclor 1221	na	1.45E-04	na	2.05E-01
11141-16-5	Aroclor 1232	na	1.45E-04	na	2.05E-01
12672-29-6	Aroclor 1248	na	2.83E-04	na	2.10E+01
12674-11-2	Aroclor 1016	2.48E+01	4.96E-05	9.80E+04	5.87E+00
14797-55-8	Nitrate	7.62E-04	na	1.74E-03	na
14797-65-0	Nitrite	1.22E-02	na	2.78E-02	na
16065-83-1	Chromium (III) (insoluble salts)	9.61E-04	na	5.97E-02	na
16984-48-8	Fluorine anion	2.05E-02	na	1.46E-01	na
18540-29-9	Chromium (VI) (soluble salts)	4.24E-01	6.73E-07	2.66E+01	6.73E-07
53469-21-9	Aroclor 1242	na	2.73E-04	na	1.93E+01
na	Uranium (soluble salts)	2.04E+00	na	1.18E+01	na
na	Total Chromium (1:6 ratio CrVI:Cr III)	6.14E-02	9.62E-08	3.85E+00	9.62E-08

Notes:

- CASRN = Chemical Abstract Service Reference Number
- The total risk to the HSRAM Recreational Visitor is calculated using intakes from 30 consecutive years. The soil concentration is zero at the start of the exposure.
- These scenario factors must be multiplied by the appropriate water concentration. The "Inland Well" column assumes all of the contaminated water comes from the well. The "Columbia River" column assumes that all of the contaminated water comes from the Columbia River.
- Results using route-to-route extrapolations are shown in Table C10.

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 0.72 mL/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: 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	7.67E-07	1.36E-06	1.8
Bc-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	1.40E-05	2.24E-05	1.6

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

Nuclide	Inland Resident	Columbia River	Ratio	Nuclide	Inland Resident	Columbia River	Ratio
Fe-55	2.20E-08	9.21E-08	4.2	Th-228+D	9.47E-06	2.25E-05	2.4
Fe-60+D	1.48E-05	3.22E-05	2.2	Th-229+D	1.53E-05	4.30E-05	2.8
Co-60	6.58E-06	8.98E-06	1.4	Th-230	2.40E-06	6.98E-06	2.9
Ni-59	7.47E-09	2.26E-08	3.0	Th-232	1.15E-05	2.90E-05	2.5
Ni-63	1.82E-08	5.42E-08	3.0	Pa-231	5.19E-06	1.00E-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	1.86E-06	2.48E-06	1.3
Sr-90+D	2.61E-06	4.77E-06	1.8	U-234	1.83E-06	2.43E-06	1.3
Zr-93	2.85E-08	1.72E-07	6.0	U-235+D	2.40E-06	3.06E-06	1.3
Nb-91	2.78E-08	1.43E-07	5.2	U-236	1.73E-06	2.30E-06	1.3
Nb-93m	2.11E-08	1.31E-07	6.2	U-238+D	2.36E-06	3.15E-06	1.3
Nb-94	9.82E-06	1.19E-05	1.2	Np-237+D	2.74E-06	3.98E-06	1.5
Mo-93	1.26E-07	1.52E-07	1.2	Pu-236	2.11E-06	2.95E-06	1.4
Tc-99	3.36E-07	3.65E-07		Pu-238	3.36E-06	5.57E-06	1.7
Ru-106+D	1.21E-06	1.42E-06	1.2	Pu-239	3.47E-06	5.90E-06	1.7
Pd-107	6.76E-09	1.09E-08	1.6	Pu-240	3.47E-06	5.90E-06	1.7
Ag-108m+D	9.11E-06	1.01E-05		Pu-241+D	4.58E-08	8.54E-08	1.9
Cd-109	1.31E-07	5.32E-07	4.1	Pu-242	3.29E-06	5.60E-06	1.7
Cd-113m	7.91E-07	3.06E-06	3.9	Pu-244+D	5.74E-06	8.68E-06	1.5
In-115	8.62E-07	1.29E-03	1,493	Am-241	2.71E-06	4.57E-06	1.7
Sn-121m+D	9.27E-08	4.69E-06	50.6	Am-242m+D	1.94E-06	3.61E-06	1.9
Sn-126+D	1.25E-05	4.91E-05	3.9	Am-243+D	3.63E-06	5.73E-06	1.6
Sb-125	6.62E-07	8.83E-07	1.3	Cm-242	9.81E-07	1.34E-06	1.4
Te-125m	8.36E-08	6.42E-07	7.7	Cm-243	2.88E-06	4.35E-06	1.5
I-129	3.84E-06	6.96E-06	1.8	Cm-244	2.14E-06	3.30E-06	1.5
Cs-134	2.77E-06	3.34E-05	12.1	Cm-245	2.99E-06	4.95E-06	1.7
Cs-135	1.36E-07	3.66E-06	26.9	Cm-246	2.62E-06	4.46E-06	1.7
Cs-137+D	3.58E-06	2.62E-05	7.3	Cm-247+D	4.41E-06	6.46E-06	1.5
Ba-133	1.25E-06	1.36E-06		Cm-248	9.60E-06	1.64E-05	1.7
Pm-147	4.37E-08	6.85E-08	1.6	Cm-250+D	5.69E-05	9.59E-05	1.7
Sm-147	9.60E-07	1.67E-06	1.7	Bk-247	3.60E-06	6.03E-06	1.7
Sm-151	1.45E-08	2.71E-08	1.9	Cf-248	1.14E-06	1.65E-06	1.4
Eu-150	7.30E-06	8.11E-06		Cf-249	5.07E-06	7.66E-06	1.5
Eu-152	4.62E-06	5.14E-06		Cf-250	2.22E-06	3.46E-06	1.6
Eu-154	4.26E-06	4.81E-06	1.1	Cf-251	3.91E-06	6.49E-06	1.7
Eu-155	1.07E-07	1.57E-07	1.5	Cf-252	1.24E-06	1.76E-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. Additional detail on the contributions from each pathway are shown in Appendix D.

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	7.12E-01	na	1.36E+01
53-70-3	Dibenz[a,h]anthracene	na	9.18E-01	na	3.93E+01
56-23-5	Carbon tetrachloride	9.85E+01	4.37E-03	1.16E+02	5.05E-03
57-12-5	Cyanide, free	3.15E+01	na	3.15E+01	na
57-14-7	1,1-Dimethylhydrazine	na	4.30E+00	na	4.30E+00
57-55-6	Propylene glycol (1,2-Propanediol)	2.23E+00	na	2.23E+00	na
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)	3.26E+02	3.52E-02	5.20E+02	6.74E-02
60-29-7	Ethyl ether (Diethyl ether)	4.11E-01	na	4.17E-01	na
60-34-4	Methylhydrazine	na	3.22E+00	na	3.22E+00
60-57-1	Dieldrin	1.52E+03	5.89E-01	2.38E+04	8.23E+00
62-75-9	N-Nitrosodimethylamine	2.02E+05	3.47E+01	2.02E+05	3.47E+01
64-18-6	Formic acid	4.73E-01	na	4.74E-01	na
67-56-1	Methanol (Methyl alcohol)	1.24E+00	na	1.24E+00	na
67-64-1	Acetone (2-Propanone)	2.54E-01	na	2.55E-01	na
67-66-3	Chloroform	1.33E+02	3.75E-03	1.34E+02	3.75E-03
67-72-1	Hexachloroethane	7.43E+01	8.92E-04	1.95E+02	1.62E-03
71-36-3	n-Butyl alcohol (n-Butanol)	1.64E+01	na	1.65E+01	na
71-43-2	Benzene	3.06E+01	2.16E-03	3.15E+01	2.25E-03
71-55-6	1,1,1-Trichloroethane (Methyl chloroform)	4.19E-01	na	4.42E-01	na
72-20-8	Endrin	6.02E+02	na	3.33E+03	na
74-83-9	Bromomethane	1.30E+02	na	1.31E+02	na
74-87-3	Methyl chloride (Chloromethane)	4.22E+00	5.45E-04	4.22E+00	5.52E-04
75-00-3	Ethyl Chloride	2.20E-01	4.83E-05	2.23E-01	4.97E-05
75-01-4	Vinyl chloride (Chloroethene)	2.76E+01	2.40E-02	2.82E+01	2.49E-02
75-05-8	Acetonitrile	6.35E+00	na	6.35E+00	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
75-07-0	Acetaldehyde	4.22E+01	3.58E-04	4.22E+01	3.58E-04
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	na	7.59E-03	na
75-68-3	Chloro-1,1-difluoroethane, 1-	7.59E-03	na	7.59E-03	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	3.03E-01	7.87E+03	7.73E+00
78-83-1	Isobutanol	4.88E-01	na	4.93E-01	na
78-87-5	1,2-Dichloropropane	9.52E+01	1.12E-03	9.52E+01	1.20E-03
78-93-3	Methyl ethyl ketone (2-Butanone)	3.45E-01	na	3.47E-01	na
79-00-5	1,1,2-Trichloroethane	1.93E+01	3.70E-03	1.98E+01	3.76E-03
79-01-6	Trichloroethylene	2.54E+02	2.54E-02	2.78E+02	2.66E-02
79-10-7	2-Propenoic acid (Acrylic acid)	6.25E+00	na	6.25E+00	na
79-34-5	1,1,2,2-Tetrachloroethane (Acetylene tetrachloride)	1.28E+00	1.30E-02	1.38E+00	1.35E-02
79-46-9	2-Nitropropane	1.90E+01	4.37E-01	1.90E+01	4.37E-01
82-68-8	Pentachloronitrobenzene (PCNB)	2.55E+01	4.66E-03	1.22E+02	3.70E-02
83-32-9	Acenaphthene	1.62E+00	na	3.07E+00	na
84-66-2	Diethyl phthalate	1.61E-01	na	1.69E-01	na
84-74-2	Dibutyl phthalate	7.83E-01	na	3.05E+00	na
85-68-7	Butyl benzyl phthalate	4.11E-01	na	2.12E+00	na
87-68-3	Hexachlorobutadiene	2.61E+02	5.11E-03	1.51E+03	1.76E-02
87-86-5	Pentachlorophenol	2.73E+00	2.44E-03	1.19E+01	1.65E-02
88-06-2	2,4,6-Trichlorophenol	9.50E+02	3.39E-04	1.19E+03	4.49E-04
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)	1.09E+02	na	1.54E+02	na
91-20-3	Naphthalene	1.31E+02	na	1.32E+02	na
92-52-4	1,1'-Biphenyl	1.77E+00	na	3.65E+00	na
95-47-6	o-Xylene	4.16E+00	na	4.26E+00	na
95-48-7	2-Methylphenol (o-Cresol)	4.48E+00	na	4.54E+00	na
95-50-1	1,2-Dichlorobenzene (ortho-)	2.71E+00	na	3.10E+00	na
95-57-8	2-Chlorophenol	3.09E+01	na	3.17E+01	na
95-63-6	1,2,4-Trimethylbenzene	6.50E+01	na	6.60E+01	na
95-95-4	2,4,5-Trichlorophenol	9.49E-01	na	1.20E+00	na
98-86-2	Acetophenone	1.48E+00	na	1.48E+00	na
98-95-3	Nitrobenzene	4.61E+02	na	4.66E+02	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
100-25-4	1,4-Dinitrobenzene (para-)	3.24E+03	na	3.25E+03	na
100-41-4	Ethyl benzene	1.10E+00	1.79E-04	1.31E+00	1.79E-04
100-42-5	Styrene	7.47E-01	na	8.24E-01	na
100-51-6	Benzyl alcohol	7.13E-01	na	7.14E-01	na
106-42-3	p-Xylene	4.16E+00	na	4.27E+00	na
106-44-5	4-Methylphenol (p-Cresol)	4.40E+01	na	4.46E+01	na
106-46-7	1,4-Dichlorobenzene (para-)	2.87E+00	1.41E-03	4.06E+00	1.78E-03
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	1.90E+03	1.79E+00	1.90E+03	1.88E+00
106-99-0	1,3-Butadiene	1.90E+02	4.88E-03	1.90E+02	4.88E-03
107-02-8	2-Propenal (Acrolein)	1.93E+04	na	1.93E+04	na
107-05-1	3-Chloropropene (Allyl chloride)	3.81E+02	na	3.81E+02	na
107-06-2	1,2-Dichloroethane (Ethylene chloride)	8.01E+01	5.94E-03	8.02E+01	5.98E-03
107-13-1	Acrylonitrile	3.28E+02	3.52E-02	3.30E+02	3.55E-02
108-10-1	Methyl isobutyl ketone (4-Methyl-2-pentanone)	1.26E+00	na	1.27E+00	na
108-38-3	m-Xylene	4.16E+00	na	4.28E+00	na
108-39-4	3-Methylphenol (m-Cresol)	4.36E+00	na	4.42E+00	na
108-67-8	1,3,5-Trimethylbenzene	6.49E+01	na	6.56E+01	na
108-87-2	Methyl cyclohexane	1.27E-01	na	1.27E-01	na
108-88-3	Toluene (Methyl benzene)	1.31E+00	na	1.36E+00	na
108-90-7	Chlorobenzene	1.02E+01	na	1.09E+01	na
108-94-1	Cyclohexanone	4.22E-02	na	4.24E-02	na
108-95-2	Phenol (Carbolic acid)	1.10E+00	na	1.10E+00	na
109-99-9	Tetrahydrofuran	1.90E+00	6.38E-04	1.91E+00	6.43E-04
110-00-9	Furan (Oxacyclopentadiene)	7.69E+01	na	7.78E+01	na
110-54-3	n-Hexane	3.34E+00	na	4.74E+00	na
110-80-5	2-Ethoxyethanol	1.34E+00	na	1.35E+00	na
110-82-7	Cyclohexane	6.35E-02	na	6.35E-02	na
110-86-1	Pyridine	2.86E+02	na	2.88E+02	na
111-76-2	2-Butoxyethanol (Ethylene Glycol Monobutyl Ether)	3.28E-01	na	3.30E-01	na
111-90-0	2-(2-Ethoxyethoxy)-ethanol (Diethylene Glycol Monoethyl Ether)	1.23E+01	na	1.23E+01	na
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)	2.82E+01	3.17E-03	4.17E+01	4.79E-03
117-84-0	Di-n-octylphthalate	7.60E+00	na	1.01E+01	na
118-74-1	Hexachlorobenzene	1.32E+02	1.24E-01	2.64E+03	1.50E+00
120-82-1	1,2,4-Trichlorobenzene	1.03E+02	na	1.12E+02	na
121-14-2	2,4-Dinitrotoluene	1.14E+02	na	1.16E+02	na
121-44-8	Triethylamine	5.43E+01	na	5.43E+01	na
122-39-4	Diphenylamine	4.10E+00	na	5.73E+00	na
123-91-1	1,4-Dioxane (Diethylene oxide)	na	1.39E-03	na	1.39E-03
126-73-8	Tributyl Phosphate	4.51E-01	1.29E-04	5.38E-01	1.68E-04

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
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)	1.64E+03	na	1.65E+03	na
127-18-4	Tetrachloroethylene	7.55E+00	8.79E-04	1.08E+01	1.61E-03
129-00-0	Pyrene	4.23E+00	na	1.96E+01	na
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	1.22E-01	na	1.24E-01	na
156-59-2	cis-1,2-Dichloroethylene	7.20E+00	na	7.43E+00	na
206-44-0	Fluoranthene (1,2-Benzacenaphthene)	3.83E+00	na	2.27E+01	na
309-00-2	Aldrin	3.79E+03	1.37E+00	2.65E+05	5.85E+01
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	1.86E+02	3.03E-01	3.19E+02	4.82E-01
319-85-7	beta-Benzene hexachloride (beta-Lindane)	4.88E+02	5.02E-02	8.12E+02	9.97E-02
541-73-1	1,3-Dichlorobenzene	8.09E+01	na	1.27E+02	na
542-75-6	1,3-Dichloropropene (cis & trans)	2.14E+01	2.31E-03	2.15E+01	2.44E-03
621-64-7	N-Nitrosodi-N-propylamine	na	9.95E-01	na	9.99E-01
1314-62-1	Vanadium pentoxide	8.13E+00	na	1.73E+01	na
1330-20-7	Xylenes (mixtures)	4.15E+00	na	4.26E+00	na
1336-36-3	Polychlorinated Biphenyls	na	3.65E-02	na	1.93E+01
1336-36-3	Polychlorinated Biphenyls (lowest risk)	na	2.56E-02	na	1.93E+01
6533-73-9	Thallium carbonate	8.52E+02	na	4.93E+04	na
7429-90-5	Aluminum	7.18E-02	na	2.70E-01	na
7439-89-6	Iron	2.30E-01	na	5.01E-01	na
7439-93-2	Lithium	3.45E+00	na	3.66E+00	na
7439-96-5	Manganese	2.08E+00	na	3.29E+00	na
7439-97-6	Mercury metal vapor	3.16E-02	na	3.16E-02	na
7439-98-7	Molybdenum	3.82E+01	na	3.94E+01	na
7440-02-0	Nickel (soluble salts)	4.00E+00	na	6.12E+00	na
7440-22-4	Silver	1.37E+01	na	1.48E+01	na
7440-24-6	Strontium, Stable	3.10E-01	na	3.55E-01	na
7440-28-0	Thallium metal	1.03E+03	na	5.98E+04	na
7440-31-5	Tin	1.18E-01	na	2.06E+00	na
7440-36-0	Antimony	1.86E+02	na	2.98E+02	na
7440-38-2	Arsenic (inorganic)	2.32E+02	2.28E-02	5.60E+02	8.55E-02
7440-39-3	Barium	1.10E+00	na	1.18E+00	na
7440-41-7	Beryllium and compounds	3.66E+01	2.85E-05	5.95E+01	2.85E-05
7440-42-8	Boron and borates only	3.43E+00	na	3.47E+00	na
7440-43-9	Cadmium	1.67E+02	2.10E-05	2.60E+02	2.10E-05
7440-45-1	Cerium (Ceric oxide 1306-38-3)	6.55E-02	na	6.55E-02	na
7440-48-4	Cobalt	4.60E+00	3.24E-05	1.06E+01	3.24E-05
7440-50-8	Copper	5.43E+00	na	7.45E+00	na
7440-62-2	Vanadium metal	1.08E+01	na	2.30E+01	na
7440-66-6	Zinc and compounds	1.50E+01	na	1.53E+01	na
7487-94-7	Mercuric chloride	3.54E+02	na	1.65E+03	na

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
7664-41-7	Ammonia	5.35E-01	na	5.35E-01	na
7723-14-0	Phosphorus, white	3.14E+04	na	6.06E+04	na
7782-41-4	Fluorine (soluble fluoride)	1.16E+00	na	1.29E+00	na
7782-49-2	Selenium and compounds	1.40E+01	na	2.74E+01	na
8001-35-2	Toxaphene	na	3.31E-02	na	1.06E+00
11096-82-5	Aroclor 1260	na	7.76E-02	na	1.72E+00
11097-69-1	Aroclor 1254	6.84E+03	3.97E-02	2.73E+06	4.68E+01
11104-28-2	Aroclor 1221	na	3.29E-02	na	2.38E-01
11141-16-5	Aroclor 1232	na	3.29E-02	na	2.38E-01
12672-29-6	Aroclor 1248	na	3.68E-02	na	2.11E+01
12674-11-2	Aroclor 1016	1.37E+03	2.58E-02	9.93E+04	5.90E+00
14797-55-8	Nitrate	3.98E-02	na	4.07E-02	na
14797-65-0	Nitrite	6.36E-01	na	6.52E-01	na
16065-83-1	Chromium (III) (insoluble salts)	5.23E-02	na	1.11E-01	na
16984-48-8	Fluorine anion	1.16E+00	na	1.29E+00	na
18540-29-9	Chromium (VI) (soluble salts)	2.34E+01	3.51E-05	4.96E+01	3.51E-05
53469-21-9	Aroclor 1242	na	3.64E-02	na	1.93E+01
na	Uranium (soluble salts)	1.16E+02	na	1.25E+02	na
na	Total Chromium (1:6 ratio CrVI:Cr III)	3.38E+00	5.02E-06	7.18E+00	5.02E-06

Notes:

- CASRN = Chemical Abstract Service Reference Number
- The total risk to the HSRAM Residential scenario is calculated using intakes from 30 consecutive years. The soil concentration is zero at the start of the exposure.
- These scenario factors must be multiplied by the appropriate water concentration. The "Inland Well" column assumes all of the contaminated water comes from the well. The "Columbia River" column assumes that all of the contaminated water comes from the Columbia River.
- Results using route-to-route extrapolations are shown in Table C12.

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 0.72 mL/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: 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	8.47E-07	1.44E-06	1.7
Be-10	1.90E-07	5.88E-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	65.5
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	1.6	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	1.40E-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	1.41E-05	2.25E-05	1.6
Fe-55	3.39E-08	1.04E-07	3.1	Th-228+D	9.48E-06	2.25E-05	2.4
Fe-60+D	1.76E-05	3.50E-05	2.0	Th-229+D	1.53E-05	4.30E-05	2.8
Co-60	6.73E-06	9.13E-06	1.4	Th-230	2.40E-06	6.99E-06	2.9
Ni-59	3.27E-08	4.78E-08	1.5	Th-232	1.21E-05	2.95E-05	2.4
Ni-63	7.94E-08	1.15E-07	1.5	Pa-231	5.20E-06	1.00E-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	2.02E-06	2.64E-06	1.3
Sr-90+D	6.43E-06	8.59E-06	1.3	U-234	1.99E-06	2.59E-06	1.3
Zr-93	2.85E-08	1.72E-07	6.0	U-235+D	2.56E-06	3.22E-06	1.3
Nb-91	2.78E-08	1.43E-07	5.1	U-236	1.88E-06	2.45E-06	1.3
Nb-93m	2.11E-08	1.31E-07	6.2	U-238+D	2.56E-06	3.35E-06	1.3
Nb-94	9.83E-06	1.19E-05	1.2	Np-237+D	2.79E-06	4.04E-06	1.4
Mo-93	1.66E-07	1.93E-07	1.2	Pu-236	2.11E-06	2.95E-06	1.4
Tc-99	4.72E-07	5.01E-07		Pu-238	3.36E-06	5.57E-06	1.7
Ru-106+D	2.61E-06	2.83E-06		Pu-239	3.47E-06	5.90E-06	1.7
Pd-107	2.27E-08	2.68E-08	1.2	Pu-240	3.47E-06	5.90E-06	1.7
Ag-108m+D	9.13E-06	1.01E-05		Pu-241+D	4.59E-08	8.55E-08	1.9
Cd-109	1.55E-07	5.56E-07	3.6	Pu-242	3.29E-06	5.60E-06	1.7
Cd-113m	9.66E-07	3.24E-06	3.4	Pu-244+D	5.74E-06	8.68E-06	1.5

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

Nuclide	Inland Resident	Columbia River	Ratio	Nuclide	Inland Resident	Columbia River	Ratio
In-115	1.08E-06	1.29E-03	1,197	Am-241	2.71E-06	4.58E-06	1.7
Sn-121m+D	3.47E-07	4.95E-06	14.3	Am-242m+D	1.94E-06	3.61E-06	1.9
Sn-126+D	1.45E-05	5.11E-05	3.5	Am-243+D	3.64E-06	5.74E-06	1.6
Sb-125	6.66E-07	8.87E-07	1.3	Cm-242	9.84E-07	1.34E-06	1.4
Te-125m	9.45E-08	6.53E-07	6.9	Cm-243	2.88E-06	4.36E-06	1.5
I-129	1.96E-05	2.27E-05	1.2	Cm-244	2.15E-06	3.31E-06	1.5
Cs-134	5.58E-06	3.62E-05	6.5	Cm-245	3.00E-06	4.96E-06	1.7
Cs-135	5.88E-07	4.12E-06	7.0	Cm-246	2.63E-06	4.47E-06	1.7
Cs-137+D	6.28E-06	2.89E-05	4.6	Cm-247+D	4.42E-06	6.47E-06	1.5
Ba-133	1.26E-06	1.38E-06		Cm-248	9.64E-06	1.64E-05	1.7
Pm-147	5.02E-08	7.50E-08	1.5	Cm-250+D	5.71E-05	9.61E-05	1.7
Sm-147	1.10E-06	1.81E-06	1.6	Bk-247	3.60E-06	6.03E-06	1.7
Sm-151	1.68E-08	2.94E-08	1.7	Cf-248	1.28E-06	1.78E-06	1.4
Eu-150	7.32E-06	8.13E-06		Cf-249	5.54E-06	8.12E-06	1.5
Eu-152	4.65E-06	5.16E-06		Cf-250	2.53E-06	3.77E-06	1.5
Eu-154	4.30E-06	4.85E-06	1.1	Cf-251	4.40E-06	6.98E-06	1.6
Eu-155	1.14E-07	1.64E-07	1.4	Cf-252	1.40E-06	1.92E-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. Additional detail on the contributions from each pathway are shown in Appendix D.

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	8.72E-01	na	1.38E+01
53-70-3	Dibenz[a,h]anthracene	na	1.56E+00	na	3.99E+01
56-23-5	Carbon tetrachloride	9.85E+01	4.37E-03	1.16E+02	5.05E-03
57-12-5	Cyanide, free	3.15E+01	na	3.15E+01	na
57-14-7	1,1-Dimethylhydrazine	na	4.30E+00	na	4.30E+00
57-55-6	Propylene glycol (1,2-Propanediol)	2.23E+00	na	2.23E+00	na
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)	3.27E+02	3.55E-02	5.21E+02	6.76E-02
60-29-7	Ethyl ether (Diethyl ether)	4.11E-01	na	4.17E-01	na
60-34-4	Methylhydrazine	na	3.22E+00	na	3.22E+00
60-57-1	Dieldrin	1.70E+03	6.49E-01	2.40E+04	8.29E+00
62-75-9	N-Nitrosodimethylamine	2.02E+05	3.47E+01	2.02E+05	3.47E+01
64-18-6	Formic acid	4.73E-01	na	4.74E-01	na
67-56-1	Methanol (Methyl alcohol)	1.24E+00	na	1.24E+00	na
67-64-1	Acetone (2-Propanone)	2.54E-01	na	2.55E-01	na
67-66-3	Chloroform	1.33E+02	3.75E-03	1.34E+02	3.75E-03
67-72-1	Hexachloroethane	7.45E+01	8.93E-04	1.95E+02	1.62E-03
71-36-3	n-Butyl alcohol (n-Butanol)	1.64E+01	na	1.65E+01	na
71-43-2	Benzene	3.06E+01	2.16E-03	3.15E+01	2.25E-03
71-55-6	1,1,1-Trichloroethane (Methyl chloroform)	4.19E-01	na	4.42E-01	na
72-20-8	Endrin	6.22E+02	na	3.35E+03	na
74-83-9	Bromomethane	1.30E+02	na	1.31E+02	na
74-87-3	Methyl chloride (Chloromethane)	4.22E+00	5.45E-04	4.22E+00	5.52E-04
75-00-3	Ethyl Chloride	2.20E-01	4.83E-05	2.23E-01	4.97E-05
75-01-4	Vinyl chloride (Chloroethene)	2.76E+01	2.40E-02	2.82E+01	2.49E-02
75-05-8	Acetonitrile	6.35E+00	na	6.35E+00	na
75-07-0	Acetaldehyde	4.22E+01	3.58E-04	4.22E+01	3.58E-04
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	na	7.59E-03	na
75-68-3	Chloro-1,1-difluoroethane, 1-	7.59E-03	na	7.59E-03	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	3.68E-01	7.94E+03	7.80E+00
78-83-1	Isobutanol	4.88E-01	na	4.93E-01	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
78-87-5	1,2-Dichloropropane	9.52E+01	1.12E-03	9.52E+01	1.20E-03
78-93-3	Methyl ethyl ketone (2-Butanone)	3.45E-01	na	3.47E-01	na
79-00-5	1,1,2-Trichloroethane	1.93E+01	3.70E-03	1.98E+01	3.76E-03
79-01-6	Trichloroethylene	2.54E+02	2.54E-02	2.78E+02	2.66E-02
79-10-7	2-Propenoic acid (Acrylic acid)	6.25E+00	na	6.25E+00	na
79-34-5	1,1,2,2-Tetrachloroethane (Acetylene tetrachloride)	1.28E+00	1.30E-02	1.38E+00	1.35E-02
79-46-9	2-Nitropropane	1.90E+01	4.37E-01	1.90E+01	4.37E-01
82-68-8	Pentachloronitrobenzene (PCNB)	2.59E+01	4.81E-03	1.23E+02	3.72E-02
83-32-9	Acenaphthene	1.62E+00	na	3.07E+00	na
84-66-2	Diethyl phthalate	1.61E-01	na	1.69E-01	na
84-74-2	Dibutyl phthalate	7.95E-01	na	3.07E+00	na
85-68-7	Butyl benzyl phthalate	4.24E-01	na	2.14E+00	na
87-68-3	Hexachlorobutadiene	2.63E+02	5.13E-03	1.51E+03	1.76E-02
87-86-5	Pentachlorophenol	2.89E+00	2.68E-03	1.20E+01	1.67E-02
88-06-2	2,4,6-Trichlorophenol	9.54E+02	3.41E-04	1.19E+03	4.50E-04
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)	1.10E+02	na	1.54E+02	na
91-20-3	Naphthalene	1.31E+02	na	1.32E+02	na
92-52-4	1,1'-Biphenyl	1.77E+00	na	3.66E+00	na
95-47-6	o-Xylene	4.16E+00	na	4.26E+00	na
95-48-7	2-Methylphenol (o-Cresol)	4.48E+00	na	4.54E+00	na
95-50-1	1,2-Dichlorobenzene (ortho-)	2.71E+00	na	3.10E+00	na
95-57-8	2-Chlorophenol	3.09E+01	na	3.17E+01	na
95-63-6	1,2,4-Trimethylbenzene	6.50E+01	na	6.60E+01	na
95-95-4	2,4,5-Trichlorophenol	9.52E-01	na	1.20E+00	na
98-86-2	Acetophenone	1.48E+00	na	1.48E+00	na
98-95-3	Nitrobenzene	4.61E+02	na	4.66E+02	na
100-25-4	1,4-Dinitrobenzene (para-)	3.24E+03	na	3.25E+03	na
100-41-4	Ethyl benzene	1.10E+00	1.79E-04	1.31E+00	1.79E-04
100-42-5	Styrene	7.47E-01	na	8.24E-01	na
100-51-6	Benzyl alcohol	7.13E-01	na	7.14E-01	na
106-42-3	p-Xylene	4.16E+00	na	4.27E+00	na
106-44-5	4-Methylphenol (p-Cresol)	4.40E+01	na	4.46E+01	na
106-46-7	1,4-Dichlorobenzene (para-)	2.87E+00	1.41E-03	4.06E+00	1.78E-03
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	1.90E+03	1.79E+00	1.90E+03	1.88E+00
106-99-0	1,3-Butadiene	1.90E+02	4.88E-03	1.90E+02	4.88E-03
107-02-8	2-Propenal (Acrolein)	1.93E+04	na	1.93E+04	na
107-05-1	3-Chloropropene (Allyl chloride)	3.81E+02	na	3.81E+02	na
107-06-2	1,2-Dichloroethane (Ethylene chloride)	8.01E+01	5.94E-03	8.02E+01	5.98E-03
107-13-1	Acrylonitrile	3.28E+02	3.52E-02	3.30E+02	3.55E-02

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
108-10-1	Methyl isobutyl ketone (4-Methyl-2-pentanone)	1.26E+00	na	1.27E+00	na
108-38-3	m-Xylene	4.16E+00	na	4.28E+00	na
108-39-4	3-Methylphenol (m-Cresol)	4.36E+00	na	4.43E+00	na
108-67-8	1,3,5-Trimethylbenzene	6.49E+01	na	6.56E+01	na
108-87-2	Methyl cyclohexane	1.27E-01	na	1.27E-01	na
108-88-3	Toluene (Methyl benzene)	1.31E+00	na	1.36E+00	na
108-90-7	Chlorobenzene	1.02E+01	na	1.09E+01	na
108-94-1	Cyclohexanone	4.22E-02	na	4.24E-02	na
108-95-2	Phenol (Carbolic acid)	1.10E+00	na	1.10E+00	na
109-99-9	Tetrahydrofuran	1.90E+00	6.38E-04	1.91E+00	6.43E-04
110-00-9	Furan (Oxacyclopentadiene)	7.69E+01	na	7.78E+01	na
110-54-3	n-Hexane	3.34E+00	na	4.74E+00	na
110-80-5	2-Ethoxyethanol	1.34E+00	na	1.35E+00	na
110-82-7	Cyclohexane	6.35E-02	na	6.35E-02	na
110-86-1	Pyridine	2.86E+02	na	2.88E+02	na
111-76-2	2-Butoxyethanol (Ethylene Glycol Monobutyl Ether)	3.28E-01	na	3.30E-01	na
111-90-0	2-(2-Ethoxyethoxy)-ethanol (Diethylene Glycol Monoethyl Ether)	1.23E+01	na	1.23E+01	na
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)	9.63E+01	1.13E-02	1.10E+02	1.30E-02
117-84-0	Di-n-octylphthalate	1.14E+02	na	1.17E+02	na
118-74-1	Hexachlorobenzene	1.41E+02	1.28E-01	2.65E+03	1.51E+00
120-82-1	1,2,4-Trichlorobenzene	1.03E+02	na	1.12E+02	na
121-14-2	2,4-Dinitrotoluene	1.14E+02	na	1.16E+02	na
121-44-8	Triethylamine	5.43E+01	na	5.43E+01	na
122-39-4	Diphenylamine	4.11E+00	na	5.74E+00	na
123-91-1	1,4-Dioxane (Diethylene oxide)	na	1.39E-03	na	1.39E-03
126-73-8	Tributyl Phosphate	4.54E-01	1.30E-04	5.41E-01	1.69E-04
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)	1.64E+03	na	1.65E+03	na
127-18-4	Tetrachloroethylene	7.56E+00	8.80E-04	1.08E+01	1.61E-03
129-00-0	Pyrene	4.35E+00	na	1.97E+01	na
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	1.22E-01	na	1.24E-01	na
156-59-2	cis-1,2-Dichloroethylene	7.20E+00	na	7.43E+00	na
206-44-0	Fluoranthene (1,2-Benzacenaphthene)	3.99E+00	na	2.28E+01	na
309-00-2	Aldrin	7.22E+03	2.12E+00	2.68E+05	5.92E+01
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	1.87E+02	3.05E-01	3.20E+02	4.83E-01
319-85-7	beta-Benzene hexachloride (beta-Lindane)	4.91E+02	5.05E-02	8.14E+02	1.00E-01
541-73-1	1,3-Dichlorobenzene	8.10E+01	na	1.27E+02	na
542-75-6	1,3-Dichloropropene (cis & trans)	2.14E+01	2.31E-03	2.15E+01	2.44E-03
621-64-7	N-Nitrosodi-N-propylamine	na	9.95E-01	na	9.99E-01

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
1314-62-1	Vanadium pentoxide	8.29E+00	na	1.75E+01	na
1330-20-7	Xylenes (mixtures)	4.15E+00	na	4.26E+00	na
1336-36-3	Polychlorinated Biphenyls	na	7.56E-02	na	1.93E+01
1336-36-3	Polychlorinated Biphenyls (lowest risk)	na	6.47E-02	na	1.93E+01
6533-73-9	Thallium carbonate	1.18E+03	na	4.97E+04	na
7429-90-5	Aluminum	7.32E-02	na	2.71E-01	na
7439-89-6	Iron	2.66E-01	na	5.37E-01	na
7439-93-2	Lithium	6.69E+00	na	6.90E+00	na
7439-96-5	Manganese	2.09E+00	na	3.30E+00	na
7439-97-6	Mercury metal vapor	3.16E-02	na	3.16E-02	na
7439-98-7	Molybdenum	4.64E+01	na	4.76E+01	na
7440-02-0	Nickel (soluble salts)	7.98E+00	na	1.01E+01	na
7440-22-4	Silver	1.40E+01	na	1.51E+01	na
7440-24-6	Strontium, Stable	4.58E-01	na	5.04E-01	na
7440-28-0	Thallium metal	1.44E+03	na	6.02E+04	na
7440-31-5	Tin	1.97E-01	na	2.14E+00	na
7440-36-0	Antimony	1.87E+02	na	2.98E+02	na
7440-38-2	Arsenic (inorganic)	2.37E+02	2.36E-02	5.64E+02	8.63E-02
7440-39-3	Barium	1.13E+00	na	1.20E+00	na
7440-41-7	Beryllium and compounds	3.69E+01	2.85E-05	5.97E+01	2.85E-05
7440-42-8	Boron and borates only	4.17E+00	na	4.20E+00	na
7440-43-9	Cadmium	1.75E+02	2.10E-05	2.69E+02	2.10E-05
7440-45-1	Cerium (Ceric oxide 1306-38-3)	6.55E-02	na	6.55E-02	na
7440-48-4	Cobalt	5.06E+00	3.24E-05	1.10E+01	3.24E-05
7440-50-8	Copper	7.39E+00	na	9.41E+00	na
7440-62-2	Vanadium metal	1.10E+01	na	2.32E+01	na
7440-66-6	Zinc and compounds	7.62E+01	na	7.65E+01	na
7487-94-7	Mercuric chloride	1.55E+03	na	2.85E+03	na
7664-41-7	Ammonia	5.35E-01	na	5.35E-01	na
7723-14-0	Phosphorus, white	1.42E+05	na	1.71E+05	na
7782-41-4	Fluorine (soluble fluoride)	2.61E+00	na	2.73E+00	na
7782-49-2	Selenium and compounds	1.69E+01	na	3.02E+01	na
8001-35-2	Toxaphene	na	4.40E-02	na	1.07E+00
11096-82-5	Aroclor 1260	na	4.50E+00	na	6.15E+00
11097-69-1	Aroclor 1254	1.47E+04	1.75E-01	2.74E+06	4.69E+01
11104-28-2	Aroclor 1221	na	3.37E-02	na	2.38E-01
11141-16-5	Aroclor 1232	na	3.37E-02	na	2.38E-01
12672-29-6	Aroclor 1248	na	7.50E-02	na	2.11E+01
12674-11-2	Aroclor 1016	1.52E+03	3.46E-02	9.95E+04	5.91E+00
14797-55-8	Nitrate	3.98E-02	na	4.07E-02	na
14797-65-0	Nitrite	6.36E-01	na	6.52E-01	na
16065-83-1	Chromium (III) (insoluble salts)	5.54E-02	na	1.14E-01	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
16984-48-8	Fluorine anion	2.61E+00	na	2.73E+00	na
18540-29-9	Chromium (VI) (soluble salts)	2.41E+01	3.51E-05	5.03E+01	3.51E-05
53469-21-9	Aroclor 1242	na	7.44E-02	na	1.93E+01
na	Uranium (soluble salts)	1.18E+02	na	1.27E+02	na
na	Total Chromium (1:6 ratio CrVI:Cr III)	3.49E+00	5.02E-06	7.29E+00	5.02E-06

Notes:

- CASRN = Chemical Abstract Service Reference Number
- The total risk to the HSRAM Agricultural scenario is calculated using intakes from 30 consecutive years. The soil concentration is zero at the start of the exposure.
- These scenario factors must be multiplied by the appropriate water concentration. The "Inland Well" column assumes all of the contaminated water comes from the well. The "Columbia River" column assumes that all of the contaminated water comes from the Columbia River.
- Results using route-to-route extrapolations are shown in Table C14.

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.

Note that there are significant differences between the MTCA-C and the HSRAM Industrial Scenario. First is the difference in water intake rate. MTCA-C uses 2 L/d while HSRAM Industrial uses 1 L/d. Second is annual exposure time. MTCA-C uses 365 d/y while

HSRAM Industrial uses 250 d/y. In effect, the HSRAM average drinking water rate is 0.7 L/d. Third is the volatilization factor used in MTCA in place of the inhalation toxicity parameter. HSRAM Industrial includes the effects of Henry's Law in the inhalation calculation, but uses the inhalation toxicity parameter (if it exists). The ratio of hazard index for MTCA-C (ground water) divided by the hazard index for HSRAM Industrial could be as large as 5.84, as shown below. This ratio could be zero if the reference dose for ingestion is not given, but an inhalation reference dose is given in Table A31.

$$\text{Hazard Index Ratio} \left[\frac{\text{MTCA - C (ground water)}}{\text{HSRAM Industrial}} \right] = \left(\frac{2 \text{ L/d}}{1 \text{ L/d}} \right) \left(\frac{365 \text{ d/y}}{250 \text{ d/y}} \right) (2) = 5.84$$

In addition to the differences noted above for non-cancer effects, the calculation of increased cancer risk uses a lifetime exposure period and an averaging period. These two are different in MTCA-C and the HSRAM Industrial. In MTCA-C the lifetime exposure period is 30 y and the averaging period is 75 y. In the HSRAM Industrial scenario the lifetime exposure period is 20 y and the averaging period is 70 y. The ratio of increased cancer risks could be as large as 8.18, as shown below.

$$\text{Increased Cancer Ratio} \left[\frac{\text{MTCA - C (ground water)}}{\text{HSRAM Industrial}} \right] = \left(\frac{2 \text{ L/d}}{1 \text{ L/d}} \right) \left(\frac{365 \text{ d/y}}{250 \text{ d/y}} \right) (2) \left(\frac{30 \text{ y}}{20 \text{ y}} \right) \left(\frac{70 \text{ y}}{75 \text{ y}} \right) = 8.18$$

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)	1.25E-01	na	1	5.71E-02	na
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)	2.08E+02	1.49E-02	1	9.52E+01	1.49E-02
60-29-7	Ethyl ether (Diethyl ether)	6.25E-01	na	2	2.86E-01	na
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	7.81E+03	5.83E-01	1	3.57E+03	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)	1.39E-01	na	2	6.35E-02	na
67-66-3	Chloroform	1.25E+01	5.26E-06	2	5.71E+00	5.26E-06
67-72-1	Hexachloroethane	6.25E+01	1.60E-04	1	2.86E+01	1.60E-04
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)	4.46E-01	na	2	2.04E-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	2.97E-04	2	na	2.97E-04
75-00-3	Ethyl Chloride	1.56E-01	3.31E-05	1	7.14E-02	3.31E-05
75-01-4	Vinyl chloride (Chloroethene)	4.17E+01	3.20E-02	2	1.90E+01	1.65E-02
75-05-8	Acetonitrile	na	na	2	na	na
75-07-0	Acetaldehyde	na	na	2	na	na
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

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
76-44-8	Heptachlor	1.25E+02	5.14E-02	1	5.71E+01	5.14E-02
78-83-1	Isobutanol	2.08E-01	na	1	9.52E-02	na
78-87-5	1,2-Dichloropropane	na	1.55E-03	2	na	1.55E-03
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	4.17E+02	9.14E-03	2	1.90E+02	9.14E-03
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)	2.08E+00	4.57E-03	2	9.52E-01	4.57E-03
79-46-9	2-Nitropropane	na	na	2	na	na
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	4.17E+02	1.78E-03	2	1.90E+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	6.25E+02	1.26E-04	1	2.86E+02	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
95-47-6	o-Xylene	6.25E-01	na	2	2.86E-01	na
95-48-7	2-Methylphenol (o-Cresol)	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
95-57-8	2-Chlorophenol	1.25E+01	na	1	5.71E+00	na
95-63-6	1,2,4-Trimethylbenzene	2.50E+00	na	2	1.14E+00	na
95-95-4	2,4,5-Trichlorophenol	6.25E-01	na	1	2.86E-01	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-)	6.25E+02	na	1	2.86E+02	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
106-42-3	p-Xylene	6.25E-01	na	2	2.86E-01	na
106-44-5	4-Methylphenol (p-Cresol)	1.25E+01	na	1	5.71E+00	na
106-46-7	1,4-Dichlorobenzene (para-)	4.17E+00	5.49E-04	2	1.90E+00	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
107-02-8	2-Propenal (Acrolein)	2.50E+02	na	2	1.14E+02	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
107-05-1	3-Chloropropene (Allyl chloride)	1.25E+00	na	1	5.71E-01	na
107-06-2	1,2-Dichloroethane (Ethylene chloride)	4.17E+00	2.08E-03	2	1.90E+00	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)	1.56E+00	na	2	7.14E-01	na
108-38-3	m-Xylene	6.25E-01	na	2	2.86E-01	na
108-39-4	3-Methylphenol (m-Cresol)	1.25E+00	na	1	5.71E-01	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
109-99-9	Tetrahydrofuran	5.95E-01	1.74E-04	2	2.72E-01	1.74E-04
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
110-80-5	2-Ethoxyethanol	1.56E-01	na	1	7.14E-02	na
110-82-7	Cyclohexane	na	na	2	na	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)	2.08E+00	na	2	9.52E-01	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	1.56E+00	na	1	7.14E-01	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
121-14-2	2,4-Dinitrotoluene	3.13E+01	na	1	1.43E+01	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	Tetrachloroethylene	1.25E+01	1.19E-03	2	5.71E+00	1.19E-03
129-00-0	Pyrene	2.08E+00	na	1	9.52E-01	na
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

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
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	1.25E+02	7.20E-02	1	5.71E+01	7.20E-02
319-85-7	beta-Benzene hexachloride (beta-Lindane)	3.13E+02	2.06E-02	1	1.43E+02	2.06E-02
541-73-1	1,3-Dichlorobenzene	1.39E+02	na	2	6.35E+01	na
542-75-6	1,3-Dichloropropene (cis & trans)	4.17E+00	2.29E-03	2	1.90E+00	2.29E-03
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	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
7439-89-6	Iron	2.08E-01	na	1	9.52E-02	na
7439-93-2	Lithium	3.13E+00	na	1	1.43E+00	na
7439-96-5	Manganese	1.34E+00	na	1	6.12E-01	na
7439-97-6	Mercury metal vapor	na	na	1	na	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
7440-28-0	Thallium metal	9.47E+02	na	1	4.33E+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
7440-45-1	Cerium (Ceric oxide 1306-38-3)	na	na	1	na	na
7440-48-4	Cobalt	3.13E+00	na	1	1.43E+00	na
7440-50-8	Copper	1.56E+00	na	1	7.14E-01	na
7440-62-2	Vanadium metal	8.93E+00	na	1	4.08E+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	1	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
11096-82-5	Aroclor 1260	na	4.57E-03	1	na	4.57E-03

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
11097-69-1	Aroclor 1254	6.25E+03	4.57E-03	2	2.86E+03	4.57E-03
11104-28-2	Aroclor 1221	na	4.57E-03	2	na	4.57E-03
11141-16-5	Aroclor 1232	na	4.57E-03	2	na	4.57E-03
12672-29-6	Aroclor 1248	na	4.57E-03	1	na	4.57E-03
12674-11-2	Aroclor 1016	8.93E+02	8.00E-04	1	4.08E+02	8.00E-04
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
16984-48-8	Fluorine anion	1.04E+00	na	1	4.76E-01	na
18540-29-9	Chromium (VI) (soluble salts)	2.08E+01	na	1	9.52E+00	na
53469-21-9	Aroclor 1242	na	4.57E-03	1	na	4.57E-03
na	Uranium (soluble salts)	1.04E+02	na	1	4.76E+01	na
na	Total Chromium (1:6 ratio CrVI:Cr III)	3.01E+00	na	1	1.38E+00	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 C16.

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)	1.25E-01	na	5.71E-02	na
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)	2.08E+02	2.93E-02	9.52E+01	1.49E-02
60-29-7	Ethyl ether (Diethyl ether)	6.25E-01	na	2.86E-01	na
60-34-4	Methylhydrazine	na	3.43E-02	na	3.43E-02
60-57-1	Dieldrin	2.21E+04	7.09E+00	8.86E+03	2.83E+00
62-75-9	N-Nitrosodimethylamine	7.81E+03	5.83E-01	3.57E+03	5.83E-01
64-18-6	Formic acid	3.13E-02	na	1.43E-02	na
67-56-1	Methanol (Methyl alcohol)	2.50E-01	na	1.14E-01	na
67-64-1	Acetone (2-Propanone)	1.39E-01	na	6.35E-02	na
67-66-3	Chloroform	1.25E+01	5.26E-06	5.71E+00	5.26E-06
67-72-1	Hexachloroethane	1.19E+02	6.64E-04	4.74E+01	2.66E-04
71-36-3	n-Butyl alcohol (n-Butanol)	6.25E-01	na	2.86E-01	na
71-43-2	Benzene	3.13E+01	1.26E-03	1.43E+01	1.26E-03
71-55-6	1,1,1-Trichloroethane (Methyl chloroform)	4.46E-01	na	2.04E-01	na
72-20-8	Endrin	2.59E+03	na	1.04E+03	na
74-83-9	Bromomethane	8.93E+01	na	4.08E+01	na
74-87-3	Methyl chloride (Chloromethane)	na	2.97E-04	na	2.97E-04
75-00-3	Ethyl Chloride	1.56E-01	3.31E-05	7.14E-02	3.31E-05
75-01-4	Vinyl chloride (Chloroethene)	4.17E+01	3.20E-02	1.90E+01	1.65E-02
75-05-8	Acetonitrile	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
78-83-1	Isobutanol	2.08E-01	na	9.52E-02	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
78-87-5	1,2-Dichloropropane	na	1.55E-03	na	1.55E-03
78-93-3	Methyl ethyl ketone (2-Butanone)	2.08E-01	na	9.52E-02	na
79-00-5	1,1,2-Trichloroethane	3.13E+01	1.30E-03	1.43E+01	1.30E-03
79-01-6	Trichloroethylene	4.17E+02	9.14E-03	1.90E+02	9.14E-03
79-10-7	2-Propenoic acid (Acrylic acid)	1.25E-01	na	5.71E-02	na
79-34-5	1,1,2,2-Tetrachloroethane (Acetylene tetrachloride)	2.08E+00	4.57E-03	9.52E-01	4.57E-03
79-46-9	2-Nitropropane	na	na	na	na
82-68-8	Pentachloronitrobenzene (PCNB)	9.59E+01	2.99E-02	3.84E+01	1.20E-02
83-32-9	Acenaphthene	1.34E+00	na	5.35E-01	na
84-66-2	Diethyl phthalate	7.81E-02	na	3.57E-02	na
84-74-2	Dibutyl phthalate	2.25E+00	na	8.98E-01	na
85-68-7	Butyl benzyl phthalate	1.69E+00	na	6.75E-01	na
87-68-3	Hexachlorobutadiene	2.46E+03	2.30E-02	9.84E+02	9.21E-03
87-86-5	Pentachlorophenol	8.94E+00	1.29E-02	3.58E+00	5.15E-03
88-06-2	2,4,6-Trichlorophenol	6.25E+02	1.26E-04	2.86E+02	1.26E-04
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)	6.25E+01	na	2.86E+01	na
91-20-3	Naphthalene	6.25E+00	na	2.86E+00	na
92-52-4	1,1'-Biphenyl	1.79E+00	na	7.14E-01	na
95-47-6	o-Xylene	6.25E-01	na	2.86E-01	na
95-48-7	2-Methylphenol (o-Cresol)	1.25E+00	na	5.71E-01	na
95-50-1	1,2-Dichlorobenzene (ortho-)	1.39E+00	na	6.35E-01	na
95-57-8	2-Chlorophenol	1.25E+01	na	5.71E+00	na
95-63-6	1,2,4-Trimethylbenzene	2.50E+00	na	1.14E+00	na
95-95-4	2,4,5-Trichlorophenol	6.25E-01	na	2.86E-01	na
98-86-2	Acetophenone	6.25E-01	na	2.86E-01	na
98-95-3	Nitrobenzene	1.25E+02	na	5.71E+01	na
100-25-4	1,4-Dinitrobenzene (para-)	6.25E+02	na	2.86E+02	na
100-41-4	Ethyl benzene	1.25E+00	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
106-42-3	p-Xylene	6.25E-01	na	2.86E-01	na
106-44-5	4-Methylphenol (p-Cresol)	1.25E+01	na	5.71E+00	na
106-46-7	1,4-Dichlorobenzene (para-)	4.17E+00	6.58E-04	1.90E+00	5.49E-04
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	na	1.94E+00	na	1.94E+00
106-99-0	1,3-Butadiene	na	na	na	na
107-02-8	2-Propenal (Acrolein)	2.50E+02	na	1.14E+02	na
107-05-1	3-Chloropropene (Allyl chloride)	1.25E+00	na	5.71E-01	na
107-06-2	1,2-Dichloroethane (Ethylene chloride)	4.17E+00	2.08E-03	1.90E+00	2.08E-03
107-13-1	Acrylonitrile	1.25E+02	1.23E-02	5.71E+01	1.23E-02

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
108-10-1	Methyl isobutyl ketone (4-Methyl-2-pentanone)	1.56E+00	na	7.14E-01	na
108-38-3	m-Xylene	6.25E-01	na	2.86E-01	na
108-39-4	3-Methylphenol (m-Cresol)	1.25E+00	na	5.71E-01	na
108-67-8	1,3,5-Trimethylbenzene	2.50E+00	na	1.14E+00	na
108-87-2	Methyl cyclohexane	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
109-99-9	Tetrahydrofuran	5.95E-01	1.74E-04	2.72E-01	1.74E-04
110-00-9	Furan (Oxacyclopentadiene)	6.25E+01	na	2.86E+01	na
110-54-3	n-Hexane	2.58E+00	na	1.03E+00	na
110-80-5	2-Ethoxyethanol	1.56E-01	na	7.14E-02	na
110-82-7	Cyclohexane	na	na	na	na
110-86-1	Pyridine	6.25E+01	na	2.86E+01	na
111-76-2	2-Butoxyethanol (Ethylene Glycol Monobutyl Ether)	2.50E-01	na	1.14E-01	na
111-90-0	2-(2-Ethoxyethoxy)-ethanol (Diethylene Glycol Monoethyl Ether)	2.08E+00	na	9.52E-01	na
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)	5.93E+00	6.64E-04	2.37E+00	2.66E-04
117-84-0	Di-n-octylphthalate	1.56E+00	na	7.14E-01	na
118-74-1	Hexachlorobenzene	2.48E+03	1.27E+00	9.94E+02	5.09E-01
120-82-1	1,2,4-Trichlorobenzene	1.92E+01	na	7.67E+00	na
121-14-2	2,4-Dinitrotoluene	3.13E+01	na	1.43E+01	na
121-44-8	Triethylamine	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	Tetrachloroethylene	1.25E+01	1.33E-03	5.71E+00	1.19E-03
129-00-0	Pyrene	1.47E+01	na	5.87E+00	na
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	6.94E-02	na	3.17E-02	na
156-59-2	cis-1,2-Dichloroethylene	1.25E+01	na	5.71E+00	na
206-44-0	Fluoranthene (1,2-Benzacenaphthene)	1.81E+01	na	7.24E+00	na
309-00-2	Aldrin	2.60E+05	5.29E+01	1.04E+05	2.12E+01
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	1.30E+02	1.64E-01	5.71E+01	7.20E-02
319-85-7	beta-Benzene hexachloride (beta-Lindane)	3.13E+02	4.51E-02	1.43E+02	2.06E-02
541-73-1	1,3-Dichlorobenzene	1.39E+02	na	6.35E+01	na
542-75-6	1,3-Dichloropropene (cis & trans)	4.17E+00	2.29E-03	1.90E+00	2.29E-03

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
621-64-7	N-Nitrosodi-N-propylamine	na	8.00E-02	na	8.00E-02
1314-62-1	Vanadium pentoxide	8.57E+00	na	3.43E+00	na
1330-20-7	Xylenes (mixtures)	6.25E-01	na	2.86E-01	na
1336-36-3	Polychlorinated Biphenyls	na	1.79E+01	na	7.16E+00
1336-36-3	Polychlorinated Biphenyls (lowest risk)	na	1.79E+01	na	7.16E+00
6533-73-9	Thallium carbonate	4.82E+04	na	1.93E+04	na
7429-90-5	Aluminum	1.93E-01	na	7.71E-02	na
7439-89-6	Iron	2.57E-01	na	1.03E-01	na
7439-93-2	Lithium	3.13E+00	na	1.43E+00	na
7439-96-5	Manganese	1.34E+00	na	6.12E-01	na
7439-97-6	Mercury metal vapor	na	na	na	na
7439-98-7	Molybdenum	1.25E+01	na	5.71E+00	na
7440-02-0	Nickel (soluble salts)	3.13E+00	na	1.43E+00	na
7440-22-4	Silver	1.25E+01	na	5.71E+00	na
7440-24-6	Strontium, Stable	1.04E-01	na	4.76E-02	na
7440-28-0	Thallium metal	5.84E+04	na	2.34E+04	na
7440-31-5	Tin	1.93E+00	na	7.71E-01	na
7440-36-0	Antimony	1.56E+02	na	7.14E+01	na
7440-38-2	Arsenic (inorganic)	3.14E+02	5.65E-02	1.25E+02	2.26E-02
7440-39-3	Barium	8.93E-01	na	4.08E-01	na
7440-41-7	Beryllium and compounds	3.13E+01	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
7440-45-1	Cerium (Ceric oxide 1306-38-3)	na	na	na	na
7440-48-4	Cobalt	5.79E+00	na	2.31E+00	na
7440-50-8	Copper	1.93E+00	na	7.71E-01	na
7440-62-2	Vanadium metal	1.10E+01	na	4.41E+00	na
7440-66-6	Zinc and compounds	3.24E-01	na	1.30E-01	na
7487-94-7	Mercuric chloride	1.29E+03	na	5.14E+02	na
7664-41-7	Ammonia	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
11096-82-5	Aroclor 1260	na	1.51E+00	na	6.05E-01
11097-69-1	Aroclor 1254	5.43E+06	8.68E+01	2.17E+06	3.47E+01
11104-28-2	Aroclor 1221	na	3.79E-01	na	1.52E-01
11141-16-5	Aroclor 1232	na	3.79E-01	na	1.52E-01
12672-29-6	Aroclor 1248	na	1.96E+01	na	7.82E+00
12674-11-2	Aroclor 1016	9.74E+04	5.45E+00	3.90E+04	2.18E+00
14797-55-8	Nitrate	3.91E-02	na	1.79E-02	na
14797-65-0	Nitrite	6.25E-01	na	2.86E-01	na

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
16065-83-1	Chromium (III) (insoluble salts)	5.14E-02	na	2.06E-02	na
16984-48-8	Fluorine anion	1.04E+00	na	4.76E-01	na
18540-29-9	Chromium (VI) (soluble salts)	2.57E+01	na	1.03E+01	na
53469-21-9	Aroclor 1242	na	1.79E+01	na	7.16E+00
na	Uranium (soluble salts)	1.04E+02	na	4.76E+01	na
na	Total Chromium (1:6 ratio CrVI:Cr III)				

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 C17.

4.0 REFERENCES

- DOE/EIS-0189, 1996, *Tank Waste Remediation System, Hanford Site, Richland, Washington, Final Environmental Impact Statement*, U.S. Department of Energy, Washington, D.C.
- DOE/LLW-93, 1991, *Performance Assessment Review Guide for DOE Low-Level Radioactive Waste Disposal Facilities*, U.S. Department of Energy, Washington, D.C.
- DOE M 435.1-1, 1999, *Radioactive Waste Management Manual*, Chapter IV, *Low Level Waste Requirements*, U.S. Department of Energy, Washington, D.C.
- DOE/ORP-2000-24 Revision 0, (formerly DOE/RL-97-69 Revision 0), 2001, *Hanford Immobilized Low-Activity Tank Waste Performance Assessment: 2001 Version*, U.S. Department of Energy - Richland, Richland, Washington.
- DOE/RL-91-45 Revision 3, 1995, *Hanford Site Risk Assessment Methodology*, U.S. Department of Energy - Richland, Richland, Washington.
- DOE/RL-96-16 Revision 1, 1997, *Screening Assessment and Requirements for a Comprehensive Assessment: Columbia River Comprehensive Impact Assessment*, U.S. Department of Energy - Richland, Richland, Washington.
- EPA/600/P-95/002Fa, 1997, *Exposure Factors Handbook*, U.S. Environmental Protection Agency, Washington, D.C.
- HNF-EP-0828, Revision 2, Mann, F. M., 1999, *Scenarios for the Hanford Immobilized Low-Activity Waste (ILAW) Performance Assessment*, Fluor Daniel Hanford, Inc., Richland, Washington.
- Miller, D. W., *Waste Disposal Effects on Ground Water*, Premier Press, Berkeley, CA, 1980.
- ORNL-TM/13401, *Performance Assessment for the Class L-II Disposal Facility*, Oak Ridge National Laboratory, Oak Ridge, Tennessee, 1997.
- PNNL-6415, Revision 11, Neitzel, D. A., ed., 1999, *Hanford Site National Environmental Policy Act (NEPA) Characterization*, Pacific Northwest National Laboratory, Richland, Washington.
- Putnam, J. J. and J. E. Allshouse, 1999, *Food Consumption, Prices, and Expenditures, 1970-97*, Statistical Bulletin No. 965, U.S. Department of Agriculture.
- RPP-13263, Revision 0, Mann, F. M., 2002, *Performance Objectives for the Hanford Immobilized Low-Activity Waste (ILAW) Performance Assessment*, CH2M Hill Hanford Group, Inc., Richland, Washington.

- RPP-14283, Revision 0, Mann, F. M., A. J. Knepp, J. W. Badden, and R. J. Puigh, 2003, *Performance Objectives for the Tank Farm Closure Risk Assessments*, CH2M Hill Hanford Group, Inc., Richland, Washington.
- SAND2001-2977, Cochran, J. R., W. E. Beyeler, D. E. Brosseau, 2001, *Compliance Assessment Document for the Transuranic Waste in the Greater Confinement Disposal Boreholes at the Nevada Test Site, Volume 2: Performance Assessment*, Sandia National Laboratories, Albuquerque, New Mexico.
- U.S. Environmental Protection Agency, 1991, *Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Factors*, OSWER Directive 9285.6-03 (March 25, 1991), Interim Final, EPA Office of Emergency and Remedial Response, Washington, D.C.
- U.S. EPA-10, 1991, *Supplemental Risk Assessment Guidance for Superfund*, U.S. Environmental Protection Agency, Region X, Seattle, Washington.
- Washington State Department of Agriculture, *Washington Agricultural Statistics 1993-1994*, 1994.
- Washington State University Cooperative Extension, *Home Gardens*, EB-422, 1980.
- WHC-SD-WM-EE-004, Revision 1, Kincaid, C. T., et al., 1995, *Performance Assessment of Grouted Double-Shell Tank Waste Disposal at Hanford*, Pacific Northwest National Laboratory and Westinghouse Hanford Company, Richland, Washington.
- WHC-EP-0645, Wood, M.I., et al., 1994, *Performance Assessment for the Disposal of Low-Level Waste in the 200 West Area Burial Grounds*, Westinghouse Hanford Company, Richland, Washington.
- WHC-SD-WM-TI-616, Rittmann, P. D., 1994, *Dose Estimates for the Solid Waste Performance Assessment*, Westinghouse Hanford Company, Richland, Washington.
- WHC-SD-WM-TI-707, Revision 0, 1995, Rittmann, P. D., *Data and Assumptions for Estimates of Radiation Doses for the Glass Low Level Waste Interim Performance Assessment*, Westinghouse Hanford Company, Richland, Washington.

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APPENDIX A
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DATA USED IN THE CALCULATIONS

This appendix summarizes the parameters and models used to calculate potential intakes of hazardous materials and convert them to radiation dose or some type of severity index for the various exposure scenarios. What follows is a description of each parameter, typical values, and the justification for the values chosen. Where these parameters differ from prior performance assessments for Hanford disposal sites, the differences are explained. The mathematical models are described to illustrate how the parameters are used in calculations.

For the most part this Revision 4 adds chemicals and updates toxicity parameters from those released in Revision 3. An additional change was made to the water inhalation amounts to use less extreme exposures. The discussion of data and models is divided into several topical areas, namely, nuclear and chemical properties, human activities, animal, plant, and soil characteristics.

An additional consideration is the potential effects on special groups of individuals who may be exposed in unique ways not normally considered. Information relevant to estimating the dose received by these special groups is included in each section.

A1.0 NUCLEAR PARAMETERS

The first parameters of interest are basic nuclear properties of the radionuclides that may be found in waste buried on the Hanford Site. The two main selection criteria for these nuclides are the radioactive half-life and the projected inventory in typical N-Reactor fuel. Radionuclides with half-lives greater than approximately one year are considered. If the nuclide is listed as a constituent in the waste stored in underground tanks or the burial grounds, it was included in the list.

Table A1 shows the decay half-life and the decay chain branching ratios. A branching ratio is the fraction of decays of a parent nuclide that produce a given progeny nuclide. These parameters are needed to determine the amount of a nuclide, and any radioactive progeny, that is present as a function of time. Values are taken from the Evaluated Nuclear Data File, Release VI (ENDF/B-VI). The conversion from seconds to years was carried out using the value 365.25 days per year.

Also shown on Table A1 are the short-lived progeny that are assumed to be in secular equilibrium with the parent. These short half-life progeny are also called "implicit daughters" because their radioactive emissions are not considered separately, but combined with the parent nuclide. When referring to the activity of these groups of nuclides, only the activity of the first member of the decay chain is shown. It is understood that there is additional activity in the progeny nuclides. For example, 1 Ci of Sr-90+D means 1 Ci Sr-90 and 1 Ci Y-90.

Table A1. Radionuclides to be Considered and Their Half Lives.

Nuclide	Half life (y)	Short-lived progeny in equilibrium with parent
H-3	12.33	
Be-10	1.600E+06	
C-14	5,730	
Na-22	2.6019	
Al-26	719,985	
Si-32+D	329.56	P-32
Cl-36	300,992	
K-40	1.277E+09	
Ca-41	102,999	
Ti-44+D	47.30	Sc-44
V-49	0.92539 (338 d)	
Mn-54	0.85454 (312.12 d)	
Fe-55	2.7299	
Fe-60	1,500,000	Co-60m
Co-60	5.2713	
Ni-59	74,999	
Ni-63	100.10	
Se-79	805,000	
Rb-87	4.800E+10	
Sr-90+D	28.149	Y-90
Zr-93	1.530E+06	
Nb-91	680	
Nb-93m	16.13	
Nb-94	20,300	
Mo-93	3,500	
Tc-99	211,097	
Ru-106+D	1.01736 (371.59 d)	Rh-106
Pd-107	6.50E+06	
Ag-108m+D	127.00	Ag-108 (0.087)
Cd-109	1.26653 (462.6 d)	
Cd-113m	14.10	
In-115	4.410E+14	
Sn-121m+D	54.998	Sn-121 (0.776)
Sn-126+D	246,000	Sb-126m, Sb-126 (0.14)
Sb-125	2.7299	
Te-125m	0.15880 (58 d)	
I-129	1.570E+07	
Cs-134	2.0619	
Cs-135	2.30E+06	
Cs-137+D	29.999	Ba-137m (0.9443)
Ba-133	10.520	
Pm-147	2.6233	
Sm-147	1.060E+11	
Sm-151	89.997	
Eu-150	35.798	
Eu-152	13.330	
Eu-154	8.5919	
Eu-155	4.680	
Gd-152	1.080E+14	
Ho-166m	1,200	
Re-187	5.000E+10	
Tl-204	3.7801	
Pb-205	1.520E+07	

Table A1. Radionuclides to be Considered and Their Half Lives.

Nuclide	Half life (y)	Short-lived progeny in equilibrium with parent
Pb-210+D	22.300	Bi-210
Bi-207	32.198	
Po-209	102.0	
Po-210	0.37886 (138.38 d)	
Ra-226+D	1,600	Rn-222, Po-218, Pb-214, Bi-214, Po-214(0.9998)
Ra-228+D	5.7498	Ac-228
Ac-227+D	21.769	Th-227(0.9862), Fr-223(0.0138), Ra-223, Rn-219, Po-215, Pb-211, Bi-211, Tl-207(.99725), Po-211(.00275)
Th-228+D	1.9129	Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Po-212(0.6406), Tl-208(0.3594)
Th-229+D	7,340	Ra-225, Ac-225, Fr-221, At-217, Bi-213, Po-213(0.9784), Tl-209(0.0216)
Th-230	75,380	
Th-232	1.405E+10	
Pa-231	32,759	
U-232	69.799	
U-233	159,198	
U-234	245,694	
U-235+D	7.037E+08	Th-231
U-236	2.342E+07	
U-238+D	4.468E+09	Th-234, Pa-234m, Pa-234 (0.0013)
Np-237+D	2.140E+06	Pa-233
Pu-236	2.8999	
Pu-238	87.697	
Pu-239	24,110	
Pu-240	6,563	
Pu-241+D	14.350	U-237 (2.39E-05)
Pu-242	373,507	
Pu-244+D	8.000E+07	U-240 (0.9988), Np-240m, Np-240 (0.0012)
Am-241	432.70	
Am-242m+D	141.00	Am-242(0.9955), Np-238(0.0045)
Am-243+D	7,370	Np-239
Cm-242	0.44611 (162.94 d)	
Cm-243	28.499	
Cm-244	18.100	
Cm-245	8,500	
Cm-246	4,730	
Cm-247+D	1.600E+07	Pu-243
Cm-248	339,981	
Cm-250+D	11,300	Pu-246(0.25), Am-246(0.25), Bk-250(0.14)
Bk-247	1,394	
Cf-248	0.91294 (333.45 d)	
Cf-249	350.60	
Cf-250	13.080	
Cf-251	897.98	
Cf-252	2.6449	

Notes:

- Parentheses in the second column show half-lives that are normally given in days.
- Parentheses in the third column show branching ratios that differ from 1.00. Short-lived progeny are radionuclides that are normally found in secular equilibrium with the parent nuclide. They typically have half-lives less than 30 days.
- Half-lives and branching ratios are from ENDF/B-VI, except for Se-79 and Sn-126. See DOE/ORP-2000-24 Revision 0, Section 3.2.2 for discussion of revisions to the half lives for Se-79 and Sn-126.

As noted in DOE/ORP-2000-24 Revision 0, *Hanford Immobilized Low-Activity Tank Waste Performance Assessment* (section 3.2.2), new measurements of the half-lives for Se-79 and Sn-126 show substantial increases. References for the revised half lives are Chu, et al. (1998), Chunsheng, et al. (1997), Yu, et al. (1993), and Zhang, et al. (1996). The newer values have been used in Table A1.

Table A2 shows the radioactive decay chains included in the exposure scenario calculations. Radioactive decay normally reduces the dose that a receptor could receive. However, in the cases shown on Table A2, the in-growth of the progeny nuclides with time may increase the dose from the parent nuclide. One example of this is Th-232, which has a very long half-life so that there is essentially no change in its activity during the year of exposure. Since the initial activity of the progeny nuclides (Ra-228 and Th-228) is assumed to be zero any increase will have maximum effect on the Th-232 doses. In addition, since the progeny accumulate according to their much shorter half-lives, they are able to increase the dose from Th-232 significantly.

The decay chains used in these calculations are limited to four radioactive members by the assumption that the decay times involved in the generation of unit dose factors will be less than 1000 years. At longer decay times, the ingrowth of progeny farther down the chain may be important. The longest decay times used in this report is 70 years.

Table A2. Decay Chains Actually Computed.

Fe-60	—<	Co-60			
	.9976				
Zr-93	—<	Nb-93m			
Mo-93	—<	Nb-93m			
Sb-125	—<	Te-125m			
	.230				
Pm-147	—<	Sm-147			
Eu-152	—<	Gd-152			
	.2792				
Pb-210	—<	Po-210			
Po-209	—<	Pb-205			
	.9974				
Ra-226	—<	Pb-210	—<	Po-210	
Ra-228	—<	Th-228			
Th-230	—<	Ra-226	—<	Pb-210	—<
					Po-210
Th-232	—<	Ra-228	—<	Th-228	
Pa-231	—<	Ac-227			
U-232	—<	Th-228			
U-233	—<	Th-229			
U-234	—<	Th-230	—<	Ra-226	—<
					Pb-210
U-235	—<	Pa-231	—<	Ac-227	
Pu-236	—<	U-232	—<	Th-228	
Pu-238	—<	U-234			
Pu-241	—<	Am-241	—<	Np-237	

Table A2. Decay Chains Actually Computed.

Pu-244	—<	Pu-240			
Am-241	—<	Np-237			
Am-242m	—< ↓ .827 —< .173	Cm-242 Pu-242	—<	Pu-238	—< U-234
Am-243	—<	Pu-239			
Cm-242	—<	Pu-238	—<	U-234	
Cm-243	—< ↓ —< .0024	Pu-239 Am-243			
Cm-244	—<	Pu-240			
Cm-245	—<	Pu-241	—<	Am-241	—< Np-237
Cm-247	—<	Am-243			
Cm-250	—< ↓ .14 —< .25	Cf-250 Cm-246	—< ↓ =		
Bk-247	—<	Am-243			
Cf-248	—<	Cm-244	—<	Pu-240	
Cf-249	—<	Cm-245	—<	Pu-241	—< Am-241
Cf-250	—<	Cm-246			
Cf-251	—<	Cm-247			
Cf-252	—<	Cm-248			
Notes:					
<ul style="list-style-type: none"> • Decay times are assumed to be less than 1000 years so that the in-growth of progeny with long half-lives can be ignored. • There is a slight increase in the Pu-238 and U-234 for the Am-242m decay chain that is not shown. This is a result of the low-probability alpha decay of Am-242m. The complete chain is, Am-242m(0.00455)→Np-238→Pu-238→U-234. 					

A2.0 CHEMICALS OF INTEREST

The list of hazardous chemicals used in the generation of unit hazard quotients and unit risk factors comes from PNNL-12040, *Regulatory Data Quality Objectives Supporting Tank Waste Remediation System Privatization Project*, 1998. Table 4.4 lists 125 organic compounds and Table 4.7 lists 51 inorganic compounds that are recommended for characterizing Hanford underground tank waste. In addition, Appendix B lists 1,227 compounds from the TWINS database. Of these, there are 410 compounds listed with at least 10 vapor hits or at least one solid/liquid hit.

The lists found in PNNL-12040 were compared with the list of chemicals for which there is toxicological data according to the Risk Assessment Information System (RAIS). The Oak Ridge National Laboratory (ORNL) maintains this toxicological data listing for human health risk assessments. The data may be obtained from the World Wide Web using the location

<http://risk.lsd.ornl.gov>. The values that were current as of March, 2004 were used for unit risk factors in the present document. The list of chemicals that are found in either the 410-chemical list (Table B.1 of PNNL-12040) or the 176-chemical list (Tables 4.4 and 4.7 of PNNL-12040) was compared with the 695-chemical RAIS database. There were 126 chemicals from PNNL-12040.

Additional sampling and analysis for the 241-C-106 Post-Retrieval Risk Assessment resulted in the addition of 35 more chemicals, bringing the new total to 161. The 161 common chemicals are shown in Table A3 along with the Chemical Abstract Service Reference Number (CASRN).

It is unlikely that any hazardous chemical has been omitted from the detailed study documented in PNNL-12040. In addition, it is assumed that the toxic materials of concern have been studied sufficiently that appropriate measures of their toxicity are available. It may be that serious toxins have not been studied in such detail at this point in time. The list given in Table A3 represents the most complete information relevant to tank waste available at the present time. The molecular weights, water solubilities, unitless Henry's Law constants (organics), and logarithms of the octanol-water constants are from the EPA software EPI Suite™ Version 3.11. EPI Suite is a collection of simple programs that can be run all at once using the EPIwin program. Molecular weights are from the DERMwin program. Water solubilities are from the WSKOWwin program. Finally, the Henry's law constants are from the HENRYwin program.

The unitless Henry's law constants for inorganics are based on observed ratios of airborne and liquid waste concentrations for radionuclides in boiling waste tanks. The number 1×10^{-10} is used rather than the default number (1.00) offered by EPI Suite Version 3.11. The application of these parameters is discussed in later sections.

Table A3. List of Chemicals.

CASRN	Chemical	Molecular Weight (g/mole)	Solubility in Water (mg/L)	Unitless Henry's Law Constant	Log(K _{ow})
50-32-8	Benzo[a]pyrene	252.32	1.62E-03	1.87E-05	6.13
53-70-3	Dibenz[a,h]anthracene	278.36	1.03E-03	5.03E-06	6.75
56-23-5	Carbon tetrachloride	153.82	7.93E+02	1.13E+00	2.83
57-12-5	Cyanide, free	27.03	1.00E+06	5.44E-03	-0.25
57-14-7	1,1-Dimethylhydrazine	60.10	1.00E+06	2.84E-06	-1.19
57-55-6	Propylene glycol (1,2-Propanediol)	76.10	1.00E+06	5.35E-09	-0.92
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)	290.83	8.00E+00	2.10E-04	3.72
60-29-7	Ethyl ether (Diethyl ether)	74.12	6.04E+04	5.03E-02	0.89
60-34-4	Methylhydrazine	46.07	1.00E+06	1.29E-06	-1.05
60-57-1	Dieldrin	380.91	2.50E-01	4.09E-04	5.40
62-75-9	N-Nitrosodimethylamine	74.08	1.00E+06	7.44E-05	-0.57
64-18-6	Formic acid	46.03	1.00E+06	6.83E-06	-0.54
67-56-1	Methanol (Methyl alcohol)	32.04	1.00E+06	1.86E-04	-0.77
67-64-1	Acetone (2-Propanone)	58.08	1.00E+06	1.62E-03	-0.24

Table A3. List of Chemicals.

CASRN	Chemical	Molecular Weight (g/mole)	Solubility in Water (mg/L)	Unitless Henry's Law Constant	Log(K _{ow})
67-66-3	Chloroform	119.38	7.95E+03	1.50E-01	1.97
67-72-1	Hexachloroethane	236.74	5.00E+01	1.59E-01	4.14
71-36-3	n-Butyl alcohol (n-Butanol)	74.12	6.32E+04	3.60E-04	0.88
71-43-2	Benzene	78.11	1.79E+03	2.27E-01	2.13
71-55-6	1,1,1-Trichloroethane (Methyl chloroform)	133.41	1.29E+03	7.03E-01	2.49
72-20-8	Endrin	380.91	2.50E-01	2.60E-04	5.20
74-83-9	Bromomethane	94.94	1.52E+04	2.55E-01	1.19
74-87-3	Methyl chloride (Chloromethane)	50.49	5.32E+03	3.61E-01	0.91
75-00-3	Ethyl Chloride	64.52	6.71E+03	4.54E-01	1.43
75-01-4	Vinyl chloride (Chloroethene)	62.50	8.80E+03	1.14E+00	1.62
75-05-8	Acetonitrile	41.05	1.00E+06	1.41E-03	-0.34
75-07-0	Acetaldehyde	44.05	1.00E+06	2.73E-03	-0.34
75-09-2	Dichloromethane (Methylene chloride)	84.93	1.30E+04	1.33E-01	1.25
75-15-0	Carbon disulfide	76.13	1.18E+03	5.89E-01	1.94
75-21-8	Ethylene Oxide (Oxirane)	44.05	1.00E+06	6.05E-03	-0.30
75-34-3	1,1-Dichloroethane (Ethylidene chloride)	98.96	5.04E+03	2.30E-01	1.79
75-35-4	1,1-Dichloroethylene	96.94	2.42E+03	1.07E+00	2.13
75-45-6	Chlorodifluoromethane	86.47	2.77E+03	1.66E+00	1.08
75-68-3	Chloro-1,1-difluoroethane, 1-	100.50	1.40E+03	2.40E+00	2.05
75-69-4	Trichlorofluoromethane	137.37	1.10E+03	3.96E+00	2.53
75-71-8	Dichlorodifluoromethane	120.91	2.80E+02	1.40E+01	2.16
76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane (CFC-113)	187.38	1.70E+02	2.15E+01	3.16
76-44-8	Heptachlor	373.32	1.80E-01	1.20E-02	6.10
78-83-1	Isobutanol	74.12	8.50E+04	4.00E-04	0.76
78-87-5	1,2-Dichloropropane	112.99	2.80E+03	1.15E-01	1.98
78-93-3	Methyl ethyl ketone (2-Butanone)	72.11	2.23E+05	2.33E-03	0.29
79-00-5	1,1,2-Trichloroethane	133.41	1.10E+03	3.37E-02	1.89
79-01-6	Trichloroethylene	131.39	1.28E+03	4.03E-01	2.42
79-10-7	2-Propenoic acid (Acrylic acid)	72.06	1.00E+06	1.51E-05	0.35
79-34-5	1,1,2,2-Tetrachloroethane (Acetylene tetrachloride)	167.85	2.87E+03	1.50E-02	2.39
79-46-9	2-Nitropropane	89.09	1.70E+04	4.86E-03	0.93
82-68-8	Pentachloronitrobenzene (PCNB)	295.34	4.40E-01	1.81E-03	4.64
83-32-9	Acenaphthene	154.21	3.90E+00	7.44E-03	3.92
84-66-2	Diethyl phthalate	222.24	1.08E+03	2.49E-05	2.42
84-74-2	Dibutyl phthalate	278.35	1.12E+01	7.40E-05	4.50
85-68-7	Butyl benzyl phthalate	312.37	2.69E+00	5.15E-05	4.73
87-68-3	Hexachlorobutadiene	260.76	3.20E+00	4.21E-01	4.78
87-86-5	Pentachlorophenol	266.34	1.40E+01	1.00E-06	5.12
88-06-2	2,4,6-Trichlorophenol	197.45	8.00E+02	1.06E-04	3.69
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)	240.22	5.20E+01	1.86E-05	3.56
91-20-3	Naphthalene	128.18	3.10E+01	1.80E-02	3.30

Table A3. List of Chemicals.

CASRN	Chemical	Molecular Weight (g/mole)	Solubility in Water (mg/L)	Unitless Henry's Law Constant	Log(K _{ow})
92-52-4	1,1'-Biphenyl	154.21	6.94E+00	1.26E-02	3.98
95-47-6	o-Xylene	106.17	1.06E+02	2.12E-01	3.12
95-48-7	2-Methylphenol (o-Cresol)	108.14	2.59E+04	4.90E-05	1.95
95-50-1	1,2-Dichlorobenzene (ortho-)	147.00	8.00E+01	7.85E-02	3.43
95-57-8	2-Chlorophenol	128.56	2.85E+04	4.58E-04	2.15
95-63-6	1,2,4-Trimethylbenzene	120.20	5.70E+01	2.52E-01	3.63
95-95-4	2,4,5-Trichlorophenol	197.45	1.20E+03	6.62E-05	3.72
98-86-2	Acetophenone	120.15	6.13E+03	4.25E-04	1.58
98-95-3	Nitrobenzene	123.11	2.09E+03	9.81E-04	1.85
100-25-4	1,4-Dinitrobenzene (para-)	168.11	6.90E+01	1.51E-05	1.46
100-41-4	Ethyl benzene	106.17	1.69E+02	3.22E-01	3.15
100-42-5	Styrene	104.15	3.10E+02	1.12E-01	2.95
100-51-6	Benzyl alcohol	108.14	4.29E+04	1.38E-05	1.10
106-42-3	p-Xylene	106.17	1.62E+02	2.82E-01	3.15
106-44-5	4-Methylphenol (p-Cresol)	108.14	2.15E+04	4.09E-05	1.94
106-46-7	1,4-Dichlorobenzene (para-)	147.00	8.13E+01	9.85E-02	3.44
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	187.86	3.91E+03	2.73E-02	1.96
106-99-0	1,3-Butadiene	54.09	7.35E+02	3.01E+00	1.99
107-02-8	2-Propenal (Acrolein)	56.06	2.12E+05	4.99E-03	-0.01
107-05-1	3-Chloropropene (Allyl chloride)	76.53	3.37E+03	4.50E-01	1.93
107-06-2	1,2-Dichloroethane (Ethylene chloride)	98.96	5.10E+03	4.82E-02	1.48
107-13-1	Acrylonitrile	53.06	7.45E+04	5.64E-03	0.25
108-10-1	Methyl isobutyl ketone (4-Methyl-2-pentanone)	100.16	1.90E+04	5.64E-03	1.31
108-38-3	m-Xylene	106.17	1.61E+02	2.93E-01	3.20
108-39-4	3-Methylphenol (m-Cresol)	108.14	2.27E+04	3.50E-05	1.96
108-67-8	1,3,5-Trimethylbenzene	120.20	4.82E+01	3.58E-01	3.42
108-87-2	Methyl cyclohexane	98.19	1.40E+01	1.76E+01	3.61
108-88-3	Toluene (Methyl benzene)	92.14	5.26E+02	2.71E-01	2.73
108-90-7	Chlorobenzene	112.56	4.98E+02	1.27E-01	2.84
108-94-1	Cyclohexanone	98.15	2.50E+04	3.68E-04	0.81
108-95-2	Phenol (Carbolic acid)	94.11	8.28E+04	1.36E-05	1.46
109-99-9	Tetrahydrofuran	72.11	1.00E+06	2.88E-03	0.46
110-00-9	Furan (Oxacyclopentadiene)	68.08	1.00E+04	2.21E-01	1.34
110-54-3	n-Hexane	86.18	9.50E+00	7.36E+01	3.90
110-80-5	2-Ethoxyethanol	90.12	1.00E+06	1.92E-05	-0.32
110-82-7	Cyclohexane	84.16	5.50E+01	6.13E+00	3.44
110-86-1	Pyridine	79.10	1.00E+06	4.50E-04	0.65
111-76-2	2-Butoxyethanol (Ethylene Glycol Monobutyl Ether)	118.18	1.00E+06	6.54E-05	0.83
111-90-0	2-(2-Ethoxyethoxy)-ethanol (Diethylene Glycol Monoethyl Ether)	134.18	1.00E+06	9.11E-10	-0.54
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)	390.57	2.70E-01	1.10E-05	7.60
117-84-0	Di-n-octylphthalate	390.57	2.00E-02	1.05E-04	8.10

Table A3. List of Chemicals.

CASRN	Chemical	Molecular Weight (g/mole)	Solubility in Water (mg/L)	Unitless Henry's Law Constant	Log(K _{ow})
118-74-1	Hexachlorobenzene	284.78	6.20E-03	6.95E-02	5.73
120-82-1	1,2,4-Trichlorobenzene	181.45	4.90E+01	5.80E-02	4.02
121-14-2	2,4-Dinitrotoluene	182.14	2.70E+02	2.21E-06	1.98
121-44-8	Triethylamine	101.19	7.37E+04	6.09E-03	1.45
122-39-4	Diphenylamine	169.23	5.30E+01	1.39E-04	3.50
123-91-1	1,4-Dioxane (Diethylene oxide)	88.11	1.00E+06	1.96E-04	-0.27
126-73-8	Tributyl Phosphate	266.32	2.80E+02	6.13E-06	4.00
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)	67.09	2.54E+04	1.01E-02	0.68
127-18-4	Tetrachloroethylene	165.83	2.06E+02	7.23E-01	3.40
129-00-0	Pyrene	202.26	1.35E-01	4.86E-04	4.88
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	88.11	8.00E+04	5.48E-03	0.73
156-59-2	cis-1,2-Dichloroethylene	96.94	3.50E+03	1.67E-01	1.86
206-44-0	Fluoranthene (1,2-Benzacenaphthene)	202.26	2.60E-01	3.62E-04	5.16
309-00-2	Aldrin	364.92	1.70E-02	1.80E-03	6.50
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	290.83	8.00E+00	4.99E-04	3.80
319-85-7	beta-Benzene hexachloride (beta-Lindane)	290.83	8.00E+00	1.80E-05	3.78
541-73-1	1,3-Dichlorobenzene	147.00	1.25E+02	1.07E-01	3.53
542-75-6	1,3-Dichloropropene (cis & trans)	110.97	2.80E+03	1.45E-01	2.03
621-64-7	N-Nitrosodi-N-propylamine	130.19	1.30E+04	2.20E-04	1.36
1314-62-1	Vanadium pentoxide	181.88	1.56E+02	1.00E-10	2.97
1330-20-7	Xylenes (mixtures)	106.17	1.06E+02	2.71E-01	3.12
1336-36-3	Polychlorinated Biphenyls	291.99	2.77E-01	1.40E-02	6.29
1336-36-3	Polychlorinated Biphenyls (lowest risk)	291.99	2.77E-01	1.40E-02	6.29
6533-73-9	Thallium carbonate	468.78	5.20E+04	1.00E-10	-0.86
7429-90-5	Aluminum	30.01	5.94E+04	1.00E-10	0.33
7439-89-6	Iron	55.85	6.24E+05	1.00E-10	-0.77
7439-93-2	Lithium	6.94	1.76E+05	1.00E-10	-0.77
7439-96-5	Manganese	54.94	8.72E+04	1.00E-10	0.23
7439-97-6	Mercury metal vapor	200.59	6.00E-02	1.00E-10	0.62
7439-98-7	Molybdenum	95.94	7.66E+04	1.00E-10	0.23
7440-02-0	Nickel (soluble salts)	58.69	4.22E+05	1.00E-10	-0.57
7440-22-4	Silver	107.87	7.05E+04	1.00E-10	0.23
7440-24-6	Strontium, Stable	87.62	8.04E+04	1.00E-10	0.23
7440-28-0	Thallium metal	204.38	2.65E+04	1.00E-10	0.23
7440-31-5	Tin	120.73	7.91E+03	1.00E-10	1.29
7440-36-0	Antimony	124.78	2.30E+04	1.00E-10	0.73
7440-38-2	Arsenic (inorganic)	77.95	3.47E+04	3.16E-09	0.68
7440-39-3	Barium	137.33	5.48E+04	1.00E-10	0.23
7440-41-7	Beryllium and compounds	9.01	1.49E+05	1.00E-10	-0.57
7440-42-8	Boron and borates only	13.84	4.37E+04	1.00E-10	0.23
7440-43-9	Cadmium	112.41	1.23E+05	1.00E-10	-0.07
7440-45-1	Cerium (Ceric oxide 1306-38-3)	140.12	5.33E+04	1.00E-10	0.23

Table A3. List of Chemicals.

CASRN	Chemical	Molecular Weight (g/mole)	Solubility in Water (mg/L)	Unitless Henry's Law Constant	Log(K _{ow})
7440-48-4	Cobalt	58.93	8.75E+04	1.00E-10	0.23
7440-50-8	Copper	63.55	4.21E+05	1.00E-10	-0.57
7440-62-2	Vanadium metal	50.94	8.64E+04	1.00E-10	0.23
7440-66-6	Zinc and compounds	67.41	3.44E+05	1.00E-10	-0.47
7487-94-7	Mercuric chloride	271.50	6.90E+04	1.00E-10	-0.22
7664-41-7	Ammonia	17.03	3.74E+03	1.41E-04	-1.38
7723-14-0	Phosphorus, white	34.00	2.05E+05	9.97E-11	-0.27
7782-41-4	Fluorine (soluble fluoride)	38.00	1.69E+00	1.00E-10	0.22
7782-49-2	Selenium and compounds	80.98	8.14E+04	3.98E-11	0.24
8001-35-2	Toxaphene	413.82	5.50E-01	2.45E-04	5.78
11096-82-5	Aroclor 1260	395.33	2.84E-04	1.37E-02	8.27
11097-69-1	Aroclor 1254	326.44	3.40E-03	1.16E-02	6.79
11104-28-2	Aroclor 1221	188.66	4.83E+00	9.32E-03	4.53
11141-16-5	Aroclor 1232	188.66	4.83E+00	9.32E-03	4.53
12672-29-6	Aroclor 1248	291.99	5.32E-02	1.80E-02	6.34
12674-11-2	Aroclor 1016	257.55	2.70E-01	8.17E-03	5.62
14797-55-8	Nitrate	62.00	9.09E+04	1.00E-10	0.21
14797-65-0	Nitrite	47.01	1.20E+05	8.38E-06	0.06
16065-83-1	Chromium (III) (insoluble salts)	52.00	na	1.00E-10	na
16984-48-8	Fluorine anion	19.00	1.69E+00	1.00E-10	0.22
18540-29-9	Chromium (VI) (soluble salts)	52.00	na	1.00E-10	na
53469-21-9	Aroclor 1242	291.99	2.77E-01	1.40E-02	6.29
na	Uranium (soluble salts)	238.00	na	1.00E-10	na

Notes:

- CASRN = Chemical Abstract Service Reference Number
- Molecular Weights, Water Solubilities, and most Unitless Henry's Law constants are from the EPI Suite software version 3.11. The Henry's Law constants for inorganic chemicals are based on observed partition fractions for radionuclides in high level tank waste.
- Missing values are indicated with "na", which means "not available".

Version 3.11 of the EPI Suite software reports some of the numbers it calculates incorrectly. This shows up in the calculation of the Log Kow values as well as numbers that are calculated from them. It occurs when more than one chemical is found with a similar structure. The software reports the last chemical on the list rather than the chemical that was requested. This error was observed for Dibenz[a,h]anthracene (53-70-3), gamma-Benzene hexachloride (gamma-Lindane) (58-89-9), Dieldrin (60-57-1), cis-1,2-Dichloroethylene (156-59-2), alpha-Benzene hexachloride (alpha-Lindane) (319-84-6), and beta-Benzene hexachloride (beta-Lindane) (319-85-7).

With the exception of the State of Washington's MTCA, the chemicals are not separated into volatile and non-volatile in the calculations presented in the main text. Instead, the appropriate chemical property is used to determine the relative volatility. One such property is the Henry's Law Constant, which is the ratio of the saturated vapor concentration to the aqueous concentration. The unitless Henry's Law Constant (H') may be converted into the units atm per

mole/L using the factor $RT=24.465 \text{ L-atm/mole}$, where R is the idea gas law constant ($0.082057 \text{ L-atm/mole-K}$) and T is the temperature (298.15 K). This is shown in the equation below.

$$K_{\text{HENRY}} = H' R T$$

The polychlorinated biphenyls (PCBs) are separated into two categories based on the types of chemicals that may be present. The lowest risk PCBs are for mixtures containing less than 0.5% of chemicals with more than 4 chlorine atoms.

Many of the organic chemicals on the list in Table A3 decompose in the environment by the action of sunlight, reactions with other chemicals (oxygen especially), heat, and biological action. The decomposition half-lives are not included in the calculations. In effect, it is assumed that the chemicals do not decompose. For inorganic chemicals this is largely true. However, many organic chemicals have measured half-lives that are less than one year. Examples from Table 1 in Jury (1990) are toluene (50 days) and xylene (110 days).

A3.0 HUMAN PARAMETERS

In the various exposure scenarios the data for humans falls into two categories. The first data category is needed to estimate the contaminant intakes. This includes the dietary consumption rates, the breathing rate, duration of external exposures, extent and duration of dermal contact, and the like. The second data category is toxicity of the various hazardous materials. For radionuclides, the measures of toxicity are the internal and external dose factors, and the cancer induction risk coefficients. For chemicals, the measures of toxicity are the hazard index and the cancer induction slope factors. Each of these parameters is discussed in this section.

A3.1 Dietary Consumption Rates

In this section the ingestion rates for all types of produce for all exposure scenarios are presented and compared. In addition, consumption rates for water and trace amounts of soil are given. Finally, garden size is discussed because the assumed garden size controls soil concentration in the garden of the post-intrusion resident.

A3.1.1 Food and Water

A summary of the food and water consumption rates is given in Table A4. Specific food items are listed in the notes to the table. All values are in units of kilograms. The items ingested are separated into three general categories, namely, plants, animal products, and miscellaneous items. Each of these categories has a short list of items that represents related foods. The columns show distinct consumers represented in the various exposure scenarios.

Edible plants are grouped in to four types. "Leafy" refers to vegetables whose leafy parts are normally eaten, such as lettuce, cabbage and spinach. "Other" is termed "protected" produce because the edible portion is underground or has some type of non-edible covering. Protected produce includes both fruit and vegetables. Examples are melons, avocados, potatoes, onions,

peanuts, tree nuts, artichokes, carrots, garlic, onions, radishes, green peas, chili peppers, and sweet corn. "Fruit" is termed "exposed" produce because airborne contaminants may deposit on the edible portion, but the surface area is small compared to leafy vegetables. Exposed produce includes both fruits and vegetables. Examples of exposed produce are apples, apricots, asparagus, bell peppers, broccoli, Brussels sprouts, cauliflower, celery, cherries, cranberries, cucumbers, eggplant, grapes, peaches, pears, plums, snap beans, squash, strawberries, and tomatoes. "Grains" refers to cereals consumed by humans, such as corn (for meal), oats, soybeans, and wheat. Rice is excluded due to the cooler climate.

For a given element, the protected and exposed categories have very similar model parameters (discussed in Section A5.0), eg., dry-to-wet ratio, crop yield, translocation factor, and root uptake factor. Thus, the issue of whether to include below ground vegetables in the protected or exposed category when dealing with soil contamination is not important. The resulting intakes of radionuclides or toxic chemicals are similar. In effect, there are only three distinct groups of garden produce, namely, leafy vegetables, grains, and everything else.

Edible animal products refer to "Beef", "Milk", "Poultry", and "Eggs". The animal products may be contaminated if the animals ingest contaminated feed and drink. The various animals raised for foods are separated into the two broad categories "Beef" and "Poultry". If the animal resembles a cow (e.g. sheep, goats or pigs), it is "Beef". If the animal resembles a bird (e.g. ducks and turkeys), it is "Poultry". The names simply refer to the most likely animal. "Milk" refers to fresh milk as well as yogurt, ice cream, and condensed milk. In addition, no distinction is made between goat's milk and cow's milk. "Eggs" refers to chicken eggs exclusively.

The miscellaneous category includes "Fish", "Game", and "Water". "Fish" refers to fresh-water fish and shellfish. "Game" refers to wild animals harvested for food, such as deer and waterfowl. "Water" refers to drinking water and beverages made from local water sources.

The column labeled "EPA" comes from an EPA analysis of the 1977-78 USDA Nationwide Food Consumption Survey (Yang and Nelson 1986). The consumption parameters for the "West" region were used in prior Hanford Site disposal facility performance assessments. These consumption rates are averages for all age groups. Game animals were not included. The non-dairy beverage consumption rates measured by the EPA (Yang and Nelson 1986) for the western region are 1.48 liters per day (540 L/y). The grouted waste performance assessment used 1.84 liters per day (672 L/y) (Roseberry and Burmaster 1992). The traditional assumption widely used in other performance assessments is 2 liters per day (730 L/y), which is 35 percent higher than the EPA average and 9 percent higher than the grouted waste PA.

The column labeled "USDA" comes from indirect estimates of average per capita food consumption based on food production in the United States (Putnam and Allshouse, 1999). Losses from exports, industrial uses, and end-of-year stocks were taken into account. The other and fruit consumption rates do not include bananas, pineapples, or citrus fruits, because they are not grown in southeastern Washington. Similarly, the grain consumption rate excludes rice. Game meat was not included in the study. The authors concede "fish consumption is likely understated". However, the EPA Exposure Factors Handbook (EPA/600-P-95/002Fa) recommends a total fish consumption rate for the general population that is just 11% larger (7.34 kg/y). Beef includes all red meats. The total milk equivalent consumed per person is given

as 579.8 lb/y (263 kg/y). Deducting cheeses and other milk products unlikely to be produced at home leaves 116 kg/y. The owner of the cow is assumed to consume 58 L of milk during the year, which is 22% of the total milk equivalent and 50% of the home milk consumption. These fractions are derived from the EPA exposure factors handbook (EPA/600-P-95/002Fa), which shows 20% to 25% for all dairy products in Table 13-71 under "Questionnaire Response". Note that when converting volumes of milk to mass units, a density of 1.03 kg/L is used. Egg consumption is given as 238.7 per person in 1997. To estimate annual consumption rate shown in Table A4, this was rounded to 240, and an average egg weight of 2 ounces (57 g) was assumed.

Comparing the food and water consumption rates from EPA with those from USDA, only fish consumption shows a small decrease. All other food items have larger intake rates. The values for exposed produce (fruit) and poultry show the largest increase. The USDA column will be used to calculate unit dose factors for the post-intrusion resident, the all pathways farmer, and the Columbia River population scenarios. This differs from previous Hanford performance assessments and leads to a small increase in the doses from the food pathway.

The column labeled "HSRAM" gives the food and water consumption rates for adults in the residential and agricultural scenarios found in DOE/RL-91-45 Revision 3, (HSRAM). The consumption parameters listed in that document for the residential and agricultural scenarios are presented in Table A4. The HSRAM gives just two types of garden produce, namely, fruit and vegetables, for the residential and agricultural scenarios. The vegetable consumption rate was separated into leafy and other by keeping the same relative amounts found in the USDA column.

The game consumption rate has been modified from the HSRAM, which lists 1 g/d animal fat. In Paustenbach (1989) the average successful hunter consumes 60 g/d (22 kg/y), which is about half of the total edible portion of one deer. The animal fat is 1.4%, hence, the animal fat consumption rate is 0.84 g/d, which is rounded to 1 g/d in HSRAM. A modifying factor of 0.19 is used to include the hunter success rate, i.e., the fraction of people who hunt that actually obtain a deer. In Table A4 the mass of deer meat is listed rather than animal fat. The hunter success rate factor is included in the value shown (4.2 kg/y).

The fish consumption rate is the HSRAM value of $(27 \text{ g/d})(365 \text{ d/y})=9,900 \text{ g/y}$, which is considerably larger than the values recommended in the Exposure Factors Handbook (EPA/600-P-95/002Fa Section 10), which lists 6.6 g/d fresh water fish, and 20.1 g/d total as the recommended population averages.

The EPA and USDA numbers must be adjusted for the fraction of food grown locally. The HSRAM values already include these adjustments. These fractions are based on the EPA Exposure Factors Handbook (EPA/600/8-89/043). For garden produce 25 percent of the vegetable diet comes from the garden. The other 75 percent is obtained from uncontaminated sources. For animal products, 50 percent of the animal products (including fish) are locally produced and thus contaminated. Note that the updated Exposure Factors Handbook (EPA/600-P-95/002Fa) gives somewhat different values. The 25 percent and 50 percent fractions continue to represent the Exposure Factors Handbook values (see Table 13-71 under Questionnaire Response). The adjusted annual intakes are shown in Table A5.

Table A4. Food and Water Consumptions Rates (kg/y).

	EPA	USDA	HSRAM	NASR
Plants:				
Leafy:	16.4	17.8	5.0	16
Other:	55.6	86.5	24.2	77
Fruit:	38.4	85.8	15.3	76
Grain:	74.0	81.9	0	73
Animal Products:				
Beef:	42.0	50.3	27.4	34
Milk:	104	116	110	226
Poultry:	10.6	29.4	0	20
Eggs:	10.6	13.6	0	9.1
Miscellaneous Items:				
Fish:	6.75	6.58	9.9	197
Game:	0	0	4.2	70
Water:	540	545	730	1,095

Notes:

- The column labeled "EPA" comes from an EPA analysis of the 1977-78 USDA Nationwide Food Consumption Survey (Yang and Nelson 1986). These values are shown for comparison with prior performance assessments.
- The column labeled "USDA" comes from indirect estimates of average per capita food consumption based on food production in the United States (Putnam and Allshouse, 1999). Losses such as from exports, industrial uses, and end-of-year stocks are taken into account. These values are used in the Post-Intrusion Resident and All Pathways Farmer exposure scenarios.
- The column labeled "HSRAM" gives the food and water consumption rates for adults in the recreational, residential, and agricultural scenarios. The water ingestion rate for children is half the value shown. The food consumption rates include adjustment for locally grown fractions.
- The column labeled "NASR" gives the food and water consumption rates for the Native American Subsistent Resident. These are based on the Columbia River Comprehensive Impact Assessment (DOE/RL-96-16). The 70 kg/y in the row labeled "Game" is composed of 22 kg/y deer, 32 kg/y wild birds, and 16 kg/y wild bird eggs.
- "Leafy" = cabbage, lettuce, and spinach
- "Other" = protected produce, namely, avocados, melons, artichokes, beets, carrots, chili peppers, sweet corn, garlic, green peas, lima beans, onions, potatoes, radishes, and tree nuts.
- "Fruit" = exposed produce, namely, apples, apricots, cherries, cranberries, grapes, peaches & nectarines, pears, plums & prunes, strawberries, asparagus, bell peppers, broccoli, brussels sprouts, cauliflower, celery, cucumbers, eggplant, snap beans, and tomatoes.
- "Grain" = wheat, rye, corn, oat, and barley (everything except rice).
- "Beef" = all red meats
- "Milk" = beverage milks, yogurt, fluid cream products, frozen dairy products, condensed & evaporated milk (to convert USDA milk volumes to units of mass, a density of 1.03 kg/L was used)
- "Poultry" = chicken and turkey
- "Eggs" = for the USDA value, the number of eggs consumed (240 per year) is converted to mass units assuming the average mass of an egg is 2 ounces (57 g)
- "Fish" = includes shellfish
- "Water" = includes water added to prepare coffee, tea, soft drinks, beer and distilled sprits, in addition, tap water consumption is assumed to be 25 gallons (95 L) per year.

The column labeled "NASR" gives the food and water consumption rates for the Native American Subsistent Resident (NASR). These are from the Columbia River Comprehensive Impact Assessment (CRCIA) (DOE/RL-96-16 Section 5.1.4.1). Slightly different parameter values are presented in a paper by Harris and Harper (1997). The CRCIA model generally leads to larger intakes and resulting doses or risks. Hence, the CRCIA model is used in this report. The CRCIA gives just one value for consumption of fruit and vegetables (660 g/d). This was separated into the four types shown by keeping the same relative amounts found in the USDA column.

The NASR values for animal protein (150 g/d) and organ meat (54 g/d) shown in Table 5.7 of DOE/RL-96-16 were assumed to include 60 g/d for deer (half of one animal per year). Thus the total consumption rate for beef, poultry, and eggs was taken to be $150+54-60=144$ g/d. This was distributed over the beef, poultry, and eggs by keeping the same relative amounts found in the USDA column. The value shown in Table A4 for game is composed of the deer (60 g/d), upland birds and waterfowl (88 g/d), and bird eggs (45 g/d).

The NASR food consumption rates are not adjusted for the fraction locally produced. All of the plant and animal products consumed by the NASR are locally grown. When the EPA and USDA columns are adjusted for the locally grown fractions, the NASR consumption rates are greatest for all food types. Thus, the NASR represents a bounding case.

Table A5. Food and Water Consumptions Rates for the Exposure Scenarios.

Food Consumed (kg/y)	All Pathways Farmer	Native American	Columbia River Population	HSRAM Recreational	HSRAM Residential	HSRAM Agricultural
Leafy	4.45	16	8.9	0	5	5
Other	21.625	77	43.25	0	24.2	24.2
Fruit	21.45	76	42.9	0	15.3	15.3
Grain	0	0	0	0	0	0
Beef	25.15	34	25.15	0	0	27.4
Milk	58	226	58	0	0	110
Poultry	14.7	20	14.7	0	0	0
Eggs	6.8	9.1	6.8	0	0	0
Fish	3.29	197	0.003	9.9	9.9	9.9
Game	0	22	0	4.2	0	4.2
Wild Birds	0	32	0	0	0	0
Wild Eggs	0	16	0	0	0	0
Water	545	1,095	545	14	730	730

Notes:

- The post-intrusion scenarios use the same dietary intakes as shown for the All Pathways Farmer. The Suburban Garden case uses only the vegetable amounts, while the Urban Pasture case uses only the milk amount.
- The HSRAM Industrial worker only consumes 1 L/d of drinking water while at work. The total annual intake is 250 L/y.
- The State of Washington MTCA scenarios use 2 L/d or 730 L/y for water. The fish consumption rate for Method B is 27 g/d (9.9 kg/y), and the fish consumption rate for Method C is 10.8 g/d (3.94 kg/y).

Wild game is not included in Table A5 for the All Pathways Farmer because this is an average individual. Hence, the game intake would be small and contribute very little to the total dose or risk or hazard index. If the average value for the HSRAM Recreational Scenario were used for the All Pathways Farmer, the meat intake would increase by about 17%. Since the wild game is not as contaminated as the cow, the resulting dose from a contaminated deer can be neglected. The consumption of wild game by the population is not included for the same reason. It is a minor addition to the total dose or risk or hazard index.

For exposure of the population along the Columbia River, parameters are scaled up by the assumed total population of 5 million. Two exceptions are water intake and fish consumption. The average drinking rate of 545 L/y per person (Putnam and Allshouse 1999) will be used. About half of this number is water, while the rest is various other beverages, most of which are derived from drinking water supplies. The contaminated fraction of the average diet is assumed to be 50%, due to widespread irrigation. The other 50% is obtained from non-irrigated sources or imported from other regions.

The quantity of contaminated fish consumed by the population along the Columbia River is limited by what the river is able to produce. The total mass of fish harvested from the Columbia River annually and consumed locally is approximately 15 metric tons (PNNL-9823). The average amount of fish consumed by 5 million people is thus 3 grams per year per person.

A3.1.2 Garden Area Determination

From the annual consumption of garden produce it is possible to estimate the minimum garden area needed to supply an individual. This area is required for intruder calculations in which the exhumed waste is spread over a garden.

The quantity of food derived from the garden is proportional to the garden size. To estimate food production per unit garden area, two approaches were considered. The first is commercial food production in Washington State (WA Department of Agriculture 1994). Values for production per acre and per square meter are shown on Table A6. "cwt" means 100 pounds. Bushels of grain were assumed to have a density 70 percent that of water (700 kg/m^3). Thus a bushel of grain is assumed to weigh about 54 lb. The categories used for human consumption are from Table A4. The average person consumes the amount shown, in kg/y. Based on the average food production rate, the necessary garden area is 233 m^2 . This total area is mostly needed for production of grains. This area also requires an efficient gardening operation to succeed.

The second approach to estimating garden size uses garden production estimates published by the Washington State University (WSU) Cooperative Extension (1980). Values are listed in Table A7. The referenced document provides estimates of pounds of produce per 10-foot row in a garden. In addition, it gives recommended row spacing. The spacing was treated as the row width to compute production per unit area. The USDA average annual consumption rates from Table A4 were used to determine garden area needs. The WSU production estimates are higher than the commercial production averages hence the needed garden area is smaller (207 m^2). These were assumed to be optimum values under excellent growing conditions.

The post-intrusion resident's garden is assumed to supply vegetables and fruit only. Grains are excluded. Thus, a 100 m² garden supplies 100% of the garden produce needs of a single adult over a year's time, or 25% of the garden produce needs of a family of four. Note that this area is half that used in the 2001 ILAW PA (DOE/ORP-2000-24) due to the elimination of grains. However, it represents a marked decrease from other Hanford performance assessments, which use a garden area of 2,500 m².

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 m² (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 m² based on food consumption.

Table A6. Commercial Food Production as a Basis for Garden Size.

Type of Produce	Yield per acre	Yield kg/m ²	Garden Area, m ²
<i>Leafy Vegetables</i>	<i>17.8 kg/y</i>	<i>2.35</i>	<i>7.6 m²</i>
Cabbage			
Chard			
Lettuce	210 cwt	2.35	
Spinach			
<i>Exposed Produce</i>	<i>85.8 kg/y</i>	<i>1.65</i>	<i>51.8 m²</i>
Apple	17 tons	3.81	
Apricots	6.23 tons	1.40	
Asparagus	35 cwt	0.39	
Broccoli			
Brussel Sprouts			
Bushberries	7,000 lb	0.78	
Cauliflower			
Cherry	6.93 tons	1.55	
Cucumber			
Eggplant			
Grape	10.83 tons	2.43	
Hops	1,884 lb	0.21	
Peach	10 tons	2.24	
Pear	15 tons	3.36	
Plums & Prunes	8.4 tons	1.88	
Rhubarb			
Snap Bean	90 cwt	1.01	
Strawberry	7,000 lb	0.78	
Tomato			
<i>Protected Produce</i>	<i>86.5 kg/y</i>	<i>2.48</i>	<i>34.9 m²</i>
Bean (dry)	19 cwt	0.21	
Beet			
Carrot	580 cwt	6.50	
Kohlrabi			
Lentils	1340 lb	0.15	
Muskmelon			
Onion	360 cwt	4.04	

Table A6. Commercial Food Production as a Basis for Garden Size.

Type of Produce	Yield per acre	Yield kg/m ²	Garden Area, m ²
Parsnip			
Peas	38 cwt	0.43	
Potato	590 cwt	6.61	
Radishes			
Squash			
Sweet Corn	150 cwt	1.68	
Tree Nuts	0.87 tons	0.20	
Turnip			
Watermelon			
<i>Grains</i>	<i>81.9 kg/y</i>	<i>0.59</i>	<i>138.3 m²</i>
Barley	67 bu	0.41	
Corn (for meal)	190 bu	1.16	
Oats	68 bu	0.41	
Rye			
Wheat	63.6 bu	0.39	
Total Garden Area:			232.6 m²
Notes:			
<ul style="list-style-type: none"> • Food production data is from <i>Washington Agricultural Statistics 1993-1994</i>. • Average consumption rates (italics) are from Putnam and Allhouse, 1999. • A bushel of grain is assumed to have a density 70% of water, so that a bushel weighs 54 lb. 			

Table A7. Homeowner Food Production as a Basis for Garden Area.

Type of Produce	Yield lb/10 ft	Row Spacing Inches	Yield kg/m ²	Garden Area, m ²
<i>Leafy Vegetables</i>	<i>17.8 kg/y</i>		<i>4.48</i>	<i>4.0 m²</i>
Cabbage	10	24	2.44	
Chard	30	18	9.76	
Lettuce	10	18	3.25	
Spinach	5	12	2.44	
<i>Exposed Produce</i>	<i>85.8 kg/y</i>		<i>2.09</i>	<i>41.0 m²</i>
Apple		12		
Apricots		12		
Asparagus	5	24	1.22	
Broccoli	10	24	2.44	
Brussel Sprouts	10	24	2.44	
Bushberries		12		
Cauliflower	8	24	1.95	
Cherry		12		
Cucumber	12	24	2.93	
Eggplant	8	36	1.30	
Grape		12		
Hops	0.1	1	0.59	
Peach		12		
Pear		12		
Plums & Prunes		12		

Table A7. Homeowner Food Production as a Basis for Garden Area.

Type of Produce	Yield lb/10 ft	Row Spacing inches	Yield kg/m ²	Garden Area, m ²
Rhubarb	15	36	2.44	
Snap Bean	6	18	1.95	
Strawberry		12		
Tomato	30	48	3.66	
<i>Protected Produce</i>	<i>86.5 kg/y</i>		<i>3.85</i>	<i>22.5 m²</i>
Bean (dry)		12		
Beet	10	12	4.88	
Carrot	12	12	5.86	
Kohlrabi	7	18	2.28	
Lentils		12		
Muskmelon	30	72	2.44	
Onion	10	12	4.88	
Parsnip	10	18	3.25	
Peas	10	18	3.25	
Potato	20	24	4.88	
Radishes	4	6	3.91	
Squash	25	48	3.05	
Sweet Corn	10	24	2.44	
Tree Nuts		12		
Turnip	20	18	6.51	
Watermelon	40	96	2.44	
<i>Grains</i>	<i>81.9 kg/y</i>		<i>0.59</i>	<i>139.8 m²</i>
Barley	0.1	1	0.59	
Corn (for meal)	0.1	1	0.59	
Oats	0.1	1	0.59	
Rye	0.1	1	0.59	
Wheat	0.1	1	0.59	
Total Garden Area:				207.3 m²
Notes:				
<ul style="list-style-type: none"> • Food production data from <i>Home Gardens</i>, WSU Cooperative Extension Report EB-422. • Average consumption rates (italics) are from Putnam and Allshouse, 1999. 				

A3.1.3 Soil Ingestion

Inadvertent soil ingestion refers to trace amounts associated with soil dust that adheres to hands and is transferred to food or cigarettes. Another route is airborne soil that deposits on the lips and is subsequently ingested. Deliberate soil ingestion is not considered in the calculations, although it may occur in children. A survey of measurements of soil ingestion is presented in NUREG/CR-5512, Section 6.3.2. Soil ingestion is also discussed in detail in the Exposure Factors Handbook, Chapter 4 (EPA/600-P-95/002Fa). Values used in the unit dose and unit risk factors are shown in Table A8. These are not bounding values, but the typical values that would represent a large number of cases.

The average adult is assumed to ingest 100 mg/d in trace amounts. In the Native American scenario, the adult soil ingestion rate is applied to both the irrigated land and shoreline

sediment, so that the annual amount ingested is nearly four times greater than the All Pathways Farmer. This is a bounding case. In three of the HSRAM exposure scenarios two daily rates are used. The child's soil intake rate is twice the adult's and applies during the first 6 years. The adult rate is used during the next 24 years. For radionuclides, the 30-year total is used to calculate the increased cancer risk from soil ingestion. For non-carcinogenic chemicals, the child's annual intake rate is used for soil ingestion. For carcinogenic chemicals, the 30-year total averaged over 70 years is used for soil ingestion.

In all prior Hanford Performance Assessments, the Post-Intrusion Resident and All Pathways Farmers ingest 36.5 g/y. In the present calculations, the Post-Intrusion cases ingest about half as much, 18 g/y. The reduction is based on the limited time of exposure to the contaminated area (garden, pasture, or field). Note that the Harris and Harper NASR ingests about half as much soil, 36 g/y.

Table A8. Inadvertent Soil Ingestion.

Exposure Scenario	Daily Soil Intake Rate (mg/day)	Exposure Frequency (days/year)	Annual Soil Ingestion (g/year)
Irrigated Land Ingestion Amounts			
Well-Driller	100	5	0.5
Post-Intrusion Scenarios	100	180	18
All Pathways Farmer	100	365	36.5
Native American	200	365	73
Columbia River Population	100	365	36.5
HSRAM Industrial	50	146	7.3
Recreational -- Child/Adult	200 / 100	7	1.4 / 0.7
Residential -- Child/Adult	200 / 100	365	73 / 36.5
Agricultural -- Child/Adult	200 / 100	365	73 / 36.5
Shoreline Sediment Ingestion Amounts			
All Pathways Farmer	100	7	0.7
Native American	200	270	54
Columbia River Population	100	5	0.5
Recreational -- Child/Adult	200 / 100	7	1.4 / 0.7
Residential -- Child/Adult	200 / 100	7	1.4 / 0.7
Agricultural -- Child/Adult	200 / 100	7	1.4 / 0.7
Notes:			
<ul style="list-style-type: none"> • Inadvertent soil ingestion refers to trace amounts ingested after transfer from hands to food or cigarettes. • Native American values are from DOE/RL-96-16, Revision 1. HSRAM values are from DOE/RL-91-45 Revision 3. • Two values are given for the last three HSRAM scenarios. The first is the rate for children, and the second is the rate for adults. 			

A3.2 Inhalation Rates for People

To determine the internal dose or risk from the inhalation of vapors and suspended particulate matter, one must compute the total activity inhaled. Values for the average air concentration, the time exposed at that concentration, and the average breathing rate during the exposure period are presented in this section. The inhalation intakes are separated into those from contaminated soil and those from contaminated water.

A3.2.1 Airborne Soil

A mass loading approach is used to estimate airborne concentrations of radionuclides for scenarios involving resuspension of contaminated soil. For the intrusion scenarios, a basic assumption regarding the waste materials in the soil is that the particle size distribution of the waste (either as exhumed waste or as contaminated irrigation water) is similar to that of the soil. If waste particles were finer than soil particles, then soil that becomes airborne would have a higher concentration of waste than the average for the garden. If waste particles were coarser than soil particles, then the airborne soil would be deficient in waste. For the irrigation scenarios, the dissolved and suspended particulate will most likely attach to the finer soil particles because that is where the greatest surface area is found.

The average mass loading in air depends on what is happening to the contaminated soil. Active gardening produces the largest average mass loading, at 0.5 mg/m^3 . Routine activities outdoors are assumed to take place at an average air concentration of 0.1 mg/m^3 . Indoor activities are assumed to take place at lower air concentrations due to the presence of other airborne particulate sources. The basis for these air concentrations is presented very effectively in NUREG/CR-5512, Section 6.3.1. It should be noted that the fine particulate suspended in air may have a greater contaminant concentration than the soil from which it is obtained. Hence, the mass loadings that have been chosen are somewhat high. (Typical annual average airborne mass loadings observed outdoors at the Hanford Site are about 0.02 mg/m^3 . This is based on the discussion in Section 4.1.7 of PNNL-6415 Revision 15)

In the well-drilling scenario, the individual is assumed to be exposed for 40 hours, spread over 5 days. This is the time needed to drill the well. During this time the individual breathes at the outdoor activity rate ($1.21 \text{ m}^3/\text{h}$) defined in Publication 66 (1994) of the International Commission on Radiological Protection (ICRP), titled *Human Respiratory Tract Model for Radiological Protection*. The actual inhalation scenario is highly variable. The worker can be exposed to a high concentration when the waste material comes out of the hole. However, this material is soon buried by clean material coming from farther down the hole. In addition, the material is likely wetted as part of the drilling operation and to minimize fugitive dust emissions. Another modeling approach is to average the contamination over the assumed spreading area and compute the total inhaled over the 40 hour work period.

In the Grouted Waste performance assessment (WHC-SD-WM-EE-004) the well-drilling worker inhales resuspended dust at a concentration of 0.1 mg/m^3 for one hour. The breathing rate ($1.20 \text{ m}^3/\text{h}$) is from ICRP Publication 23, *Report of the Task Group on Reference Man* (1975). However, the air concentration was not based on the waste concentration, but rather on the average soil concentration after spreading. In effect, the 0.64 m^3 of waste exhumed in the Grouted Waste PA was diluted to a total volume of $15 \text{ m}^3 = (100 \text{ m}^2)(0.15 \text{ m})$. These assumptions

lead to the inhalation of 0.12 mg soil containing 0.0051 mg of waste, as shown in the calculations below. Note that the soil density in the well is assumed to be the same as the soil density of the tailings to simplify the comparison with the prior performance assessments.

$$\text{Soil Inhaled (Grout PA)} = (1 \text{ h})(1.2 \text{ m}^3/\text{h})(0.1 \text{ mg}/\text{m}^3) = 0.12 \text{ mg soil inhaled}$$

$$\begin{aligned} \text{Waste Inhaled (Grout PA)} &= (0.12 \text{ mg soil}) \left(\frac{0.64 \text{ m}^3 \text{ grout}}{15 \text{ m}^3 \text{ soil}} \right) \\ &= 0.0051 \text{ mg grout inhaled} \end{aligned}$$

In the 2001 ILAW PA (DOE/ORP-2000-24 Revision 0) the driller inhales suspended soil for a period of 40 hours. The airborne soil is diluted to the average concentration of the well tailings (80 m well depth assumed) in addition to the dilution that results when the exhumed material is spread over an area of 100 m² to a depth of 0.15 m. Finally, the 2001 ILAW PA assumes that 1% of the exhumed waste is available for inhalation. The inhalation intakes are shown below.

$$\text{Soil Inhaled (ILAW PA)} = (40 \text{ h})(1.2 \text{ m}^3/\text{h})(0.1 \text{ mg}/\text{m}^3) = 4.8 \text{ mg soil inhaled}$$

$$\begin{aligned} \text{Waste Inhaled (ILAW PA)} &= (4.8 \text{ mg soil}) \left(\frac{0.272 \text{ m}^3 \text{ waste}}{5.84 \text{ m}^3 \text{ borehole}} \right) \left(\frac{0.272 \text{ m}^3 \text{ waste}}{15 \text{ m}^3 \text{ soil}} \right) (0.01) \\ &= 0.000041 \text{ mg waste inhaled} \end{aligned}$$

In the present report, the dilution of the well tailings to a volume of 15 m³ is eliminated. The driller inhales 4.84 mg of the average soil concentration taken from the well. The well depth is 100 m and the waste depth is assumed to be 8 m. If 10% of the exhumed waste is available for inhalation, then the resulting inhalation intake is shown below.

$$\text{Soil Inhaled (Tank Waste PA)} = (40 \text{ h})(1.21 \text{ m}^3/\text{h})(0.1 \text{ mg}/\text{m}^3) = 4.84 \text{ mg soil inhaled}$$

$$\begin{aligned} \text{Waste Inhaled (Tank Waste PA)} &= (4.84 \text{ mg soil}) \left(\frac{8 \text{ m waste}}{100 \text{ m well}} \right) (0.1) \\ &= 0.039 \text{ mg waste inhaled} \end{aligned}$$

For estimating inhalation exposure in the suburban garden scenario, the individual spends the entire year living in the contaminated area. The Grouted Waste performance assessment (WHC-SD-WM-EE-004) used an average inhalation rate of 8,520 m³ per year and an average air concentration of 0.1 mg/m³. The annual amount of soil inhaled was 852 mg. The 200 West Area Burial Ground performance assessment (WHC-EP-0645) used more detailed inhalation assumptions based on PNNL-6312. The inhalation dose was based on an annual inhalation of 445 milligrams.

The inhaled amounts for the tank waste PA are updated from the 2001 ILAW PA (DOE/ORP-2000-24 Revision 0). These amounts are a refinement of the model used for the 200 West Area Burial Ground (WHC-EP-0645). They are also very similar to the method discussed

in NUREG/CR-5512. The post-intrusion residents spend a portion of the day in various average air concentrations. These are shown in Table A9 for all three of the post-intrusion residents as well as the all pathways farmer (irrigation scenario). The breathing rates shown on Table A9 are from ICRP Publication 66 Table B.16B. In Table A9 the 3,102 hour period asleep is 8.5 hours per day (ICRP 66), 365 days per year. The exposed individual is outdoors for a certain number of hours each day for 180 days in every case.

The suburban resident with a garden spends 2 h/d (360 h/y) in or near his garden. Of this, about 10 hours are spent in relatively dusty conditions. Due to the small size of the garden (100 m²), it is assumed that the average air concentration during the non-outdoor periods is 10% of the air quality standard, $(0.10)(0.050 \text{ mg/m}^3)=0.005 \text{ mg/m}^3$. This is the concentration of contaminated soil in the air breathed by the resident. There are other (i.e., uncontaminated) sources for airborne particulate. The annual soil mass inhaled by the suburban gardener is 87 mg/y, as shown in Table A9.

The rural resident with a cow spends 4 h/d (720 h/y) in or near his pasture and hay field. Of this, about 10 hours are spent in relatively dusty conditions. Due to the size of the pasture and hay field (5,000 m²), it is assumed that the average air concentration during the non-outdoor periods is 20% of the air quality standard. The larger value is based on the larger area of the pasture and hay field. The annual soil mass inhaled by the rural cow owner is 169 mg/y, as shown in Table A9.

The commercial farmer spends 8 h/d (1,440 h/y) in or near his fields. Of this, about 10 hours are spent in relatively dusty conditions. Due to the size of the field (160 acre, or 647,500 m²), it is assumed that the average air concentration during the non-outdoor periods is 20% of the air quality standard. The larger value is based on the larger area of the pasture and hay field. The annual soil mass inhaled by the rural cow owner is 169 mg/y, as shown in Table A9.

The all pathways farmer spends a portion of his time in various average air concentrations. These are shown in Table A9. For 180 days the individual is outdoors. The all pathways farmer spends 10 h/d (1800 h/y) exposed to higher levels of dust outdoors. Of this, about 100 hours are spent in relatively dusty conditions. In Table A9 the 3,102 hour period asleep is 8.5 hours per day (ICRP 66), 365 days per year. Due to the small size of the garden, it is assumed that the average air concentration during the non-outdoor periods is at the air quality standard as shown in Table A9. The annual soil mass inhaled by the all pathways farmer is 539 mg.

The outdoor air concentrations used in the table are discussed at length in NUREG/CR-5512, Section 6.3.1. The values chosen represent conservative bounds on likely concentrations for the activities indicated. The exposure times are also based on the NUREG/CR-5512, although the document is not as explicit as to the assumptions behind the time periods used. It appears that NUREG/CR-5512 includes a vacation period of 2 weeks away from the residence. This is a minor (3%) reduction in the mass inhaled, and is not included. The combinations shown on Table A9 for the post-intrusion resident and all pathways farmer scenarios lead to the annual inhalation amounts shown. Dividing these by the volume of air inhaled in a year (8,094 m³) gives the average concentrations shown in the table subheadings.

Table A9. Calculation of the Soil Inhalation Amounts.

Activity	Air Concentration (mg/m ³)	Exposure Time (hours/year)	Breathing Rate (m ³ /hour)	Mass Inhaled (mg/year)
Post-Intrusion Resident – Suburban Garden (Annual Average is 0.0107 mg/m³)				
Asleep	0.005	3,102	0.45	7.0
Indoors	0.005	5,298	1.18	31.3
Outdoor	0.1	350	1.21	42.4
Gardening	0.5	10	1.21	6.1
Away		0		0.0
Total Time:		8,760	Soil Inhaled:	87
Post-Intrusion Resident – Rural Pasture (Annual Average is 0.0209 mg/m³)				
Asleep	0.01	3,102	0.45	14.0
Indoors	0.01	4,938	1.18	58.3
Outdoor	0.1	700	1.21	84.7
Gardening	0.5	20	1.21	12.1
Away		0		0.0
Total Time:		8,760	Soil Inhaled:	169
Post-Intrusion Resident – Commercial Farm (Annual Average is 0.0397 mg/m³)				
Asleep	0.02	3,102	0.45	27.9
Indoors	0.02	4,218	1.18	99.5
Outdoor	0.1	1,400	1.21	169.4
Gardening	0.5	40	1.21	24.2
Away		0		0.0
Total Time:		8,760	Soil Inhaled:	321
All Pathways Farmer (Annual Average is 0.0666 mg/m³)				
Asleep	0.05	3,102	0.45	69.8
Indoors	0.05	3,858	1.18	227.6
Outdoor	0.1	1,750	1.21	211.8
Gardening	0.5	50	1.21	30.3
Away		0		0.0
Total Time:		8,760	Soil Inhaled:	539
Notes:				
<ul style="list-style-type: none"> • Air concentrations for the All Pathways Farmer are from NUREG/CR-5512, Section 6.3.1. The reduced values for the post-intrusion scenarios depend on the affected area. • Each individual spends 8.5 hours per day, 365 days per year asleep. For 180 days the post-intrusion resident spends 2, 4, or 8 h/d outdoors, while the all pathways farmer spends 10 h/d outdoors. • Breathing rates are from ICRP 66 (1994). • The All Pathways Farmer is exposed to the more ubiquitous soil contamination resulting from a contaminated water supply. Hence, the air concentration is at the ambient air quality guideline. The Post-intrusion Resident is exposed less frequently. Hence, the air concentration is smaller by a factor of 10. 				

If the intakes are averaged over one year, and the annual average breathing rate from ICRP 66 (8,094 m³/y) is applied to calculate the amount inhaled, then the average air concentration for the all pathways farmer is 0.0666 mg/m³ and the average air concentration for the post-intrusion resident is 0.0158 mg/m³. These are shown on Table A10.

The Native American inhales at the much higher rate from DOE/RL-96-16, 30 m³/d at an average concentration of 0.1 mg/m³ (DOE/RL-96-16 Table 5.7). Thus the annual intake is 1,095 mg soil. As with the food pathways, this is greater than the all-pathways farmer. The inhalation intakes of resuspended soil are summarized in Table A10.

The Columbia River population average is based on an exposure of 12 hours per day to a mass loading of 0.05 mg/m³ at the daily average breathing rate. This leads to an annual inhalation of 405 milligrams of soil, as shown below. This is nearly the same intake as used in the 2001 ILAW PA (416 mg/y). In the 200 West Area Burial Ground PA (WHC-EP-0645) the annual inhalation was twice as great. This is unrealistically high, since the air concentration of contaminated material (0.1 mg/m³) is a bounding value. In addition, there are other sources of airborne material that are not contaminated. Hence the estimate shown below will be used for population dose.

$$(8,094 \text{ m}^3/\text{y})(0.05 \text{ mg/m}^3) = 405 \text{ mg/y}$$

Table A10. Inhalation of Contaminated Soil.

Exposure Scenario	Breathing Rate (m ³ /day)	Average Air Concentration (mg/m ³)	Exposure Frequency (days/year)	Annual Soil Inhalation (mg/y)
Well-Driller	9.68	0.1	5	4.84
Post-Intrusion Suburban Resident	22.175	0.0107	365	87
Post-Intrusion Rural Resident	22.175	0.0209	365	169
Post-Intrusion Commercial Farm	22.175	0.0397	365	321
All Pathways Farmer	22.175	0.0666	365	539
Native American	30	0.1	365	1,095
Columbia River Population	22.175	0.05	365	405
• HSRAM Industrial	20	0.05	250	250
Recreational -- Child/Adult	10 / 20	0.05	7	3.5 / 7
Residential -- Child/Adult	10 / 20	0.05	365	182.5 / 365
Agricultural -- Child/Adult	10 / 20	0.05	365	182.5 / 365

Notes:

- Breathing rates for the Well Driller and the All Pathways Farmer are from Table B.16B of ICRP 66 for the adult mail sedentary worker. Breathing rate for the Native American comes from DOE/RL-96-16. Breathing rates for the HSRAM scenarios are from the HSRAM. Two values are given for the last three HSRAM scenarios. In these scenarios, non-carcinogens are inhaled at the child's rate (10 m³/d), while carcinogens are inhaled at the adult's (20 m³/d).
- The Average Air Concentrations for the post-intrusion residents and the all pathways farmer are from Table A9.
- The annual soil inhalation is calculated as the product of the breathing rate, the air concentration and the exposure frequency.

In the HSRAM scenarios, the average air concentration is the national ambient air quality standard, 0.05 mg/m³. The daily inhalation rate is either 10 m³/d or 20 m³/d. The smaller number is the breathing rate for children. The intake of non-carcinogens is evaluated using the child's inhalation rate (10 m³/d). The inhalation of carcinogens is modeled at the adult inhalation rate (20 m³/d). In the industrial scenario there are no children, so the larger breathing rate is used for all materials. In the industrial scenario, the annual inhalation time is 250 days so that the total annual inhalation is 250 mg soil. In the recreational scenario the annual inhalation time is

7 days, so the total annual inhalation is 3.5 mg soil for non-carcinogens and 7.0 mg soil for carcinogens. In the residential and agricultural scenarios the annual inhalation time is 365 days so that the total annual inhalation is 182.5 mg soil for non-carcinogens and 365 mg soil for carcinogens. The HSRAM inhalation intakes are therefore lower than the residential gardener commonly used in Hanford Site performance assessments.

Special Model for Tritium

Airborne concentrations of tritium in the irrigation scenarios are based on airborne water described in the next section. The contribution from the soil is included in the airborne water, and is not calculated separately. Airborne concentrations of tritium for the post-intrusion scenarios are calculated using an evaporation model derived from the RESRAD manual (ANL/EAD/LD-2). The simple box model used for the tank waste PA assumes there is a volume of air directly over the garden that has a tritium concentration fed by evaporation and diminished by movement of air through the volume. The air volume is the garden area times a vertical height selected to represent the average extent of contamination. The rapid turnover of water during the irrigation season means that all of the tritium has left the soil in a few weeks. The rate at which the tritium leaves the surface soil layer decreases with time due to leaching, evaporation, and radioactive decay. The evaporation rate is the amount currently in the garden times the evaporation constant (λ_E). The leaching and evaporation are discussed in Section A6.0. The time dependence of the airborne tritium in the volume of interest is shown in the equations below.

$$\text{Tritium evaporation from garden} = \lambda_E Q_0 e^{-\lambda_T t}$$

$$\lambda_E = \frac{E}{\theta L T_{\text{irr}}} \quad \text{and} \quad \lambda_T = \frac{P+I}{\theta L T_{\text{irr}}} + \lambda_R$$

$$\text{Wind removal from box} = UH\sqrt{A} C_A = \mu W$$

$$C_A = \frac{W}{AH} \quad \text{and} \quad \mu = \frac{U}{\sqrt{A}}$$

$$\frac{dW}{dt} = \lambda_E Q_0 e^{-\lambda_T t} - \mu W$$

where

- A = surface area of the garden, 100 m²
- C_A = tritium air concentration in the volume (AH) above the garden, in Ci/m³
- E = total evapo-transpiration during the irrigation season, 0.7806 m from Section A6.0
- H = effective vertical height above the garden for estimating air concentrations from Table A11a
- I = total irrigation water applied during the irrigation season, in 0.823 m. Nearly all of this is deposited during the 6 month period from April to September.
- L = thickness of the surface soil layer from which contaminants migrate, 0.15 m (5.9 inches).
- 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 0.05766 m (PNNL-13859).
- Q₀ = initial total tritium activity in the garden, in Ci

- t = elapsed time, in years. At $t=0$ the well was drilled and spread in the garden and irrigation begins.
 T_{irr} = irrigation period, 0.5 y
 U = harmonic wind speed average through the volume of interest, 2.05 m/s from PNNL-13859 for the years 1955 to 2001
 W = amount of tritium in the volume of air, Ci
 λ_E = surface soil layer removal constant for removal by evaporation during the irrigation season, 52.04 per year
 λ_R = radioactive decay constant for tritium, 0.05622 per year
 λ_T = total tritium removal constant during the irrigation season, 58.76 per year
 μ = effective removal constant by wind moving through a volume of air over the contaminated area. Calculated values are shown in Table A11a
 θ = volumetric water content of the surface soil, milliliters of water per cubic centimeter of soil. A value of 0.2 ml/cc is assumed (Section A6.0).

The solution for the activity in the volume of interest (W) is shown below. The total activity inhaled by the resident is the time integral of the air concentration over the irrigation season. Because the removal constants are large, this is effectively an integral from 0 to infinity. The equation for the activity of tritium inhaled by the post-intrusion resident is shown below.

$$W = \frac{\lambda_E Q_0}{\lambda_T - \mu} (e^{-\mu t} - e^{-\lambda_T t})$$

$$\text{Tritium Inhaled} = \frac{\lambda_E Q_0 F_{PI} BR}{A H \mu \lambda_T} = \frac{\lambda_E Q_0 F_{PI} BR}{\sqrt{A} H U \lambda_T}$$

where

- A = surface area of the garden, 100 m²
 BR = breathing rate for the post-intrusion resident when outdoors in his garden, 1.21 m³/h from ICRP 66
 F_{PI} = fraction of air that the individual breathes while located in the contaminated area. Computed as the volume of air inhaled during the hours outdoors divided by the volume inhaled in 1 day. For the suburban gardener this is $(2 \text{ h})(1.21 \text{ m}^3/\text{h})/(22.175 \text{ m}^3) = 0.109$
 H = effective vertical height above the garden for estimating air concentrations, as shown in Table A11a
 Q_0 = initial total tritium activity in the garden, in Ci
 t = elapsed time, in years. At $t=0$ the well was drilled and spread in the garden and irrigation begins.
 U = harmonic wind speed average through the volume of interest, 2.05 m/s from PNNL-13859 for the years 1955 to 2001
 W = amount of tritium in the volume of air, Ci
 λ_E = evaporation constant during the irrigation season, 52.04 per year
 λ_T = total tritium removal constant during the irrigation season, 58.76 per year
 μ = effective removal constant by wind moving through a volume of air over the contaminated area. Calculated values are shown in Table A11a

Input assumptions and calculated results are shown in the table below. The last column shows the fraction of tritium exhumed that is inhaled by the exposed individuals. This fraction is used to calculate the soil inhalation dose from tritium for the post intrusion scenarios.

Table A11a. Calculation of Tritium Inhaled from Soil Contamination.

Post-Intrusion Scenario	Time Exposed (h/d)	Inhaled Air Fraction, F_{PI}	Averaging Area (m^2)	Wind Loss Rate, μ (per h)	Effective Mixing Height (m)	Tritium Inhalation Fraction
Suburban Garden	2	0.1091	100	737.9	1	1.585E-06
Rural Pasture	4	0.2183	5,000	104.4	2	2.241E-07
Commercial Farm	8	0.4365	647,500	9.170	4	1.970E-08

The harmonic average wind speed is the inverse of the average of the inverse wind speeds from PNNL-13859 for the years 1955 to 2001. The inverse speeds are weighted by the fraction of the hourly readings that have wind speeds in that group. The calm group in PNNL-13859 is assumed to have a wind speed of 1 mile/hour. During the year, the average wind speed is slightly greater during the summer months, but this has a small effect on the average speed.

The atmospheric dispersion parameter used in the EPA Soil Screening Guidance documents (EPA/540/R-96/018 and EPA/540/R95/128) to relate the surface emission rate (g/m^2 per second) to the average air concentration at the ground surface (kg/m^3) is known as Q/C. It is calculated using the EPA software ISCST3 (EPA-454/B-95-003) for area sources. The value given in the soil screening guidance is $68.81 g/m^2$ per second per kg/m^3 calculated using Los Angeles wind data and a 0.5-acre-square source. ($0.5 \text{ acre} = 2,023 m^2$). It is an annual average value at an elevation of zero meters above the soil surface. In the formalism shown above for tritium, the quantity Q/C is defined as shown below for the suburban garden. For the rural pasture (i.e. $H = 2 m$ and $A = 5,000 m^2$) the Q/C is $58.0 g/m^2$ per second per kg/m^3 .

$$Q/C = \frac{HU}{\sqrt{A}} = \frac{(1 m)(2.05 m/s)}{\sqrt{100 m^2}} = 0.205 m/s = 205 \frac{g}{m^2 s} \text{ per } \frac{kg}{m^3}$$

The effective Q/C value used in this report leads to smaller amounts of tritium inhaled than using the value presented in the EPA soil screening guidance documents. The value chosen can be regarded as an approximation of the result for an elevation greater than zero meters above the contaminated soil. Table A11b summarizes some ISCST results using Hanford Site wind data collected at the 200 East area tower for the years 1992 to 1996. Air concentrations were calculated for a unit release rate for two contaminated areas at various radial distances and elevations. The peak values are shown in the table below. An example input file is shown in the first attachment.

The Hanford Site-specific result for the Q/C parameter shown in Table A11b is somewhat smaller than the EPA default value of $68.81 g/m^2$ per second per kg/m^3 . However, the numbers from the box model use a more realistic assumption of non-zero receptor elevation. For comparison, the Q/C values for the suburban garden, rural pasture, and commercial farm for tritium inhalation are 205, 58.0, and $10.2 g/m^2$ per second per kg/m^3 , respectively.

Table A11b. Values for Q/C from ISCST3.

Source Area	Receptor Elevation (m)	Peak Radial Distance from Source Center (m)	Air Concentration from ISCST3 (g/m ³)	Q/C (g/m ² -s per kg/m ³)
100 m ²	0	1.5	9.235	108.3
Suburban Garden	0.5	8	1.200	833.2
	1	15	0.3712	2,694
1/2 Acre (2,023 m ²) EPA Standard	0	8	19.49	51.30
	0.5	8	7.473	133.8
	1	14	3.298	303.3
5,000 m ² Rural Pasture	0	12	23.093	43.30
	0.5	12	10.783	92.74
	1	15	5.824	171.7

Notes:

- The source area is square with an emission rate of 1 g/m² per second.
- Hanford Site wind data from the 200 East Area for the years 1992 to 1996 was used.
- The quantity Q/C is calculated as 1000 divided by the ISCST3 results.

A3.2.2 Airborne Water

For scenarios with inhalation of radionuclides suspended in water, three situations are modeled. The first is inhalation of airborne contaminants from ambient sources such as overhead irrigation, wind blowing across puddles, drops falling off foliage, and indoor sources such as washing and cooking. The second is inhalation of spray during a shower. The third is inhalation of contaminants in water that flashes to steam in a wet sauna or "sweat lodge". These moisture inhalation pathways were used in the 2001 ILAW PA (DOE/ORP-2000-24), but not in prior Hanford performance assessments.

Because tritium is modeled as water (HTO), an equilibrium approach is used for tritium. The ratio of airborne tritium to total water in the air is the same as the concentration of the tritium in the water. For other radionuclides, air concentrations are estimated using entrainment factors suitable for the processes that aerosolize the liquid. For chemicals the air concentration is estimated using Henry's Law. To be consistent with the NASR in DOE/RL-96-16 (CRCLA), the waterborne air concentration in the sweat lodge is set to 0.1 L/m³, which means each cubic meter of air inhaled contains the contaminants found in 0.1 L of water.

The entrainment of dissolved inorganic materials into the air requires some physical process, such as a water spray during irrigation or showering, to create droplets that will remain airborne for a time. While these droplets are airborne they evaporate and leave behind any suspended solids as airborne particles. The air concentration of the dissolved materials is therefore proportional to the total water content of the air. The constant of proportionality is assumed to be represented by measured entrainment factors for evaporation and boiling of aqueous solutions. There are other sources of humidity that involve no entrained contaminants, e.g., green plants and moisture carried in by regional air movements. Neglecting these lends conservatism to the air concentration estimates.

In *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities, Volume 1* (DOE-HDBK-3010-94) data for aqueous solutions under various conditions are presented. Section 3.1 recommends a median entrainment factor of $6E-7$ for non-boiling aqueous solutions of inorganic compounds. This number will be used for ambient conditions, as shown in Table A12. The sudden depressurization of superheated aqueous solutions is summarized on page 3-4 of the DOE handbook. The recommended bounding value (0.1) could be used to represent the sweat lodge, in which water flashes to steam when poured on hot rocks. Because the bounding case air concentration from DOE/RL-96-16 is used in the calculations, this entrainment factor is not needed.

During the showering activity there is evaporative entrainment of dissolved inorganic chemicals that could be included but was not due to competing processes like plateout and washout. Instead, the air concentration during the shower is based on a water droplet concentration in air of 10 mg liquid per m^3 air, a value characteristic of fogs (Hinds 1982). This fog is only included in the shower and not the ambient case. The tritium is present as tritiated water, so the tritium concentration is based on the estimated water vapor concentration shown in Table A12.

In Table A12, the ambient contribution to water inhaled is divided into the irrigation months (April through September) and the non-irrigation months (October through March). Because the irrigation season is largely outdoor activity, Hanford Site averages from PNNL-13859 are used for the average temperature (19.46 C) and the average relative humidity (40.2%). At this temperature and humidity the water vapor concentration is 0.89% or $6.7 g/m^3$. The conversion of vapor concentration from mole fraction to mass concentration uses the molecular weight for water (18.0153 g/gmole) and the ideal gas law, as shown below. Note that the temperature is in degrees Kelvin rather than Celsius, and also that Table A12 uses cubic meters (m^3) as the unit for volume rather than liters.

$$\text{Mass of water vapor per unit volume} = \\ (18.0153 \text{ g/gmole})(\text{Vapor Mole Fraction})/(0.082057 \text{ L-atm/gmole/K})/(\text{Temperature})$$

During the non-irrigation season, time indoors is increased, so average indoor temperature (20 C) and humidity (30%) is used in the calculation of waterborne air concentration. A small amount of dilution by uncontaminated water sources brought into the home is assumed (90%).

The entrainment factors described above are next applied to the airborne water content to calculate the equivalent concentration of dissolved particulate that is airborne. The airborne concentration of entrained contaminants is shown in Table A12 in the line below the entrainment factors. The units of g/m^3 should be interpreted as the mass of contaminated water (i.e., ground water or Columbia River water) that is present in each cubic meter of air. The mass airborne can be converted to volume airborne using an assumed density for dilute aqueous solutions of 1,000 g/L.

The total concentration of the contaminated water in air is the sum of the "Entrained Contaminants" and "Droplet Concentration". For ambient conditions an additional factor corrects for the presence of uncontaminated sources of moisture. This is the line labeled "Dilution Factor". As discussed in Section A6.2, this leads to a factor of 93.5% during the

irrigation season. During the remainder of the year (without irrigation) the airborne water contamination is based on approximate indoor conditions.

The "Total Contaminant Airborne" is the product of the rainfall "Dilution Factor" and the sum of the "Entrained Contaminant" and the "Droplet Concentration". For tritium, the "Tritium Airborne" is the product of the rainfall "Dilution Factor" and the sum of the "Water Vapor Concentration" and the "Droplet Concentration".

The annual intakes in the various exposure scenarios are calculated using the air concentrations from Table A12 and the breathing rates and annual exposure times shown in Table A13. The volume of liquid inhaled during the year is the product of these three factors. The assumed density of the irrigation water is 1.0 kg/L.

Table A12. Water Concentration in Air.

Parameter	Ambient April - September	Ambient October - March	Shower
Air Temperature, C	19.46	20	40
Air Temperature, F	67.03	68	104
Air Temperature, K	292.61	293.15	313.15
Relative Humidity	40.2%	30%	80%
Water Vapor Concentration	0.89%	0.69%	5.82%
Water Vapor Concentration	6.7 g/m ³	5.1 g/m ³	40.8 g/m ³
Entrainment Factor	6.0E-7	6.0E-7	not used
<i>Entrained Contaminant</i>	<i>4.02E-6 g/m³</i>	<i>3.06E-6 g/m³</i>	not used
<i>Droplet Concentration</i>	not used	not used	<i>0.01 g/m³</i>
Dilution Factor	93.5%	90%	100%
Total Contaminant Airborne	3.76E-6 g/m ³	2.75E-6 g/m ³	0.01 g/m ³
Tritium Airborne	6.26 g/m ³	4.59 g/m ³	40.8 g/m ³

Notes:

- The first column of ambient conditions uses air temperature, relative humidity, and rainfall dilution from Hanford meteorological data (PNNL-13859). The second column uses reasonable assumptions based on indoor conditions. The two are similar in magnitude.
- Water Vapor Concentration is given as both a mole fraction and mass concentration.
- The Entrainment Factors is recommended for resuspension from non-boiling liquids in Section 3.1 of DOE-HDBK-3010-94, Volume I.
- The shower temperature is based on typical hot water settings. The relative humidity during the shower is a value selected from the likely range of 60% to 100%.
- The airborne concentrations are the effective mass of solution per cubic meter of air.

The All Pathways Farmer takes a shower every day that lasts 15 minutes. Since the indoor activity breathing rate is 1.18 m³/h, the volume of air inhaled during the shower is 0.295 m³. This volume has been subtracted from the daily air volume inhaled (22.175 m³) because the air concentrations during the shower include the effect of ambient conditions. Hence, the ambient daily volume inhaled is 21.88 m³. The resulting annual inhalation of 0.0011 L (48 L tritium) is considerably lower than the inhaled water amount used in the 2001 ILAW PA (DOE/ORP-2000-24), namely, 0.084 L (43.5 L tritium).

The Native American Sweat Lodge, or wet sauna, uses parameters listed in DOE/RL-96-16 (CRCIA). The Native American spends 1 hour in the sweat lodge every day.

The NASR breathing rate during this activity is the daily average, 30 m³/d divided by 24 h/d, or 1.25 m³/h. The daily total is not adjusted for the hour spent in the sweat lodge. The resulting annual inhalation of 45.6 L (105 L tritium) is larger than the intakes used in the 2001 ILAW PA, namely, 0.179 L (53 L tritium). The present NASR model is more consistent with the CRCIA.

Table A13. Water Inhalation of Radionuclides by Scenario.

Exposure Scenario	Daily Volume Inhaled (m ³ /day)	Air Concentration (g/m ³)		Exposure Frequency (days/year)	Annual Inhalation (L/year)	
		Other	Tritium		Other	Tritium
All Pathways Farmer				<i>Total</i>	<i>1.10E-03</i>	<i>48</i>
Ambient	21.88	3.0E-06	5.43	365	2.40E-05	43.4
Shower	0.295	0.01	40.8	365	1.08E-03	4.4
Native American				<i>Total</i>	<i>4.56E+01</i>	<i>105</i>
Ambient	30	3.0E-06	5.43	365	3.29E-05	59.5
Sweat Lodge	1.25	100	100	365	4.56E+01	45.6
Columbia River Population				<i>Total</i>	<i>7.43E-04</i>	<i>46</i>
Ambient	21.98	3.0E-06	5.43	365	2.41E-05	43.6
Shower	0.197	0.01	40.8	365	7.19E-04	2.9
HSRAM Industrial				<i>Total</i>	<i>5.08E-04</i>	<i>29</i>
Ambient	20	3.0E-06	5.43	250	1.50E-05	27
Shower	0.197	0.01	40.8	250	4.93E-04	2.0
HSRAM Recreational				<i>Total</i>	<i>1.38E-05</i>	<i>0.056</i>
Ambient	0	3.0E-06	5.43	7	0	0
Shower	0.197	0.01	40.8	7	1.38E-05	0.056
HSRAM Residential				<i>Total</i>	<i>7.35E-04</i>	<i>33</i>
Ambient	15	3.0E-06	5.43	365	1.64E-05	29.7
Shower	0.197	0.01	40.8	365	7.19E-04	2.9
HSRAM Agricultural				<i>Total</i>	<i>7.35E-04</i>	<i>33</i>
Ambient	15	3.0E-06	5.43	365	1.64E-05	29.7
Shower	0.197	0.01	40.8	365	7.19E-04	2.9

Notes:

- The ambient breathing rates for the non-HSRAM scenarios have been reduced to remove the breathing that takes place during the shower. No adjustment is made for the NASR. In the HSRAM residential and agricultural scenarios, the average indoor breathing rate (15 m³/d) is used.
- The All Pathways Farmer showers 15 minutes per day. The Columbia River Population and HSRAM individuals shower 10 minutes per day. The sweat lodge lasts 1 hour and occurs every other day.
- The annual intakes for the child in the Recreational scenario are half the values shown.
- The air concentration for the NASR Sweat Lodge is from DOE/RL-96-16. The other air concentrations are calculated in Table A10. The ambient concentration is the average of the two shown in Table A10.
- The annual inhalation is the equivalent volume of water that is inhaled each year. It is calculated as the product of the breathing rate, the air concentration, and the exposure frequency.

Note that the Harris and Harper (1997) model for the NASR uses a higher air concentration in the sweat lodge, 164 g/m³. However, this concentration is breathed at a slower rate, which results in a minor increase in the total inhaled during the year, 50 L/y.

The Columbia River Population is assumed to take 10-minute showers every day of the year. Since the indoor breathing rate is $1.18 \text{ m}^3/\text{h}$ (ICRP 66), the volume of air inhaled during the shower is 0.197 m^3 . This volume has been subtracted from the daily air volume inhaled because the air concentrations during the shower include the effect of ambient conditions. Hence, the ambient daily volume inhaled is 21.978 m^3 rather than 22.175 m^3 . The resulting annual intake shown in Table A13 ($7.43\text{E-}4 \text{ L}$, 46 L tritium) is smaller than the intakes used in the 2001 ILAW PA (0.084 L , 43.5 L tritium).

Dissolved chemicals are assumed to have air concentrations at 50% of the saturation value given by Henry's Law. The maximum air concentration allowed is the water concentration (in mg/L) times 0.5 L/m^3 , the bounding value given in the HSRAM. This approach bypasses the need to classify chemicals as volatiles. In the HSRAM scenarios, the daily air inhalation rates are reduced to 75% of the daily adult rate to represent indoor inhalation rates. The resulting annual air intakes for chemicals are shown in Table A14.

Table A14. Annual Air Intakes by Scenario.

Exposure Scenario	Daily Volume Inhaled (m^3/day)	Exposure Frequency (days/year)	Annual Volume of Air Inhaled (m^3/year)
All Pathways Farmer		<i>Total</i>	<i>8,094</i>
Ambient	21.88	365	7,986
Shower	0.295	365	108
Native American		<i>Total</i>	<i>11,406</i>
Ambient	30	365	10,950
Sweat Lodge	1.25	365	456
Columbia River Population		<i>Total</i>	<i>8,094</i>
Ambient	21.978	365	8,022
Shower	0.197	365	72
HSRAM Industrial		<i>Total</i>	<i>5,049</i>
Ambient	20	250	5,000
Shower	0.197	250	49
HSRAM Recreational		<i>Total</i>	<i>0.69 / 1.38</i>
Ambient	0	7	0.00
Shower	0.0985 / 0.197	7	0.69 / 1.38
HSRAM Residential		<i>Total</i>	<i>5,547</i>
Ambient	15	365	5,475
Shower	0.197	365	72
HSRAM Agricultural		<i>Total</i>	<i>5,547</i>
Ambient	15	365	5,475
Shower	0.197	365	72
Notes:			
<ul style="list-style-type: none"> • The breathing rates are from Table A11, with the exception of the NASR. The NASR breathing rate for ambient conditions is from the CRCIA. • In the HSRAM recreational scenario inhalation of volatiles occurs during the shower only. Non-carcinogens are inhaled at the child's rate ($0.0985 \text{ m}^3/\text{d}$), while carcinogens are inhaled at the adult's rate ($0.197 \text{ m}^3/\text{d}$). • The annual volume of air inhaled is calculated as the product of the daily volume inhaled and the exposure frequency. 			

The air concentration for each chemical is calculated using the unitless Henry's Law Constants from Table A3. Owing to ventilation effects in occupied spaces, the actual air concentration will not be at the upper limit given by Henry's law. The average saturation fraction (F_{SAT}) is 50% in analogy with the relative humidity. The formula used to calculate the air concentrations (C_A) is shown below along with the equation for the partial pressure (P_{GAS}) of the vapor in equilibrium with the liquid. The ideal gas law is used to relate the partial pressure and air concentration. The ratio C_A/C_W expresses the air concentration in terms of the equivalent volume of water per m^3 of air. This ratio is not allowed to exceed the HSRAM number ($0.5 L/m^3$). From the last equation, this means the HSRAM limit is reached when $H' > 0.001$, or $K_{HENRY} > 0.0245 L\text{-atm/mole}$.

$$P_{GAS} = \frac{H' R T C_W}{(1000 \text{ mg/g}) M_{MOLE}}$$

$$C_A = F_{SAT} \frac{(1000 L/m^3)(1000 \text{ mg/g}) M_{MOLE} P_{GAS}}{R T}$$

$$C_A = F_{SAT} (1000 L/m^3) H' C_W$$

$$\frac{C_A}{C_W} = F_{SAT} (1000 L/m^3) H' < 0.5 L/m^3$$

where,

- C_A = concentration of the chemical in air, in mg/m^3
- C_W = concentration of the dissolved chemical in water, in mg/L
- 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
- H' = unitless Henry's Law Constant from Table A3
- M_{MOLE} = molecular weight of the compound, in $g/mole$
- P_{GAS} = partial pressure of the chemical in the air, in atm
- R = ideal gas law constant, $0.082057 L\text{-atm/mole-K}$
- T = absolute temperature of the gas, $298.15 K (20 C)$
- $1000 L/m^3$ = volume conversion factor
- $1000 mg/g$ = mass conversion factor

The airborne chemical concentrations also have a lower bound calculated from the non-tritium annual water inhalation volumes (L/y) shown in Table A13 divided by the annual air inhalation volumes (m^3/y) shown in Table A14. In this way the inorganic chemicals with very small Henry's Law constants are treated as any inert material would be.

A3.3 External Exposure Times

The external dose from radionuclides in soil depends on the radionuclide concentration (in Ci/m²) and the time of exposure (in hours). The exposure scenarios define what the radionuclide concentration will be. This section discusses the determination of the effective time of exposure for each exposure scenario. The annual exposure times are listed in Table A15.

Table A15. Annual External Exposure Times.

Exposure Scenario	Daily (hours/day)	Dose Rate Reduction Factor	Exposure Frequency (days/year)	Annual Exposure Time (hours/year)
Irrigated Land				
Well-Driller	8	1	5	40
Suburban Garden	2	0.5	180	180
Rural Pasture	4	0.5	180	360
Commercial Farm	8	0.5	180	720
All Pathways Farmer	12	0.941	365	4,120
Native American	24	0.8	365	7,008
Columbia River Population	24	0.5	365	4,380
HSRAM Industrial	8	0.8	146	934
HSRAM Recreational	8	0.8	7	45
HSRAM Residential	24	0.8	365	7,008
HSRAM Agricultural	24	0.8	365	7,008
Shoreline Sediments				
All Pathways Farmer	8	0.2	7	11
Native American	12	0.2	270	648
Columbia River Population	5	0.2	5	5
HSRAM Recreational	8	0.2	7	11
HSRAM Residential	8	0.2	7	11
HSRAM Agricultural	8	0.2	7	11
Swimming and Boating				
Native American	2.6	0.5	70	91
HSRAM Recreational	2.6	0.5	7	9.1
HSRAM Residential	2.6	0.5	7	9.1
HSRAM Agricultural	2.6	0.5	7	9.1

Notes:

- The Annual Exposure Time for the Post-Intrusion Resident is reduced because of the small size of the contaminated area. For the All Pathways Farmer it is the total time outdoors plus one-third of the total time indoors. For the Native American it is the same as the HSRAM Residential and HSRAM Agricultural. The Columbia River Population uses a value from prior performance assessments.
- The HSRAM Residential and Agricultural parameters have been assumed to match the parameters for the HSRAM Recreational Scenario.
- The annual external exposure time is calculated as the product of the daily time, the reduction factor, and the exposure frequency.

During the drilling operation, the worker is exposed to varying dose rates. Until the waste is exhumed this dose rate is zero. While the waste comes from the hole, the dose rate is high.

Since the volume of waste exhumed is small (less than 1 m³), the dose rate varies inversely with the square of the worker's distance from the waste. The waste is soon covered with clean soil from deeper in the well, which reduces the dose rate. To represent the potential dose to the worker, the waste is assumed spread near the well to a depth of 5 cm. The volume of soil tailings from a well 6.5 inches in diameter and 100 m deep is 2.43 m³, as explained in Section 2.1. If this volume of soil is spread to an average depth of 5 cm, its area is 49 m². The external dose rate factors from an infinite slab that is 5 cm thick are used to estimate the dose from 40 hours of exposure. This approach differs from previous performance assessments, which assume the well tailings are mixed with the soil in an area of 100 m² to a depth of 15 cm. The approach used in this report leads to larger external doses for the well driller.

For the post-intrusion scenarios, the contamination is localized to the area contaminated by the exhumed waste. The external dose rate is greatest in the center of this area. At the edge of the contaminated area the dose rate has dropped to roughly half the value at the center. At a distance of 5 meters from the edge of the contamination the dose rate has dropped by an order of magnitude. Note that the dramatic decrease in dose rate is not the case for the airborne dust concentration. The annual average concentration of suspended dust from the garden decreases by diffusion and turbulent mixing rather slowly with distance, falling to perhaps half the peak value at a distance of 100 m in the downwind direction.

In the post-intrusion scenarios, because the external dose rate decreases rapidly with distance from the contaminated area, the time indoors or asleep (Table A9) will be assigned zero exposure. It will be assumed that the resident spends most of the time outdoors away from the contaminated area. The annual average exposure is half the peak value for an infinite plane because the exposed individual spends time in all parts of the contaminated area. For comparison with the effective annual exposure times shown in Table A15, the 2001 ILAW PA (DOE/ORP-2000-24) used 900 hours, the Grouted Waste PA (WHC-SD-WM-EE-004) used 4,383 hours, and the 200 West Area Burial Ground PA (WHC-EP-0645) used 3,260 hours. In addition, the prior Hanford PA's spread the exposure over the entire year rather than calculating the accumulated dose during the first half of the year.

In the irrigation scenarios most of the area near the person's dwelling is contaminated. The extent of the contaminated areas will affect the calculation of external dose in the two exposure situations. The exposure to soil contamination is divided into two time periods during the year. The first period is the time actually spent standing in the contamination. The second period is the total time near the contamination, or indoors.

In the irrigation scenarios, it is assumed that the entire time outdoors (1800 hours) is spent in exposure conditions similar to the center of an irrigated field. However, the dose rate indoors is reduced by a factor of 3. This factor of 3 is discussed in detail in NUREG/CR-5512, Section 6.7.4. Therefore the effective time of exposure at the unshielded dose rate is 4,120 hours per year, as shown below.

$$(1,800 \text{ hr}) + (3,102 + 3,858 \text{ hr})/3 = 4,120 \text{ hours}$$

The dose rate reduction factor shown in Table A15 is calculated from this effective exposure time for completeness. The calculation is shown below.

$$(4,120 \text{ h/y}) / (12 \text{ h/d} * 365 \text{ d/y}) = 0.941$$

The 2001 ILAW PA used the same time period for the all pathways farmer, 4,120 h. The Grouted Waste performance assessment used an effective time of 4,383 hours and the 200 West Area Burial Ground performance assessment used an effective time of 3,260 hours.

The Native American exposure scenario also uses 7,008 h/y for the effective external annual exposure time. This is unchanged from the 2001 ILAW PA. However, when the contaminated water is from the Columbia River there is now an additional contribution from shoreline sediments and swimming and boating. These were not included in the 2001 ILAW PA.

The annual exposure time for the Columbia River population is chosen to be 4,380 hours (12 h/d for 365 d). This is the same as used in prior performance assessments.

For the HSRAM scenarios, the external exposure parameters for irrigated land are from the HSRAM. The shoreline, swimming and boating activities for the residential and agricultural scenarios are assumed to match the recreational scenario.

A3.4 Absorption Through the Skin

Each exposure scenario includes dermal contact with the contaminated medium. The driller and post-intrusion resident get the contaminated soil on their skin. The ground water scenarios have contaminated water being used for showers and saunas. This section evaluates the likely intakes due to contaminants being absorbed through the skin into body fluids.

A3.4.1 Dermal Absorption of Radionuclides

The internal dose from radionuclides absorbed through the skin is the product of the amount absorbed each day and an internal dose factor for dermal absorption. Internal dose factors for radionuclides absorbed through the skin can be estimated by dividing the ingestion dose factor by the gut-to-body-fluid transfer fraction (f_1). This is somewhat inexact because the material in the gut is wet and contains a variety of chemicals secreted by the body to aid in the absorption of nutrients. In addition, the interior surface area of the small intestine is larger than the skin area of the entire body by two orders of magnitude.

The amount absorbed through the skin depends on the surface concentration of the contaminant, the area contaminated, and how often this happens during the year. The transfer from the skin to the body fluids is assumed proportional to the f_1 parameter. The annual intake would then be multiplied by the internal dose factor constructed by dividing the ingestion dose factor by the f_1 . The f_1 transfer fraction thus cancels out of the calculation, and dermal contact can be regarded as another type of ingestion dose.

An exception is for tritium as water vapor. The inhalation dose factor for tritium includes absorption through the skin in addition to the lungs by increasing the value by 50%. The ingestion dose factor is not modified.

Contaminated Soil. Soil adheres to the skin, permitting materials in the soil to be absorbed through the skin into body fluids. The adult body has a median skin area of about 20,000 cm², Chapter 6 (EPA/600-P-95/002Fa). The recommended area for contact with soil outdoors is 5,000 cm², which is 25% of the total. Typical soil adherence values range from 0.1 mg/cm² to 5 mg/cm² (EPA/600-P-95/002Fa). Actual soil adherence depends on soil properties such as moisture content and particle size, type of activity, and parts of the body surface exposed. The values selected for the performance assessment exposure scenarios are shown in Table A16. The numbers are at the low end of the range, but are consistent with values selected for the HSRAM and NASR scenarios.

A small fraction of the contamination present on the skin will be absorbed into the body through the skin. This fraction is assumed to be 0.001 times the f_1 value based on typical values for the dermal absorption factor for inorganic chemicals (see Table A20). Table A16 summarizes the affected skin areas, soil adherence, and annual contact events for each of the exposure scenarios. The product of these factors gives the equivalent annual soil ingestion due to dermal contact. The values shown are much smaller than the values for direct ingestion of soil presented in Table A8 (less than 3%). Hence the approach taken in DOE/RL-91-45 to neglect dermal absorption of radionuclides will be adopted in this report also.

Table A16. Dermal Absorption of Radionuclides in Soil.

Scenario	Soil Adherence (mg/cm ²)	Exposure Frequency (days/year)	Equivalent Ingestion (g/year)	Fraction of Inadvertent Soil Ingested
Well-Driller	0.25	5	0.0063	1.3%
Post-Intrusion Scenarios	0.25	180	0.23	1.3%
All Pathways Farmer	0.25	365	0.46	1.3%
Native American	1.0	365	1.8	2.5%
Columbia River Population	0.2	365	0.37	1.0%

Notes:

- The recommended adult surface area involved in outdoor soil contact is 5,000 cm² from the Exposure Factors Handbook, Chapter 6 (EPA/600-P-95/002Fa).
- The "Equivalent Ingestion" is the product of the adult surface area for outdoor contact, the soil adherence, the exposure frequency, and the assumed dermal absorption factor, 0.001.
- The fractions shown in the last column are the annual dermal intake divided by the annual inadvertent soil ingestion shown in Table A7.

Contaminated Irrigation Water. Waterborne contaminants in contact with the skin may potentially be absorbed through the skin into the body fluids. The leading dermal contact events are showers and the sauna or sweat lodge. Since these expose the entire skin surface, the potential for significant absorption exists. However, contact time is limited to 10 or 15 minutes for showers and 1 hour for the sauna or sweat lodge. The recommended adult total surface area is 20,000 cm² from the Exposure Factors Handbook, Chapter 6 (EPA/600-P-95/002Fa). Based on this area and typical values for the dermal absorption (permeability) constant (0.01 cm/h from Table A20), the dermal absorption intakes shown in Table A17 may be calculated.

The last column in Table A17 shows the ratio of the annual dermal intake to the annual average ingestion intake of water (545 L from Table A4). The dermal absorption adds less than 1 percent to the total. Therefore, the dermal absorption of radionuclides in water will not be explicitly included in the calculations in this report.

Table A17. Dermal Absorption of Radionuclides in Water.

Scenario	Daily Contact Time (hours/day)	Exposure Frequency (days/year)	Equivalent Ingestion (L/year)	Fraction of Total Water Ingested
All Pathways Farmer	0.25	365	1.8	0.3%
Native American Sweat Lodge	1	365	7.3	0.7%
Columbia River Population	0.167	365	1.2	0.2%

Notes:

- The daily contact times are the sweat lodge duration for the Native American, and the shower duration for the others.
- The "Equivalent Ingestion" is the product of the adult surface area (20,000 cm²), the daily contact time, the exposure frequency, and the assumed permeability coefficient, 0.01 cm/h.
- The fractions shown in the last column are the equivalent ingestion per year divided by the annual water ingestion from Table A4.

A3.4.2 Dermal Absorption of Chemicals

The dermal absorption of chemicals occurs as a result of contact with contaminated soil or water. Annual dermal exposure factors are shown in Table A18 for soil and A19 for water. The exposure factors need to be multiplied by the chemical-specific dermal absorption factor (soil contact) or the permeability coefficient (water contact). Because reference doses and slope factors for dermal exposure have not been developed, a form of route-to-route extrapolation is used. The dermal exposures are treated as a form of ingestion, and the ingestion reference dose and slope factor are used. The only modification factor is the gut-to-body fluid transfer factor (f₁). The exposures are adjusted to an effective amount ingested (i.e., outside the body) by dividing by the gut-to-body fluid transfer fraction.

Table A18. Dermal Absorption of Chemicals in Soil.

Scenario	Skin Contact Area (cm ²)	Soil Adherence (mg/cm ²)	Exposure Frequency (days/year)	Annual Dermal Exposure (g/year)
Irrigated Land				
All Pathways Farmer	5,000	0.25	365	456
Native American	5,000	1.0	365	1,825
Columbia River Population	5,000	0.2	180	365
HSRAM Industrial	5,000	0.2	146	146
Recreational – Child/Adult	2500 / 5000	0.2	7	3.5 / 7
Residential – Child/Adult	2500 / 5000	0.2	180	90 / 180
Agricultural – Child/Adult	2500 / 5000	0.2	180	90 / 180
Shoreline Sediment				
All Pathways Farmer	5,000	0.25	7	8.8
Native American	5,000	1.0	270	1,350
Columbia River Population	5,000	0.2	5	5.0
Recreational – Child/Adult	2500 / 5000	0.2	7	3.5 / 7
Residential – Child/Adult	2500 / 5000	0.2	7	3.5 / 7
Agricultural – Child/Adult	2500 / 5000	0.2	7	3.5 / 7
Notes:				
<ul style="list-style-type: none"> The recommended adult surface area involved in outdoor soil contact is 5,000 cm² from the Exposure Factors Handbook, Chapter 6 (EPA/600-P-95/002Fa). The child's surface area for contact with soil outdoors is half the adult value. For the last three HSRAM scenarios, the first 6 years are at the child's rate while the next 24 years are at the adult rate. Soil adherence and exposure frequency numbers for the All Pathways and Columbia River scenarios are assumed. Values for the HSRAM scenarios are from the HSRAM. Values for the NASR are from the CRCIA. The "Annual Dermal Exposure" is the product of the skin contact area, the soil adherence, and the exposure frequency. In the absence of reference doses and slope factors for dermal absorptions, the dermal route is treated as a form of ingestion. The effective amount ingested is the product of the annual dermal exposure and dermal absorption factor (Table A20) divided by the GI absorption factor (Table A20). 				

The dermal absorption factors for contact with contaminated soil shown in Table A20 are from EPA guidance listed below. Note that values for carbon disulfide and PCBs are given in the second and third reference.

- (1) United States Environmental Protection Agency. 1995. Supplemental Guidance to RAGS: Region 4 Bulletins, Human Health Risk Assessment (Interim Guidance). Waste Management Division, Office of Health Assessment. In general, the dermal absorption factor is 1% for organics and 0.1% for inorganics.
- (2) United States Environmental Protection Agency. 1992. Dermal Exposure Assessment: Principles and Application. Interim Report. EPA/600/8-91/011B. Office of Research and Development, Washington, D.C. Section 6.3 recommends the use of 6% for PCBs.
- (3) ATSDR (Agency for Toxic Substances and Disease Registry). 1992. Toxicological Profile for Carbon Disulfide. ATSDR/U.S. Public Health Service.

Table A19. Dermal Absorption of Chemicals in Water.

Scenario	Daily Dermal Contact Time (hours/day)	Exposure Frequency (days/year)	Annual Dermal Exposure (L/year per cm/h)
All Pathways Farmer Shower	0.25	365	1,825
Native American Sweat Lodge	1	365	7,300
Native American Swimming	2.6	70	3,640
Columbia River Population Shower	0.167	365	1,217
HSRAM Industrial Shower	0.167	250	833
Recreational Shower	0.167	7	23
Surface Water Swimming	2.6	7	364
Residential Shower	0.167	365	1,217
Agricultural Shower	0.167	365	1,217

Notes:

- The "Surface Water Swimming" is not used in the All Pathways Farmer or HSRAM Industrial scenarios. All others use this contact time in addition to contact during bathing.
- The "Annual Dermal Exposure" is the product of the adult surface area (20,000 cm²), the daily contact time, and the exposure frequency.
- In the absence of reference doses and slope factors for dermal absorptions, the dermal route is treated as a form of ingestion. The effective amount ingested is the product of the annual dermal exposure of water and the permeability coefficient (Table A20) divided by the GI absorption factor (Table A20).

The permeability constants for contact with contaminated water shown in Table A20 are calculated from the formula below from *Dermal Exposure Assessment: Principles and Application. Interim Report* (EPA/600/8-91/011B). Values for the logarithm of the octanol-water constant (Log K_{OW}) and molecular weights (MW) for each chemical are listed in Table A3. The formula below was used even for inorganic compounds, provided there was a value for Log K_{OW}. For the few chemicals with no value for Log K_{OW}, the default value of 0.001 cm/h was used.

$$\text{Log } U_D = 0.71(\text{Log } K_{OW}) - 0.0061 * \text{MW} - 2.72$$

The gastro-intestinal absorption factors shown in Table A20 are from the RAIS database. Values in the database are from a large list of technical publications. The internet address for these references is <http://risk.lsd.ornl.gov/tox/giabsref.shtml>. The GI absorption factors and references may also be accessed by chemical using http://risk.lsd.ornl.gov/cgi-bin/tox/TOX_select?select=nrاد.

Table A20. Dermal Absorption Parameters for Chemicals.

CASRN	Chemical Name	Dermal Absorption Factor	Permeability Constant (cm/h)	GI Absorption Factor (f1)
50-32-8	Benzo[a]pyrene	0.01	1.240E+00	0.31
53-70-3	Dibenz[a,h]anthracene	0.01	1.680E+00	0.31
56-23-5	Carbon tetrachloride	0.01	2.240E-02	0.65
57-12-5	Cyanide, free	0.01	8.660E-04	0.17
57-14-7	1,1-Dimethylhydrazine	0.01	1.170E-04	0.5
57-55-6	Propylene glycol (1,2-Propanediol)	0.01	1.450E-04	0.5
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)	0.01	2.790E-02	0.97
60-29-7	Ethyl ether (Diethyl ether)	0.01	2.882E-03	0.8
60-34-4	Methylhydrazine	0.01	1.790E-04	0.5
60-57-1	Dieldrin	0.01	4.450E-02	0.5
62-75-9	N-Nitrosodimethylamine	0.01	2.650E-04	0.5
64-18-6	Formic acid	0.01	4.130E-04	0.5
67-56-1	Methanol (Methyl alcohol)	0.01	3.450E-04	0.8
67-64-1	Acetone (2-Propanone)	0.01	5.690E-04	0.83
67-66-3	Chloroform	0.01	8.920E-03	0.2
67-72-1	Hexachloroethane	0.01	5.960E-02	0.5
71-36-3	n-Butyl alcohol (n-Butanol)	0.01	2.840E-03	0.5
71-43-2	Benzene	0.01	2.070E-02	0.97
71-55-6	1,1,1-Trichloroethane (Methyl chloroform)	0.01	1.710E-02	0.9
72-20-8	Endrin	0.01	4.450E-02	0.02
74-83-9	Bromomethane	0.01	3.510E-03	0.8
74-87-3	Methyl chloride (Chloromethane)	0.01	4.150E-03	0.8
75-00-3	Ethyl Chloride	0.01	7.980E-03	0.8
75-01-4	Vinyl chloride (Chloroethene)	0.01	1.130E-02	1
75-05-8	Acetonitrile	0.01	6.140E-04	0.8
75-07-0	Acetaldehyde	0.01	5.890E-04	0.8
75-09-2	Dichloromethane (Methylene chloride)	0.01	4.460E-03	0.95
75-15-0	Carbon disulfide	0.25	1.560E-02	0.63
75-21-8	Ethylene Oxide (Oxirane)	0.01	6.280E-04	0.8
75-34-3	1,1-Dichloroethane (Ethylidene chloride)	0.01	8.860E-03	1
75-35-4	1,1-Dichloroethylene	0.01	1.590E-02	1
75-45-6	Chlorodifluoromethane	0.01	3.310E-03	0.8
75-68-3	Chloro-1,1-difluoroethane, 1-	0.01	1.330E-02	0.8
75-69-4	Trichlorofluoromethane	0.01	1.730E-02	0.23
75-71-8	Dichlorodifluoromethane	0.01	1.190E-02	0.23
76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane (CFC-113)	0.01	2.400E-02	0.8
76-44-8	Heptachlor	0.01	2.160E-01	0.72
78-83-1	Isobutanol	0.01	2.330E-03	0.8
78-87-5	1,2-Dichloropropane	0.01	9.920E-03	0.74
78-93-3	Methyl ethyl ketone (2-Butanone)	0.01	1.110E-03	0.8
79-00-5	1,1,2-Trichloroethane	0.01	6.430E-03	0.81
79-01-6	Trichloroethylene	0.01	1.570E-02	0.15

Table A20. Dermal Absorption Parameters for Chemicals.

CASRN	Chemical Name	Dermal Absorption Factor	Permeability Constant (cm/h)	GI Absorption Factor (f1)
79-10-7	2-Propenoic acid (Acrylic acid)	0.01	1.230E-03	0.5
79-34-5	1,1,2,2-Tetrachloroethane (Acetylene tetrachloride)	0.01	8.970E-03	0.7
79-46-9	2-Nitropropane	0.01	2.490E-03	0.8
82-68-8	Pentachloronitrobenzene (PCNB)	0.01	5.930E-02	0.8
83-32-9	Acenaphthene	0.01	1.330E-01	0.31
84-66-2	Diethyl phthalate	0.01	4.390E-03	0.9
84-74-2	Dibutyl phthalate	0.01	5.980E-02	1
85-68-7	Butyl benzyl phthalate	0.01	5.410E-02	0.61
87-68-3	Hexachlorobutadiene	0.01	1.210E-01	0.5
87-86-5	Pentachlorophenol	0.01	1.950E-01	1
88-06-2	2,4,6-Trichlorophenol	0.01	4.960E-02	0.5
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)	0.01	2.200E-02	0.5
91-20-3	Naphthalene	0.01	6.940E-02	0.8
92-52-4	1,1'-Biphenyl	0.01	1.460E-01	0.5
95-47-6	o-Xylene	0.01	7.040E-02	0.8
95-48-7	2-Methylphenol (o-Cresol)	0.01	1.010E-02	0.5
95-50-1	1,2-Dichlorobenzene (ortho-)	0.01	6.590E-02	0.8
95-57-8	2-Chlorophenol	0.01	1.050E-02	0.5
95-63-6	1,2,4-Trimethylbenzene	0.01	1.330E-01	0.8
95-95-4	2,4,5-Trichlorophenol	0.01	5.210E-02	0.5
98-86-2	Acetophenone	0.01	4.670E-03	0.8
98-95-3	Nitrobenzene	0.01	6.960E-03	0.97
100-25-4	1,4-Dinitrobenzene (para-)	0.01	1.950E-03	0.5
100-41-4	Ethyl benzene	0.01	7.390E-02	0.97
100-42-5	Styrene	0.01	5.480E-02	0.8
100-51-6	Benzyl alcohol	0.01	2.520E-03	0.66
106-42-3	p-Xylene	0.01	7.390E-02	0.8
106-44-5	4-Methylphenol (p-Cresol)	0.01	9.950E-03	0.65
106-46-7	1,4-Dichlorobenzene (para-)	0.01	6.690E-02	0.9
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	0.01	3.350E-03	0.8
106-99-0	1,3-Butadiene	0.01	2.310E-02	0.8
107-02-8	2-Propenal (Acrolein)	0.01	8.530E-04	0.8
107-05-1	3-Chloropropene (Allyl chloride)	0.01	1.530E-02	0.8
107-06-2	1,2-Dichloroethane (Ethylene chloride)	0.01	5.340E-03	1
107-13-1	Acrylonitrile	0.01	1.360E-03	0.8
108-10-1	Methyl isobutyl ketone (4-Methyl-2-pentanone)	0.01	3.970E-03	0.8
108-38-3	m-Xylene	0.01	8.020E-02	0.8
108-39-4	3-Methylphenol (m-Cresol)	0.01	1.030E-02	0.5
108-67-8	1,3,5-Trimethylbenzene	0.01	9.440E-02	0.8
108-87-2	Methyl cyclohexane	0.01	1.750E-01	0.8
108-88-3	Toluene (Methyl benzene)	0.01	4.530E-02	0.8
108-90-7	Chlorobenzene	0.01	4.070E-02	0.31

Table A20. Dermal Absorption Parameters for Chemicals.

CASRN	Chemical Name	Dermal Absorption Factor	Permeability Constant (cm/h)	GI Absorption Factor (f1)
108-94-1	Cyclohexanone	0.01	1.800E-03	0.8
108-95-2	Phenol (Carbolic acid)	0.01	5.530E-03	0.9
109-99-9	Tetrahydrofuran	0.01	1.470E-03	0.5
110-00-9	Furan (Oxacyclopentadiene)	0.01	6.550E-03	0.8
110-54-3	n-Hexane	0.01	3.340E-01	0.8
110-80-5	2-Ethoxyethanol	0.01	3.180E-04	0.5
110-82-7	Cyclohexane	0.01	1.620E-01	1
110-86-1	Pyridine	0.01	1.820E-03	0.5
111-76-2	2-Butoxyethanol (Ethylene Glycol Monobutyl Ether)	0.01	1.410E-03	0.5
111-90-0	2-(2-Ethoxyethoxy)-ethanol (Diethylene Glycol Monoethyl Ether)	0.01	1.200E-04	0.5
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)	0.01	1.970E+00	0.19
117-84-0	Di-n-octylphthalate	0.01	4.450E+00	0.9
118-74-1	Hexachlorobenzene	0.01	4.080E-01	0.5
120-82-1	1,2,4-Trichlorobenzene	0.01	1.070E-01	0.97
121-14-2	2,4-Dinitrotoluene	0.01	3.760E-03	0.85
121-44-8	Triethylamine	0.01	4.920E-03	0.8
122-39-4	Diphenylamine	0.01	5.400E-02	0.5
123-91-1	1,4-Dioxane (Diethylene oxide)	0.01	3.560E-04	0.8
126-73-8	Tributyl Phosphate	0.01	3.130E-02	0.5
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)	0.01	2.260E-03	0.8
127-18-4	Tetrachloroethylene	0.01	4.810E-02	1
129-00-0	Pyrene	0.01	3.240E-01	0.31
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	0.01	1.820E-03	0.8
156-59-2	cis-1,2-Dichloroethylene	0.01	1.490E-02	1
206-44-0	Fluoranthene (1,2-Benzacenaphthene)	0.01	5.130E-01	0.31
309-00-2	Aldrin	0.01	4.670E-01	0.5
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	0.01	2.790E-02	0.97
319-85-7	beta-Benzene hexachloride (beta-Lindane)	0.01	2.790E-02	0.91
541-73-1	1,3-Dichlorobenzene	0.01	7.750E-02	0.8
542-75-6	1,3-Dichloropropene (cis & trans)	0.01	1.110E-02	0.55
621-64-7	N-Nitrosodi-N-propylamine	0.01	2.830E-03	0.25
1314-62-1	Vanadium pentoxide	0.001	1.910E-02	0.2
1330-20-7	Xylenes (mixtures)	0.01	7.040E-02	0.92
1336-36-3	Polychlorinated Biphenyls	0.06	9.220E-01	0.9
1336-36-3	Polychlorinated Biphenyls (lowest risk)	0.06	9.220E-01	0.9
6533-73-9	Thallium carbonate	0.01	6.440E-07	0.5
7429-90-5	Aluminum	0.001	2.140E-03	0.1
7439-89-6	Iron	0.001	2.470E-04	0.15
7439-93-2	Lithium	0.001	4.900E-04	0.8
7439-96-5	Manganese	0.001	1.280E-03	0.04
7439-97-6	Mercury metal vapor	0.001	3.140E-04	0.0001
7439-98-7	Molybdenum	0.001	7.200E-04	0.38

Table A20. Dermal Absorption Parameters for Chemicals.

CASRN	Chemical Name	Dermal Absorption Factor	Permeability Constant (cm/h)	GI Absorption Factor (f1)
7440-02-0	Nickel (soluble salts)	0.001	3.290E-04	0.27
7440-22-4	Silver	0.001	6.090E-04	0.18
7440-24-6	Strontium, Stable	0.001	8.090E-04	0.2
7440-28-0	Thallium metal	0.001	1.570E-04	0.15
7440-31-5	Tin	0.001	2.880E-03	0.1
7440-36-0	Antimony	0.001	1.090E-03	0.02
7440-38-2	Arsenic (inorganic)	0.001	1.930E-03	0.41
7440-39-3	Barium	0.001	4.030E-04	0.07
7440-41-7	Beryllium and compounds	0.001	6.600E-04	0.01
7440-42-8	Boron and borates only	0.001	2.280E-03	0.9
7440-43-9	Cadmium	0.01	3.500E-04	0.05
7440-45-1	Cerium (Ceric oxide 1306-38-3)	0.001	3.878E-04	0.001
7440-48-4	Cobalt	0.001	1.210E-03	0.8
7440-50-8	Copper	0.001	3.070E-04	0.3
7440-62-2	Vanadium metal	0.001	1.350E-03	0.01
7440-66-6	Zinc and compounds	0.001	3.420E-04	0.2
7487-94-7	Mercuric chloride	0.001	2.940E-05	0.07
7664-41-7	Ammonia	0.001	1.570E-04	0.2
7723-14-0	Phosphorus, white	0.001	7.590E-04	0.2
7782-41-4	Fluorine (soluble fluoride)	0.001	1.610E-03	0.97
7782-49-2	Selenium and compounds	0.001	9.030E-04	0.44
8001-35-2	Toxaphene	0.01	7.240E-02	0.5
11096-82-5	Aroclor 1260	0.06	5.480E+00	0.9
11097-69-1	Aroclor 1254	0.06	1.290E+00	0.9
11104-28-2	Aroclor 1221	0.06	2.220E-01	0.9
11141-16-5	Aroclor 1232	0.06	2.220E-01	0.9
12672-29-6	Aroclor 1248	0.06	9.920E-01	0.9
12674-11-2	Aroclor 1016	0.06	5.000E-01	0.9
14797-55-8	Nitrate	0.001	1.120E-03	0.5
14797-65-0	Nitrite	0.001	1.080E-03	0.5
16065-83-1	Chromium (III) (insoluble salts)	0.001	0.001	0.005
16984-48-8	Fluorine anion	0.001	0.00161	0.97
18540-29-9	Chromium (VI) (soluble salts)	0.001	0.001	0.02
53469-21-9	Aroclor 1242	0.06	0.922	0.9
na	Uranium (soluble salts)	0.001	0.001	0.85

Notes:

- Dermal Absorption Factors and GI Absorption Factors are from the EPA references listed in the text. The listing in this table is from the Risk Assessment Information System (RAIS) as of March, 2004.
- The Permeability Constants are calculated from the molecular weight and octanol-water constants or the default value of 0.001 cm/h as described in the text.

A3.5 Internal Dose Factors for Radionuclides

To assist the reader in understanding the nomenclature surrounding radiation exposures, the adjectives in the table below add particular nuances to the word “dose”. Note that all cases a radiation dose comes from either internal or external sources. Internal sources are inside the body, while external sources are outside the body.

absorbed	The energy deposited by the radiation per unit mass of material (living tissue in the present context).
equivalent	Relates an absorbed dose to some reference biological measure of effect.
committed	Infers that the dose is accumulated over a period of 50 years. A necessary condition is that the dose comes from internally deposited radionuclides.
effective	Infers that the dose is the weighted sum of organ doses.
total	Emphasizes that the dose includes both internal and external contributions.

The quantity “absorbed dose” has units of gray (or rad), while the quantity “dose equivalent” has units of sievert (or rem). The “dose equivalent” is calculated from the “absorbed dose” using appropriate “quality factors”. The quality factors are independent of the tissue or organ under consideration, and also the biological endpoint. They only depend on something called the “linear energy transfer”, i.e., the energy deposited in the tissue per unit length of travel of the radiation particle. Some ambiguity arises because there is a second set of scale factors that may be applied to the dose equivalent for an organ to relate the risk from the organ dose to the equivalent risk that accompanies a whole body dose of gamma rays. These scale factors are called “organ weighting factors”.

The term “committed dose equivalent” (CDE) is the dose equivalent received by an organ over a period of 50 years following an intake of radioactivity. The term “intake” refers to the amount inhaled or ingested or absorbed through the skin. The effect on the organ depends on both the total dose commitment and the rate at which the dose accumulates. For example, a CDE of 2 Sv (200 rem) received in a few days will likely impair the functioning of that organ, while a CDE of 2 Sv received over a period of several years might have no effect at all on the functioning of the organ.

Inhaled, ingested, or dermally absorbed radioactivity affects more than one organ. Not only is the activity transported by the blood to various organs, but photons emitted in one organ can give a dose to other organs. To describe the effect on the whole person, the term “committed effective dose equivalent” (CEDE) was created. The CEDE is the weighted sum of the committed dose equivalents to the various organs of the body following an intake of radioactivity. Thus, the CEDE relates the CDE calculated for the various organs to the overall risk of some “stochastic effect” (a genetic effect or cancer) on the person. The “organ weighting factors” mentioned earlier are used to calculate CEDE from the various organ CDEs.

Internal dose factors specify the committed effective dose equivalent (CEDE) from a unit intake (ingested or inhaled) of a radionuclide. The dose is accumulated over a period of 50

years, known as the dose commitment period. This dose commitment period was set by the International Commission on Radiological Protection (ICRP) in Publication 26 (1977) when determining internal dose and relating it to an equivalent whole body exposure.

If a nuclide has radioactive progeny with short half-lives (i.e. nuclides with a "+D" at the end of the name), then the internal dose factors for these progeny are included with the parent isotope. It is assumed that the progeny are in secular equilibrium with the parent nuclide. The internal dose factors for the progeny are multiplied by the branching ratio (see Table A1) and a decay half life factor, and added to the parent dose factor.

Four internal dose factor collections will be considered. The first was widely used in performance assessments for the United States Department of Energy (DOE/EH-0071). The second was prepared under the sponsorship of the United States Environmental Protection Agency (EPA-520/1-88-020). This set is now recommended for use in performance assessments at DOE sites (DOE/LLW-93 and DOE M 435.1-1 Implementation Guide Chapter IV). The third was computed for the GENII software (PNNL-6584), which was often used at the Hanford Site. The GENII internal dose factors are based on the 1993 revision (WHC-SD-WM-TI-596). The fourth set of internal dose factors uses improved anatomical models and revised metabolic data adopted by the ICRP beginning in 1990. The summary compilation of internal dose factors for various age groups was released in ICRP Publication 72.

The internal dose factors from the first three collections (GENII, EPA, and DOE) are listed in Tables A21 (ingestion) and A22 (inhalation). The ICRP 72 internal dose factors for the average adult are shown in Table A23. The internal dose factors have been converted to the common units of mrem per pCi intake. For the ingestion dose factors, the assumed values for f_1 , which is the fraction of the activity ingested that enters body fluids is shown. For the inhalation dose factors, the assumed activity median aerodynamic diameter of the particles is 1 μm . The lung model category is shown in the tables. The "Water" for tritium stands for tritiated water vapor (HTO), and includes a 50 percent increase due to absorption through the skin. The "Organic" for C-14 means that the carbon is assumed to have an organic chemical form rather than gaseous. The "D", "W", and "Y" mean the material clears the lungs in a matter of days, weeks, or years, respectively. The improved lung model uses the designations "F", "M", and "S" which stand for fast, moderate, and slow. The chemical forms originally classified as "D", "W", or "Y" should be now be regarded as "F", "M", or "S", respectively.

The assumed lung clearance rate for many of the radionuclides was changed to incorporate the recommendations of the ICRP in Report Number 71 (ICRP 1996). In Publication 71 the ICRP recommends default lung clearance types for particulate aerosols when no specific information is available. No recommendations were given for beryllium, silicon, titanium, vanadium, cadmium, indium, tin, promethium, gadolinium, rhenium, bismuth, actinium, or protactinium. For these elements, the solubility class with the largest inhalation dose factor was selected. An exception to this approach was made for titanium. The largest inhalation dose factors are for class Y material, but the slow lung clearance was only observed for one compound, SrTiO_3 . Because this compound is unlikely to be found in Hanford tank waste, the titanium compounds were assumed to be class D.

Comparison ratios of the GENII and DOE dose factors divided by the EPA dose factors are shown in Tables A21 and A22. Dose factors that differ less than 5% from the EPA numbers

are not shown in the ratio columns. The only nuclides with differences greater than 25 percent are Co-60, Nb-94, Tc-99, Ru-106, Ag-108m, In-115, Sn-126, Re-187, Bi-207, Ra-226, Ra-228, Th-228, Np-237, Pu-241, and Bk-247.

The dose factor collection from the EPA (EPA-520/1-88-020) will be used in the tank waste PA. These are the only internal dose factors currently approved by the DOE for use in performance assessments (DOE M 435.1-1). The difference between the GENII, EPA, and DOE internal dose factors is minor because they are all based on the methods given in ICRP 30. However, the difference between the EPA and the ICRP 72 internal dose factors is appreciable in some cases. The ratios between the EPA and ICRP 72 internal dose factors are shown in Table A23.

The internal dose factors for Nb-91 are not listed in any dose factor collection and were assumed bounded by the values for Nb-93m. Both nuclides emit low energy electrons and photons, as shown on the nuclear decay data summary of Table A24. For Nb-91, there is a continuous spectrum of low energy photons associated with the electron capture and positron decay. However, this continuous spectrum is a minor addition to the photon spectrum. The total electron plus photon energy for Nb-91 (15 keV) is less than that for Nb-93m (26 keV). Therefore, the internal dose factor for Nb-91 should be less than that for Nb-93m.

An additional consideration is the half-life of the two isotopes compared with expected residence times in the body. Inhalation class Y niobium is retained in the lungs for a considerable length of time. Most is removed during the first several years, but some is retained indefinitely. The organ with the largest dose for class Y Nb-93m is the lung. Most (87%) of the dose from Nb-93m accrues during the first 10 years after inhalation. Thus, the effect of Nb-93m's shorter half-life is small. It will be assumed that the internal dose factors for Nb-91 are bounded by those for Nb-93m.

In addition to Nb-91, the internal dose factors for Po-209 are not listed in any dose factor collection and were computed by comparison with Po-210. Corrections were made for the energy of the alpha particles emitted, and the decay half-life using the equation shown below.

$$\text{Dose Factor} \propto \frac{E_{\alpha}}{\lambda_{\text{eff}}} [1 - \text{Exp}(-\lambda_{\text{eff}} T_d)]$$

where

E_{α} = total alpha energy per decay. For Po-209 this is 4.866 Mev per decay, while for Po-210 this is 5.304 Mev per decay.

λ_{eff} = effective removal constant, which combines both the biological elimination and the radioactive decay of the nuclide, i.e., $\lambda_{\text{eff}} = \lambda_{\text{bio}} + \lambda_{\text{rad}}$.

T_d = dose commitment period used in the dose factor collections shown in Tables A21 and A22, namely, 50 years.

From ICRP 30, the biological removal half time for polonium is 50 days ($\lambda_{\text{bio}} = \text{Ln}(2)/50\text{d} = 0.01386$ per day). The decay half-life of Po-209 is 102 year ($\lambda_{\text{rad}} = \text{Ln}(2)/102\text{y}/365.25 = 0.00002$ per day), thus its λ_{eff} is 0.01388 per day. The decay half-life of Po-210 is 138.38 days ($\lambda_{\text{rad}} = \text{Ln}(2)/138.38\text{d} = 0.00501$ per day), thus its λ_{eff} is 0.01887 per day. Thus, the dose integration term in brackets is nearly equal to 1 after 50 years. The ratio of Po-209 to Po-210

internal dose factors is shown below. This ratio was applied to the Po-210 inhalation and ingestion dose factors to arrive at the Po-209 internal dose factors.

$$\frac{\text{Po - 209 Dose Factor}}{\text{Po - 210 Dose Factor}} = \frac{(4.866 \text{ MeV})(0.01887 \text{ per day})}{(5.304 \text{ MeV})(0.01388 \text{ per day})} = 1.247$$

Special groups of people such as children and diabetics, will have different internal dose factors due to differences in organ mass and retention times in the various tissues of the body. Internal dose factors for different age groups have been computed by the ICRP in Publication 72 (1996). Unit dose factors for individuals whose metabolic characteristics differ considerably from those of the reference individual will also differ from those presented in Tables A21 and A22. As explained in DOE M 435.1-1 Chapter IV, the use of dose factors for representative members of the public is desirable to avoid overly conservative results. A bounding case exposure scenario evaluates possible upper limits.

Absorption through the skin, and injection from an injury are not considered since they are not likely to add significantly to the doses computed in the intruder and irrigation scenarios. These may be computed using an internal dosimetry program such as CINDY (PNNL-7493). Values have been published (PNNL-10190) and are basically the ingestion dose factor divided by the internal transfer factor (f_i).

Any special exposure pathways associated with extended dermal contact with contaminated soil or vegetation will require appropriate dermal absorption dose factors. Dermal absorption methods for radionuclides have been included in the MEPAS¹ program (PNNL-10523).

¹MEPAS is a registered trademark of Battelle Memorial Institute.

Table A21. Ingestion Dose Factors, mrem/pCi Ingested.

Nuclide	f1	GENII	EPA	DOE	GENII / EPA	DOE / EPA
H-3	1	6.12E-08	6.40E-08	6.30E-08		
Be-10	0.005	4.70E-06	4.66E-06	4.20E-06		0.90
C-14	1	2.06E-06	2.09E-06	2.10E-06		
Na-22	1	1.06E-05	1.15E-05	1.20E-05	0.92	
Al-26	0.01	1.42E-05	1.46E-05	1.30E-05		0.89
Si-32+D	0.01	1.11E-05	1.10E-05	9.40E-06		0.86
Cl-36	1	2.95E-06	3.03E-06	3.00E-06		
K-40	1	1.79E-05	1.86E-05	1.90E-05		
Ca-41	0.3	1.20E-06	1.27E-06	1.20E-06		
Ti-44+D	0.01	2.35E-05	2.46E-05	2.04E-05		0.83
V-49	0.01	6.04E-08	6.14E-08	5.40E-08		0.88
Mn-54	0.1	2.76E-06	2.77E-06	2.70E-06		
Fe-55	0.1	6.15E-07	6.07E-07	5.80E-07		
Fe-60+D	0.1	na	1.52E-04	1.50E-04		
Co-60	0.3	2.65E-05	2.69E-05	2.60E-05		
Ni-59	0.05	2.05E-07	2.10E-07	2.00E-07		
Ni-63	0.05	5.72E-07	5.77E-07	5.40E-07		0.94
Se-79	0.8	8.33E-06	8.70E-06	8.30E-06		
Rb-87	1	4.73E-06	4.92E-06	4.80E-06		
Sr-90+D	0.3	1.31E-04	1.53E-04	1.40E-04	0.85	0.91
Zr-93	0.002	1.64E-06	1.66E-06	1.60E-06		
Nb-91	0.01	5.05E-07	5.22E-07	5.30E-07		
Nb-93m	0.01	5.05E-07	5.22E-07	5.30E-07		
Nb-94	0.01	7.25E-06	7.14E-06	5.10E-06		0.71
Mo-93	0.8	1.21E-06	1.35E-06	1.30E-06	0.90	
Tc-99	0.8	2.23E-06	1.46E-06	1.30E-06	1.53	0.89
Ru-106+D	0.05	2.73E-05	2.74E-05	2.10E-05		0.77
Pd-107	0.005	1.50E-07	1.49E-07	1.40E-07		0.94
Ag-108m+D	0.05	7.58E-06	7.62E-06	7.50E-06		
Cd-109	0.05	1.32E-05	1.31E-05	1.20E-05		0.91
Cd-113m	0.05	1.62E-04	1.61E-04	1.50E-04		0.93
In-115	0.02	8.68E-05	1.58E-04	1.40E-04	0.55	0.89
Sn-121m+D	0.02	2.24E-06	2.25E-06	1.99E-06		0.88
Sn-126+D	0.02	2.08E-05	2.10E-05	1.83E-05		0.87
Sb-125	0.1	2.83E-06	2.81E-06	2.40E-06		0.85
Te-125m	0.2	3.72E-06	3.67E-06	3.40E-06		0.93
I-129	1	2.49E-04	2.76E-04	2.80E-04	0.90	
Cs-134	1	6.82E-05	7.33E-05	7.40E-05	0.93	
Cs-135	1	6.86E-06	7.07E-06	7.10E-06		
Cs-137+D	1	4.74E-05	5.00E-05	5.00E-05	0.95	
Ba-133	0.1	3.05E-06	3.40E-06	3.20E-06	0.90	0.94

Table A21. Ingestion Dose Factors, mrem/pCi Ingested.

Nuclide	f1	GENII	EPA	DOE	GENII / EPA	DOE / EPA
Pm-147	0.0003	1.06E-06	1.05E-06	9.50E-07		0.91
Sm-147	0.0003	1.86E-04	1.85E-04	1.80E-04		
Sm-151	0.0003	3.87E-07	3.89E-07	3.40E-07		0.88
Eu-150	0.001	6.34E-06	6.36E-06	6.20E-06		
Eu-152	0.001	6.48E-06	6.48E-06	6.00E-06		0.93
Eu-154	0.001	9.61E-06	9.55E-06	9.10E-06		
Eu-155	0.001	1.53E-06	1.53E-06	1.30E-06		0.85
Gd-152	0.0003	1.61E-04	1.61E-04	1.50E-04		0.93
Ho-166m	0.0003	8.13E-06	8.07E-06	7.80E-06		
Re-187	0.8	1.45E-08	9.51E-09	8.30E-09	1.52	0.87
Tl-204	1	3.46E-06	3.36E-06	3.20E-06		
Pb-205	0.2	1.64E-06	1.63E-06	1.50E-06		0.92
Pb-210+D	0.2	5.40E-03	5.37E-03	5.11E-03		
Bi-207	0.05	5.49E-06	5.48E-06	4.90E-06		0.89
Po-209	0.1	2.39E-03	2.37E-03	2.00E-03		0.84
Po-210	0.1	1.90E-03	1.90E-03	1.60E-03		0.84
Ra-226+D	0.2	9.51E-04	1.33E-03	1.10E-03	0.72	0.83
Ra-228+D	0.2	8.44E-04	1.44E-03	1.20E-03	0.59	0.84
Ac-227+D	0.001	1.44E-02	1.48E-02	1.46E-02		
Th-228+D	0.0002	5.79E-04	8.11E-04	7.54E-04	0.71	0.93
Th-229+D	0.0002	3.87E-03	4.03E-03	3.91E-03		
Th-230	0.0002	5.48E-04	5.48E-04	5.30E-04		
Th-232	0.0002	2.73E-03	2.73E-03	2.80E-03		
Pa-231	0.001	1.06E-02	1.06E-02	1.10E-02		
U-232	0.05	1.31E-03	1.31E-03	1.30E-03		
U-233	0.05	2.90E-04	2.89E-04	2.70E-04		0.93
U-234	0.05	2.84E-04	2.83E-04	2.60E-04		0.92
U-235+D	0.05	2.67E-04	2.67E-04	2.51E-04		0.94
U-236	0.05	2.69E-04	2.69E-04	2.50E-04		0.93
U-238+D	0.05	2.70E-04	2.68E-04	2.43E-04		0.91
Np-237+D	0.001	5.22E-03	4.44E-03	3.90E-03	1.17	0.88
Pu-236	0.001	1.16E-03	1.17E-03	1.30E-03		1.12
Pu-238	0.001	3.19E-03	3.20E-03	3.80E-03		1.19
Pu-239	0.001	3.53E-03	3.54E-03	4.30E-03		1.22
Pu-240	0.001	3.53E-03	3.54E-03	4.30E-03		1.22
Pu-241+D	0.001	6.79E-05	6.85E-05	8.60E-05		1.26
Pu-242	0.001	3.35E-03	3.36E-03	4.10E-03		1.22
Pu-244+D	0.001	3.32E-03	3.32E-03	4.00E-03		1.20
Am-241	0.001	3.62E-03	3.64E-03	4.50E-03		1.24
Am-242m+D	0.001	3.50E-03	3.52E-03	4.20E-03		1.19
Am-243+D	0.001	3.62E-03	3.63E-03	4.50E-03		1.24
Cm-242	0.001	1.15E-04	1.15E-04	1.10E-04		

Table A21. Ingestion Dose Factors, mrem/pCi Ingested.

Nuclide	f1	GENII	EPA	DOE	GENII / EPA	DOE / EPA
Cm-243	0.001	2.50E-03	2.51E-03	2.90E-03		1.15
Cm-244	0.001	2.01E-03	2.02E-03	2.30E-03		1.14
Cm-245	0.001	3.73E-03	3.74E-03	4.50E-03		1.20
Cm-246	0.001	3.70E-03	3.70E-03	4.50E-03		1.22
Cm-247+D	0.001	3.40E-03	3.42E-03	4.10E-03		1.20
Cm-248	0.001	1.36E-02	1.36E-02	1.60E-02		1.18
Cm-250+D	0.001	7.76E-02	7.77E-02	7.77E-02		
Bk-247	0.001	3.81E-03	4.70E-03	2.30E-03	0.81	0.49
Cf-248	0.001	3.39E-04	3.34E-04	2.80E-04		0.84
Cf-249	0.001	4.75E-03	4.74E-03	4.60E-03		
Cf-250	0.001	2.13E-03	2.13E-03	1.90E-03		0.89
Cf-251	0.001	4.82E-03	4.85E-03	4.60E-03		0.95
Cf-252	0.001	1.09E-03	1.08E-03	9.40E-04		0.87

Notes:

- GENII ingestion dose factors are based on the 1993 revision (WHC-SD-WM-TI-596). EPA ingestion dose factors from Federal Guidance Report Number 11, EPA-520/1-88-020, Sept 1988. DOE ingestion dose factors from DOE/EH-0071, (DE88-014297), July 1988. All doses are 50 year committed effective dose equivalent (CEDE).
- "f1" is the fraction of the ingested activity reaching body fluids.
- The short-lived radioactive progeny shown on Table A1 are assumed to be in secular equilibrium with their parent nuclide. The dose factors for implicit daughters have been multiplied by the branching ratios in Table A1 and added to the parent dose factor to give the values shown.
- The last two columns show ratios of GENII and DOE ingestion dose factors to the EPA dose factors. Ratios of dose factors within 5% of the EPA value are not shown.

Table A22. Inhalation Dose Factors, mrem/pCi Inhaled.

Nuclide	Lung Model	GENII	EPA	DOE	GENII / EPA	DOE / EPA
H-3	Water	9.02E-08	9.60E-08	9.45E-08	0.94	
Be-10	Y	3.54E-04	3.54E-04	3.50E-04		
C-14	Organic	2.06E-06	2.09E-06	2.10E-06		
Na-22	D	7.11E-06	7.66E-06	8.00E-06	0.93	
Al-26	W	6.95E-05	7.22E-05	5.90E-05		0.82
Si-32+D	Y	1.02E-03	1.03E-03	1.01E-03		
Cl-36	W	2.21E-05	2.19E-05	2.00E-05		0.91
K-40	D	1.19E-05	1.24E-05	1.20E-05		
Ca-41	W	1.29E-06	1.35E-06	1.30E-06		
Ti-44+D	D	4.18E-04	4.52E-04	4.50E-04	0.92	
V-49	W	3.46E-07	3.45E-07	2.80E-07		0.81
Mn-54	W	6.36E-06	6.70E-06	6.40E-06	0.95	
Fe-55	W	1.36E-06	1.34E-06	1.20E-06		0.90
Fe-60+D	W	na	2.70E-04	2.70E-04		
Co-60	W	3.20E-05	3.31E-05	3.00E-05		0.91
Ni-59	W	9.00E-07	9.18E-07	7.00E-07		0.76
Ni-63	W	2.30E-06	2.30E-06	1.90E-06		0.83
Se-79	D	6.13E-06	6.55E-06	6.20E-06	0.94	0.95
Rb-87	D	3.18E-06	3.23E-06	3.30E-06		
Sr-90+D	D	2.09E-04	2.47E-04	2.37E-04	0.85	
Zr-93	W	8.16E-05	8.33E-05	8.10E-05		
Nb-91	W	2.88E-06	3.21E-06	4.10E-06	0.90	1.28
Nb-93m	W	2.88E-06	3.21E-06	4.10E-06	0.90	1.28
Nb-94	W	3.38E-05	3.61E-05	2.60E-05	0.94	0.72
Mo-93	Y	2.80E-05	2.84E-05	2.80E-05		
Tc-99	W	9.00E-06	8.33E-06	7.50E-06	1.08	0.90
Ru-106+D	W	1.18E-04	1.18E-04	9.30E-05		0.79
Pd-107	Y	1.29E-05	1.28E-05	1.30E-05		
Ag-108m+D	W	2.44E-05	2.53E-05	1.90E-05		0.75
Cd-109	D	1.15E-04	1.14E-04	1.00E-04		0.87
Cd-113m	D	1.54E-03	1.53E-03	1.40E-03		0.92
In-115	D	2.02E-03	3.74E-03	3.40E-03	0.54	0.91
Sn-121m+D	W	1.18E-05	1.19E-05	9.26E-06		0.78
Sn-126+D	W	9.99E-05	1.01E-04	7.54E-05		0.75
Sb-125	W	1.23E-05	1.22E-05	9.80E-06		0.80
Te-125m	W	7.18E-06	7.29E-06	6.70E-06		0.92
I-129	D	1.51E-04	1.74E-04	1.80E-04	0.87	
Cs-134	D	4.28E-05	4.63E-05	4.70E-05	0.93	
Cs-135	D	4.49E-06	4.55E-06	4.50E-06		

Table A22. Inhalation Dose Factors, mrem/pCi Inhaled.

Nuclide	Lung Model	GENII	EPA	DOE	GENII / EPA	DOE / EPA
Cs-137+D	D	2.98E-05	3.19E-05	3.20E-05	0.93	
Ba-133	D	6.00E-06	7.81E-06	6.90E-06	0.77	0.88
Pm-147	Y	3.92E-05	3.92E-05	3.40E-05		0.87
Sm-147	W	7.48E-02	7.47E-02	7.10E-02		0.95
Sm-151	W	3.01E-05	3.00E-05	2.90E-05		
Eu-150	W	2.50E-04	2.68E-04	2.70E-04	0.93	
Eu-152	W	2.11E-04	2.21E-04	2.20E-04		
Eu-154	W	2.78E-04	2.86E-04	2.60E-04		0.91
Eu-155	W	4.12E-05	4.14E-05	3.90E-05		0.94
Gd-152	D	2.44E-01	2.43E-01	2.40E-01		
Ho-166m	W	7.46E-04	7.73E-04	7.20E-04		0.93
Re-187	W	5.86E-08	5.44E-08	4.90E-08	1.08	0.90
Tl-204	D	2.46E-06	2.41E-06	2.30E-06		
Pb-205	D	3.97E-06	3.92E-06	3.70E-06		0.94
Pb-210+D	D	1.37E-02	1.36E-02	1.30E-02		
Bi-207	W	1.96E-05	2.00E-05	1.40E-05		0.70
Po-209	W	1.15E-02	1.07E-02	1.01E-02	1.07	0.94
Po-210	W	8.63E-03	8.58E-03	8.10E-03		0.94
Ra-226+D	W	8.22E-03	8.60E-03	7.91E-03		0.92
Ra-228+D	W	4.18E-03	4.86E-03	4.29E-03	0.86	0.88
Ac-227+D	W	1.74E+00	1.74E+00	1.72E+00		
Th-228+D	Y	3.47E-01	3.42E-01	3.13E-01		0.92
Th-229+D	Y	1.75E+00	1.74E+00	1.72E+00		
Th-230	Y	2.62E-01	2.62E-01	2.60E-01		
Th-232	Y	1.15E+00	1.15E+00	1.10E+00		
Pa-231	W	1.29E+00	1.28E+00	1.30E+00		
U-232	W	1.52E-02	1.49E-02	1.30E-02		0.87
U-233	W	8.01E-03	7.99E-03	7.10E-03		0.89
U-234	W	7.99E-03	7.88E-03	7.10E-03		0.90
U-235+D	W	7.48E-03	7.29E-03	6.70E-03		0.92
U-236	W	7.49E-03	7.44E-03	6.70E-03		0.90
U-238+D	W	7.03E-03	7.06E-03	6.23E-03		0.88
Np-237+D	W	6.32E-01	5.40E-01	4.90E-01	1.17	0.91
Pu-236	W	1.45E-01	1.45E-01	1.60E-01		1.11
Pu-238	W	3.90E-01	3.92E-01	4.60E-01		1.17
Pu-239	W	4.30E-01	4.29E-01	5.10E-01		1.19
Pu-240	W	4.30E-01	4.29E-01	5.10E-01		1.19
Pu-241+D	W	8.17E-03	8.25E-03	1.00E-02		1.21
Pu-242	W	4.08E-01	4.11E-01	4.80E-01		1.17

Table A22. Inhalation Dose Factors, mrem/pCi Inhaled.

Nuclide	Lung Model	GENII	EPA	DOE	GENII / EPA	DOE / EPA
Pu-244+D	W	4.03E-01	4.03E-01	4.80E-01		1.19
Am-241	W	4.41E-01	4.44E-01	5.20E-01		1.17
Am-242m+D	W	4.24E-01	4.26E-01	5.10E-01		1.20
Am-243+D	W	4.41E-01	4.40E-01	5.20E-01		1.18
Cm-242	W	1.75E-02	1.73E-02	1.70E-02		
Cm-243	W	3.07E-01	3.07E-01	3.50E-01		1.14
Cm-244	W	2.48E-01	2.48E-01	2.70E-01		1.09
Cm-245	W	4.55E-01	4.55E-01	5.40E-01		1.19
Cm-246	W	4.51E-01	4.51E-01	5.40E-01		1.20
Cm-247+D	W	4.15E-01	4.14E-01	4.90E-01		1.18
Cm-248	W	1.65E+00	1.65E+00	1.90E+00		1.15
Cm-250+D	W	9.43E+00	9.40E+00	9.40E+00		
Bk-247	W	4.65E-01	5.74E-01	5.50E-01	0.81	
Cf-248	W	4.44E-02	4.44E-02	3.80E-02		0.86
Cf-249	W	5.77E-01	5.77E-01	5.50E-01		
Cf-250	W	2.63E-01	2.62E-01	2.20E-01		0.84
Cf-251	W	5.87E-01	5.88E-01	5.60E-01		
Cf-252	W	1.37E-01	1.37E-01	1.20E-01		0.88

Notes:

- The inhaled particulate is assumed to have an activity median aerodynamic diameter of 1 μm .
- GENII inhalation dose factors are based on the 1993 revision (WHC-SD-WM-TI-596). EPA inhalation dose factors from Federal Guidance Report Number 11, EPA-520/1-88-020, Sept 1988. DOE inhalation dose factors from DOE/EH-0071, (DE88-014297), July 1988. All doses are 50 year committed effective dose equivalent (CEDE).
- "Lung Model" refers to the ICRP 30 lung model classification, "Water" is water vapor (for which the inhalation dose factor has been increased by 50% to include absorption through the skin), "Organic" means organically bound carbon, "D" is days, "W" is weeks, and "Y" is years. The value shown are those recommended in ICRP Report Number 71 for unknown chemical types.
- The short-lived radioactive progeny shown on Table A1 are assumed to be in secular equilibrium with their parent nuclide. The dose factors for implicit daughters have been multiplied by the branching ratios in Table A1 and added to the parent dose factor to give the values shown.
- The last two columns show ratios of GENII and DOE inhalation dose factors to the EPA dose factors. Ratios of dose factors within 5% of the EPA value are not shown.

Table A23. Internal Dose Factors for Adults from ICRP 72, mrem/pCi.

Nuclide	f1	Ingestion	EPA / ICRP 72	Lung Model	Inhalation	EPA / ICRP 72
H-3	1	6.66E-08		M	1.67E-07	0.58
Be-10	0.005	4.07E-06	1.15	S	1.30E-04	2.74
C-14	1	2.15E-06		M	7.40E-06	0.28
Na-22	1	1.18E-05		F	4.81E-06	1.59
Al-26	0.01	1.30E-05	1.13	M	7.40E-05	
Si-32+D	0.01	1.10E-05		S	4.20E-04	2.45
Cl-36	1	3.44E-06	0.88	M	2.70E-05	0.81
K-40	1	2.29E-05	0.81	F	7.77E-06	1.59
Ca-41	0.3	7.03E-07	1.81	M	3.52E-07	3.83
Ti-44+D	0.01	2.28E-05	1.08	F	2.26E-04	2.00
V-49	0.01	6.66E-08	0.92	M	1.26E-07	2.74
Mn-54	0.1	2.63E-06	1.05	M	5.55E-06	1.21
Fe-55	0.1	1.22E-06	0.50	M	1.41E-06	0.95
Fe-60+D	0.1	4.07E-04	0.37	M	5.18E-04	0.52
Co-60	0.1	1.26E-05	2.14	M	3.70E-05	0.89
Ni-59	0.05	2.33E-07	0.90	M	4.81E-07	1.91
Ni-63	0.05	5.55E-07		M	1.78E-06	1.30
Se-79	0.8	1.07E-05	0.81	F	4.07E-06	1.61
Rb-87	1	5.55E-06	0.89	F	1.85E-06	1.75
Sr-90+D	0.3	1.14E-04	1.35	M	1.38E-04	1.79
Zr-93	0.01	4.07E-06	0.41	M	3.70E-05	2.25
Nb-91	0.01	4.44E-07	1.18	M	1.89E-06	1.70
Nb-93m	0.01	4.44E-07	1.18	M	1.89E-06	1.70
Nb-94	0.01	6.29E-06	1.14	M	4.07E-05	0.89
Mo-93	1	1.15E-05	0.12	M	2.18E-06	13.0
Tc-99	0.5	2.37E-06	0.62	M	1.48E-05	0.56
Ru-106+D	0.05	2.59E-05	1.06	M	1.04E-04	1.14
Pd-107	0.005	1.37E-07	1.09	S	2.18E-06	5.85
Ag-108m+D	0.05	8.51E-06	0.90	M	2.74E-05	0.92
Cd-109	0.05	7.40E-06	1.78	F	3.00E-05	3.81
Cd-113m	0.05	8.51E-05	1.89	F	4.07E-04	3.75
In-115	0.02	1.18E-04	1.33	F	1.44E-03	2.59
Sn-121m+D	0.02	2.07E-06	1.09	M	1.73E-05	0.69
Sn-126+D	0.02	1.88E-05	1.12	M	1.05E-04	
Sb-125	0.1	4.07E-06	0.69	M	1.78E-05	0.69
Te-125m	0.3	3.22E-06	1.14	M	1.26E-05	0.58
I-129	1	4.07E-04	0.68	F	1.33E-04	1.30
Cs-134	1	7.03E-05		F	2.44E-05	1.89
Cs-135	1	7.40E-06		F	2.55E-06	1.78

Table A23. Internal Dose Factors for Adults from ICRP 72, mrem/pCi.

Nuclide	f1	Ingestion	EPA / ICRP 72	Lung Model	Inhalation	EPA / ICRP 72
Cs-137+D	1	4.81E-05		F	1.70E-05	1.88
Ba-133	0.2	5.55E-06	0.61	M	1.15E-05	0.68
Pm-147	0.0005	9.62E-07	1.09	S	1.81E-05	2.16
Sm-147	0.0005	1.81E-04		M	3.55E-02	2.10
Sm-151	0.0005	3.63E-07	1.07	M	1.48E-05	2.03
Eu-150	0.0005	4.81E-06	1.32	M	1.96E-04	1.37
Eu-152	0.0005	5.18E-06	1.25	M	1.55E-04	1.42
Eu-154	0.0005	7.40E-06	1.29	M	1.96E-04	1.46
Eu-155	0.0005	1.18E-06	1.29	M	2.55E-05	1.62
Gd-152	0.0005	1.52E-04	1.06	F	7.03E-02	3.46
Ho-166m	0.0005	7.40E-06	1.09	M	4.44E-04	1.74
Re-187	0.8	1.89E-08	0.50	M	2.33E-08	2.33
Tl-204	1	4.44E-06	0.76	F	1.44E-06	1.67
Pb-205	0.2	1.04E-06	1.58	M	9.25E-07	4.24
Pb-210+D	0.2	2.56E-03	2.10	M	4.41E-03	3.08
Bi-207	0.05	4.81E-06	1.14	M	2.07E-05	
Po-209	0.5	5.54E-03	0.43	M	1.52E-02	0.70
Po-210	0.5	4.44E-03	0.43	M	1.22E-02	0.70
Ra-226+D	0.2	1.04E-03	1.28	M	1.31E-02	0.66
Ra-228+D	0.2	2.55E-03	0.56	M	9.68E-03	0.50
Ac-227+D	0.0005	4.47E-03	3.30	M	8.73E-01	2.00
Th-228+D	0.0005	5.31E-04	1.53	S	1.61E-01	2.12
Th-229+D	0.0005	2.27E-03	1.77	S	3.23E-01	5.40
Th-230	0.0005	7.77E-04	0.70	S	5.18E-02	5.05
Th-232	0.0005	8.51E-04	3.21	S	9.25E-02	12.4
Pa-231	0.0005	2.63E-03	4.03	M	5.18E-01	2.48
U-232	0.02	1.22E-03	1.07	M	2.89E-02	0.52
U-233	0.02	1.89E-04	1.53	M	1.33E-02	0.60
U-234	0.02	1.81E-04	1.56	M	1.30E-02	0.61
U-235+D	0.02	1.75E-04	1.53	M	1.15E-02	0.64
U-236	0.02	1.74E-04	1.54	M	1.18E-02	0.63
U-238+D	0.02	1.79E-04	1.50	M	1.08E-02	0.66
Np-237+D	0.0005	4.10E-04	10.8	M	8.51E-02	6.35
Pu-236	0.0005	3.22E-04	3.62	M	7.40E-02	1.96
Pu-238	0.0005	8.51E-04	3.76	M	1.70E-01	2.30
Pu-239	0.0005	9.25E-04	3.82	M	1.85E-01	2.32
Pu-240	0.0005	9.25E-04	3.82	M	1.85E-01	2.32
Pu-241+D	0.0005	1.78E-05	3.85	M	3.33E-03	2.48
Pu-242	0.0005	8.88E-04	3.78	M	1.78E-01	2.31

Table A23. Internal Dose Factors for Adults from ICRP 72, mrem/pCi.

Nuclide	f1	Ingestion	EPA / ICRP 72	Lung Model	Inhalation	EPA / ICRP 72
Pu-244+D	0.0005	8.92E-04	3.73	M	1.74E-01	2.32
Am-241	0.0005	7.40E-04	4.92	M	1.55E-01	2.86
Am-242m+D	0.0005	7.04E-04	4.99	M	1.37E-01	3.11
Am-243+D	0.0005	7.43E-04	4.88	M	1.52E-01	2.90
Cm-242	0.0005	4.44E-05	2.58	M	1.92E-02	0.90
Cm-243	0.0005	5.55E-04	4.53	M	1.15E-01	2.68
Cm-244	0.0005	4.44E-04	4.54	M	9.99E-02	2.48
Cm-245	0.0005	7.77E-04	4.81	M	1.55E-01	2.93
Cm-246	0.0005	7.77E-04	4.76	M	1.55E-01	2.90
Cm-247+D	0.0005	7.03E-04	4.86	M	1.44E-01	2.87
Cm-248	0.0005	2.85E-03	4.78	M	5.55E-01	2.98
Cm-250+D	0.0005	1.63E-02	4.77	M	3.11E+00	3.02
Bk-247	0.0005	1.30E-03	3.63	M	2.55E-01	2.25
Cf-248	0.0005	1.04E-04	3.23	M	3.26E-02	1.36
Cf-249	0.0005	1.30E-03	3.66	M	2.59E-01	2.23
Cf-250	0.0005	5.92E-04	3.60	M	1.26E-01	2.08
Cf-251	0.0005	1.33E-03	3.64	M	2.63E-01	2.24
Cf-252	0.0005	3.33E-04	3.26	M	7.40E-02	1.85

Notes:

- The ingestion and inhalation doses are from ICRP Publication 72 for adults. All doses are 50 year committed effective dose equivalent. The inhalation dose factors assume the particle size distribution has an activity median aerodynamic diameter of 1 μm .
- "Lung Model" refers to the ICRP 66 lung model classification, "F" is fast, "M" is moderate, and "S" is slow absorption of inhaled particulate material into body fluids.
- The short-lived radioactive progeny shown on Table A1 are assumed to be in secular equilibrium with their parent nuclide. The dose factors for implicit daughters have been multiplied by the branching ratios in Table A1 and added to the parent dose factor to give the values shown.
- The ratios of the EPA dose factors divided by the ICRP 72 dose factors are shown if the difference between them is greater than 5%.

Table A24. Nuclear Decay Data for Nb-91 and Nb-93m.

Nb-91 (680 y)	Particle energy, keV	fraction of decays	Weighted energy, keV
electron capture	1254.6	0.99836	417.51
positron	232.6	0.00164	0.13
electron	13.47	0.2348	3.16
photon	15.69	0.18319	2.87
	15.77	0.35027	5.52
	17.66	0.10136	1.79
	511	0.00328	1.68
Total for electrons + photons:			15 keV
Nb-93m(16.13 y)	Particle energy, keV	fraction of decays	Weighted energy, keV
isomeric transition	30.77	1	30.77
electron	11.78	0.1440	1.70
	14.15	0.0365	0.52
	28.07	0.1340	3.76
	28.31	0.0262	0.74
	28.40	0.4710	13.38
	30.39	0.1360	4.13
photon	16.52	0.0310	0.51
	16.61	0.0590	0.98
	18.61	0.0175	0.33
	30.77	5.5 E-06	0.00
Total for electrons + photons:			26 keV
<p>Note: The last column shows the product of the particle energies and the fraction of decays with this energy particle. Although the Nb-93m half-life is short enough that the total retained in the body (and hence the dose) decreases partly by radioactive decay, its total electron plus positron energy is large enough to make up for the loss by decay. Data from ENDF/B-VI.</p>			

A3.6 External Dose-Rate Factors for Radionuclides

External dose-rate factors give the expected dose equivalent rate to an individual standing near radioactive contamination. The composition and shape of the contaminated region determines the dose equivalent rates at a given concentration in the medium. Four contaminated regions will be described in this section, a 15-cm soil layer, a large cloud of airborne activity, and at the surface of a body of water. The doses from external exposure with the radioactivity distributed in air or water will be shown to be negligible in comparison to the inhalation or ingestion dose that normally accompanies the external exposure.

A3.6.1 External Dose-Rate Factors for Radionuclides in Surface Soil

To assist the reader in understanding the nomenclature surrounding radiation exposures, the term "external effective dose equivalent" (EED) will be defined and applied in a manner similar to "committed effective dose equivalent" (CED) from the previous section. Radiation sources outside the body give doses to various organs of the person. Each organ receives a different dose during the period that the exposure takes place. To describe the effect on the whole person, the term "external effective dose equivalent" (EED) will be used. The EED is the weighted sum of the external dose equivalents to the various organs of the body from a radiation source outside the body. The EED relates the external dose equivalent calculated for the various organs to the overall risk of some "stochastic effect" (a genetic effect or cancer) on the person. The "organ weighting factors" mentioned in the previous section are used to calculate EED from the various organ dose equivalents.

External dose rate factors specify the external effective dose equivalent (EED) rate from a particular distribution of the radioactivity around the person. Three often used distributions are (1) submersion in a contaminated atmospheric cloud, (2) immersion in contaminated water, and (3) standing above contaminated soil. For the present, the third external dose rate factor is most useful. The contamination is assumed uniformly spread over a very large area with a thickness of 15 cm (6 in.). The external dose rate factors have units of EED per unit area of contaminated soil. A large area is assumed so that the actual area doesn't matter. Once the contaminated area is larger than a few hundred square meters, the dose rate factors are independent of the area. The thickness of the contaminated layer affects the dose rate and must be considered. For typical exposure scenarios the soil thickness is 15 cm. Radionuclides are assumed to be uniformly distributed through this thickness as a result of cultivating the soil for the purpose of growing a garden.

External dose rates from a layer of contaminated surface soil are available from various references. Three references that have been used on the Hanford Site are the DOE surface gamma dose-rate conversion factors (DOE/EH-0070), the EPA values in Federal Guidance Report Number 12 (EPA-402-R-93-081), and the external dose factors recently computed for the GENII program. The three sets of external dose rate factors are shown in Table A25. They have been converted to the common units of mrem/hour per Ci/m² for purposes of comparison.

The DOE surface gamma conversion factors (DOE/EH-0070) are derived from an assumed contamination thickness of zero. The contamination lies on top of the soil surface in a

layer that is infinitely thin, perfectly flat, and infinite in extent. These assumptions necessarily exaggerate the dose rates. Strong beta-emitting nuclides such as Sr-90 produce no external dose since the production of bremsstrahlung radiation was ignored.

The GENII external dose rate factors (PNNL-6584) were computed using a version of the ISOSHL program known as EXTDF, which is part of the GENII software package. Bremsstrahlung radiation is computed for all beta emitters. The dose rate factors are calculated 1 m above a contamination thickness of 0.05 m and 0.15 m. The surface soil is given a density of 1.5 grams per cubic centimeter. Again the surface layer is perfectly flat and infinite in extent. The finite thickness adds realism, since the contamination thickness assumed for the well-driller (0.05 m) is increased to 0.15 m during normal tilling operations that are part of the post-drilling scenarios. The 0.15-m dose rate factors have been used in prior Hanford Site performance assessments.

The EPA external dose rate factors (EPA-402-R-93-081) were computed using a Monte Carlo approach with the best available input data and dosimetric models, except that ICRP 30 organ weighting factors rather than ICRP 60 weighting factors were used. The EPA external dose rate factors also include exposure to the skin using a weighting factor of 0.01. These are considered to be the best external dose rate factors currently available and will be used in the tank waste PA. The EPA values shown in Table A25 are for a soil contamination thickness of 5 cm and 15 cm. The number shown for Eu-150 is listed as Eu-150b in the EPA compilation. The reference does not give values for Nb-91 and Po-210. Therefore, the values computed by EXTDF were used instead.

The GENII and EPA external dose rate factors are available as dose rate per unit concentration in the soil. The unit concentration was converted to a unit area by multiplying by the contamination thickness. The DOE dose rate factors are already in area units. Note that the EPA dose rate factors were developed for a soil density of 1.6 g/cc. However, the tank waste PA will use a soil density for the surface layer of 1.5 g/cc. Therefore, the EPA dose rate factors were multiplied by the ratio of densities (1.067) to give the values shown on Table A25.

The three external dose factor collections are compared in Table A25. What is shown on this table are ratios of the GENII (15 cm) and DOE collections divided by the EPA (15 cm) collection. Differences less than 10 percent are not shown. Ratios for dose rate factors that are zero were not computed.

The GENII external dose rate factors agree fairly well (within 26%) for nuclides that emit penetrating gamma rays and have the largest dose rate factors. Examples are Na-22, Al-26, Ti-44, Mn-54, Fe-60, Co-60, Nb-94, Ag-108m, Sn-126, Cs-134, Cs-137, Eu-150, Eu-152, Eu-154, Ho-166m, Bi-207, Ra-226, Ra-228, and Th-228. The disagreement between GENII and the EPA collections is over the low energy photon emitters. However, for these nuclides the internal doses are typically much greater than the external, so the different external dose rate factors would not affect the total doses.

Table A25. External Dose Rate Factors, mrem/h per Ci/m².

Nuclide	GENII using EXTDF		EPA Federal Guidance Report Number 12		DOE	GENII / EPA (0.15 m)	DOE / EPA (0.15 m)
	5 cm	15 cm	5 cm	15 cm			
H-3	1.05E-07	3.49E-08	0	0	0	EPA=0	
Be-10	1.06E+00	4.33E-01	1.26E+00	5.37E-01	0	0.806	DOE=0
C-14	2.16E-02	7.51E-03	1.92E-02	6.82E-03	0		DOE=0
Na-22	1.22E+04	6.75E+03	1.12E+04	5.98E+03	2.40E+04	1.13	4.01
Al-26	1.60E+04	9.15E+03	1.35E+04	7.32E+03	2.85E+04	1.25	3.89
Si-32+D	2.03E+01	9.62E+00	1.22E+01	5.70E+00	0	1.69	DOE=0
Cl-36	2.03E+00	8.58E-01	2.52E+00	1.16E+00	5.32E-04	0.74	0.000459
K-40	8.61E+02	4.87E+02	7.90E+02	4.33E+02	1.56E+03	1.12	3.6
Ca-41	0	0	0	0	8.60E-01		EPA=0
Ti-44+D	1.30E+04	7.10E+03	1.15E+04	6.00E+03	2.57E+04	1.18	4.28
V-49	0	0	0	0	8.60E-01		EPA=0
Mn-54	4.64E+03	2.53E+03	4.29E+03	2.27E+03	9.59E+03	1.11	4.22
Fe-55	3.22E-01	1.07E-01	0	0	2.52E+00	EPA=0	EPA=0
Fe-60+D	1.91E+01	1.02E+01	2.05E+01	1.05E+01	5.38E+01		5.13
Co-60	1.34E+04	7.51E+03	1.26E+04	6.87E+03	2.59E+04		3.77
Ni-59	3.92E-01	1.31E-01	0	0	4.75E+00	EPA=0	EPA=0
Ni-63	5.72E-04	1.91E-04	0	0	0	EPA=0	
Se-79	1.55E-02	5.37E-03	2.64E-02	9.44E-03	0	0.569	DOE=0
Rb-87	1.08E-01	4.02E-02	1.84E-01	7.13E-02	0	0.564	DOE=0
Sr-90+D	4.08E+01	1.97E+01	2.45E+01	1.17E+01	0	1.68	DOE=0
Zr-93	4.02E-04	1.34E-04	0	0	0	EPA=0	
Nb-91	1.09E+01	5.74E+00	1.09E+01	5.74E+00	8.36E+01		18.6
Nb-93m	1.30E-01	4.33E-02	1.58E-01	5.28E-02	1.17E+01	0.82	222
Nb-94	8.61E+03	4.67E+03	8.13E+03	4.29E+03	1.81E+04		4.22
Mo-93	7.28E-01	2.43E-01	8.98E-01	2.99E-01	6.59E+01	0.813	220
Tc-99	1.35E-01	5.04E-02	1.63E-01	6.35E-02	7.14E-03	0.794	0.112
Ru-106+D	1.36E+03	7.32E+02	1.12E+03	5.83E+02	2.40E+03	1.26	4.12
Pd-107	1.25E-05	4.16E-06	0	0	0	EPA=0	
Ag-108m+D	1.00E+04	5.37E+03	8.39E+03	4.37E+03	1.90E+04	1.23	4.35
Cd-109	2.13E+01	2.61E+00	1.95E+01	7.47E+00	1.08E+02	0.349	14.5
Cd-113m	1.05E+00	4.28E-01	7.70E-01	3.24E-01	0	1.32	DOE=0
In-115	6.38E-01	2.56E-01	4.89E-01	2.01E-01	0	1.27	DOE=0
Sn-121m+D	1.54E+01	5.15E+00	3.18E+00	1.07E+00	0	4.81	DOE=0
Sn-126+D	1.22E+04	6.56E+03	1.03E+04	5.36E+03	2.37E+04	1.22	4.42
Sb-125	1.73E+03	1.49E+03	2.18E+03	1.12E+03	5.05E+03	1.33	4.51
Te-125m	2.58E+01	8.78E+00	2.27E+01	7.67E+00	2.40E+02	1.14	31.3
I-129	1.66E+01	5.54E+00	1.97E+01	6.57E+00	2.51E+02	0.843	38.2
Cs-134	9.71E+03	5.23E+03	8.04E+03	4.24E+03	1.80E+04	1.23	4.25
Cs-135	4.09E-02	1.46E-02	5.26E-02	1.94E-02	0	0.753	DOE=0
Cs-137+D	3.39E+03	1.82E+03	2.93E+03	1.53E+03	6.58E+03	1.19	4.3
Ba-133	2.16E+03	1.10E+03	1.89E+03	9.36E+02	4.78E+03	1.18	5.11
Pm-147	7.30E-02	2.74E-02	6.51E-02	2.53E-02	4.68E-02		1.85
Sm-147	0	0	0	0	0		
Sm-151	5.85E-03	1.95E-03	1.50E-03	4.99E-04	5.93E-02	3.91	119
Eu-150	9.37E+03	5.04E+03	7.65E+03	3.96E+03	0	1.27	DOE=0

Table A25. External Dose Rate Factors, mrem/h per Ci/m².

Nuclide	GENII using EXTDF		EPA Federal Guidance Report Number 12		DOE	GENII / EPA (0.15 m)	DOE / EPA (0.15 m)
	5 cm	15 cm	5 cm	15 cm			
Eu-152	6.53E+03	3.60E+03	5.77E+03	3.05E+03	1.27E+04	1.18	4.16
Eu-154	6.80E+03	3.74E+03	6.28E+03	3.34E+03	1.38E+04	1.12	4.13
Eu-155	2.19E+02	8.98E+01	2.26E+02	9.24E+01	8.16E+02		8.83
Gd-152	0	0	0	0	0		
Ho-166m	8.78E+03	4.67E+03	8.95E+03	4.64E+03	1.88E+04		4.05
Re-187	0	0	0	0	0		
Tl-204	4.85E+00	1.93E+00	5.14E+00	2.04E+00	1.48E+01		7.25
Pb-205	2.63E-01	8.75E-02	1.07E-02	3.58E-03	8.61E+00	24.4	2410
Pb-210+D	9.36E+00	3.85E+00	7.59E+00	3.00E+00	3.42E+01	1.28	11.4
Bi-207	8.95E+03	4.92E+03	7.79E+03	4.11E+03	1.72E+04	1.2	4.18
Po-209	1.72E+01	8.95E+00	1.72E+01	8.95E+00	4.10E+01		4.6
Po-210	4.92E-02	2.68E-02	4.38E-02	2.32E-02	9.81E-02	1.16	4.23
Ra-226+D	1.01E+04	5.61E+03	8.92E+03	4.78E+03	1.92E+04	1.17	4.02
Ra-228+D	5.49E+03	3.04E+03	4.92E+03	2.62E+03	1.04E+04	1.16	3.97
Ac-227+D	2.16E+03	1.08E+03	1.96E+03	9.61E+02	5.00E+03	1.12	5.2
Th-228+D	8.65E+03	4.92E+03	7.69E+03	4.20E+03	1.66E+04	1.17	3.95
Th-229+D	1.78E+03	9.04E+02	1.52E+03	7.45E+02	4.09E+03	1.21	5.49
Th-230	1.06E+00	4.11E-01	1.48E+00	6.05E-01	1.03E+01	0.679	17
Th-232	5.61E-01	2.13E-01	6.71E-01	2.63E-01	7.60E+00	0.81	28.9
Pa-231	1.80E+02	9.09E+01	1.84E+02	9.11E+01	4.08E+02		4.48
U-232	7.99E-01	3.10E-01	1.10E+00	4.52E-01	1.17E+01	0.686	25.9
U-233	1.13E+00	4.81E-01	1.51E+00	6.86E-01	5.70E+00	0.701	8.31
U-234	4.93E-01	1.89E-01	5.17E-01	2.03E-01	9.21E+00		45.4
U-235+D	5.84E+02	2.52E+02	7.98E+02	3.74E+02	2.17E+03	0.674	5.8
U-236	2.81E-01	9.85E-02	2.87E-01	1.08E-01	8.36E+00		77.4
U-238+D	1.39E+02	7.10E+01	1.20E+02	5.87E+01	2.81E+02	1.21	4.79
Np-237+D	1.41E+03	7.13E+02	1.09E+03	5.28E+02	3.06E+03	1.35	5.8
Pu-236	2.74E-01	9.45E-02	3.13E-01	1.14E-01	1.13E+01	0.829	99.1
Pu-238	3.10E-01	1.06E-01	2.16E-01	7.65E-02	9.79E+00	1.39	128
Pu-239	3.51E-01	1.59E-01	3.27E-01	1.44E-01	4.31E+00	1.1	29.9
Pu-240	2.05E-01	7.29E-02	2.11E-01	7.43E-02	9.35E+00		126
Pu-241+D	2.13E-02	9.43E-03	2.10E-02	9.29E-03	4.40E-02		4.74
Pu-242	2.73E-01	9.57E-02	1.83E-01	6.49E-02	7.78E+00	1.47	120
Pu-244+D	2.18E+03	1.17E+03	1.72E+03	9.04E+02	3.86E+03	1.29	4.27
Am-241	4.18E+01	1.45E+01	6.20E+01	2.22E+01	3.41E+02	0.653	15.4
Am-242m+D	7.98E+01	3.58E+01	7.33E+01	3.28E+01	2.66E+02		8.11
Am-243+D	1.01E+03	4.49E+02	9.80E+02	4.42E+02	2.94E+03		6.65
Cm-242	1.76E-01	5.97E-02	2.44E-01	8.59E-02	1.07E+01	0.695	125
Cm-243	6.34E+02	2.90E+02	6.08E+02	2.86E+02	1.67E+03		5.84
Cm-244	1.51E-01	5.09E-02	1.92E-01	6.39E-02	9.46E+00	0.797	148
Cm-245	3.11E+02	1.32E+02	3.89E+02	1.71E+02	9.74E+02	0.772	5.7
Cm-246	1.26E-01	4.19E-02	1.77E-01	5.89E-02	8.37E+00	0.711	142
Cm-247+D	2.44E+03	1.30E+03	1.74E+03	8.74E+02	4.16E+03	1.49	4.76
Cm-248	1.13E-01	3.83E-02	1.34E-01	4.45E-02	6.71E+00	0.861	151
Cm-250+D	2.17E+03	1.20E+03	1.65E+03	8.55E+02	4.40E+03	1.4	5.15

Table A25. External Dose Rate Factors, mrem/h per Ci/m².

Nuclide	GENII using EXTDF		EPA Federal Guidance Report Number 12		DOE	GENII / EPA (0.15 m)	DOE / EPA (0.15 m)
	5 cm	15 cm	5 cm	15 cm			
Bk-247	5.01E+02	2.32E+02	4.72E+02	2.14E+02	0		DOE=0
Cf-248	1.03E-01	3.43E-02	1.90E-01	6.32E-02	7.68E+00	0.543	122
Cf-249	1.89E+03	9.82E+02	1.72E+03	8.71E+02	4.02E+03	1.13	4.62
Cf-250	1.53E-01	5.37E-02	1.80E-01	6.01E-02	7.81E+00	0.894	130
Cf-251	5.46E+02	2.40E+02	5.68E+02	2.62E+02	1.55E+03		5.92
Cf-252	1.24E-01	4.25E-02	2.46E-01	8.91E-02	7.23E+00	0.477	81.1

Notes:

- GENII external dose rate factors were computed using the EXTDF program. EPA external dose rate factors are from Federal Guidance Report Number 12, EPA 402-R-93-081 (Sept 1993). DOE external dose rate factors are from DOE/EH-0070 (July 1988). All are effective dose equivalent from radiation sources outside the body.
- Short-lived radioactive progeny included in the "+D" nuclides are in secular equilibrium with their parent nuclide.
- The conversion to area units from volume units assumes a thickness of 0.05 m or 0.15 m. The density correction applied to the EPA (1993) dose rate factors is 1.067. Because Nb-91 and Po-209 are not part of the EPA compilation, the GENII values were used.
- The last two columns show ratios of GENII (0.15 m) and DOE external dose rate factors to the EPA (0.15 m) dose rate factors. Ratios within 10% of the EPA value are not shown.

In general, the DOE external dose rate factors are larger than the 15-cm EPA dose rate factors by more than a factor of 4. The exceptions (Be-10, C-14, Si-32, Cl-36, Se-79, Rb-87, Sr-90, Tc-99, Cd-113m, In-115, Sn-121m, Cs-135, and Pm-147) are for nuclides, which produce most of their photons through bremsstrahlung. For these nuclides, the DOE external dose rate factors are much too small. The 5-cm EPA dose rate factors are closer to DOE numbers due to the thinner source.

In all three references used in Table A25 the dose rates were computed at a height of 1 meter above the soil. The actual height has little effect on the dose rate. Table A26 demonstrates this by comparing dose rate factors computed by the EXTDF program at 100 cm and 10 cm. The table shows the ratios of the 10 cm dose rate divided by the 100 cm dose rate for nuclides where the difference between dose rate factors was greater than 10 percent. It must be noted that all these nuclides have external dose rates that are insignificant compared with the internal. The exclusively low energy photons emitted by these nuclides are noticeably attenuated by the additional 90 cm of air.

Some of the external exposure pathways noted in Table 3 for the low water infiltration case are much smaller than internal pathways that accompany the external exposure. For example, the external exposure to an individual whose livestock drinks contaminated well water is much smaller than the internal dose resulting from the consumption of the animal products (milk, meat, poultry, and eggs). This follows from the observation that the dose resulting from a given amount of radioactivity outside the body (leading to an external dose) is orders of magnitude lower than the dose resulting from the same amount of radioactivity ingested or inhaled (leading to an internal dose). Admittedly, the individual will not eat all of the radioactivity present in an animal, since the radioactivity will be present in organs and tissues that are not normally eaten. However, the use of all four animal pathways combined with the

observation that the individual is in close proximity to the animal for only short periods during the day gives assurance that this external pathway can be ignored.

Table A26. Ratios of Dose Rate Factors at Two Elevations.

Nuclide	Ratio	Nuclide	Ratio
H-3	1.61	U-236	1.26
Fe-55	1.61	Pu-236	1.35
Ni-59	1.18	Pu-238	1.27
Ni-63	1.18	Pu-240	1.37
Zr-93	1.20	Pu-242	1.46
Nb-93m	1.61	Cm-242	1.46
Mo-93	1.61	Cm-244	1.48
Pd-107	1.52	Cm-246	1.52
Sm-151	1.21	Cm-248	1.46
Pb-205	1.61	Cf-248	1.55
Th-232	1.12	Cf-250	1.36
U-232	1.13	Cf-252	1.42
U-234	1.16		

Notes:

- The ratios are the dose rate factor (DRF) at 10 cm above the soil surface divided by the dose rate factor at 1 meter above the soil. Both DRFs are from EXTDF.
- Nuclides having DRFs within 10% at the two elevations are not shown.

A3.6.2 External Dose-Rate Factors for Radionuclides in Air

External dose rate factors for immersion in contaminated air are listed in Table A27. Values are from Federal Guidance Report Number 12 (EPA-402-R-93-081). The dose rate factors were computed assuming the individual is located at the center of a hemisphere of infinite extent. Hence these are also referred to as semi-infinite cloud dose rate factors. Values for Nb-91 and Po-209 are from the EXTDF program of the GENII software package.

The columns labeled "Ratio" compare the external dose from submersion in contaminated air with the typical inhalation dose that accrues during the same period. The inhalation dose is computed as the product of the air concentration, the exposure time, the breathing rate (0.95 m³/h), and the inhalation dose factor (Table A22). The submersion dose is computed as the product of the air concentration, the exposure time, and the submersion dose rate factor. Thus the ratio of inhalation dose to submersion dose is the product of the breathing rate and the inhalation dose factor divided by the air submersion dose rate factor. This ratio is shown in Table A27. The light activity-breathing rate could also be used, but leads to larger ratios.

For the nuclides used in this report (Table A1), the smallest ratio is 5.06 for Na-22. This is the only isotope with a ratio smaller than 10. In any exposure scenario involving Na-22 there is additional external exposure from soil contamination and ingestion doses. Thus the submersion dose is a minor contributor to the overall total dose.

In Table A27, nuclides notable for large inhalation doses, like insoluble transuranic (TRU) isotopes, have ratios greater than 1 million. Because the activity inhaled by the individual is

considerably smaller than the activity ingested, the inhalation dose for non-TRU isotopes is a small part of the total. Therefore, the air submersion dose from airborne particulate will not be included in the dose calculations.

Table A27. External Dose Rate Factors for Air, mrem/h per pCi/m³.

Nuclide	Air DRF	Ratio	Nuclide	Air DRF	Ratio
H-3	4.41E-12	2.07E+04	Pb-210+D	1.19E-09	1.09E+07
Be-10	1.49E-10	2.26E+06	Bi-207	1.00E-06	1.89E+01
C-14	2.98E-12	6.64E+05	Po-209	2.43E-09	4.19E+06
Na-22	1.44E-06	5.06E+00	Po-210	5.54E-12	1.47E+09
Al-26	1.81E-06	3.78E+01	Ra-226+D	1.18E-06	6.92E+03
Si-32+D	1.33E-09	7.38E+05	Ra-228+D	6.37E-07	7.26E+03
Cl-36	2.97E-10	7.02E+04	Ac-227+D	2.47E-07	6.70E+06
K-40	1.07E-07	1.09E+02	Th-228+D	1.08E-06	3.02E+05
Ti-44+D	1.47E-06	2.92E+02	Th-229+D	1.98E-07	8.38E+06
Mn-54	5.45E-07	1.17E+01	Th-230	2.32E-10	1.07E+09
Fe-60+D	2.89E-09	8.88E+04	Th-232	1.16E-10	9.41E+09
Co-60	1.68E-06	1.87E+01	Pa-231	2.29E-08	5.32E+07
Se-79	4.04E-12	1.54E+06	U-232	1.89E-10	7.47E+07
Rb-87	2.42E-11	1.27E+05	U-233	2.17E-10	3.50E+07
Sr-90+D	2.63E-09	8.93E+04	U-234	1.02E-10	7.37E+07
Nb-91	2.05E-09	1.49E+03	U-235+D	1.03E-07	6.73E+04
Nb-93m	5.91E-11	5.16E+04	U-236	6.67E-11	1.06E+08
Nb-94	1.03E-06	3.34E+01	U-238+D	1.57E-08	4.26E+05
Mo-93	3.36E-10	8.04E+04	Np-237+D	1.38E-07	3.71E+06
Tc-99	2.16E-11	3.67E+05	Pu-236	8.46E-11	1.62E+09
Ru-106+D	1.39E-07	8.07E+02	Pu-238	6.50E-11	5.73E+09
Ag-108m+D	1.04E-06	2.31E+01	Pu-239	5.65E-11	7.22E+09
Cd-109	3.92E-09	2.77E+04	Pu-240	6.33E-11	6.44E+09
Cd-113m	9.24E-11	1.57E+07	Pu-241+D	2.87E-12	2.73E+09
In-115	5.99E-11	5.92E+07	Pu-242	5.34E-11	7.30E+09
Sn-121m+D	8.26E-10	1.37E+04	Pu-244+D	2.17E-07	1.76E+06
Sn-126+D	1.28E-06	7.50E+01	Am-241	1.09E-08	3.87E+07
Sb-125	2.69E-07	4.31E+01	Am-242m+D	1.02E-08	3.96E+07
Te-125m	6.03E-09	1.15E+03	Am-243+D	1.31E-07	3.18E+06
I-129	5.06E-09	3.26E+04	Cm-242	7.58E-11	2.17E+08
Cs-134	1.01E-06	4.36E+01	Cm-243	7.83E-08	3.72E+06
Cs-135	7.53E-12	5.74E+05	Cm-244	6.54E-11	3.60E+09
Cs-137+D	3.62E-07	8.37E+01	Cm-245	5.27E-08	8.20E+06
Ba-133	2.37E-07	3.13E+01	Cm-246	5.94E-11	7.22E+09
Pm-147	9.23E-12	4.04E+06	Cm-247+D	2.14E-07	1.84E+06
Sm-151	4.81E-13	5.92E+07	Cm-248	4.52E-11	3.48E+10
Eu-150	9.55E-07	2.67E+02	Cm-250+D	2.11E-07	4.23E+07
Eu-152	7.53E-07	2.79E+02	Bk-247	6.27E-08	8.68E+06
Eu-154	8.18E-07	3.32E+02	Cf-248	6.30E-11	6.69E+08

Table A27. External Dose Rate Factors for Air, mrem/h per pCi/m³.

Nuclide	Air DRF	Ratio	Nuclide	Air DRF	Ratio
Eu-155	3.32E-08	1.19E+03	Cf-249	2.10E-07	2.61E+06
Ho-166m	1.13E-06	6.53E+02	Cf-250	5.99E-11	4.15E+09
Tl-204	7.45E-10	3.07E+03	Cf-251	7.43E-08	7.52E+06
Pb-205	6.74E-12	5.53E+05	Cf-252	6.74E-11	1.93E+09

Notes:

- External dose rate factors (DRF) for submersion in contaminated air are from Federal Guidance Report Number 12, EPA 402-R-93-081 (Sept 1993). Because Nb-91 and Po-209 are not part of the EPA compilation, the GENII values were used. Short-lived radioactive progeny included in the "+D" nuclides are in secular equilibrium with their parent nuclide. The nuclide is dispersed uniformly in a hemisphere of infinite extent. The receptor is at the center of the hemisphere. The following were omitted from the table because the DRF is zero: Ca-41, V-49, Fe-55, Ni-59, Ni-63, Sm-147, Gd-152, and Re-187.
- The "Ratio" columns compare the inhalation dose to the external dose. The ratio is computed as the inhalation dose factor times the daily average breathing rate (0.95 m³/h) divided by the submersion dose rate factor.

A3.6.3 External Dose-Rate Factors for Radionuclides in Water

External dose rate factors for immersion in contaminated water are from Federal Guidance Report Number 12 (EPA-402-R-93-081). The dose rate factors in this reference were computed assuming the individual is located at the center of a sphere of infinite extent. Hence these are also referred to as infinite medium dose rate factors. Values for Nb-91 and Po-209 are from the EXTDF program of the GENII software package.

The EPA values have been converted from Sv/s per Bq/m³ for an infinite medium to mrem/h per pCi/L for a semi-infinite medium. These are listed in Table A28. The semi-infinite medium corresponds to the dose rate at the surface of a body of water. It may include swimming or shoreline activities. The relationship between infinite medium dose rate factors and semi-infinite medium dose rate factors is simply a factor of two.

The columns labeled "Ratio" compare the external dose from swimming in contaminated water with the ingestion dose from drinking water. The doses are calculated according to the usage parameters for the recreational scenario given in the HSRAM Rev 3. The daily ingestion dose is computed as the product of the water concentration, the volume consumed (2 L/d), and the ingestion dose factor (Table A21). The surface water dose is computed as the product of the water concentration, the exposure time (2.6 h/d), and the dose rate factor (Table A28). Thus the ratio of ingestion dose to external dose is the ingestion dose factor times 2/2.6=0.769 L/h divided by the surface water dose rate factor. This ratio is shown in Table A28.

For the nuclides used in this report (Table A1), the smallest ratio is 3.6 for Mn-54. Nuclides with ratios less than 10 are Mn-54, Bi-207, Eu-150, Nb-94, Ho-166m, Ag-108m+D, Na-22, Eu-152, Sb-125, and Eu-154. Each of these also has dose contributions from other pathways (mainly external) that are about the same size as the drinking water ingestion dose. Thus, the largest increase in the recreational scenario first year total dose is 14% for Mn-54. The water submersion dose increases by less than 10% for all other radionuclides being considered. This is a small enough increase it can be ignored. The recreational scenario using ground water was chosen to maximize the effect of the water submersion dose on the total dose. All other

scenarios have other pathways or increased ingestion dose which makes the water submersion contribution even less important.

Table A28. External Dose Rate Factors for Water, mrem/h per pCi/L.

Nuclide	Water DRF	Ratio	Nuclide	Water DRF	Ratio
H-3	0.00E+00	0.00E+00	Pb-210+D	1.29E-09	3.19E+06
Be-10	1.45E-10	2.48E+04	Bi-207	1.09E-06	3.86E+00
C-14	2.92E-12	5.49E+05	Po-209	2.90E-09	6.30E+05
Na-22	1.57E-06	5.64E+00	Po-210	6.01E-12	2.43E+08
Al-26	1.96E-06	5.73E+00	Ra-226+D	1.28E-06	7.95E+02
Si-32+D	1.27E-09	6.62E+03	Ra-228+D	6.93E-07	1.60E+03
Cl-36	2.98E-10	7.80E+03	Ac-227+D	2.71E-07	4.18E+04
K-40	1.16E-07	1.23E+02	Th-228+D	1.17E-06	5.33E+02
Ti-44+D	1.60E-06	1.18E+01	Th-229+D	2.17E-07	1.42E+04
Mn-54	5.91E-07	3.60E+00	Th-230	2.62E-10	1.61E+06
Fe-60+D	3.16E-09	3.71E+04	Th-232	1.33E-10	1.58E+07
Co-60	1.82E-06	1.14E+01	Pa-231	2.52E-08	3.23E+05
Sc-79	3.95E-12	1.69E+06	U-232	2.14E-10	4.70E+06
Rb-87	2.36E-11	1.61E+05	U-233	2.42E-10	9.17E+05
Sr-90+D	2.51E-09	4.69E+04	U-234	1.17E-10	1.87E+06
Nb-91	2.68E-09	1.49E+02	U-235+D	1.14E-07	1.81E+03
Nb-93m	6.93E-11	5.79E+03	U-236	7.73E-11	2.67E+06
Nb-94	1.11E-06	4.94E+00	U-238+D	1.70E-08	1.21E+04
Mo-93	3.94E-10	2.63E+03	Np-237+D	1.52E-07	2.25E+04
Tc-99	2.09E-11	5.38E+04	Pu-236	9.86E-11	9.10E+06
Ru-106+D	1.49E-07	1.41E+02	Pu-238	7.59E-11	3.24E+07
Ag-108m+D	1.13E-06	5.20E+00	Pu-239	6.39E-11	4.26E+07
Cd-109	4.51E-09	2.24E+03	Pu-240	7.39E-11	3.68E+07
Cd-113m	8.92E-11	1.39E+06	Pu-241+D	3.20E-12	1.65E+07
In-115	5.79E-11	2.09E+06	Pu-242	6.23E-11	4.15E+07
Sn-121m+D	9.63E-10	1.80E+03	Pu-244+D	2.35E-07	1.09E+04
Sn-126+D	1.40E-06	1.16E+01	Am-241	1.25E-08	2.24E+05
Sb-125	2.92E-07	7.39E+00	Am-242m+D	1.14E-08	2.37E+05
Tc-125m	7.06E-09	4.00E+02	Am-243+D	1.46E-07	1.91E+04
I-129	5.93E-09	3.58E+04	Cm-242	8.86E-11	9.96E+05
Cs-134	1.09E-06	5.16E+01	Cm-243	8.66E-08	2.23E+04
Cs-135	7.33E-12	7.42E+05	Cm-244	7.66E-11	2.03E+07
Cs-137+D	3.94E-07	9.76E+01	Cm-245	5.89E-08	4.88E+04
Ba-133	2.60E-07	1.00E+01	Cm-246	6.99E-11	4.07E+07
Pm-147	9.32E-12	8.64E+04	Cm-247+D	2.33E-07	1.13E+04
Sm-151	5.66E-13	5.28E+05	Cm-248	5.30E-11	1.98E+08
Eu-150	1.04E-06	4.71E+00	Cm-250+D	2.30E-07	2.60E+05
Eu-152	8.19E-07	6.08E+00	Bk-247	6.99E-08	5.17E+04
Eu-154	8.86E-07	8.29E+00	Cf-248	7.39E-11	3.48E+06

Table A28. External Dose Rate Factors for Water, mrem/h per pCi/L.

Nuclide	Water DRF	Ratio	Nuclide	Water DRF	Ratio
Eu-155	3.74E-08	3.15E+01	Cf-249	2.30E-07	1.59E+04
Ho-166m	1.23E-06	5.06E+00	Cf-250	7.06E-11	2.32E+07
Tl-204	8.13E-10	3.18E+03	Cf-251	8.26E-08	4.51E+04
Pb-205	7.79E-12	1.61E+05	Cf-252	7.86E-11	1.06E+07

Notes:

- External dose rate factors (DRF) for submersion in contaminated water are from Federal Guidance Report Number 12, EPA 402-R-93-081 (Sept 1993). Because Nb-91 and Po-209 are not part of the EPA compilation, the GENII values were used. Short-lived radioactive progeny included in the "+D" nuclides are in secular equilibrium with their parent nuclide. The nuclide is dispersed uniformly in a hemisphere of infinite extent. The receptor is at the center of the hemisphere. The following were omitted from the table because the DRF is zero: Ca-41, V-49, Fe-55, Ni-59, Ni-63, Sm-147, Gd-152, and Re-187.
- The "Ratio" columns compare the ingestion dose to the external dose for the HSRAM recreational scenario. The ratio is computed as the ingestion dose factor times 0.769 L/h divided by the water submersion dose rate factor.

Nuclides notable for large ingestion doses, such as the transuranic (TRU) isotopes, have ratios greater than 100,000. Thus, the water surface external dose will not be included in the dose calculations. It should be noted that Federal Guidance Report Number 13 does not provide unit risk factors for submersion in water.

A3.7 Cancer Morbidity Risk Coefficients for Radionuclides

The HSRAM exposure scenarios are used to determine the potential lifetime intakes of hazardous materials left in the waste. The toxicity of those intakes depends on the chemical and nuclear characteristics of the material. Of primary interest is the risk to the exposed individual of developing some type of cancer, whether or not the cancer is fatal. For radionuclides, the recommended cancer morbidity risk coefficients are found in Federal Guidance Report Number 13 (EPA-402-R-99-001).

Federal Guidance Report 13 provides both mortality (death from cancer) and morbidity (cancer induction) risk coefficients for an average member of the population. The risk is averaged over the age and gender distributions of a group of people whose survival fraction and cancer induction rates are based on recent data for the United States. While these do change with time, they will nevertheless be used to estimate cancer induction risks to persons exposed hundred of years in the future. The risk coefficients can be used for short duration exposures to an entire population, or to lifetime exposures of one individual.

For the radionuclides of interest in this report, the cancer morbidity risk coefficients are shown in Table A29 and A30. The GI absorption fractions and lung clearance types assumed previously are used here. Note that the ingestion and inhalation risk coefficients for Nb-91, Po-209, Cm-248, Cm-250, and Cf-252 were not given in Federal Guidance Report Number 13. Values for these were estimated from other nuclides with risk coefficients.

The ingestion and inhalation risk coefficients for Nb-91 are assumed bounded by those for Nb-93m. The external risk coefficient is calculated from the external risk coefficient for Nb-93m and the GENII external DRFs for Nb-91 and Nb-93m shown in Table A25 using a simple proportionality, as shown below. In the equation below, "SF" refers to the morbidity risk coefficient.

$$\begin{aligned} SF(^{91}\text{Nb}) &= \frac{\text{DRF}(^{91}\text{Nb})}{\text{DRF}(^{93\text{m}}\text{Nb})} SF(^{93\text{m}}\text{Nb}) \\ &= \frac{5.74 \text{ mrem/h per Ci/m}^2}{0.0433 \text{ mrem/h per Ci/m}^2} (3.83 \times 10^{-11} \text{ risk/y per pCi/g}) \\ &= 5.07 \times 10^{-9} \text{ risk/y per pCi/g} \end{aligned}$$

In a similar manner, the ingestion and inhalation risk coefficients for Po-209 are calculated from the risk coefficients for Po-210 using the constant of proportionality, 1.247, derived in Section A3.5. The external risk coefficient is calculated from the external risk coefficient for Po-210 and the GENII external DRFs for Po-209 and Po-210 shown in Table A25 using a simple proportionality, as shown below.

$$\begin{aligned}
 SF(^{209}\text{Po}) &= \frac{\text{DRF}(^{209}\text{Po})}{\text{DRF}(^{210}\text{Po})} SF(^{210}\text{Po}) \\
 &= \frac{8.95 \text{ mrem/h per Ci/m}^2}{0.0268 \text{ mrem/h per Ci/m}^2} (3.95 \times 10^{-11} \text{ risk/y per pCi/g}) \\
 &= 1.32 \times 10^{-8} \text{ risk/y per pCi/g}
 \end{aligned}$$

Finally, the ingestion and inhalation risk coefficients for Cm-248, Cm-250, and Cf-252 are calculated from the risk coefficients for Cm-246, Cm-246, and Cf-250, respectively. The ratios between internal dose factors from ICRP 72 shown in Table A23 are used for this purpose. These surrogates were chosen because they have alpha particle energies that are roughly the same. The average alpha particle energies for Cm-246, Cm-248, and Cm-250 are 5,377 MeV, 5,070 MeV, and 5,190 MeV, respectively. The average alpha particle energies for Cf-250 and Cf-252 are 6,024 MeV and 6,111 MeV. An example calculation of risk coefficient for inhalation of Cm-248 is shown below.

$$\begin{aligned}
 SF(^{248}\text{Cm}) &= \frac{\text{DF}(^{248}\text{Cm})}{\text{DF}(^{246}\text{Cm})} SF(^{246}\text{Cm}) \\
 &= \frac{0.555 \text{ mrem/pCi}}{0.155 \text{ mrem/pCi}} (2.77 \times 10^{-8} \text{ risk/pCi inhaled}) \\
 &= 9.89 \times 10^{-8} \text{ risk/pCi}
 \end{aligned}$$

Table A29. Cancer Morbidity Risk Coefficients for Internal Exposures, risk/pCi.

Nuclide	GI Absorption Fraction (f ₁)	Ingestion Risk Coefficients (risk/pCi ingested)			ICRP Lung Class	Inhalation (risk/pCi inhaled)
		Water	Food	Soil		
H-3	1	1.12E-13	1.44E-13	2.20E-13	M	1.99E-13
Be-10	0.005	7.03E-12	1.02E-11	2.02E-11	S	9.40E-11
C-14	1	1.55E-12	2.00E-12	2.79E-12	M	7.07E-12
Na-22	1	9.62E-12	1.26E-11	1.97E-11	F	3.89E-12
Al-26	0.01	1.73E-11	2.49E-11	4.70E-11	M	6.92E-11
Si-32+D	0.01	1.24E-11	1.73E-11	3.19E-11	S	3.05E-10
Cl-36	1	3.30E-12	4.44E-12	7.66E-12	M	2.50E-11
K-40	1	2.47E-11	3.43E-11	6.18E-11	F	1.03E-11
Ca-41	0.3	3.53E-13	4.37E-13	5.74E-13	M	2.09E-13
Ti-44+D	0.01	2.72E-11	3.87E-11	7.15E-11	F	2.02E-10
V-49	0.01	1.22E-13	1.79E-13	3.53E-13	M	1.47E-13
Mn-54	0.1	2.28E-12	3.11E-12	5.14E-12	M	5.88E-12
Fe-55	0.1	8.62E-13	1.16E-12	2.09E-12	M	7.99E-13
Fe-60+D	0.1	1.80E-10	2.39E-10	3.53E-10	M	1.84E-10
Co-60	0.1	1.57E-11	2.23E-11	4.03E-11	M	3.58E-11
Ni-59	0.05	2.74E-13	3.89E-13	7.33E-13	M	4.66E-13
Ni-63	0.05	6.70E-13	9.51E-13	1.79E-12	M	1.64E-12
Se-79	0.8	7.29E-12	9.69E-12	1.60E-11	F	3.33E-12

Table A29. Cancer Morbidity Risk Coefficients for Internal Exposures, risk/pCi.

Nuclide	GI Absorption Fraction (f ₁)	Ingestion Risk Coefficients (risk/pCi Ingested)			ICRP Lung Class	Inhalation (risk/pCi Inhaled)
		Water	Food	Soil		
Rb-87	1	5.22E-12	7.07E-12	1.25E-11	F	2.14E-12
Sr-90+D	0.3	7.40E-11	9.53E-11	1.44E-10	M	1.13E-10
Zr-93	0.01	1.11E-12	1.44E-12	2.12E-12	M	7.29E-12
Nb-91	0.01	8.03E-13	1.17E-12	2.31E-12	M	1.90E-12
Nb-93m	0.01	8.03E-13	1.17E-12	2.31E-12	M	1.90E-12
Nb-94	0.01	7.77E-12	1.11E-11	2.05E-11	M	3.77E-11
Mo-93	1	3.35E-12	4.18E-12	5.29E-12	M	1.27E-12
Tc-99	0.5	2.75E-12	4.00E-12	7.66E-12	M	1.41E-11
Ru-106+D	0.05	4.22E-11	6.11E-11	1.19E-10	M	1.02E-10
Pd-107	0.005	2.50E-13	3.67E-13	7.25E-13	S	1.69E-12
Ag-108m+D	0.05	8.14E-12	1.12E-11	1.92E-11	M	2.67E-11
Cd-109	0.05	5.00E-12	6.70E-12	1.14E-11	F	1.48E-11
Cd-113m	0.05	2.87E-11	3.64E-11	5.11E-11	F	1.30E-10
In-115	0.02	3.38E-11	4.33E-11	5.85E-11	F	4.03E-10
Sn-121m+D	0.02	3.50E-12	5.12E-12	1.00E-11	M	1.62E-11
Sn-126+D	0.02	2.72E-11	3.92E-11	7.50E-11	M	1.01E-10
Sb-125	0.1	4.37E-12	6.14E-12	1.12E-11	M	1.66E-11
Te-125m	0.3	3.33E-12	4.70E-12	8.92E-12	M	1.17E-11
I-129	1	1.48E-10	1.93E-10	2.71E-10	F	6.07E-11
Cs-134	1	4.22E-11	5.14E-11	5.81E-11	F	1.65E-11
Cs-135	1	4.74E-12	5.88E-12	7.18E-12	F	1.86E-12
Cs-137+D	1	3.04E-11	3.74E-11	4.33E-11	F	1.19E-11
Ba-133	0.2	6.81E-12	9.44E-12	1.39E-11	M	1.16E-11
Pm-147	0.0005	1.69E-12	2.48E-12	4.88E-12	S	1.61E-11
Sm-147	0.0005	3.74E-11	4.77E-11	7.59E-11	M	6.88E-09
Sm-151	0.0005	5.55E-13	8.07E-13	1.59E-12	M	4.88E-12
Eu-150	0.0005	4.33E-12	6.07E-12	1.08E-11	M	1.12E-10
Eu-152	0.0005	6.07E-12	8.70E-12	1.62E-11	M	9.10E-11
Eu-154	0.0005	1.03E-11	1.49E-11	2.85E-11	M	1.15E-10
Eu-155	0.0005	1.90E-12	2.77E-12	5.40E-12	M	1.48E-11
Gd-152	0.0005	2.97E-11	3.85E-11	6.29E-11	F	9.10E-09
Ho-166m	0.0005	8.03E-12	1.14E-11	2.10E-11	M	3.09E-10
Re-187	0.8	1.79E-14	2.56E-14	4.81E-14	M	2.51E-14
Tl-204	1	5.85E-12	8.25E-12	1.54E-11	F	2.45E-12
Pb-205	0.2	6.33E-13	8.25E-13	1.26E-12	M	6.44E-13
Pb-210+D	0.2	8.90E-10	1.19E-09	1.87E-09	M	3.09E-09
Bi-207	0.05	5.66E-12	8.14E-12	1.49E-11	M	2.10E-11
Po-209	(l)	4.70E-10	2.81E-09	9.93E-10	M	1.35E-08
Po-210	(l)	3.77E-10	2.25E-09	7.96E-10	M	1.08E-08
Ra-226+D	0.2	3.86E-10	5.15E-10	7.30E-10	M	1.16E-08
Ra-228+D	0.2	1.04E-09	1.43E-09	2.29E-09	M	5.21E-09
Ac-227+D	0.0005	4.87E-10	6.54E-10	1.16E-09	M	1.40E-07
Th-228+D	0.0005	3.01E-10	4.24E-10	8.12E-10	S	1.43E-07

Table A29. Cancer Morbidity Risk Coefficients for Internal Exposures, risk/pCi.

Nuclide	GI Absorption Fraction (f ₁)	Ingestion Risk Coefficients (risk/pCi Ingested)			ICRP Lung Class	Inhalation (risk/pCi Inhaled)
		Water	Food	Soil		
Th-229+D	0.0005	5.28E-10	7.16E-10	1.29E-09	S	2.21E-07
Th-230	0.0005	9.10E-11	1.19E-10	2.02E-10	S	2.85E-08
Th-232	0.0005	1.01E-10	1.33E-10	2.31E-10	S	4.33E-08
Pa-231	0.0005	1.73E-10	2.26E-10	3.74E-10	M	4.07E-08
U-232	0.02	2.92E-10	3.85E-10	5.74E-10	M	1.95E-08
U-233	0.02	7.18E-11	9.69E-11	1.60E-10	M	1.16E-08
U-234	0.02	7.07E-11	9.55E-11	1.58E-10	M	1.14E-08
U-235+D	0.02	7.18E-11	9.76E-11	1.63E-10	M	1.01E-08
U-236	0.02	6.70E-11	9.03E-11	1.49E-10	M	1.05E-08
U-238+D	0.02	8.71E-11	1.21E-10	2.10E-10	M	9.35E-09
Np-237+D	0.0005	6.74E-11	9.10E-11	1.62E-10	M	1.77E-08
Pu-236	0.0005	7.47E-11	9.92E-11	1.74E-10	M	2.28E-08
Pu-238	0.0005	1.31E-10	1.69E-10	2.72E-10	M	3.36E-08
Pu-239	0.0005	1.35E-10	1.74E-10	2.76E-10	M	3.33E-08
Pu-240	0.0005	1.35E-10	1.74E-10	2.77E-10	M	3.33E-08
Pu-241+D	0.0005	1.76E-12	2.28E-12	3.29E-12	M	3.34E-10
Pu-242	0.0005	1.28E-10	1.65E-10	2.63E-10	M	3.13E-08
Pu-244+D	0.0005	1.44E-10	1.90E-10	3.14E-10	M	2.93E-08
Am-241	0.0005	1.04E-10	1.34E-10	2.17E-10	M	2.81E-08
Am-242m+D	0.0005	7.25E-11	9.03E-11	1.34E-10	M	1.57E-08
Am-243+D	0.0005	1.08E-10	1.42E-10	2.32E-10	M	2.70E-08
Cm-242	0.0005	3.85E-11	5.48E-11	1.05E-10	M	1.51E-08
Cm-243	0.0005	9.47E-11	1.23E-10	2.05E-10	M	2.69E-08
Cm-244	0.0005	8.36E-11	1.08E-10	1.81E-10	M	2.53E-08
Cm-245	0.0005	1.04E-10	1.35E-10	2.18E-10	M	2.77E-08
Cm-246	0.0005	1.02E-10	1.31E-10	2.12E-10	M	2.77E-08
Cm-247+D	0.0005	1.00E-10	1.31E-10	2.12E-10	M	2.50E-08
Cm-248	0.0005	3.74E-10	4.80E-10	7.77E-10	M	9.89E-08
Cm-250+D	0.0005	2.14E-09	2.75E-09	4.45E-09	M	5.54E-07
Bk-247	0.0005	1.24E-10	1.60E-10	2.49E-10	M	3.26E-08
Cf-248	0.0005	4.44E-11	6.22E-11	1.18E-10	M	1.81E-08
Cf-249	0.0005	1.27E-10	1.63E-10	2.54E-10	M	3.40E-08
Cf-250	0.0005	8.62E-11	1.12E-10	1.85E-10	M	2.66E-08
Cf-251	0.0005	1.32E-10	1.70E-10	2.67E-10	M	3.40E-08
Cf-252	0.0005	4.85E-11	6.30E-11	1.04E-10	M	1.56E-08

Notes:

- The risk coefficients are cancer morbidity values from Federal Guidance Report Number 13 (EPA-402-R-99-001). Values for five nuclides were obtained using proportions between the ICRP 72 internal dose factors shown in Table A21. In particular, Nb-91 values come from Nb-93m, Po-209 comes from Po-210, Cm-248 comes from Cm-246, Cm-250 comes from Cm-246, and Cf-252 comes from Cf-250.
- GI absorption fractions (i.e., f₁ values), and lung types are the same as used in Table A21.
- For I-129, the ingestion of milk has a risk coefficient of 3.22E-10 per pCi ingested.
- Short-lived radioactive progeny included in the "+D" nuclides are in secular equilibrium with their parent nuclide.

Table A30. Risk Coefficients for External Exposure, risk/y per pCi/g.

Nuclide	Risk Coefficient	Nuclide	Risk Coefficient	Nuclide	Risk Coefficient
H-3	0.00E+00	Sn-121m+D	9.86E-10	Pa-231	1.39E-07
Be-10	7.43E-10	Sn-126+D	8.83E-06	U-232	5.98E-10
C-14	7.83E-12	Sb-125	1.81E-06	U-233	9.82E-10
Na-22	1.03E-05	Te-125m	6.95E-09	U-234	2.52E-10
Al-26	1.33E-05	I-129	6.10E-09	U-235+D	5.43E-07
Si-32+D	9.43E-09	Cs-134	7.10E-06	U-236	1.25E-10
Cl-36	1.74E-09	Cs-135	2.36E-11	U-238+D	9.64E-08
K-40	7.97E-07	Cs-137+D	2.54E-06	Np-237+D	7.97E-07
Ca-41	0.00E+00	Ba-133	1.44E-06	Pu-236	1.19E-10
Ti-44+D	1.02E-05	Pm-147	3.21E-11	Pu-238	7.22E-11
V-49	0.00E+00	Sm-147	0.00E+00	Pu-239	2.00E-10
Mn-54	3.89E-06	Sm-151	3.60E-13	Pu-240	6.98E-11
Fe-55	0.00E+00	Eu-150	6.49E-06	Pu-241+D	1.31E-11
Fe-60+D	1.86E-08	Eu-152	5.30E-06	Pu-242	6.25E-11
Co-60	1.24E-05	Eu-154	5.83E-06	Pu-244+D	1.52E-06
Ni-59	0.00E+00	Eu-155	1.24E-07	Am-241	2.76E-08
Ni-63	0.00E+00	Gd-152	0.00E+00	Am-242m+D	4.75E-08
Se-79	1.10E-11	Ho-166m	7.69E-06	Am-243+D	6.36E-07
Rb-87	9.11E-11	Re-187	0.00E+00	Cm-242	7.73E-11
Sr-90+D	1.96E-08	Tl-204	2.76E-09	Cm-243	4.19E-07
Zr-93	0.00E+00	Pb-205	3.50E-12	Cm-244	4.85E-11
Nb-91	5.07E-09	Pb-210+D	4.17E-09	Cm-245	2.38E-07
Nb-93m	3.83E-11	Bi-207	7.08E-06	Cm-246	4.57E-11
Nb-94	7.29E-06	Po-209	1.32E-08	Cm-247+D	1.37E-06
Mo-93	2.17E-10	Po-210	3.95E-11	Cm-248	3.42E-11
Tc-99	8.14E-11	Ra-226+D	8.49E-06	Cm-250+D	1.43E-06
Ru-106+D	9.66E-07	Ra-228+D	4.53E-06	Bk-247	3.09E-07
Pd-107	0.00E+00	Ac-227+D	1.47E-06	Cf-248	4.73E-11
Ag-108m+D	7.19E-06	Th-228+D	7.81E-06	Cf-249	1.37E-06
Cd-109	8.73E-09	Th-229+D	1.16E-06	Cf-250	4.48E-11
Cd-113m	4.45E-10	Th-230	8.19E-10	Cf-251	3.76E-07
In-115	2.70E-10	Th-232	3.42E-10	Cf-252	8.66E-11

Notes:

- The risk coefficients for external exposure are cancer morbidity values from Federal Guidance Report Number 13 (EPA-402-R-99-001). Values for Nb-91 and Po-209 were estimated from the dose rate factors in Table A23 as described in the text.
- Short-lived radioactive progeny included in the "+D" nuclides are in secular equilibrium with their parent nuclide.

A3.8 Slope Factors and Reference Doses for Chemicals

For chemicals, the risk to the exposed individual of developing some type of cancer as well as non-cancer effects are of interest in human health risk assessments. The cancer risk is based on cancer induction slope factors (SF), while the hazard from non-cancer effects is based on reference doses (RfD). Reference doses and cancer induction slope factors for the chemicals of interest are listed in Table A31. The source of these numbers is noted beside each.

In January 1991, EPA began to replace inhalation Reference Doses (RfD) for noncancer toxicity and inhalation slope factors for carcinogenicity, previously available on the IRIS data base, with Reference Concentrations (RfC) and inhalation unit risks, respectively. RfCs and unit risks are expressed in terms of concentration in air (mg/m^3), not in terms of "dose" ($\text{mg}/\text{kg}\text{-day}$) like the RfDs and the oral and inhalation slope factors.

EPA's decision to replace inhalation slope factors and RfDi values expressed in $\text{mg}/\text{kg}\text{-day}$ with unit risk and RfC values expressed in mg/m^3 was based on two major factors: (1) the EPA workgroups felt that it was technically more accurate to base toxicity values directly on measured air concentrations instead of making the metabolic pharmacokinetic and/or surface area adjustments required to estimate an "internal dose"; and (2) there are compounds that elicit route-of-entry effects (e.g., sensitizers and irritants) where the toxic effect is to the respiratory system or exchange boundary where a measure of "internal dose" might inappropriately imply effects to other organ systems or effects from other exposure routes.

Converting the air concentration data to a dose (in $\text{mg}/\text{kg}\text{-day}$) is carried out using the equations shown below. Note that the adult body weight and breathing rates are used for the conversions.

$$\text{RfDi} = \text{RfC} \frac{\text{BRa}}{\text{BWa}} \quad \text{and} \quad \text{SFi} = (\text{Unit Risk}) \frac{\text{BWa}}{\text{BRa}} (1000 \mu\text{g}/\text{mg})$$

Where

- RfDi = Inhalation reference dose, in $\text{mg}/\text{kg}\text{-day}$, is an estimate of a daily inhalation dose to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime.
- RfC = Reference concentration, in mg/m^3 , is an estimate of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime.
- Bra = standard adult breathing rate for EPA risk assessment, $20 \text{ m}^3/\text{day}$
- BWa = standard adult body weight for EPA risk assessment, 70 kg
- SFi = Inhalation slope factor, in risk per ($\text{mg}/\text{kg}\text{-day}$), gives an upper bound on the probability that some type of cancer develops as a result of a lifetime exposed to a given chemical.
- Unit Risk = Unit Risk, in risk per ($\mu\text{g}/\text{m}^3$), gives an upper bound on the probability that some type of cancer develops as a result of a lifetime exposed to a given chemical.

Table A31. Reference Doses and Cancer Induction Slope Factors for Chemicals.

CASRN	Chemical Name	Reference Dose (RfD) (mg/kg-day)		Cancer Slope Factor (SF) (mg/kg-day) ⁻¹	
		Ingestion	Inhalation	Ingestion	Inhalation
50-32-8	Benzo[a]pyrene	na	na	7.30E+00 e	3.08E+00 t
53-70-3	Dibenz[a,h]anthracene	na	na	7.30E+00 o	3.08E+00 t
56-23-5	Carbon tetrachloride	7.00E-04 e	na	1.30E-01 e	5.20E-02 e
57-12-5	Cyanide, free	2.00E-02 e	na	na	na
57-14-7	1,1-Dimethylhydrazine	na	na	3.00E+00 o	1.72E+01 o
57-55-6	Propylene glycol (1,2-Propanediol)	5.00E-01 s	8.57E-04 s	na	na
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)	3.00E-04 e	na	1.30E+00 h	na
60-29-7	Ethyl ether (Diethyl ether)	2.00E-01 e	na	na	na
60-34-4	Methylhydrazine	na	na	3.00E+00 o	1.72E+01 o
60-57-1	Dieldrin	5.00E-05 e	na	1.60E+01 e	1.60E+01 e
62-75-9	N-Nitrosodimethylamine	8.00E-06 s	na	5.10E+01 e	5.10E+01 e
64-18-6	Formic acid	2.00E+00 h	na	na	na
67-56-1	Methanol (Methyl alcohol)	5.00E-01 e	na	na	na
67-64-1	Acetone (2-Propanone)	9.00E-01 e	na	na	na
67-66-3	Chloroform	1.00E-02 e	8.60E-04 n	2.30E-04 e	8.05E-02 e
67-72-1	Hexachloroethane	1.00E-03 e	na	1.40E-02 e	1.40E-02 e
71-36-3	n-Butyl alcohol (n-Butanol)	1.00E-01 e	2.60E-03 n	na	na
71-43-2	Benzene	4.00E-03 e	8.57E-03 e	5.50E-02 e	2.73E-02 e
71-55-6	1,1,1-Trichloroethane (Methyl chloroform)	2.80E-01 n	6.29E-01 o	na	na
72-20-8	Endrin	3.00E-04 e	na	na	na
74-83-9	Bromomethane	1.40E-03 e	1.43E-03 e	na	na
74-87-3	Methyl chloride (Chloromethane)	na	2.57E-02 e	1.30E-02 h	6.30E-03 h
75-00-3	Ethyl Chloride	4.00E-01 n	2.86E+00 e	2.90E-03 n	na
75-01-4	Vinyl chloride (Chloroethene)	3.00E-03 e	2.86E-02 e	1.40E+00 e	3.08E-02 e
75-05-8	Acetonitrile	na	1.71E-02 e	na	na
75-07-0	Acetaldehyde	na	2.57E-03 e	na	7.70E-03 e
75-09-2	Dichloromethane (Methylene chloride)	6.00E-02 e	8.57E-01 h	7.50E-03 e	1.65E-03 e
75-15-0	Carbon disulfide	1.00E-01 e	2.00E-01 e	na	na
75-21-8	Ethylene Oxide (Oxirane)	na	na	1.02E+00 h	3.50E-01 h
75-34-3	1,1-Dichloroethane (Ethylidene chloride)	1.00E-01 h	1.43E-01 h	na	na
75-35-4	1,1-Dichloroethylene	5.00E-02 e	5.71E-02 e	na	na
75-45-6	Chlorodifluoromethane	na	1.43E+01 e	na	na
75-68-3	Chloro-1,1-difluoroethane, 1-	na	1.43E+01 e	na	na
75-69-4	Trichlorofluoromethane	3.00E-01 e	2.00E-01 h	na	na
75-71-8	Dichlorodifluoromethane	2.00E-01 e	5.71E-02 h	na	na
76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane (CFC-113)	3.00E+01 e	8.57E+00 h	na	na
76-44-8	Heptachlor	5.00E-04 e	na	4.50E+00 e	4.50E+00 e
78-83-1	Isobutanol	3.00E-01 e	na	na	na
78-87-5	1,2-Dichloropropane	na	1.14E-03 e	6.80E-02 h	na
78-93-3	Methyl ethyl ketone (2-Butanone)	6.00E-01 e	1.43E+00 e	na	na
79-00-5	1,1,2-Trichloroethane	4.00E-03 e	na	5.70E-02 e	5.70E-02 e
79-01-6	Trichloroethylene	3.00E-04 n	1.14E-02 n	4.00E-01 o	4.00E-01 o

Table A31. Reference Doses and Cancer Induction Slope Factors for Chemicals.

CASRN	Chemical Name	Reference Dose (RfD) (mg/kg-day)		Cancer Slope Factor (SF) (mg/kg-day) ⁻¹	
		Ingestion	Inhalation	Ingestion	Inhalation
79-10-7	2-Propenoic acid (Acrylic acid)	5.00E-01 e	2.86E-04 e	na	na
79-34-5	1,1,2,2-Tetrachloroethane (Acetylene tetrachloride)	6.00E-02 n	na	2.00E-01 e	2.00E-01 e
79-46-9	2-Nitropropane	na	5.71E-03 e	na	9.40E+00 h
82-68-8	Pentachloronitrobenzene (PCNB)	3.00E-03 e	na	2.60E-01 h	na
83-32-9	Acenaphthene	6.00E-02 e	na	na	na
84-66-2	Diethyl phthalate	8.00E-01 e	na	na	na
84-74-2	Dibutyl phthalate	1.00E-01 e	na	na	na
85-68-7	Butyl benzyl phthalate	2.00E-01 e	na	na	na
87-68-3	Hexachlorobutadiene	3.00E-04 n	na	7.80E-02 e	7.80E-02 e
87-86-5	Pentachlorophenol	3.00E-02 e	na	1.20E-01 e	na
88-06-2	2,4,6-Trichlorophenol	1.00E-04 n	na	1.10E-02 e	1.10E-02 e
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)	1.00E-03 e	na	na	na
91-20-3	Naphthalene	2.00E-02 e	8.57E-04 e	na	na
92-52-4	1,1'-Biphenyl	5.00E-02 e	na	na	na
95-47-6	o-Xylene	2.00E-01 e	2.86E-02 e	na	na
95-48-7	2-Methylphenol (o-Cresol)	5.00E-02 e	na	na	na
95-50-1	1,2-Dichlorobenzene (ortho-)	9.00E-02 e	5.71E-02 h	na	na
95-57-8	2-Chlorophenol	5.00E-03 e	na	na	na
95-63-6	1,2,4-Trimethylbenzene	5.00E-02 o	1.71E-03 o	na	na
95-95-4	2,4,5-Trichlorophenol	1.00E-01 e	na	na	na
98-86-2	Acetophenone	1.00E-01 e	na	na	na
98-95-3	Nitrobenzene	5.00E-04 e	5.71E-04 h	na	na
100-25-4	1,4-Dinitrobenzene (para-)	1.00E-04 o	na	na	na
100-41-4	Ethyl benzene	1.00E-01 e	2.86E-01 e	na	3.85E-03 n
100-42-5	Styrene	2.00E-01 e	2.86E-01 e	na	na
100-51-6	Benzyl alcohol	3.00E-01 h	na	na	na
106-42-3	p-Xylene	2.00E-01 e	2.86E-02 e	na	na
106-44-5	4-Methylphenol (p-Cresol)	5.00E-03 h	na	na	na
106-46-7	1,4-Dichlorobenzene (para-)	3.00E-02 n	2.29E-01 e	2.40E-02 h	2.20E-02 n
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	na	5.71E-05 h	8.50E+01 e	7.70E-01 e
106-99-0	1,3-Butadiene	na	5.71E-04 e	na	1.05E-01 e
107-02-8	2-Propenal (Acrolein)	5.00E-04 e	5.71E-06 e	na	na
107-05-1	3-Chloropropene (Allyl chloride)	5.00E-02 h	2.86E-04 e	na	na
107-06-2	1,2-Dichloroethane (Ethylene chloride)	3.00E-02 n	1.40E-03 n	9.10E-02 e	9.10E-02 e
107-13-1	Acrylonitrile	1.00E-03 h	5.71E-04 e	5.40E-01 e	2.38E-01 e
108-10-1	Methyl isobutyl ketone (4-Methyl-2-pentanone)	8.00E-02 h	8.57E-01 e	na	na
108-38-3	m-Xylene	2.00E-01 e	2.86E-02 e	na	na
108-39-4	3-Methylphenol (m-Cresol)	5.00E-02 e	na	na	na
108-67-8	1,3,5-Trimethylbenzene	5.00E-02 o	1.71E-03 o	na	na
108-87-2	Methyl cyclohexane	na	8.57E-01 o	na	na
108-88-3	Toluene (Methyl benzene)	2.00E-01 e	1.14E-01 e	na	na
108-90-7	Chlorobenzene	2.00E-02 e	1.70E-02 n	na	na

Table A31. Reference Doses and Cancer Induction Slope Factors for Chemicals.

CASRN	Chemical Name	Reference Dose (RfD) (mg/kg-day)		Cancer Slope Factor (SF) (mg/kg-day) ⁻¹	
		Ingestion	Inhalation	Ingestion	Inhalation
108-94-1	Cyclohexanone	5.00E+00 e	na	na	na
108-95-2	Phenol (Carbolic acid)	3.00E-01 e	na	na	na
109-99-9	Tetrahydrofuran	2.10E-01 n	8.57E-02 n	7.60E-03 n	6.80E-03 n
110-00-9	Furan (Oxacyclopentadiene)	1.00E-03 e	na	na	na
110-54-3	n-Hexane	6.00E-02 h	5.71E-02 e	na	na
110-80-5	2-Ethoxyethanol	4.00E-01 h	5.71E-02 e	na	na
110-82-7	Cyclohexane	na	1.71E+00 e	na	na
110-86-1	Pyridine	1.00E-03 e	na	na	na
111-76-2	2-Butoxyethanol (Ethylene Glycol Monobutyl Ether)	5.00E-01 e	3.71E+00 e	na	na
111-90-0	2-(2-Ethoxyethoxy)-ethanol (Diethylene Glycol Monoethyl Ether)	6.00E-02 s	8.60E-04 s	na	na
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)	2.00E-02 e	na	1.40E-02 e	na
117-84-0	Di-n-octylphthalate	4.00E-02 o	na	na	na
118-74-1	Hexachlorobenzene	8.00E-04 e	na	1.60E+00 e	1.60E+00 e
120-82-1	1,2,4-Trichlorobenzene	1.00E-02 e	1.14E-03 o	na	na
121-14-2	2,4-Dinitrotoluene	2.00E-03 e	na	na	na
121-44-8	Triethylamine	na	2.00E-03 e	na	na
122-39-4	Diphenylamine	2.50E-02 e	na	na	na
123-91-1	1,4-Dioxane (Diethylene oxide)	na	na	1.10E-02 e	na
126-73-8	Tributyl Phosphate	2.00E-01 o	na	5.40E-03 o	na
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)	1.00E-04 e	2.00E-04 h	na	na
127-18-4	Tetrachloroethylene	1.00E-02 e	1.70E-01 n	5.20E-02 o	2.03E-03 o
129-00-0	Pyrene	3.00E-02 e	na	na	na
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	9.00E-01 e	na	na	na
156-59-2	cis-1,2-Dichloroethylene	1.00E-02 h	na	na	na
206-44-0	Fluoranthene (1,2-Benzacenaphthene)	4.00E-02 e	na	na	na
309-00-2	Aldrin	3.00E-05 e	na	1.70E+01 e	1.70E+01 e
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	5.00E-04 n	na	6.30E+00 e	6.30E+00 e
319-85-7	beta-Benzene hexachloride (beta-Lindane)	2.00E-04 n	na	1.80E+00 e	1.80E+00 e
541-73-1	1,3-Dichlorobenzene	9.00E-04 n	na	na	na
542-75-6	1,3-Dichloropropene (cis & trans)	3.00E-02 e	5.71E-03 e	1.00E-01 e	1.40E-02 e
621-64-7	N-Nitrosodi-N-propylamine	na	na	7.00E+00 e	na
1314-62-1	Vanadium pentoxide	9.00E-03 e	na	na	na
1330-20-7	Xylenes (mixtures)	2.00E-01 e	2.86E-02 e	na	na
1336-36-3	Polychlorinated Biphenyls	na	na	4.00E-01 e	4.00E-01 e
1336-36-3	Polychlorinated Biphenyls (lowest risk)	na	na	7.00E-02 e	7.00E-02 e
6533-73-9	Thallium carbonate	8.00E-05 e	na	na	na
7429-90-5	Aluminum	1.00E+00 o	1.43E-03 o	na	na
7439-89-6	Iron	3.00E-01 n	na	na	na
7439-93-2	Lithium	2.00E-02 w	na	na	na
7439-96-5	Manganese	4.67E-02 e	1.43E-05 e	na	na
7439-97-6	Mercury metal vapor	na	8.57E-05 e	na	na

Table A31. Reference Doses and Cancer Induction Slope Factors for Chemicals.

CASRN	Chemical Name	Reference Dose (RfD) (mg/kg-day)		Cancer Slope Factor (SF) (mg/kg-day) ⁻¹	
		Ingestion	Inhalation	Ingestion	Inhalation
7439-98-7	Molybdenum	5.00E-03 e	na	na	na
7440-02-0	Nickel (soluble salts)	2.00E-02 e	na	na	na
7440-22-4	Silver	5.00E-03 e	na	na	na
7440-24-6	Strontium, Stable	6.00E-01 e	na	na	na
7440-28-0	Thallium metal	6.60E-05 ix	na	na	na
7440-31-5	Tin	6.00E-01 h	na	na	na
7440-36-0	Antimony	4.00E-04 e	na	na	na
7440-38-2	Arsenic (inorganic)	3.00E-04 e	na	1.50E+00 e	1.51E+01 e
7440-39-3	Barium	7.00E-02 e	1.43E-04 h	na	na
7440-41-7	Beryllium and compounds	2.00E-03 e	5.71E-06 e	na	8.40E+00 e
7440-42-8	Boron and borates only	9.00E-02 e	5.71E-03 h	na	na
7440-43-9	Cadmium	5.00E-04 e	na	na	6.30E+00 e
7440-45-1	Cerium (Ceric oxide 1306-38-3)	na	5.71E-05 o	na	na
7440-48-4	Cobalt	2.00E-02 o	5.71E-06 o	na	9.80E+00 o
7440-50-8	Copper	4.00E-02 h	na	na	na
7440-62-2	Vanadium metal	7.00E-03 h	na	na	na
7440-66-6	Zinc and compounds	3.00E-01 e	na	na	na
7487-94-7	Mercuric chloride	3.00E-04 e	na	na	na
7664-41-7	Ammonia	na	2.86E-02 e	na	na
7723-14-0	Phosphorus, white	2.00E-05 e	na	na	na
7782-41-4	Fluorine (soluble fluoride)	6.00E-02 e	na	na	na
7782-49-2	Selenium and compounds	5.00E-03 e	na	na	na
8001-35-2	Toxaphene	na	na	1.10E+00 e	1.10E+00 e
11096-82-5	Aroclor 1260	na	na	4.00E-01 e	4.00E-01 e
11097-69-1	Aroclor 1254	2.00E-05 e	na	4.00E-01 e	4.00E-01 e
11104-28-2	Aroclor 1221	na	na	4.00E-01 e	4.00E-01 e
11141-16-5	Aroclor 1232	na	na	4.00E-01 e	4.00E-01 e
12672-29-6	Aroclor 1248	na	na	4.00E-01 e	4.00E-01 e
12674-11-2	Aroclor 1016	7.00E-05 e	na	7.00E-02 e	7.00E-02 e
14797-55-8	Nitrate	1.60E+00 e	na	na	na
14797-65-0	Nitrite	1.00E-01 e	na	na	na
16065-83-1	Chromium (III) (insoluble salts)	1.50E+00 e	na	na	na
16984-48-8	Fluorine anion	6.00E-02 e	na	na	na
18540-29-9	Chromium (VI) (soluble salts)	3.00E-03 e	2.29E-06 e	na	4.20E+01 e
53469-21-9	Aroclor 1242	na	na	4.00E-01 e	4.00E-01 e
na	Uranium (soluble salts)	6.00E-04 c	na	na	na

Table A31. Reference Doses and Cancer Induction Slope Factors for Chemicals.

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

Values for reference doses and slope factors adopted by the EPA are listed in the Integrated Risk Information System (IRIS) database, which may be examined at <http://www.epa.gov/IRIS>. This is the primary reference, but is incomplete. Additional toxicity parameters are available from the EPA-540/R-97/036, *Health Effects Assessment Summary Tables (HEAST) FY 1997*. Additional toxicity parameters not available in IRIS or HEAST were found in the table of preliminary remediation goals from EPA Region 9. This table may be obtained at the internet address www.epa.gov/docs/region09/waste/sfund/prg/index.html. A few additional numbers were obtained from the EPA Superfund risk assessment web site, for which the address is <http://www.epa.gov/superfund/index.htm>. Data for additional chemicals is available from the Risk Assessment Information System (RAIS). The Oak Ridge National Laboratory (ORNL) maintains this toxicological data listing for human health risk assessments. The data may be obtained from the World Wide Web using the location <http://risk.lsd.ornl.gov>.

The reference dose and cancer slope factors are expressed in terms of the average daily dose. This dose is normalized to the mass of the recipient, and has units of mg/kg per day. The routes of intake are ingestion and inhalation. Reference doses and cancer induction slope factors

for dermal absorption use the ingestion values. The reference doses and cancer induction slope factors for children and adults are assumed to be the same.

Several chemicals have a reference dose or slope factor given for ingestion, but none for inhalation, or vice-versa. Rather than omit this chemical, the calculations were carried out with only the given route of exposure (inhalation or ingestion/dermal). The missing route was ignored. Since this omission can grossly underestimate the risk from a chemical, the importance of the missing value was examined in Appendix C. Simple estimates for the missing reference doses or slope factors are given in Table C1. Other tables give the hazard index and increased cancer risk unit factors for each exposure scenario using the imputed numbers. Table C17 shows the largest ratios observed between the unit factors in the main report and those in Appendix C.

A4.0 ANIMAL PARAMETERS

The animal parameters discussed here are those pertaining to the eventual concentration of a contaminant in animal products consumed as food, such as fish, milk, meat, poultry, and eggs. The model used to represent various animals assumes contaminants are taken in by inhalation, ingestion, and dermal absorption at a rate that changes slowly during the year. The concentration in the animal reaches a steady-state maximum related to the concentration in its environment. This is a type of equilibrium in which the intake rate of a contaminant is the same as the loss rate, hence, the concentration in the animal product is constant.

Note that the radiation doses received by the animals are assumed to be low enough to not affect their health or metabolism. In equilibrium, the contaminant concentration in the animal product is proportional to the ingestion rate of contamination by the animal. The constants of proportionality are called bioaccumulation factors, or equilibrium transfer factors.

Not all animals have transfer factors developed for them. It is assumed that other aquatic animals such as bottom-dwelling fish, crustaceans and mollusks are consumed in minimal amounts. If a group of people is identified who consume significant quantities of these creatures then efforts will be made to quantify the transfer factors that would apply to them. Other land animals such as pigs or goats or deer are assumed to have transfer factors that differ very little from cattle.

The contaminant concentration in cattle and poultry depends on the rate at which the contaminant is consumed. The cattle and poultry diets are discussed in the next section. The equilibrium transfer factors for these animals are discussed afterward.

A4.1 General Animal Parameters and Pasture Area

The daily intake rates assumed for cattle and poultry are listed in Table A32. These are from NUREG/CR-5512, Section 6.5.1. No distinction is made between the diets of poultry raised for food and egg-laying hens. For comparison with prior Hanford Site performance assessments, the default intake rates used by the GENII program (PNNL-6584) are also shown in Table A32. The water intake rates are the same for both. Note that the GENII program does not

distinguish between the two types of stored feed (i.e. hay or grain), nor does it allow the animals to ingest soil directly.

To calculate the contaminant concentrations in the animal foods, it is necessary to introduce a "dry-to-wet ratio". The "dry-to-wet ratio" is a unitless quantity measured as the ratio of the dry weight of the item to its wet weight. The "dry-to-wet ratio" for stored hay applies at the time of harvest. (In practice the hay is dried before being fed to cattle. Thus the "dry-to-wet ratio" for sun-cured hay is reported as approximately 0.9, similar to stored grain.)

Table A32. Animal Feed, Water, and Soil Intake Rates.

Values from NUREG/CR-5512 for use in the tank waste PA							
Type of Feed	dry-to-wet ratio	Beef, kg/d		Milk, kg/d		Poultry, kg/d	
		dry	wet	dry	wet	dry	wet
Fresh Forage	0.22	3	27	8	36	0.0275	0.13
Stored Hay	0.22	6	14	6	29	0	0
Stored Grain	0.91	3	3	2	2	0.0825	0.09
Total Feed, kg/d:		12	44	16	67	0.110	0.22
Soil Ingestion Rate:		0.6 kg/d		0.8 kg/d		0.011 kg/d	
Drinking Water:		50 L/d		60 L/d		0.3 L/d	
Values from GENII Version 1.485 (PNNL-6584) used in previous Hanford Site PAs							
Type of Feed	dry-to-wet ratio	Beef, kg/d		Milk, kg/d		Poultry, kg/d	
		dry	wet	dry	wet	dry	wet
Fresh Forage	0.20	10	51	8	41	0	0
Stored Hay	0.18	3	17	2	14	0.022	0.12
Stored Grain	NA	NA	NA	NA	NA	NA	NA
Total Feed, kg/d:		13	68	10	55	0.022	0.12
Soil Ingestion Rate:		NA		NA		NA	
Drinking Water:		50 L/d		60 L/d		0.3 L/d	
The wet weights for fresh forage and stored hay are at the time of harvest or grazing. The GENII software (Version 1.485) has one type of stored feed that uses the soil-to-plant concentration factors for grains. In addition, GENII does not consider ingestion of soil by grazing animals.							

The intake rates found in NUREG/CR-5512 will be used in the current performance assessment, as they were in the 2001 ILAW PA (DOE/ORP-2000-24). The principal reason for this change from prior Hanford performance assessments is the extra detail provided for the diet. Previous performance assessments relied on the GENII software Version 1.485, which is unable to accommodate this detail. The tank waste PA for the low-level waste glass form will utilize hand calculations that incorporate the added detail.

The exposure of special groups living near waste sites or near locations where the ground water enters the Columbia River would probably include the consumption of some type of native game animals. These animals could acquire radioactivity from drinking and grazing near locations where ground water enters the river. The larger examples of these, such as deer, would graze over a large area. Thus only a small portion of the deer's plant intakes would be contaminated. Similarly, the smaller animals might derive all of their nourishment from a contaminated area. However, such animals would have to be harvested from many locations over the course of a year. The average concentration from all such animals would be much lower due to the large forage area needed for hunting and gathering. For the cases where the ground water is the main source of contamination, it will be assumed that the game animals are contaminated at such a low level compared with the domesticated animals that the dose from game animals can be ignored. For the cases where the Columbia River is the main source of contaminated water, the animals will be assumed to obtain all of their drinking water from the river, but their vegetation intakes will be assumed uncontaminated. The transfer factors for beef will be used to represent transfer to the edible portion of the deer. The daily water intake for the deer is assumed to be 25% that of the milk cow. Waterfowl are similarly represented using the poultry data, except there is no difference in the daily water intake.

It should be noted that animals killed by native hunters would be more efficiently scavenged than common farm animals. Some of the internal organs would be eaten. The animal skins could be used for clothing, and larger bones could be used as tools or ceremonial items. The more extensive use of animal parts could increase the exposed person's radiation dose. Nevertheless, it will be assumed that this dose is small compared with that from farm animals.

The land area needed to support a cow can be calculated from the consumption rates given in Table A32. A search of the internet for "pasture size" or "animal unit month" uncovers numerous reports dealing with estimating how much land is needed to support grazing cows. One common factor in the calculations is the fraction of the grass lost to trampling. The usual factor is 40%, which will be used here also. An additional consideration is the fraction of the standing biomass that the cow can eat. The usual factor is 50%, which will be used here also. Additional factors, such as the standing biomass and growing period are presented in Table A39 below. An irrigation period of 0.5 y means that there are 6 crops of grass (30 d each). The irrigation period (i.e., the grazing period) cancels out of the equation below.

$$A_{\text{Grass}} = \frac{M_{\text{Grass}} T_{\text{Grow,Grass}}}{Y_{\text{Grass}} F_{\text{Eaten}} (1 - F_{\text{Trample}})} = \frac{(36 \text{ kg/d})(30 \text{ d})}{(1.5 \text{ kg/m}^2)(0.5)(1 - 0.4)} = 2,400 \text{ m}^2$$

where,

- A_{Grass} = pasture grass area needed for the milk cow, 2,400 m²
- F_{Eaten} = fraction of standing biomass eaten by the cow while grazing, 0.5
- F_{Trample} = fraction of the standing biomass trampled by the cow while grazing, 0.4
- M_{Grass} = mass of grass eaten each day by the cow from Table A32, 36 kg (wet)/d
- $T_{\text{Grow,Grass}}$ = growing period for the grass from Table A39, 30 days
- Y_{Grass} = standing biomass for mature grass from Table A39, 1.5 kg/m²

A similar equation is needed for the hay field. The hay grows during the irrigation period and is consumed by the cow during the remainder of the year, the no-irrigation period. An irrigation period of 0.5 y means there are 4 crops of hay (45 d each). Since the hay growing

period is the same length as the hay consumption period, it cancels out of the equation below. The loss from trampling is not needed, but the fraction harvested is used. The harvested fraction is assumed to be the same as the fraction that the cow eats while grazing, 50%.

$$A_{\text{Hay}} = \frac{M_{\text{Hay}} T_{\text{Grow,Hay}}}{Y_{\text{Hay}} F_{\text{Harvest}}} = \frac{(29 \text{ kg/d})(45 \text{ d})}{(1.0 \text{ kg/m}^2)(0.5)} = 2,600 \text{ m}^2$$

where,

- A_{Hay} = hay field area needed for the milk cow, 2,600 m²
- F_{Harvest} = fraction of standing biomass harvested for the cow, 0.5
- M_{Hay} = mass of hay eaten each day by the cow from Table A32, 29 kg (wet)/d
- $T_{\text{Grow,Hay}}$ = growing period for the grass from Table A39, 45 days
- Y_{Hay} = standing biomass for mature grass from Table A39, 1.5 kg/m²

A4.2 Equilibrium Transfer Factors for Radionuclides

The equilibrium transfer factors for cattle and poultry relate the rate of intake of a radionuclide to the eventual steady-state concentration in meat or milk or eggs. These parameters are the ratio of the equilibrium concentration of a nuclide in the animal product to the daily intake by the animal. For beef, poultry and eggs the units are Ci/kg per Ci/d (equivalent to d/kg), while for milk the units are Ci/L(milk) per Ci/d (equivalent to d/L). Transfer factors for organs such as liver or brain are not available. Since some elements may be found in higher concentrations in these tissues, individuals who consume the organs would receive higher doses from the radioactive isotopes of the elements.

The concentration of waterborne contaminants in fish is assumed to be proportional to the concentration of the contaminant in the water environment of the fish. The constant of proportionality for fish is called a "bioaccumulation" factor. It is the average concentration of the contaminant in the edible portion of the fish divided by the concentration in the water. This parameter has units of L/kg. The transfer factors used in the present report for cows, chickens and fish are shown in Table A33. Bioaccumulation factors include the effects of contaminants in sediments, plant life, and other aquatic organisms contribute to contamination in the edible portions of the fish.

There are several sources for these transfer factors, as indicated by the letter beside each number in Table A33. The following hierarchy is used for selecting values. The first values are chosen from PNWD-2023. This report compiled Hanford-specific data developed for dose reconstruction of historical atmospheric releases from the Hanford Site. For elements that are not discussed in PNWD-2023, values from IAEA Technical Report 364 were chosen. The IAEA report is a compilation from many sources. For elements not discussed in the IAEA report, values from ORNL-5786 were used. For elements not discussed in these reports, values from NUREG/CR-5512 Volume 1 were chosen. For elements not discussed in those reports, values from NCRP-123 were used. A few elements still had no assigned values. In these cases values were assumed based on chemical similarities.

For cows and chickens it was necessary to assume values for berkelium (Bk). These were assumed to be the same as americium (Am). For the chicken it was necessary to assume values for boron (B), aluminum (Al), titanium (Ti), and vanadium (V). These were assumed to be the

same as silicon (Si), gallium (Ga), scandium (Sc), and chromium (Cr), respectively.

For accumulation in cows and chickens, the PNWD-2023 report only supplied a value for transfer of iodine (I) to milk. The transfer factors for the other animal products are specified as a range and this range covers the values given in the IAEA report. For accumulation in fish, PNWD-2023 provides values for the elements sodium (Na), phosphorus (P), arsenic (As), and neptunium (Np). It is assumed that plutonium (Pu), americium (Am), and curium (Cm) share the same accumulation factor as Np.

Table A33. Transfer Factors for Radionuclides to Cows, Chickens, and Fish.

Element	Meat (day/kg)	Milk (day/L)	Poultry (day/kg)	Eggs (day/kg)	Fish (L/kg)	Atomic Number
H	na	na	na	na	1.0 b	1
Be	1.0E-03 c	9.0E-07 c	0.40 d	0.020 d	100 b	4
B	8.0E-04 c	1.5E-03 c	0.20 d	0.80 d	5.0 e	5
C	0.0489 f	0.0105 f	4.16 f	3.12 f	50,000 b	6
F	0.15 c	1.0E-03 c	0.010 d	2.0 d	10 d	9
Na	0.080 b	0.016 b	0.010 d	6.0 b	8.0 a	11
Al	1.5E-03 c	2.0E-04 c	0.30 d	0.80 d	500 e	13
Si	4.0E-05 c	2.0E-05 c	0.20 d	0.80 d	20 e	14
P	0.050 b	0.016 b	0.19 d	10 d	1,500 a	15
Cl	0.020 b	0.017 b	0.030 d	2.0 d	50 d	17
K	0.020 b	7.2E-03 b	0.40 d	1.0 b	1,000 d	19
Ca	2.0E-03 b	3.0E-03 b	0.040 b	0.40 b	40 d	20
Ti	0.030 c	0.010 c	4.0E-03 d	3.0E-03 d	1,000 e	22
V	2.5E-03 c	2.0E-05 c	0.20 d	0.80 d	200 e	23
Mn	5.0E-04 b	3.0E-05 b	0.050 b	0.060 b	400 b	25
Fe	0.020 b	3.0E-05 b	1.0 b	1.0 b	200 b	26
Co	0.010 b	3.0E-04 b	2.0 b	0.10 b	300 b	27
Ni	5.0E-03 b	0.016 b	1.0E-03 d	0.10 d	100 b	28
As	2.0E-03 c	6.0E-05 c	0.83 d	0.80 d	244 a	33
Se	0.015 c	4.0E-03 c	9.0 b	9.0 b	170 d	34
Rb	0.010 b	0.012 b	2.0 d	3.0 d	2,000 b	37
Sr	8.0E-03 b	2.8E-03 b	0.080 b	0.20 b	60 b	38
Y	1.0E-03 b	2.0E-05 c	0.010 b	2.0E-03 b	30 b	39
Zr	1.0E-06 b	5.5E-07 b	6.0E-05 b	2.0E-04 b	300 b	40
Nb	3.0E-07 b	4.1E-07 b	3.0E-04 b	1.0E-03 b	300 b	41
Mo	1.0E-03 b	1.7E-03 b	1.0 b	0.90 b	10 b	42
Tc	1.0E-04 b	1.4E-04 b	0.030 b	3.0 b	20 b	43
Ru	0.050 b	3.3E-06 b	0.24 b	5.0E-03 b	10 b	44
Pd	4.0E-03 c	0.010 c	3.0E-04 d	4.0E-03 d	10 d	46
Ag	3.0E-03 b	5.0E-05 b	2.0 b	0.50 d	5.0 b	47
Cd	4.0E-04 b	1.0E-03 c	0.80 b	0.10 b	200 d	48
In	8.0E-03 c	1.0E-04 c	0.30 d	0.80 d	100,000 d	49
Sn	0.080 c	1.0E-03 c	0.20 d	0.80 d	3,000 b	50
Sb	4.0E-05 b	2.5E-05 b	6.0E-03 d	0.070 d	100 b	51
Te	7.0E-03 b	4.5E-04 b	0.60 b	5.0 b	400 b	52
I	0.040 b	0.012 a	0.010 b	3.0 b	40 b	53
Cs	0.050 b	7.9E-03 b	2.0 b	0.40 b	2,000 b	55

Table A33. Transfer Factors for Radionuclides to Cows, Chickens, and Fish.

Element	Meat (day/kg)	Milk (day/L)	Poultry (day/kg)	Eggs (day/kg)	Fish (L/kg)	Atomic Number
Ba	2.0E-04 b	4.8E-04 b	9.0E-03 b	0.90 b	4.0 b	56
Ce	2.0E-05 b	3.0E-05 b	4.0E-03 b	9.0E-05 b	30 b	58
Pm	5.0E-03 c	2.0E-05 c	2.0E-03 b	0.020 b	30 b	61
Sm	5.0E-03 c	2.0E-05 c	4.0E-03 d	7.0E-03 d	25 d	62
Eu	5.0E-03 c	2.0E-05 c	4.0E-03 d	7.0E-03 d	50 b	63
Gd	3.5E-03 c	2.0E-05 c	4.0E-03 d	7.0E-03 d	25 d	64
Ho	4.5E-03 c	2.0E-05 c	4.0E-03 d	7.0E-03 d	25 d	67
Re	8.0E-03 c	1.5E-03 c	0.040 d	0.40 d	120 d	75
Hg	0.25 c	4.7E-04 b	0.030 b	0.20 d	1,000 b	80
Tl	0.040 c	2.0E-03 c	0.30 d	0.80 d	10,000 e	81
Pb	4.0E-04 b	2.5E-04 c	0.20 d	0.80 d	300 b	82
Bi	4.0E-04 c	5.0E-04 c	0.10 d	0.80 d	10 b	83
Po	5.0E-03 b	3.4E-04 b	0.90 d	7.0 d	50 b	84
Ra	9.0E-04 b	1.3E-03 b	0.030 d	2.0E-05 d	50 b	88
Ac	2.5E-05 c	2.0E-05 c	4.0E-03 d	2.0E-03 d	25 d	89
Th	6.0E-06 c	5.0E-06 c	4.0E-03 d	2.0E-03 d	100 b	90
Pa	1.0E-05 c	5.0E-06 c	4.0E-03 d	2.0E-03 d	10 b	91
U	3.0E-04 b	4.0E-04 b	1.0 b	1.0 b	10 b	92
Np	1.0E-03 b	5.0E-06 b	4.0E-03 d	2.0E-03 d	21 a	93
Pu	1.0E-05 b	1.1E-06 b	3.0E-03 b	5.0E-04 b	21 a	94
Am	4.0E-05 b	1.5E-06 b	6.0E-03 b	4.0E-03 b	21 a	95
Cm	3.5E-06 c	2.0E-05 c	4.0E-03 d	2.0E-03 d	21 a	96
Bk	4.0E-05 b	1.5E-06 b	6.0E-03 b	4.0E-03 b	25 e	97
Cf	5.0E-03 d	7.5E-07 d	4.0E-03 d	2.0E-03 d	25 d	98

Notes:

- All of the transfer factors are derived using the wet weights. Note that Egg values are for egg contents rather than the whole egg.
- Cow and chicken parameters were selected using the following hierarchy: (a) PNWD-2023, (b) IAEA #364, (c) ORNL-5786, and (d) NUREG/CR-5512. Bk is assumed the same as Am for all cow and chicken parameters. Cow and chicken transfer factors for carbon were computed from the equilibrium model described in the text (f). Values for hydrogen are not used in the calculations (na) because an equilibrium transfer model is used instead.
- For the Poultry and Egg (i.e. chicken), the values for Si are used for B, the values for Ga are used for Al, the values for Sc are used for Ti, and the values for Cr are used for V.
- Fish bioaccumulation factors were selected using the following hierarchy: (a) PNWD-2023, (b) IAEA #364, (c) ORNL-5786, (d) NUREG/CR-5512, and (e) NCRP #123.

Transfer factors for tritium (H-3) are not needed because the animal concentration is calculated using the equilibrium model described in the discussion of scenario dose factors. The transfer factors for C-14 are computed from an equilibrium model. The ratio of radioactive C-14 to the non-radioactive carbon in the animal's diet is assumed to be reproduced in the food product. The equilibrium transfer factor is then the fraction of carbon in the food product divided by the daily intake of carbon. The assumed element fractions are listed in Table A34 below. Values in this table were taken from NUREG/CR-5512. The formula to describe the calculation of C-14 transfer factors is shown below. Note that the carbon content of water is assumed insignificant.

$$B_{A,q,C-14} = \frac{F_{C,q}}{F_{C,s}M_{S,q} + \sum_p F_{C,p}M_{V,p,q}}$$

where,

- $B_{A,q,C-14}$ = animal transfer factor for C-14 into animal product type q shown in Table A33, in day/kg
- $F_{C,p}$ = mass fraction of carbon in fodder type p from Table A34
- $F_{C,q}$ = mass fraction of carbon in animal product type q from Table A34
- $F_{C,s}$ = mass fraction of carbon in garden soil from Table A34
- $M_{S,q}$ = 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

Table A34. Hydrogen and Carbon Fractions for Equilibrium Models.

Food Pathway Item	Hydrogen Fraction	Carbon Fraction
Garden Soil	0.0149	0.03
Leafy Vegetables	0.10	0.09
Other Vegetables	0.10	0.09
Fruit	0.10	0.09
Grain	0.068	0.40
Fresh Forage	0.10	0.09
Stored Hay	0.10	0.09
Stored Grain	0.068	0.40
Beef	0.10	0.24
Milk	0.11	0.07
Poultry	0.10	0.20
Eggs	0.11	0.15

Notes:

- All fractions listed above are based on the wet weight of the item. The effective water fraction is the hydrogen fraction times 8.94, which is the ratio of molecular weights for water and hydrogen.
- All fractions are taken from NUREG/CR-5512, except for the hydrogen fraction in garden soil, which is calculated as the product of the soil moisture content (20% by volume) and the density of water (1.0 kg/L) divided by the product of the soil density (1.5 kg/L) and 8.94.
- Hydrogen fractions include organically bound hydrogen as well as water.
- The carbon fraction for garden soil assumes the presence of organic matter not found in subsurface Hanford soil.

The bioaccumulation factors shown in Table A33 are used to estimate total population dose from fish consumption to people living near the Columbia River. The edible portion of fish is the muscle normally cooked and consumed. The rest of the fish is assumed to be discarded. If there are individuals who eat or otherwise use other parts of the fish they could receive additional dose.

A subject requiring research is the equilibrium transfer factors for wild animals consuming native vegetation. These species may be "harvested" by humans for food. In addition, since standard uptake factors are for muscle tissue only, there would need to be organ-specific uptake factors for those organ meats that are consumed by special groups of people.

A4.3 Equilibrium Transfer Factors for Chemicals

As with radionuclides, the equilibrium transfer factors for cattle and poultry relate the rate of intake of a chemical to the eventual steady-state concentration in meat or milk or eggs. These parameters are the ratio of the equilibrium concentration of a chemical in the animal product to the daily intake by the animal. The units are g/kg per g/d (equivalent to d/kg). Transfer factors for chemicals are scarce. The need to estimate concentrations in the animal products consumed by people motivated the creation of methods to estimate these parameters. For organic chemicals, the transfer factors for beef, milk, and eggs were estimated from the octanol-water partition coefficient (K_{OW}) of the chemical using formulas presented by McKone (1994). Values for Log K_{OW} are given in Table A3. Numbers for the accumulation of organic chemicals in fish were obtained from the EPI Suite software version 3.11. In particular, the program named BCFwin was used to calculate the transfer factors for fish.

$$F_{BEEF} = (2.5 \times 10^{-8}) K_{OW}$$

$$F_{MILK} = (7.9 \times 10^{-9}) K_{OW}$$

$$F_{EGG} = (8.0 \times 10^{-6}) K_{OW}$$

For inorganic chemicals, the transfer coefficients are obtained from Table A33. No method was found to estimate the transfer of organic chemicals into poultry. The missing values were assigned values of zero for the calculations of unit risk factors. It is assumed that the poultry contribution to the total hazard index or cancer risk is small because poultry is only considered along with beef, milk, and eggs. The list of equilibrium transfer factors for the chemicals of interest in the representative animal products is shown in Table A35.

Table A35. Transfer Factors for Chemicals into Cows, Chickens, and Fish.

CASRN	Chemical	Beef (d/kg)	Milk (d/kg)	Poultry (d/kg)	Eggs (d/kg)	Fish (L/kg)
50-32-8	Benzo[a]pyrene	3.37E-02	1.07E-02	na	1.08E+01	1.05E+04
53-70-3	Dibenz[a,h]anthracene	1.41E-01	4.44E-02	na	4.50E+01	3.14E+04
56-23-5	Carbon tetrachloride	1.69E-05	5.34E-06	na	5.41E-03	3.01E+01
57-12-5	Cyanide, free	1.41E-08	4.44E-09	na	4.50E-06	3.16E+00
57-14-7	1,1-Dimethylhydrazine	1.61E-09	5.10E-10	na	5.17E-07	3.16E+00
57-55-6	Propylene glycol (1,2-Propanediol)	3.01E-09	9.50E-10	na	9.62E-07	3.16E+00
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)	1.31E-04	4.15E-05	na	4.20E-02	1.46E+02
60-29-7	Ethyl ether (Diethyl ether)	1.94E-07	6.13E-08	na	6.21E-05	3.16E+00
60-34-4	Methylhydrazine	2.23E-09	7.04E-10	na	7.13E-07	3.16E+00
60-57-1	Dieldrin	6.28E-03	1.98E-03	na	2.01E+00	2.87E+03
62-75-9	N-Nitrosodimethylamine	6.73E-09	2.13E-09	na	2.15E-06	3.16E+00
64-18-6	Formic acid	7.21E-09	2.28E-09	na	2.31E-06	3.16E+00

Table A35. Transfer Factors for Chemicals into Cows, Chickens, and Fish.

CASRN	Chemical	Beef (d/kg)	Milk (d/kg)	Poultry (d/kg)	Eggs (d/kg)	Fish (L/kg)
67-56-1	Methanol (Methyl alcohol)	4.25E-09	1.34E-09	na	1.36E-06	3.16E+00
67-64-1	Acetone (2-Propanone)	1.44E-08	4.55E-09	na	4.60E-06	3.16E+00
67-66-3	Chloroform	2.33E-06	7.37E-07	na	7.47E-04	6.56E+00
67-72-1	Hexachloroethane	3.45E-04	1.09E-04	na	1.10E-01	3.07E+02
71-36-3	n-Butyl alcohol (n-Butanol)	1.90E-07	5.99E-08	na	6.07E-05	3.16E+00
71-43-2	Benzene	3.37E-06	1.07E-06	na	1.08E-03	8.71E+00
71-55-6	1,1,1-Trichloroethane (Methyl chloroform)	7.73E-06	2.44E-06	na	2.47E-03	1.65E+01
72-20-8	Endrin	3.96E-03	1.25E-03	na	1.27E+00	2.01E+03
74-83-9	Bromomethane	3.87E-07	1.22E-07	na	1.24E-04	1.65E+00
74-87-3	Methyl chloride (Chloromethane)	2.03E-07	6.42E-08	na	6.50E-05	3.16E+00
75-00-3	Ethyl Chloride	6.73E-07	2.13E-07	na	2.15E-04	2.52E+00
75-01-4	Vinyl chloride (Chloroethene)	1.04E-06	3.29E-07	na	3.33E-04	3.53E+00
75-05-8	Acetonitrile	1.14E-08	3.61E-09	na	3.66E-06	3.16E+00
75-07-0	Acetaldehyde	1.14E-08	3.61E-09	na	3.66E-06	3.16E+00
75-09-2	Dichloromethane (Methylene chloride)	4.45E-07	1.40E-07	na	1.42E-04	1.83E+00
75-15-0	Carbon disulfide	2.18E-06	6.88E-07	na	6.97E-04	6.22E+00
75-21-8	Ethylene Oxide (Oxirane)	1.25E-08	3.96E-09	na	4.01E-06	3.16E+00
75-34-3	1,1-Dichloroethane (Ethylidene chloride)	1.54E-06	4.87E-07	na	4.93E-04	4.77E+00
75-35-4	1,1-Dichloroethylene	3.37E-06	1.07E-06	na	1.08E-03	8.71E+00
75-45-6	Chlorodifluoromethane	3.01E-07	9.50E-08	na	9.62E-05	1.35E+00
75-68-3	Chloro-1,1-difluoroethane, 1-	2.81E-06	8.86E-07	na	8.98E-04	7.56E+00
75-69-4	Trichlorofluoromethane	8.47E-06	2.68E-06	na	2.71E-03	1.77E+01
75-71-8	Dichlorodifluoromethane	3.61E-06	1.14E-06	na	1.16E-03	9.19E+00
76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane (CFC-113)	3.61E-05	1.14E-05	na	1.16E-02	5.41E+01
76-44-8	Heptachlor	3.15E-02	9.95E-03	na	1.01E+01	9.93E+03
78-83-1	Isobutanol	1.44E-07	4.55E-08	na	4.60E-05	3.16E+00
78-87-5	1,2-Dichloropropane	2.39E-06	7.54E-07	na	7.64E-04	6.68E+00
78-93-3	Methyl ethyl ketone (2-Butanone)	4.87E-08	1.54E-08	na	1.56E-05	3.16E+00
79-00-5	1,1,2-Trichloroethane	1.94E-06	6.13E-07	na	6.21E-04	5.69E+00
79-01-6	Trichloroethylene	6.58E-06	2.08E-06	na	2.10E-03	1.46E+01
79-10-7	2-Propenoic acid (Acrylic acid)	5.60E-08	1.77E-08	na	1.79E-05	3.16E+00
79-34-5	1,1,2,2-Tetrachloroethane (Acetylene tetrachloride)	6.14E-06	1.94E-06	na	1.96E-03	1.38E+01
79-46-9	2-Nitropropane	2.13E-07	6.72E-08	na	6.81E-05	3.16E+00
82-68-8	Pentachloronitrobenzene (PCNB)	1.09E-03	3.45E-04	na	3.49E-01	7.46E+02
83-32-9	Acenaphthene	2.08E-04	6.57E-05	na	6.65E-02	2.08E+02
84-66-2	Diethyl phthalate	6.58E-06	2.08E-06	na	2.10E-03	1.46E+01
84-74-2	Dibutyl phthalate	7.91E-04	2.50E-04	na	2.53E-01	5.82E+02
85-68-7	Butyl benzyl phthalate	1.34E-03	4.24E-04	na	4.30E-01	8.75E+02
87-68-3	Hexachlorobutadiene	1.51E-03	4.76E-04	na	4.82E-01	9.56E+02
87-86-5	Pentachlorophenol	3.30E-03	1.04E-03	na	1.05E+00	6.96E+02
88-06-2	2,4,6-Trichlorophenol	1.22E-04	3.87E-05	na	3.92E-02	5.51E+01
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)	9.08E-05	2.87E-05	na	2.90E-02	1.10E+02

Table A35. Transfer Factors for Chemicals into Cows, Chickens, and Fish.

CASRN	Chemical	Beef (d/kg)	Milk (d/kg)	Poultry (d/kg)	Eggs (d/kg)	Fish (L/kg)
91-20-3	Naphthalene	4.99E-05	1.58E-05	na	1.60E-02	6.93E+01
92-52-4	1,1'-Biphenyl	2.39E-04	7.54E-05	na	7.64E-02	2.32E+02
95-47-6	o-Xylene	3.30E-05	1.04E-05	na	1.05E-02	5.04E+01
95-48-7	2-Methylphenol (o-Cresol)	2.23E-06	7.04E-07	na	7.13E-04	6.33E+00
95-50-1	1,2-Dichlorobenzene (ortho-)	6.73E-05	2.13E-05	na	2.15E-02	8.73E+01
95-57-8	2-Chlorophenol	3.53E-06	1.12E-06	na	1.13E-03	9.03E+00
95-63-6	1,2,4-Trimethylbenzene	1.07E-04	3.37E-05	na	3.41E-02	1.24E+02
95-95-4	2,4,5-Trichlorophenol	1.31E-04	4.15E-05	na	4.20E-02	5.81E+01
98-86-2	Acetophenone	9.50E-07	3.00E-07	na	3.04E-04	4.75E-01
98-95-3	Nitrobenzene	1.77E-06	5.59E-07	na	5.66E-04	5.30E+00
100-25-4	1,4-Dinitrobenzene (para-)	7.21E-07	2.28E-07	na	2.31E-04	2.66E+00
100-41-4	Ethyl benzene	3.53E-05	1.12E-05	na	1.13E-02	5.31E+01
100-42-5	Styrene	2.23E-05	7.04E-06	na	7.13E-03	3.73E+01
100-51-6	Benzyl alcohol	3.15E-07	9.95E-08	na	1.01E-04	3.14E-01
106-42-3	p-Xylene	3.53E-05	1.12E-05	na	1.13E-02	5.31E+01
106-44-5	4-Methylphenol (p-Cresol)	2.18E-06	6.88E-07	na	6.97E-04	6.22E+00
106-46-7	1,4-Dichlorobenzene (para-)	6.89E-05	2.18E-05	na	2.20E-02	8.89E+01
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	2.28E-06	7.20E-07	na	7.30E-04	6.44E+00
106-99-0	1,3-Butadiene	2.44E-06	7.72E-07	na	7.82E-04	6.80E+00
107-02-8	2-Propenal (Acrolein)	2.44E-08	7.72E-09	na	7.82E-06	3.16E+00
107-05-1	3-Chloropropene (Allyl chloride)	2.13E-06	6.72E-07	na	6.81E-04	6.11E+00
107-06-2	1,2-Dichloroethane (Ethylene chloride)	7.55E-07	2.39E-07	na	2.42E-04	2.75E+00
107-13-1	Acrylonitrile	4.45E-08	1.40E-08	na	1.42E-05	3.16E+00
108-10-1	Methyl isobutyl ketone (4-Methyl-2-pentanone)	5.10E-07	1.61E-07	na	1.63E-04	2.04E+00
108-38-3	m-Xylene	3.96E-05	1.25E-05	na	1.27E-02	5.81E+01
108-39-4	3-Methylphenol (m-Cresol)	2.28E-06	7.20E-07	na	7.30E-04	6.44E+00
108-67-8	1,3,5-Trimethylbenzene	6.58E-05	2.08E-05	na	2.10E-02	8.58E+01
108-87-2	Methyl cyclohexane	1.02E-04	3.22E-05	na	3.26E-02	1.20E+02
108-88-3	Toluene (Methyl benzene)	1.34E-05	4.24E-06	na	4.30E-03	2.52E+01
108-90-7	Chlorobenzene	1.73E-05	5.47E-06	na	5.53E-03	3.07E+01
108-94-1	Cyclohexanone	1.61E-07	5.10E-08	na	5.17E-05	3.16E+00
108-95-2	Phenol (Carbolic acid)	7.21E-07	2.28E-07	na	2.31E-04	2.66E+00
109-99-9	Tetrahydrofuran	7.21E-08	2.28E-08	na	2.31E-05	3.16E+00
110-00-9	Furan (Oxacyclopentadiene)	5.47E-07	1.73E-07	na	1.75E-04	2.15E+00
110-54-3	n-Hexane	1.99E-04	6.28E-05	na	6.35E-02	2.01E+02
110-80-5	2-Ethoxyethanol	1.20E-08	3.78E-09	na	3.83E-06	3.16E+00
110-82-7	Cyclohexane	6.89E-05	2.18E-05	na	2.20E-02	8.89E+01
110-86-1	Pyridine	1.12E-07	3.53E-08	na	3.57E-05	3.16E+00
111-76-2	2-Butoxyethanol (Ethylene Glycol Monobutyl Ether)	1.69E-07	5.34E-08	na	5.41E-05	3.16E+00
111-90-0	2-(2-Ethoxyethoxy)-ethanol (Diethylene Glycol Monoethyl Ether)	7.21E-09	2.28E-09	na	2.31E-06	3.16E+00
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)	9.95E-01	3.15E-01	na	3.18E+02	3.08E+02
117-84-0	Di-n-octylphthalate	3.15E+00	9.95E-01	na	1.01E+03	6.35E+01
118-74-1	Hexachlorobenzene	1.34E-02	4.24E-03	na	4.30E+00	5.15E+03

Table A35. Transfer Factors for Chemicals into Cows, Chickens, and Fish.

CASRN	Chemical	Beef (d/kg)	Milk (d/kg)	Poultry (d/kg)	Eggs (d/kg)	Fish (L/kg)
120-82-1	1,2,4-Trichlorobenzene	2.62E-04	8.27E-05	na	8.38E-02	2.49E+02
121-14-2	2,4-Dinitrotoluene	2.39E-06	7.54E-07	na	7.64E-04	6.68E+00
121-44-8	Triethylamine	7.05E-07	2.23E-07	na	2.25E-04	2.61E+00
122-39-4	Diphenylamine	7.91E-05	2.50E-05	na	2.53E-02	9.89E+01
123-91-1	1,4-Dioxane (Diethylene oxide)	1.34E-08	4.24E-09	na	4.30E-06	3.16E+00
126-73-8	Tributyl Phosphate	2.50E-04	7.90E-05	na	8.00E-02	3.98E+01
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)	1.20E-07	3.78E-08	na	3.83E-05	3.16E+00
127-18-4	Tetrachloroethylene	6.28E-05	1.98E-05	na	2.01E-02	8.28E+01
129-00-0	Pyrene	1.90E-03	5.99E-04	na	6.07E-01	1.14E+03
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	1.34E-07	4.24E-08	na	4.30E-05	3.16E+00
156-59-2	cis-1,2-Dichloroethylene	1.81E-06	5.72E-07	na	5.80E-04	5.40E+00
206-44-0	Fluoranthene (1,2-Benzacenaphthene)	3.61E-03	1.14E-03	na	1.16E+00	1.88E+03
309-00-2	Aldrin	7.91E-02	2.50E-02	na	2.53E+01	2.02E+04
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	1.58E-04	4.98E-05	na	5.05E-02	1.68E+02
319-85-7	beta-Benzene hexachloride (beta-Lindane)	1.51E-04	4.76E-05	na	4.82E-02	1.62E+02
541-73-1	1,3-Dichlorobenzene	8.47E-05	2.68E-05	na	2.71E-02	1.04E+02
542-75-6	1,3-Dichloropropene (cis & trans)	2.68E-06	8.47E-07	na	8.57E-04	7.30E+00
621-64-7	N-Nitrosodi-N-propylamine	5.73E-07	1.81E-07	na	1.83E-04	2.22E+00
1314-62-1	Vanadium pentoxide	2.50E-03	2.00E-05	2.00E-01	8.00E-01	2.00E+02
1330-20-7	Xylenes (mixtures)	3.30E-05	1.04E-05	na	1.05E-02	5.04E+01
1336-36-3	Polychlorinated Biphenyls	4.87E-02	1.54E-02	na	1.56E+01	5.80E+04
1336-36-3	Polychlorinated Biphenyls (lowest risk)	4.87E-02	1.54E-02	na	1.56E+01	5.80E+04
6533-73-9	Thallium carbonate	4.00E-02	2.00E-03	3.00E-01	8.00E-01	1.00E+04
7429-90-5	Aluminum	1.50E-03	2.00E-04	3.00E-01	8.00E-01	5.00E+02
7439-89-6	Iron	2.00E-02	3.00E-05	1.00E+00	1.00E+00	2.00E+02
7439-93-2	Lithium	1.00E-02	2.00E-02	1.00E-02	6.00E+00	1.00E+00
7439-96-5	Manganese	5.00E-04	3.00E-05	5.00E-02	6.00E-02	4.00E+02
7439-97-6	Mercury metal vapor	2.50E-01	4.70E-04	3.00E-02	2.00E-01	1.00E+03
7439-98-7	Molybdenum	1.00E-03	1.70E-03	1.00E+00	9.00E-01	1.00E+01
7440-02-0	Nickel (soluble salts)	5.00E-03	1.60E-02	1.00E-03	1.00E-01	1.00E+02
7440-22-4	Silver	3.00E-03	5.00E-05	2.00E+00	5.00E-01	5.00E+00
7440-24-6	Strontium, Stable	8.00E-03	2.80E-03	8.00E-02	2.00E-01	6.00E+01
7440-28-0	Thallium metal	4.00E-02	2.00E-03	3.00E-01	8.00E-01	1.00E+04
7440-31-5	Tin	8.00E-02	1.00E-03	2.00E-01	8.00E-01	3.00E+03
7440-36-0	Antimony	4.00E-05	2.50E-05	6.00E-03	7.00E-02	1.00E+02
7440-38-2	Arsenic (inorganic)	2.00E-03	6.00E-05	8.30E-01	8.00E-01	2.44E+02
7440-39-3	Barium	2.00E-04	4.80E-04	9.00E-03	9.00E-01	4.00E+00
7440-41-7	Beryllium and compounds	1.00E-03	9.00E-07	4.00E-01	2.00E-02	1.00E+02
7440-42-8	Boron and borates only	8.00E-04	1.50E-03	2.00E-01	8.00E-01	5.00E+00
7440-43-9	Cadmium	4.00E-04	1.00E-03	8.00E-01	1.00E-01	2.00E+02
7440-45-1	Cerium (Ceric oxide 1306-38-3)	2.00E-05	3.00E-05	4.00E-03	9.00E-05	3.00E+01
7440-48-4	Cobalt	1.00E-02	3.00E-04	2.00E+00	1.00E-01	3.00E+02
7440-50-8	Copper	9.00E-03	1.50E-03	5.00E-01	5.00E-01	2.00E+02
7440-62-2	Vanadium metal	2.50E-03	2.00E-05	2.00E-01	8.00E-01	2.00E+02

Table A35. Transfer Factors for Chemicals into Cows, Chickens, and Fish.

CASRN	Chemical	Beef (d/kg)	Milk (d/kg)	Poultry (d/kg)	Eggs (d/kg)	Fish (L/kg)
7440-66-6	Zinc and compounds	1.00E-01	1.00E-02	7.00E+00	3.00E+00	2.52E+02
7487-94-7	Mercuric chloride	2.50E-01	4.70E-04	3.00E-02	2.00E-01	1.00E+03
7664-41-7	Ammonia	1.04E-09	3.29E-10	na	3.33E-07	3.16E+00
7723-14-0	Phosphorus, white	5.00E-02	1.60E-02	1.90E-01	1.00E+01	1.50E+03
7782-41-4	Fluorine (soluble fluoride)	1.50E-01	1.00E-03	1.00E-02	2.00E+00	1.00E+01
7782-49-2	Selenium and compounds	1.50E-02	4.00E-03	9.00E+00	9.00E+00	1.70E+02
8001-35-2	Toxaphene	1.51E-02	4.76E-03	na	4.82E+00	5.63E+03
11096-82-5	Aroclor 1260	4.66E+00	1.47E+00	na	1.49E+03	4.90E+03
11097-69-1	Aroclor 1254	1.54E-01	4.87E-02	na	4.93E+01	1.41E+05
11104-28-2	Aroclor 1221	8.47E-04	2.68E-04	na	2.71E-01	6.14E+02
11141-16-5	Aroclor 1232	8.47E-04	2.68E-04	na	2.71E-01	6.14E+02
12672-29-6	Aroclor 1248	5.47E-02	1.73E-02	na	1.75E+01	6.34E+04
12674-11-2	Aroclor 1016	1.04E-02	3.29E-03	na	3.33E+00	1.77E+04
14797-55-8	Nitrate	na	na	na	na	3.16E+00
14797-65-0	Nitrite	na	na	na	na	3.16E+00
16065-83-1	Chromium (III) (insoluble salts)	9.00E-03	1.00E-05	2.00E-01	8.00E-01	2.00E+02
16984-48-8	Fluorine anion	1.50E-01	1.00E-03	1.00E-02	2.00E+00	1.00E+01
18540-29-9	Chromium (VI) (soluble salts)	9.00E-03	1.00E-05	2.00E-01	8.00E-01	2.00E+02
53469-21-9	Aroclor 1242	4.87E-02	1.54E-02	na	1.56E+01	5.80E+04
na	Uranium (soluble salts)	3.00E-04	4.00E-04	1.00E+00	1.00E+00	1.00E+01

Notes:

- CASRN = Chemical Abstract Service Reference Number
- The transfer factors into beef, milk, and eggs for organic chemicals are calculated from the octanol-water coefficients in Table A3. The numbers for fish are from the EPI Suite software version 3.11. All numbers for the inorganic chemicals are from Table A32.
- Missing values are indicated with "na", which means "not available".

A5.0 PLANT PARAMETERS

Living plants eaten by people fall into two broad categories, aquatic plants and terrestrial plants. It will be assumed that aquatic plants contribute very little to the typical human diet. If exceptions are identified then a suitable set of parameters and models for contaminant uptake by aquatic plants and subsequent consumptions by humans will be utilized. All plants eaten are assumed to be terrestrial rather than aquatic.

The calculation of radionuclide concentrations in living terrestrial plants uses three main routes, (1) root uptake, (2) resuspension to leaves (also called "rain splash"), and (3) direct deposition of irrigation water on foliage. Each of these will be considered separately below. The three uptake routes are then combined to obtain the total concentration in edible portions of plants.

A5.1 Root Uptake

The model for root uptake of a contaminant into terrestrial plants assumes that the concentration in the edible portion is proportional to the concentration in the soil at the time of harvest. The constants of proportionality are known as the soil-to-plant concentration ratios. These concentration ratios are measured as the concentration of the dry produce item divided by the soil concentration. They have no units, since the soil and food items have the same mass-based concentration units, e.g., pCi/kg.

Because the human consumption rates for plants shown in Table A4 are the wet weights, it is necessary to select suitable constants to convert to dry weight. These constants are known as "dry-to-wet ratios". They are simply the dry weight of the food item divided by the wet weight of the item. The "dry-to-wet ratios" from three sources are listed in Table A36. The values chosen for the tank waste PA are from PNWD-2023 for leafy vegetables and NUREG/CR-5512 for the others. The chosen values for the tank waste PA appear in the last column of Table A36. The values under the "GENII" column have been used in prior Hanford Site performance assessments.

Table A36. Dry-to-Wet Ratios for Vegetation Consumed by Humans.

Type of Produce	GENII	ORNL-5786	Tank Waste PA
Leafy Vegetables	0.10	0.067	0.09
Other (protected)	0.25	0.222	0.25
Fruit (exposed)	0.18	0.126	0.18
Grains	0.18	0.888	0.91

The tank waste PA values are from PNWD-2023 and NUREG/CR-5512.
The dry-to-wet ratio used for uptake of chemicals is 0.2 based on the weighted sum of the above values. The weighting factors are the mass of each type of vegetation consumed annually. Note that grains are not irrigated and therefore not included in the weighed sum.

The GENII dry-to-wet ratios for grains differ greatly from the other collections. However, it has been assumed in prior performance assessments that grains would be unlikely to become contaminated in the intruder or irrigation scenarios. The intruder would probably not raise grains in his home garden, and the principal grain crop in this area (dry-land wheat) would not be irrigated. For the tank waste PA, grains are not included as contaminated vegetable intakes.

Root uptake for radionuclides will be calculated using concentration ratios listed in Table A37. The ratios for four types of vegetables are given on this table. The definition of the four types was presented with the consumption rates and will not be repeated here. The value for the iodine concentration ratio in leafy vegetables is from the more recent HEDR assessment (PNWD-2023 1994). The values for hydrogen were calculated using an equilibrium assumption. The ratio of tritium to hydrogen in the soil is assumed to also exist in the plant. Thus, the effective soil-to-plant transfer factor is the hydrogen concentration in the plant divided by the hydrogen concentration in the soil and the dry-to-wet ratio for the plant.

The soil-to-plant concentration ratios were selected using the following hierarchy: PNWD-2023, IAEA Technical Report Number 364, ORNL-5786, and NUREG/CR-5512. The letter next to the number in Table A37 shows the source for each number.

The transfer factors for manganese (Mn), cobalt (Co), and technetium (Tc) into leafy vegetables from IAEA Technical Report Number 364, are the weighted sum of concentration ratios for cabbage, lettuce, and spinach. The weighting is based on the USDA consumption rates found in Statistical Bulletin Number 965 (1999). In this bulletin the average individual eats 10.6 lb cabbage, 28.2 lb lettuce, and 0.5 lb of spinach annually. In terms of percentages these correspond to 27.0%, 71.8%, and 1.3%. The mean transfer factors for cabbage, lettuce and spinach were multiplied by these percentages to arrive at the weighted transfer factor.

Similarly, for several nuclides in IAEA Technical Report Number 364 the transfer factors into root vegetables are the weighted sum of concentration ratios for root vegetables (i.e., onions, carrots, radishes, potatoes, pods, corn, and other crops). The weighting is based on the USDA consumption rates found in Statistical Bulletin Number 965 (1999). In this bulletin the average individual eats 16.8 lb onions, 12.1 lb carrots, 0.4 lb radishes, 82.9 lb potatoes, 3.5 lb pods, 7.4 lb corn, and 67.5 lb others annually. The mean transfer factors for the root crops that are listed in the IAEA report are weighted by these consumption rates to arrive at the weighted transfer factor shown in Table A37. The elements for which this was carried out are manganese (Mn), cobalt (Co), zinc (Zn), strontium (Sr), technetium (Tc), cesium (Cs), lead (Pb), radium (Ra), thorium (Th), uranium (U), neptunium (Np), plutonium (Pu), americium (Am), and curium (Cm).

Table A37. Transfer Factors for Radionuclides into Plants.

Element	Plant/Soil Concentration Ratios (dry)				Atomic Number
	Leafy	Root	Fruit	Grain	
H	na	na	na	na	1
Be	0.010 c	1.5E-03 c	1.5E-03 c	1.5E-03 c	4
B	4.0 c	2.0 c	2.0 c	2.0 c	5
C	0.70 d	0.70 d	0.70 d	0.70 d	6
F	0.060 c	6.0E-03 c	6.0E-03 c	6.0E-03 c	9
Na	0.30 b	0.30 b	0.30 b	0.30 b	11
Al	4.0E-03 c	6.5E-04 c	6.5E-04 c	6.5E-04 c	13
Si	0.35 c	0.070 c	0.070 c	0.070 c	14
P	3.5 c	3.5 c	3.5 c	3.5 c	15
Cl	70 c	70 c	70 c	70 c	17
K	1.0 c	0.55 c	0.55 c	0.55 c	19
Ca	3.5 c	0.35 c	0.35 c	0.35 c	20
Ti	5.5E-03 c	3.0E-03 c	3.0E-03 c	3.0E-03 c	22
V	5.5E-03 c	3.0E-03 c	3.0E-03 c	3.0E-03 c	23
Mn	0.69 b	0.28 b	0.19 b	0.30 b	25
Fe	4.0E-03 b	4.0E-03 b	4.0E-03 b	4.0E-03 b	26
Co	0.22 b	0.068 b	7.0E-03 c	3.7E-03 b	27
Ni	0.060 c	0.060 c	0.060 c	0.030 b	28
As	0.040 c	6.0E-03 c	6.0E-03 c	6.0E-03 c	33
Se	0.025 c	0.025 c	0.025 c	0.025 c	34
Rb	0.90 b	0.90 b	0.90 b	0.90 b	37
Sr	3.0 b	0.61 b	0.20 b	0.21 b	38
Y	0.010 b	0.010 b	0.010 b	0.010 b	39
Zr	1.0E-03 b	1.0E-03 b	1.0E-03 b	1.0E-03 b	40
Nb	0.017 b	0.017 b	0.017 b	0.017 b	41
Mo	0.80 b	0.80 b	0.80 b	0.80 b	42

Table A37. Transfer Factors for Radionuclides into Plants.

Element	Plant/Soil Concentration Ratios (dry)				Atomic Number
	Leafy	Root	Fruit	Grain	
Tc	180 b	0.77 b	1.5 c	0.73 b	43
Ru	0.20 b	0.040 b	0.040 b	5.0E-03 b	44
Pd	0.15 c	0.040 c	0.040 c	0.040 c	46
Ag	2.7E-04 b	1.3E-03 b	8.0E-04 b	0.15 b	47
Cd	0.55 c	0.15 c	0.15 c	0.15 c	48
In	4.0E-03 c	4.0E-04 c	4.0E-04 c	4.0E-04 c	49
Sn	0.030 c	6.0E-03 c	6.0E-03 c	6.0E-03 c	50
Sb	0.20 c	5.6E-04 b	0.030 c	0.030 c	51
Te	0.025 c	4.0E-03 c	4.0E-03 c	4.0E-03 c	52
I	0.050 a	0.020 b	0.020 b	0.020 b	53
Cs	0.46 b	0.13 b	0.22 b	0.026 b	55
Ba	0.15 c	0.030 b	0.030 b	0.030 b	56
Ce	0.030 b	0.030 b	0.030 b	0.030 b	58
Pm	0.010 c	4.0E-03 c	4.0E-03 c	4.0E-03 c	61
Sm	0.010 c	4.0E-03 c	4.0E-03 c	4.0E-03 c	62
Eu	0.010 c	4.0E-03 c	4.0E-03 c	4.0E-03 c	63
Gd	0.010 c	4.0E-03 c	4.0E-03 c	4.0E-03 c	64
Ho	0.010 c	4.0E-03 c	4.0E-03 c	4.0E-03 c	67
Re	1.5 c	0.35 c	0.35 c	0.35 c	75
Hg	0.90 c	0.20 c	0.20 c	0.20 c	80
Tl	4.0E-03 c	4.0E-04 c	4.0E-04 c	4.0E-04 c	81
Pb	0.010 b	6.2E-03 b	9.0E-03 c	4.7E-03 b	82
Bi	0.035 c	5.0E-03 c	5.0E-03 c	5.0E-03 c	83
Po	1.2E-03 b	7.0E-03 b	4.0E-04 c	2.3E-03 b	84
Ra	0.049 b	2.5E-03 b	6.1E-03 b	1.2E-03 b	88
Ac	3.5E-03 c	3.5E-04 c	3.5E-04 c	3.5E-04 c	89
Th	1.8E-03 b	2.5E-04 b	8.5E-05 c	3.4E-05 b	90
Pa	2.5E-03 c	2.5E-04 c	2.5E-04 c	2.5E-04 c	91
U	8.3E-03 b	0.012 b	4.0E-03 c	1.3E-03 b	92
Np	0.037 b	0.014 b	0.010 c	2.7E-03 b	93
Pu	6.0E-05 b	5.8E-04 b	9.0E-05 b	8.6E-06 b	94
Am	4.3E-04 b	4.1E-04 b	2.5E-04 c	2.2E-05 b	95
Cm	7.7E-04 b	4.6E-04 b	1.5E-05 c	2.1E-05 b	96
Bk	4.3E-04 b	4.1E-04 b	2.5E-04 c	2.2E-05 b	97
Cf	0.010 d	0.010 d	0.010 d	0.010 d	98

Notes:

- These parameters were selected using the following hierarchy: (a) PNWD-2023, (b) IAEA Technical Report Number 364, (c) ORNL-5786, and (d) NUREG/CR-5512. The values for Leafy and Root in IAEA #364 are weighted sums of leafy or protected crops discussed in the text.
- Transfer factors for Bk are assumed to be the same as Am.
- Transfer factors for hydrogen are not shown (na) because a different model is used to calculate tritium concentrations in plants.

Concentration ratios for berkelium (Bk) were assumed to be the same as those for americium (Am), because none of the references supplied any values for berkelium.

Animal fodder is not shown separately in Table A37. Pasture grass (fresh) and hay (stored) are represented using the transfer factors for leafy vegetables. The stored grain is represented using the factors for grain.

Root uptake for chemicals into plants will be calculated using concentration ratios listed in Table A38. The ratios for just one type of plant are given on this table. The concentration ratios for organic chemicals are from the octanol-water constants shown in Table A3. The formula used to calculate the soil-to-plant (wet) factors is from McKone (1994) and is shown below. The factors for the dry plant are calculated by dividing the wet plant numbers by the dry-to-wet ratio, 0.2 from Table A36.

$$F_{\text{PLANTS}} = 7.7 (K_{\text{OW}})^{-0.58}$$

The concentration ratios for the inorganic chemicals are obtained from Table A37. The concentration ratios for the four plant types were combined into one using the USDA consumption amounts shown in Table A4 and the dry-to-wet ratios shown in Table A36. Grains were omitted from the weighting because they are assumed to have no contaminated irrigation water. For this generic garden crop a dry-to-wet ratio of 0.2 is assumed.

The last three columns in Table A38 are used in Section A6.0 to model the garden soil. The soil-water partition coefficients were calculated as the product of the organic carbon partition coefficient (from EPI Suite version 3.11) and the assumed carbon fraction in soil, 3%, discussed in Section A6.1. The PCKOCwin program was used to calculate the organic carbon partition coefficients. Leaching factors and soil-water partition coefficients (K_d) for inorganic chemicals are from Table A40. Numbers for Nitrate, Nitrite, and Chromium (VI) are the same as for tritium due to their high mobility. The leaching factors were calculated as described in Section A6.1.

Table A38. Transfer Factors for Chemicals into Garden Produce, and Leaching from the Surface Soil.

CASRN	Chemical	Soil-to-Plant (dry) Transfer Factor	Leaching Factor (per year)	Soil-Water Partition Coefficient	Organic Carbon Partition Coefficient
50-32-8	Benzo[a]pyrene	1.07E-02	1.88E-05	2.36E+04	7.87E+05
53-70-3	Dibenz[a,h]anthracene	4.68E-03	5.65E-06	7.87E+04	2.62E+06
56-23-5	Carbon tetrachloride	8.79E-01	2.79E-01	1.46E+00	4.86E+01
57-12-5	Cyanide, free	5.38E+01	4.43E-02	9.90E+00	2.71E+00
57-14-7	1,1-Dimethylhydrazine	1.89E+02	6.12E-01	5.93E-01	1.98E+01
57-55-6	Propylene glycol (1,2-Propanediol)	1.32E+02	2.72E+00	3.00E-02	1.00E+00
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)	2.68E-01	4.38E-03	1.01E+02	3.38E+03
60-29-7	Ethyl ether (Diethyl ether)	1.17E+01	1.68E+00	1.32E-01	4.40E+00
60-34-4	Methylhydrazine	1.56E+02	6.65E-01	5.35E-01	1.78E+01
60-57-1	Dieldrin	2.84E-02	1.40E-03	3.18E+02	1.06E+04
62-75-9	N-Nitrosodimethylamine	8.24E+01	3.47E-01	1.15E+00	3.82E+01
64-18-6	Formic acid	7.92E+01	2.72E+00	3.00E-02	1.00E+00
67-56-1	Methanol (Methyl alcohol)	1.08E+02	2.72E+00	3.00E-02	1.00E+00
67-64-1	Acetone (2-Propanone)	5.30E+01	2.31E+00	5.94E-02	1.98E+00

Table A38. Transfer Factors for Chemicals into Garden Produce, and Leaching from the Surface Soil.

CASRN	Chemical	Soil-to-Plant (dry) Transfer Factor	Leaching Factor (per year)	Soil-Water Partition Coefficient	Organic Carbon Partition Coefficient
67-66-3	Chloroform	2.77E+00	3.75E-01	1.05E+00	3.50E+01
67-72-1	Hexachloroethane	1.53E-01	6.47E-02	6.74E+00	2.25E+02
71-36-3	n-Butyl alcohol (n-Butanol)	1.19E+01	2.15E+00	7.33E-02	2.44E+00
71-43-2	Benzene	2.24E+00	8.72E-02	4.97E+00	1.66E+02
71-55-6	1,1,1-Trichloroethane (Methyl chloroform)	1.38E+00	2.79E-01	1.46E+00	4.86E+01
72-20-8	Endrin	3.71E-02	1.40E-03	3.18E+02	1.06E+04
74-83-9	Bromomethane	7.86E+00	7.90E-01	4.29E-01	1.43E+01
74-87-3	Methyl chloride (Chloromethane)	1.14E+01	7.90E-01	4.29E-01	1.43E+01
75-00-3	Ethyl Chloride	5.70E+00	5.26E-01	7.12E-01	2.37E+01
75-01-4	Vinyl chloride (Chloroethene)	4.42E+00	5.26E-01	7.12E-01	2.37E+01
75-05-8	Acetonitrile	6.06E+01	1.66E+00	1.35E-01	4.50E+00
75-07-0	Acetaldehyde	6.06E+01	2.49E+00	4.49E-02	1.50E+00
75-09-2	Dichloromethane (Methylene chloride)	7.25E+00	5.26E-01	7.12E-01	2.37E+01
75-15-0	Carbon disulfide	2.89E+00	2.72E+00	3.00E-02	1.00E+00
75-21-8	Ethylene Oxide (Oxirane)	5.75E+01	2.52E+00	4.31E-02	1.44E+00
75-34-3	1,1-Dichloroethane (Ethylidene chloride)	3.53E+00	3.75E-01	1.05E+00	3.50E+01
75-35-4	1,1-Dichloroethylene	2.24E+00	3.75E-01	1.05E+00	3.50E+01
75-45-6	Chlorodifluoromethane	9.10E+00	3.75E-01	1.05E+00	3.50E+01
75-68-3	Chloro-1,1-difluoroethane, 1-	2.49E+00	2.79E-01	1.46E+00	4.86E+01
75-69-4	Trichlorofluoromethane	1.31E+00	2.79E-01	1.46E+00	4.86E+01
75-71-8	Dichlorodifluoromethane	2.15E+00	2.79E-01	1.46E+00	4.86E+01
76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane (CFC-113)	5.66E-01	6.47E-02	6.74E+00	2.25E+02
76-44-8	Heptachlor	1.12E-02	2.83E-04	1.57E+03	5.24E+04
78-83-1	Isobutanol	1.40E+01	2.28E+00	6.14E-02	2.05E+00
78-87-5	1,2-Dichloropropane	2.74E+00	2.05E-01	2.03E+00	6.77E+01
78-93-3	Methyl ethyl ketone (2-Butanone)	2.61E+01	1.79E+00	1.15E-01	3.83E+00
79-00-5	1,1,2-Trichloroethane	3.09E+00	2.05E-01	2.03E+00	6.77E+01
79-01-6	Trichloroethylene	1.52E+00	2.05E-01	2.03E+00	6.77E+01
79-10-7	2-Propenoic acid (Acrylic acid)	2.41E+01	2.62E+00	3.60E-02	1.20E+00
79-34-5	1,1,2,2-Tetrachloroethane (Acetylene tetrachloride)	1.58E+00	1.33E-01	3.20E+00	1.07E+02
79-46-9	2-Nitropropane	1.11E+01	5.04E-01	7.49E-01	2.50E+01
82-68-8	Pentachloronitrobenzene (PCNB)	7.84E-02	6.15E-03	7.22E+01	2.41E+03
83-32-9	Acenaphthene	2.05E-01	2.42E-03	1.84E+02	6.12E+03
84-66-2	Diethyl phthalate	1.52E+00	1.13E-01	3.79E+00	1.26E+02
84-74-2	Dibutyl phthalate	9.45E-02	1.01E-02	4.38E+01	1.46E+03
85-68-7	Butyl benzyl phthalate	6.95E-02	1.58E-03	2.81E+02	9.36E+03
87-68-3	Hexachlorobutadiene	6.50E-02	1.48E-02	2.98E+01	9.94E+02
87-86-5	Pentachlorophenol	4.13E-02	4.38E-03	1.01E+02	3.38E+03
88-06-2	2,4,6-Trichlorophenol	2.79E-01	1.24E-02	3.56E+01	1.19E+03
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)	3.32E-01	4.18E-03	1.06E+02	3.54E+03

Table A38. Transfer Factors for Chemicals into Garden Produce, and Leaching from the Surface Soil.

CASRN	Chemical	Soil-to-Plant (dry) Transfer Factor	Leaching Factor (per year)	Soil-Water Partition Coefficient	Organic Carbon Partition Coefficient
91-20-3	Naphthalene	4.69E-01	8.05E-03	5.51E+01	1.84E+03
92-52-4	1,1'-Biphenyl	1.89E-01	2.37E-03	1.88E+02	6.25E+03
95-47-6	o-Xylene	5.97E-01	3.31E-02	1.33E+01	4.43E+02
95-48-7	2-Methylphenol (o-Cresol)	2.85E+00	3.31E-02	1.33E+01	4.43E+02
95-50-1	1,2-Dichlorobenzene (ortho-)	3.95E-01	3.31E-02	1.33E+01	4.43E+02
95-57-8	2-Chlorophenol	2.18E+00	3.31E-02	1.33E+01	4.43E+02
95-63-6	1,2,4-Trimethylbenzene	3.02E-01	2.05E-02	2.15E+01	7.18E+02
95-95-4	2,4,5-Trichlorophenol	2.68E-01	1.24E-02	3.56E+01	1.19E+03
98-86-2	Acetophenone	4.67E+00	2.93E-01	1.39E+00	4.62E+01
98-95-3	Nitrobenzene	3.25E+00	7.59E-02	5.72E+00	1.91E+02
100-25-4	1,4-Dinitrobenzene (para-)	5.48E+00	6.60E-02	6.60E+00	2.20E+02
100-41-4	Ethyl benzene	5.73E-01	2.84E-02	1.55E+01	5.18E+02
100-42-5	Styrene	7.49E-01	2.84E-02	1.55E+01	5.18E+02
100-51-6	Benzyl alcohol	8.86E+00	7.37E-01	4.70E-01	1.57E+01
106-42-3	p-Xylene	5.73E-01	3.38E-02	1.30E+01	4.34E+02
106-44-5	4-Methylphenol (p-Cresol)	2.89E+00	3.38E-02	1.30E+01	4.34E+02
106-46-7	1,4-Dichlorobenzene (para-)	3.89E-01	3.38E-02	1.30E+01	4.34E+02
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	2.81E+00	3.07E-01	1.31E+00	4.38E+01
106-99-0	1,3-Butadiene	2.70E+00	3.07E-01	1.31E+00	4.38E+01
107-02-8	2-Propenal (Acrolein)	3.90E+01	2.06E+00	8.29E-02	2.76E+00
107-05-1	3-Chloropropene (Allyl chloride)	2.92E+00	3.07E-01	1.31E+00	4.38E+01
107-06-2	1,2-Dichloroethane (Ethylene chloride)	5.33E+00	3.07E-01	1.31E+00	4.38E+01
107-13-1	Acrylonitrile	2.76E+01	1.16E+00	2.49E-01	8.30E+00
108-10-1	Methyl isobutyl ketone (4-Methyl-2-pentanone)	6.69E+00	9.65E-01	3.27E-01	1.09E+01
108-38-3	m-Xylene	5.36E-01	3.38E-02	1.30E+01	4.34E+02
108-39-4	3-Methylphenol (m-Cresol)	2.81E+00	3.38E-02	1.30E+01	4.34E+02
108-67-8	1,3,5-Trimethylbenzene	4.00E-01	2.09E-02	2.11E+01	7.03E+02
108-87-2	Methyl cyclohexane	3.10E-01	5.44E-02	8.04E+00	2.68E+02
108-88-3	Toluene (Methyl benzene)	1.00E+00	5.44E-02	8.04E+00	2.68E+02
108-90-7	Chlorobenzene	8.67E-01	5.44E-02	8.04E+00	2.68E+02
108-94-1	Cyclohexanone	1.31E+01	7.56E-01	4.55E-01	1.52E+01
108-95-2	Phenol (Carbolic acid)	5.48E+00	5.44E-02	8.04E+00	2.68E+02
109-99-9	Tetrahydrofuran	2.08E+01	1.59E+00	1.46E-01	4.88E+00
110-00-9	Furan (Oxacyclopentadiene)	6.43E+00	1.57E-01	2.69E+00	8.97E+01
110-54-3	n-Hexane	2.11E-01	9.65E-02	4.47E+00	1.49E+02
110-80-5	2-Ethoxyethanol	5.90E+01	2.72E+00	3.00E-02	1.00E+00
110-82-7	Cyclohexane	3.89E-01	8.72E-02	4.97E+00	1.66E+02
110-86-1	Pyridine	1.62E+01	3.96E-01	9.90E-01	3.30E+01
111-76-2	2-Butoxyethanol (Ethylene Glycol Monobutyl Ether)	1.27E+01	2.72E+00	3.00E-02	1.00E+00
111-90-0	2-(2-Ethoxyethoxy)-ethanol (Diethylene Glycol Monoethyl Ether)	7.92E+01	2.72E+00	3.00E-02	1.00E+00

Table A38. Transfer Factors for Chemicals into Garden Produce, and Leaching from the Surface Soil.

CASRN	Chemical	Soil-to-Plant (dry) Transfer Factor	Leaching Factor (per year)	Soil-Water Partition Coefficient	Organic Carbon Partition Coefficient
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)	1.50E-03	8.96E-05	4.96E+03	1.65E+05
117-84-0	Di-n-octylphthalate	7.72E-04	7.58E-05	5.87E+03	1.96E+05
118-74-1	Hexachlorobenzene	1.83E-02	4.38E-03	1.01E+02	3.38E+03
120-82-1	1,2,4-Trichlorobenzene	1.79E-01	2.05E-02	2.15E+01	7.18E+02
121-14-2	2,4-Dinitrotoluene	2.74E+00	4.02E-02	1.09E+01	3.64E+02
121-44-8	Triethylamine	5.55E+00	1.33E-01	3.22E+00	1.07E+02
122-39-4	Diphenylamine	3.59E-01	7.83E-03	5.66E+01	1.89E+03
123-91-1	1,4-Dioxane (Diethylene oxide)	5.52E+01	2.72E+00	3.00E-02	1.00E+00
126-73-8	Tributyl Phosphate	1.84E-01	7.83E-03	5.66E+01	1.89E+03
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)	1.55E+01	8.58E-01	3.85E-01	1.28E+01
127-18-4	Tetrachloroethylene	4.11E-01	1.33E-01	3.20E+00	1.07E+02
129-00-0	Pyrene	5.69E-02	2.13E-04	2.08E+03	6.94E+04
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	1.45E+01	1.40E+00	1.84E-01	6.13E+00
156-59-2	cis-1,2-Dichloroethylene	3.21E+00	3.07E-01	1.31E+00	4.38E+01
206-44-0	Fluoranthene (1,2-Benzacenaphthene)	3.91E-02	2.09E-04	2.13E+03	7.09E+04
309-00-2	Aldrin	6.54E-03	1.40E-04	3.17E+03	1.06E+05
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	2.41E-01	4.38E-03	1.01E+02	3.38E+03
319-85-7	beta-Benzene hexachloride (beta-Lindane)	2.47E-01	4.38E-03	1.01E+02	3.38E+03
541-73-1	1,3-Dichlorobenzene	3.45E-01	3.38E-02	1.30E+01	4.34E+02
542-75-6	1,3-Dichloropropene (cis & trans)	2.56E+00	1.74E-01	2.42E+00	8.08E+01
621-64-7	N-Nitrosodi-N-propylamine	6.26E+00	3.03E-02	1.46E+01	4.85E+02
1314-62-1	Vanadium pentoxide	3.12E-03	4.44E-04	1.00E+03	1.93E+02
1330-20-7	Xylenes (mixtures)	5.97E-01	3.31E-02	1.33E+01	4.43E+02
1336-36-3	Polychlorinated Biphenyls	8.65E-03	3.31E-04	1.34E+03	4.48E+04
1336-36-3	Polychlorinated Biphenyls (lowest risk)	8.65E-03	3.31E-04	1.34E+03	4.48E+04
6533-73-9	Thallium carbonate	5.75E-04	2.96E-04	1.50E+03	8.25E+00
7429-90-5	Aluminum	8.13E-04	2.96E-04	1.50E+03	1.43E+01
7439-89-6	Iron	4.00E-03	1.27E-04	3.50E+03	1.43E+01
7439-93-2	Lithium	5.02E-03	1.48E-03	3.00E+02	1.43E+01
7439-96-5	Manganese	2.73E-01	1.85E-04	2.40E+03	1.43E+01
7439-97-6	Mercury metal vapor	2.34E-01	4.39E-02	1.00E+01	1.43E+01
7439-98-7	Molybdenum	8.00E-01	5.90E-02	7.40E+00	1.43E+01
7440-02-0	Nickel (soluble salts)	6.00E-02	1.85E-04	2.40E+03	1.43E+01
7440-22-4	Silver	1.10E-03	4.93E-03	9.00E+01	1.43E+01
7440-24-6	Strontium, Stable	6.04E-01	2.47E-03	1.80E+02	1.43E+01
7440-28-0	Thallium metal	5.75E-04	2.96E-04	1.50E+03	1.43E+01
7440-31-5	Tin	7.17E-03	4.94E-04	9.00E+02	1.43E+01
7440-36-0	Antimony	1.90E-02	8.89E-05	5.00E+03	1.43E+01
7440-38-2	Arsenic (inorganic)	7.65E-03	2.22E-03	2.00E+02	1.43E+01
7440-39-3	Barium	3.58E-02	7.39E-03	6.00E+01	1.43E+01
7440-41-7	Beryllium and compounds	1.91E-03	1.85E-03	2.40E+02	1.43E+01

Table A38. Transfer Factors for Chemicals into Garden Produce, and Leaching from the Surface Soil.

CASRN	Chemical	Soil-to-Plant (dry) Transfer Factor	Leaching Factor (per year)	Soil-Water Partition Coefficient	Organic Carbon Partition Coefficient
7440-42-8	Boron and borates only	2.10E+00	1.42E-01	3.00E+00	1.43E+01
7440-43-9	Cadmium	1.69E-01	6.00E-03	7.40E+01	1.43E+01
7440-45-1	Cerium (Ceric oxide 1306-38-3)	3.00E-02	2.96E-04	1.50E+03	1.43E+01
7440-48-4	Cobalt	5.72E-02	7.39E-03	6.00E+01	1.43E+01
7440-50-8	Copper	8.00E-01	1.27E-02	3.50E+01	1.43E+01
7440-62-2	Vanadium metal	3.12E-03	4.44E-04	1.00E+03	1.43E+01
7440-66-6	Zinc and compounds	2.26E+01	2.22E-03	2.00E+02	1.43E+01
7487-94-7	Mercuric chloride	2.34E-01	4.39E-02	1.00E+01	2.37E+01
7664-41-7	Ammonia	2.43E+02	7.90E-01	4.29E-01	1.43E+01
7723-14-0	Phosphorus, white	3.50E+00	4.87E-02	9.00E+00	1.43E+01
7782-41-4	Fluorine (soluble fluoride)	8.63E-03	2.96E-03	1.50E+02	1.43E+01
7782-49-2	Selenium and compounds	2.50E-02	2.08E-01	2.00E+00	1.43E+01
8001-35-2	Toxaphene	1.71E-02	1.49E-04	2.98E+03	9.93E+04
11096-82-5	Aroclor 1260	6.15E-04	7.16E-05	6.20E+03	2.07E+05
11097-69-1	Aroclor 1254	4.44E-03	1.96E-04	2.27E+03	7.56E+04
11104-28-2	Aroclor 1221	9.08E-02	1.43E-03	3.10E+02	1.03E+04
11141-16-5	Aroclor 1232	9.08E-02	1.43E-03	3.10E+02	1.03E+04
12672-29-6	Aroclor 1248	8.10E-03	3.37E-04	1.32E+03	4.39E+04
12674-11-2	Aroclor 1016	2.12E-02	5.46E-04	8.13E+02	2.71E+04
14797-55-8	Nitrate	na	0.533	0.70	1.43E+01
14797-65-0	Nitrite	na	0.533	0.70	2.37E+01
16065-83-1	Chromium (III) (insoluble salts)	1.00E-03	6.62E-03	6.70E+01	na
16984-48-8	Fluorine anion	8.63E-03	2.96E-03	1.50E+02	1.43E+01
18540-29-9	Chromium (VI) (soluble salts)	1.00E-03	0.533	0.70	na
53469-21-9	Aroclor 1242	8.65E-03	3.31E-04	1.34E+03	4.48E+04
na	Uranium (soluble salts)	9.44E-03	6.23E-02	7.00E+00	na

Notes:

- CASRN = Chemical Abstract Service Reference Number
- The soil-to-plant transfer factors for organic chemicals are from EPI Suite version 3.11. Numbers for the inorganic chemicals are from Table A36.
- Soil-water partition coefficients for organic chemicals were calculated as the product of the organic carbon partition coefficient (from EPI Suite version 3.11) and the assumed carbon fraction in soil, 3%, discussed in Section A6.1. Numbers for inorganic chemicals are from Table A40. Numbers for Nitrate, Nitrite, and Chromium (VI) are the same as for tritium.
- Leaching factors are calculated from the Soil-Water Partition Coefficients as described in Section A6.0.
- Missing values are indicated with "na", which means "not available".

The Hanford Site is very dry and sandy, so that plant uptake factors would likely differ from the generic values listed in Tables A37 and A38. However, the preparation of the soil for a garden changes the properties of surface layer. The tilling, watering and addition of fertilizers and organic material produces soil that resembles the generic garden soil. It is therefore assumed that the concentration ratios in Tables A37 and A38 are adequate to describe plant uptakes in possible future gardens on the Hanford Site.

Groups of people gathering native vegetation for nourishment and other household needs may require special consideration. The soil-to-plant transfer factors for species not usually considered as garden plants growing without cultivation could differ considerably from the values shown on Tables A37 and A38. Soils deficient in some mineral may have much higher uptake factors for materials that are chemically similar to what is missing. The converse is also true. In addition, the distribution of the contaminant in the native vegetation during the growth of the plant is important. For example, Native American Indians use various parts of the cattail over its growth stages (CTUIR 1995). However, the tank waste PA exposure scenarios involve localized areas of contaminated soil resulting from intrusion or irrigation with contaminated ground water. In general, the transfer factors for native plant species are not needed because the contaminated portion would be an insignificant part of the overall diet.

A5.2 Rain Splash

The term "rain splash" refers to all the processes that cause soil to deposit on the surfaces of plants. It includes the transport of soil by the irrigation water, rain drops, and the wind. The standard model (NRC 1977) then includes a "translocation" factor, which is the fraction of activity deposited on plant surfaces that ends up in the edible portions of the plant. There are two basic approaches to estimating the concentration in plants due to resuspension of contaminated soil. The standard approach begins with an estimate of the average air concentration and then computes the activity deposition rate on the plant. The other approach (NUREG/CR-5512 1992) simply treats rain splash in a manner similar to root uptake.

In NUREG/CR-5512, Vol. 1, the amount of rain splash is characterized by a "mass loading" factor, which is the ratio of foliage contamination due to rain splash divided by the concentration in the soil nearby. It is similar to the root uptake concentration ratio described in the previous section. The value recommended in NUREG/CR-5512, Section 6.5.2 is 0.1 Ci/kg (dry produce) per Ci/kg soil for all plant types. In addition, this value "includes consideration of translocation of activity in soil from plant surfaces to edible parts of the plant." The only other parameter used to estimate the actual plant concentration from rain splash is the dry-to-wet ratio. Using a generic dry-to-wet ratio of 0.2 means that about $(0.1)(0.2)=2\%$ of the wet mass of the plant comes from attached soil. This large value applies to irrigation methods that involve large water drops and planting methods that leave considerable space between plants even at the time of harvest.

In IAEA Technical Report 364 (1994) the soil adhesion is given a range from 0.010 (short plants) to 0.25 for leafy vegetation. Using a representative dry-to-wet ratio of 0.1 for leafy vegetables means the mass loadings range from 0.1% to 2.5%. In NCRP Report Number 123 Section 5.1, the soil-to-plant concentration ratio has a minimum value of 0.001. In effect this is the soil adhesion term for the wet plant. Thus, the effective mass loading is 0.1%.

In the arid environment of southeastern Washington, irrigation methods that reduce evaporative loss are preferred. This has the effect of lowering the amount of soil transferred to plant surfaces during irrigation. The model used at Hanford and elsewhere (eg., SAND2001-2977) begins with an average air concentration near the plants and computes a deposition rate onto plant surfaces. The RESRAD program (ANL/EAD/LD-2) has a default mass loading air concentration of 0.1 mg/m^3 . The default value in GENII is 0.225 mg/m^3 . Both of these use a

deposition speed of 0.001 m/sec, which is suitable for respirable particles. The resulting deposition rate in RESRAD is 8.64 mg/m² per day, while in GENII Version 1.485 it is 19.44 mg/m² per day. However, these assumptions lead to rain splash transfers that are two or three orders of magnitude below the experimental data referenced in NUREG/CR-5512, Vol. 1.

For the tank waste PA the customary soil deposition model will be used rather than the effective mass loading approach of NUREG/CR-5512. However, the assumed average deposition rate will be taken to be 270 mg/m² per day, which is larger than used in GENII (19.44 mg/m² per day), but smaller than was used in the 2001 ILAW PA (864 mg/m² per day).

The decrease from the 2001 ILAW PA (DOE/ORP-2000-24) stems from the fact that irrigation is not continuous, but takes place for a relatively short period (less than 1 hour) every day or so. Thus the average involves large deposition rates during short periods with little deposited between due to the moist conditions. For a small garden, much of the soil that adheres may come from sources of dust outside the garden. The average air concentration of 1 mg/m³ with a deposition speed of 0.01 m/s used in the 2001 ILAW PA represents conditions during active irrigation. However, the average deposition rate will be some factor lower due to the intermittent nature of the irrigation process.

The increase from the deposition rate used in other performance assessments is based on the need to match the minimum value listed in the IAEA Technical Report Number 364 and NCRP Report Number 123. With a deposition rate of 270 mg/m² per day, the mass loading in leafy vegetables is about 0.1%. The calculation is shown below.

$$\frac{J_{\text{SPLASH}} F_{\text{INT}} F_{\text{TRANS}} T_{\text{W}}}{Y_{\text{V}}} = \frac{(2.7 \times 10^{-4} \text{ kg/m}^2 \text{ per day})(0.407)(1.0)(18 \text{ d})}{2.0 \text{ kg/m}^2} = 9.89 \times 10^{-4}$$

where,

- F_{INT} = interception fraction for airborne dust on exposed surfaces of leafy vegetables, 0.407, from Table A39
- F_{TRANS} = translocation factor from exposed surfaces to the edible portion of leafy vegetables, 1.0, from Table A39
- J_{SPLASH} = average soil deposition rate due to rain splash, 2.7×10^{-4} kg/m² per day
- T_{W} = effective exposure time for leafy vegetables, 18.0 days, from Table B1. This is derived from a 45-day growing period with a weathering half life of 14 days.
- Y_{V} = yield of leafy vegetables, from Table A39, 2.0 kg(wet)/m²

In particular, the effective wet concentration ratios for leafy, other, fruit, and grains are calculated using the formula shown in Section 3.2 for the post-intrusion resident ingestion dose. The wet ratios are 0.099%, 0.022%, 0.015%, and 0.025% respectively. Since NUREG/CR-5512 recommended a number of about 2%, the model selected for the tank waste PA remains much lower, to some extent consistent with previous Hanford performance assessments.

Other parameters that are part of the standard model for foliar deposition, are the interception fraction, the crop yield (biomass), the translocation factor, the weathering half-life, and the growing period.

The interception fraction is the portion of the airborne contamination depositing in a unit area that initially attaches to vegetation. It includes the fraction of the ground surface that is covered by vegetation. Values for interception fraction for various crops are given in ORNL-5786. More recent publications described in PNNL-6584 (Section 4.7.4) will be used as the basis of the interception fractions for this performance assessment. The empirical relationship between interception fraction and standing biomass (dry weight) is shown below.

$$\text{Interception Fraction} = 1.0 - \text{Exp}[-(P)(\text{Dry Yield})]$$

The parameter P depends on the type of vegetation, as discussed in PNL-6584 Volume 1. For leafy vegetables, grains, grass and hay the measured value for P is 2.9 m²/kg, while for fruits and other plants the measured value for P is 3.6 m²/kg. The "Dry Yield" is the mass per unit area of the standing biomass at the time of harvest, adjusted for water content. The "Dry Yield" is calculated as the product of the dry-to-wet ratio and the crop yield (wet). Values for biomass and interception fraction are shown on the Table A39.

Table A39. Various Crop-Specific Parameters.

Type of Produce	Dry-to-wet Ratio	Crop Yield kg(wet)/m ²	Interception Fraction	Translocation Factor	Growing Period
Generic Vegetables	0.2	2	0.5	0.2	60 d
Leafy Vegetables	0.09	2.0	0.407	1.0	45 d
Other (protected)	0.25	2.0	0.835	0.1	90 d
Fruit (exposed)	0.18	3.0	0.857	0.1	90 d
Grains	0.20	0.8	0.371	0.1	90 d
Fresh Forage - Cow	0.22	1.5	0.616	1.0	30 d
Stored Hay - Cow	0.22	1.0	0.472	1.0	45 d
Stored Grain - Cow	0.91	1.0	0.472	0.1	90 d
Forage - Poultry	0.22	1.0	0.472	1.0	30 d
Grain - Poultry	0.91	1.0	0.472	0.1	90 d

Notes:

- The "Generic Vegetables" is used in the calculations for chemicals.
- The dry-to-wet ratio for leafy vegetables is from PNWD-2023. All other values are from NUREG/CR-5512 Section 6.5.7.
- Interception fractions are calculated using the formula described in the text (PNNL-6584 Section 4.7.4).

The translocation factor is the fraction of what deposits on the foliage that reaches the edible parts of the plant. The values are shown on Table A39 are widely used in calculations of this type (NRC 1977; PNNL-6584 1988; NUREG/CR-5512 1992) and will be used in the tank waste PA. The value shown for "Generic Vegetables" is used in the calculations for chemicals. It is selected so that the consumption weighted mass of soil deposited on the foliage is the same

as for the total leafy, protected, and exposed crops used with radionuclides in the all pathways exposure scenario.

The weathering half-life is the time required for half the contamination initially deposited on plant foliage to be removed by the action of wind, rain and irrigation. The value chosen for both chemicals and radionuclides is 14 days, based on the recommendations of NRC (1977) and the review given in ORNL-5786.

The growing period is the time that a plant is subject to the mechanical action of weathering prior to be harvested. The growing period varies with crop type. It is the time needed to produce one crop. During the irrigation season more than one crop may be harvested.

A5.3 Direct Deposition

The models for root uptake and rain splash contributions to growing plants depend only on the soil concentration at the time of harvest. Direct deposition is unique to overhead irrigation. It refers to the transfer of contamination from irrigation water to the foliage intercepting the water as it falls.

A key parameter to model the contamination of foliage by direct deposition is the interception fraction. The value recommended for all plant types by the NRC (1977) will be used, 0.25. This value is not well documented, but is widely used in other reviews (PNNL-6584 1988; NUREG/CR-5512 1992).

The other parameters determining plant concentrations exposed to contaminated irrigation water are the translocation factors, the weathering half-life, and the growing periods. The same parameters used for describing rain splash will also be used for direct deposition. The translocation factors and growing periods are shown on Table A39, while the weathering half-life is 14 days.

If a special group of people were using overhead irrigation to increase growth density and crop yield, then the same parameters used for the standard group would apply to them also. No special modeling would be required unless the individuals were using the crop in some manner that could produce more dose than simply eating it.

A6.0 SOIL PARAMETERS

The soil parameters of interest are those pertaining to the various exposure pathways and to retention of contaminants that have been introduced by spreading exhumed waste, or irrigation with contaminated water. The two main types of exposure are from external and internal sources. In addition, the internal exposure can be divided into inhalation and ingestion intakes. Each of these routes of exposure will be discussed below.

The principal effect of the soil on the external radiation exposure received by someone living nearby is through the soil density, chemical composition, and roughness. The surface soil density is assumed to be 1.5 g/cc. The contamination of interest is distributed through the top 15 cm. The assumed composition is primarily silicon dioxide, with various additions, such as water. Over time the radioactive contaminants have been observed to migrate into deeper layers. The radioactive elements are affected by the average flow of water through the surface layer into deeper layers. Some elements, such as hydrogen and iodine are very soluble and leach from the surface layer in a few years. Other elements, such as cesium and plutonium hardly move at all.

The principal relationship between soil contamination and inhalation dose is through the ease with which contaminants in the soil become airborne. The presence of ground cover and moisture reduces the air concentration. Hand-tilling activities increase the air concentration. The gradual leaching of radioactive contamination to deeper layers of soil reduces the air concentration as well. The particle size distributions of the soil and any exhumed waste are important indicators of whether the mass-loading approach for estimating air concentrations could bias the expected contaminant concentration. If the contaminants tend to be found in the smaller particles, then the air concentration of contaminants would be higher than predicted because the average concentration in soil would be lower than the average concentration in dust.

The principal relationship between soil contamination and ingestion dose is through the ease with which contaminants in the soil become incorporated in plant and animal produce. It is assumed that the effects of tilling and fertilizers lead to soils that are similar to those for which the concentration ratios shown in Tables A37 and A38 were derived. The gradual leaching of contaminants into deeper layers of soil (below the root zone) reduces the concentration in plant and animal products as well. An additional consideration is how easily the contaminants adhere to exposed skin. Better adherence leads to increased dermal absorption.

A6.1 Leaching from the Surface Layer

Soil-specific parameters related to leaching are the soil composition (sand, clay, silt and organic), the distribution coefficients, the density, porosity, and the water content. The composition of the surface layer is assumed to be sandy, where sandy is defined to have greater than 70 percent sand-sized particles. With few exceptions this is what lies near the surface of the entire Hanford Site. The soil-to-plant concentration ratios and distribution coefficients depend on this assumption. However, the preparation of the soil for a garden changes the properties of surface layer. The tilling, watering and addition of fertilizers and organic material produces soil that tends to reduce the mobility of contaminants.

Leaching factors and distribution coefficients for chemicals are shown in Table A38. The value for the cyanide ion (CAS 57-12-5) is from Table C-4 in the EPA *Soil Screen Guidance User's Guide* (EPA/540/R-96/018). Values for other organic chemicals were calculated from the product of the organic carbon partition coefficient from Table A38 and the soil carbon fraction (3%) from Table A34. The formula used is shown below.

$$K_d = (0.03) K_{OC}$$

The organic carbon partition coefficients listed in Table A38 are from the EPI Suite Software Version 3.11. The program used for this purpose was PCKOCwin.

The carbon fraction in garden soil is taken from NUREG/CR-5512. Sandy soils typically have fractions less than 0.01. The larger number is due to the addition of organic matter to the garden or pasture soil. Larger carbon fractions lead to larger retardation factors in the surface soil, which leads to less leaching from the surface soil layer with time. Less leaching from the surface soil means the contaminant concentration decreases slowly with time, maximizing potential intakes. Thus, the assumed soil carbon fraction is chosen to be larger than it needs to be. When the transport of organic chemicals through the soil into ground water is evaluated (for example in EPA-540/R95/128), much smaller carbon fractions are assumed to decrease the retardation and maximize the amount reaching the ground water.

The distribution coefficients for inorganic chemicals were taken from Table A40. Because nitrate, nitrite, and chromium (VI) are very mobile, the K_d for tritium shown in Table A40 (0.7 ml/g) was assumed to apply. Thus, the leaching coefficients for nitrate, nitrite, and chromium (VI) are all 0.533.

Leaching factors and distribution coefficients for radionuclides are shown in Table A40. The hierarchy used for selecting values was first the Hanford-specific values for agricultural soils in PNNL-14041. For elements with no values in PNNL-14041, IAEA Technical Report Number 364 was used. Sandy soil was used to represent the Hanford area. The next report consulted was ORNL-5786. Last of all came NUREG/CR-5512. The values shown for iodine lie within the range of possible values given in PNWD-2023, so PNWD-2023 was not needed.

Leaching factors and distribution coefficients for berkelium (Bk) were assumed to be the same as those for americium (Am), because none of the references supplied any values for berkelium.

The thickness of the surface soil of interest in the dose calculations is the top 15 centimeters. This thickness represents typical cultivation depths for mechanical mixing of deposited activity. In addition, it represents typical root depths. This thickness has been used in all prior Hanford Site performance assessments.

Table A40. Leaching Factors for Radionuclides in Garden Soil.

Element	Leach (per year)	Kd	Atomic Number	Element	Leach (per year)	Kd	Atomic Number
H	na	0.70 a	1	In	2.96E-04	1,500 c	49
Be	1.85E-03	240 b	4	Sn	4.94E-04	900 a	50
B	1.42E-01	3.0 c	5	Sb	8.89E-05	5,000 a	51
C	6.23E-02	7.0 a	6	Te	1.48E-03	300 c	52
F	2.96E-03	150 c	9	I	2.94E-02	15 a	53
Na	4.44E-03	100 c	11	Cs	2.22E-04	2,000 a	55
Al	2.96E-04	1,500 c	13	Ba	7.39E-03	60 c	56
Si	1.34E-02	33 b	14	Ce	2.96E-04	1,500 a	58
P	4.87E-02	9.0 b	15	Pm	6.84E-04	650 c	61
Cl	3.92E-01	1.0 a	17	Sm	1.85E-03	240 b	62
K	4.39E-02	10 a	19	Eu	6.84E-04	650 c	63
Ca	4.87E-02	9.0 b	20	Gd	6.84E-04	650 c	64
Ti	4.44E-04	1,000 c	22	Ho	1.85E-03	240 b	67
V	4.44E-04	1,000 c	23	Re	5.55E-03	80 a	75
Mn	1.85E-04	2,400 a	25	Hg	4.39E-02	10 c	80
Fe	1.27E-04	3,500 a	26	Tl	2.96E-04	1,500 c	81
Co	7.39E-03	60 b	27	Pb	5.56E-06	80,000 a	82
Ni	1.85E-04	2,400 a	28	Bi	4.94E-04	900 a	83
As	2.22E-03	200 c	33	Po	4.04E-04	1,100 a	84
Se	2.08E-01	2.0 a	34	Ra	8.89E-04	500 a	88
Rb	8.06E-03	55 b	37	Ac	2.96E-04	1,500 a	89
Sr	2.47E-03	180 a	38	Th	7.41E-07	600,000 a	90
Y	2.96E-04	1,500 a	39	Pa	1.23E-04	3,600 a	91
Zr	7.41E-04	600 b	40	U	6.23E-02	7.0 a	92
Nb	2.78E-03	160 b	41	Np	1.77E-02	25 a	93
Mo	5.90E-02	7.4 b	42	Pu	8.89E-05	5,000 a	94
Tc	2.08E-01	2.0 a	43	Am	2.96E-04	1,500 a	95
Ru	8.89E-04	500 a	44	Cm	2.96E-04	1,500 a	96
Pd	8.06E-03	55 b	46	Bk	2.96E-04	1,500 a	97
Ag	4.93E-03	90 b	47	Cf	8.71E-04	510 d	98
Cd	6.00E-03	74 b	48				

Notes:

- These distribution coefficients were selected using the following hierarchy: (a) PNNL-14041, (b) IAEA Technical Report Number 364, (c) ORNL-5786, and (d) NUREG/CR-5512. The leaching coefficient for hydrogen is not used in the calculations (na).
- Note that the distribution coefficient for Bk is assumed to be the same as Am.

The density and thickness of the affected surface layer determine the external dose rate factors, as well as the leaching coefficients computed for the surface layer. Leaching is the process by which contaminants migrate from the surface layer of soil into deeper layers below. The driving force behind the leaching process is the application of water to the soil. Leaching is treated as a removal rate constant giving the fraction of the material in the surface layer that is removed per unit of time. It is calculated using the equation shown below.

$$\lambda_S = \frac{P + I - E}{\theta d \left(1 + \rho K_d / \theta \right) T_{\text{irr}}}$$

where,

- d** = thickness of the surface soil layer from which nuclides migrate, 15 cm (5.9 inches).
- E** = total evapo-transpiration during the irrigation season, in cm. For the population scenario a value of 59.27 cm is assumed. For the other scenarios a value 78.06 cm is assumed. These assumptions lead to a total over-irrigation (P+I-E) of 10 cm. This over-irrigation assumption is consistent with PNWD-2023, which assumed that farmers over-irrigate by 10 percent.
- I** = total irrigation water applied during the irrigation season, in cm. For the population scenarios this is 63.5 cm (25 in.). For the other scenarios it is 82.3 cm (32.4 inches). Nearly all of this is deposited during the 6 month period from April to September.
- K_d** = distribution coefficient in surface soil for an element, in ml/g. Values for chemicals are shown on Table A38. Values for radionuclides are shown in Table A40.
- 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).
- T_{irr}** = irrigation period, 0.5 y
- λ_S** = average soil leaching coefficient, fraction removed from a soil layer of thickness "d" during the time that irrigation occurs, per year.
- ρ** = bulk density of the surface soil, 1.5 g/cc.
- θ** = volumetric water content of the surface soil, milliliters of water per cubic centimeter of soil. A value of 0.2 ml/cc is assumed. Because the total soil porosity is about 0.4 ml/cc, the saturation ratio is about 50%.

The values assigned to the variables in the above equation were used in prior Hanford performance assessments. The annual irrigation total (82.3 cm/y) is based on the Specific Information on the Terrestrial Environment (SITE) database referenced ORNL-5786. The SITE database reports that a large percentage of the drier western states falls into the range from 70 to 85 cm/y. The values chosen in NUREG/CR-5512 is 76 cm/y, while the value more appropriate to Hanford is 82.3 cm/y (WHC-SD-WM-EE-004). The Hanford value is based on irrigation rates in the counties surrounding the site. Note that the amount of irrigation is assumed to be the same for all plant types including grains.

For the population living along the Columbia River, the annual irrigation amount is reduced to account for the greater precipitation closer to the ocean. In addition, the average irrigation rate along the river is 25 in/y (63.5 cm/y) (WHC-SD-WM-EE-004). This value was obtained as an average in counties along the Columbia River, and thereby differs from the irrigation rate assumed for individuals living near the Hanford Site. Because this average is over a large population it will have an insignificant range.

Leaching coefficients computed from the above equation are listed in Table A40 along with the distribution coefficient. The numerator represents the excess water added each year. It is taken to be about 10 cm during the irrigation season based on the discussion in PNWD-2023.

The Hanford Environmental Dose Reconstruction Project (HEDR) found the irrigation rate in the counties surrounding the Hanford Site ranged from 61 cm/y to 98 cm/y (PNWD-2023, Rev 1). The excess watering term in the numerator (P+I-E) then ranges from 0 to 26 cm/y, and the leaching coefficients range from 0 to 2.5 times the chosen values. This range has little effect on the resulting doses for most nuclides because the leaching coefficients are generally small.

The leaching factor for tritium includes both evaporation as well as percolation out of the surface layer. The evaporative losses are estimated assuming the soil gains no water. Thus, the amount deposited as irrigation or precipitation is the amount that leaves. During the irrigation season, April through September, there is 5.77 cm precipitation (PNNL-13859). The remainder of the year the precipitation average is 11.96 cm. Irrigation is 82.3 cm for the individuals, and 63.5 for the Columbia River population. The effective leaching coefficient for water during the irrigation months is 46.18 per year for the population and 58.71 per year for the individuals. During the non-irrigation months the effective leaching coefficient is 7.975 per year. These are calculated using the equations below. The numerators in both cases are the amount of evaporation that is assumed. The variables were defined in previous equations.

$$\begin{aligned} \text{Tritium Emanation} &= \frac{P + I - 10 \text{ cm/y}}{\theta d T_{\text{irr}}} \quad \text{during irrigation months} \\ &= \frac{P}{\theta d T_{\text{no}}} \quad \text{during non - irrigation months} \end{aligned}$$

A6.2 Garden Soil Concentration

A two-part removal rate from the soil has been adopted for use in the tank waste PA. It is assumed that significant irrigation occurs during 6 months of the year. The rest of the year has very little water infiltration. During the no-irrigation period there is no leaching from the surface layer. Tritium is an exception that is discussed below.

In the post-intrusion residential scenario, the irrigation water is free of contaminants and acts to reduce the surface soil concentration. The surface soil concentration decreases exponentially with time. The removal constant is the sum of the leaching coefficient and the decay coefficient. The equation below shows the factor that is applied to the initial garden soil concentration to calculate the concentration at the end of the year.

$$\begin{aligned} F_{\text{NS}} &= \text{Exp}(-\lambda T_{\text{irr}}) \text{Exp}(-\lambda_{\text{R}} T_{\text{no}}) \\ \text{and } \lambda &= \lambda_{\text{S}} + \lambda_{\text{R}} \quad \text{and } T_{\text{irr}} + T_{\text{no}} = 1 \text{ y} \end{aligned}$$

where,

- F_{NS} = fraction of the initial soil concentration that is left at the end of 1 year when the irrigation water adds no contaminants
- T_{irr} = irrigation period, 0.5 y

- T_{no} = no irrigation period, 1 y - $T_{irr} = 0.5$ y
 λ = total removal constant, per year
 λ_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).
 λ_S = average soil leaching coefficient, fraction removed from a soil layer of thickness "d", per year

Each year the same factor is applied to calculate the soil concentration at the end of the year. Thus the soil concentration after N years is F_{NS} raised to the Nth power.

The initial tritium concentration in soil decreases according to the above formula, with one exception. During the no-irrigation season, the removal constant (8.032 per year) is the decay constant (0.05622 per year for tritium) plus the evaporation constant (7.975 per year).

In the various irrigation scenarios, the irrigation water is contaminated and adds to the surface soil concentration. The surface soil concentration increases during the irrigation season, and decreases during the no-irrigation season. The equation below shows the factor that is applied to the irrigated soil total concentration (amount deposited per unit area during the year divided by the area density of the soil) to calculate the concentration at the end of the year.

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

and $\lambda = \lambda_S + \lambda_R$ and $T_{irr} + T_{no} = 1$ y

where,

- 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
 T_{irr} = irrigation period, 0.5 y
 T_{no} = no irrigation period, 1 y - $T_{irr} = 0.5$ y
 λ = total removal constant, per year
 λ_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).
 λ_S = average soil leaching coefficient, fraction removed from a soil layer of thickness "d", per year

Each year the same amount is added to the soil by ongoing irrigation, and the amounts deposited in prior years decrease by the factor F_{NS} each year. After N years of irrigation, the soil concentration is the total soil concentration (amount deposited per unit area during one year divided by the area density of the soil) times the factor shown below.

$$F_{IS} \frac{1 - (F_{NS})^N}{1 - F_{NS}}$$

Natural precipitation acts to dilute contaminated irrigation water slightly. It adds water that is not contaminated. The formula below shows the dilution factors [i.e., $I/(I+P)$] used in these calculations during the irrigation season. These factors are used wherever F_{IS} is used.

$$\text{Dilution Adjustment (individual)} = (82.3 \text{ cm}) / (82.3 + 5.77 \text{ cm}) = 0.9345$$

$$\text{Dilution Adjustment (population)} = (63.5 \text{ cm}) / (63.5 + 5.77 \text{ cm}) = 0.9168$$

The tritium concentration in irrigated soil is calculated using an equilibrium model. The tritium is chemically bound in a water molecule and thus goes with the water. The concentration of tritium in irrigation water, is similar to the concentration in the water in the soil. The soil hydrogen fraction is 0.0149 kg hydrogen per kg soil, as shown in Table A34. Thus the effective moisture content of the soil is calculated as shown below. The density of water is 1.0 kg/L.

$$(8.94 \text{ g H}_2\text{O/g H}_2)(0.0149 \text{ kg H}_2/\text{kg soil}) / (1.0 \text{ kg/L}) = 0.133 \text{ L H}_2\text{O/kg soil}$$

This value may also be calculated from the assumed value for the volumetric water content of soil (0.2 ml/cc) and its density (1.5 kg/L). Note that the value reported in NUREG/CR-5512 is 0.1 L/kg. A somewhat higher value is being used in the tank waste PA, which leads to higher tritium concentrations in soil during the irrigation season.

The tritium concentration in irrigated soils during the irrigation season is this soil water concentration times the concentration of tritium in the irrigation water times the natural precipitation dilution fraction. During the non-irrigation season the tritium concentration decreases exponentially using the evaporation plus decay removal constant (8.032 per year) discussed above. By the end of the year, the tritium concentration is essentially zero. Thus, there is no accumulation of tritiated water in soil in the present model.

A6.3 Shoreline Sediment Concentration

Shoreline sediments accumulate contaminants present in river water much the same as garden soil. A simple model to represent this accumulation is based on models from BNWL-1754 and NCRP Report No. 76. In the former, the accumulated sediment concentration depends on the water concentration, a deposition factor, and the radioactive half life. In the latter, the accumulation depends only on the water concentration and the distribution coefficient for sediment. The model chosen for these calculations is a combination of the two and is shown below.

$$C_D = \frac{C_w V_s}{\rho d \lambda} [1 - \text{Exp}(-\lambda T)] \quad \text{and} \quad \lambda = \lambda_s + \lambda_R$$

where,

- C_D = concentration of the contaminant in shoreline sediment, in Ci/kg
- C_w = concentration of the contaminant in the river water, in Ci/L
- d = thickness of the shoreline sediment layer that holds the contaminants, 15 cm (5.9 inches) assumed
- T = time at which the sediment concentration is calculated, in years

- V_s = effective river to sediment deposition rate, 25,300 L/m² per year (BNWL-1754 and PNNL-6584)
 λ = total removal constant, per year
 λ_R = decay or decomposition constant, per year
 λ_s = average soil leaching coefficient, fraction removed from a soil layer of thickness "d", per year
 ρ = bulk density of the shoreline sediment layer, 1.5 g/cc assumed

If the product (λT) is small, the sediment concentration grows linearly with time. If this product is large, the sediment concentration is proportional to the inverse of the total removal constant (λ), which depends on both the decay half life and the distribution coefficient. In general, sediment concentrations are much larger than garden soil concentrations. For an irrigation rate of 82.3 cm/y, there is 823 L/m² applied by irrigation each year. The shoreline sediment increases by 25,300 L/m² each year, a factor of 30 greater.

A6.4 Volatile Emissions from the Soil Surface

Chemicals dissolved in water that is applied to the soil for irrigation purposes will evaporate much like the water does. A simple model to represent this process was developed by Jury, et al. (1983, 1984, and 1990). EPA has adopted a simplified version for estimating inhalation dose from volatile chemical emissions from the soil surface (EPA/540/R95/128). The simple model represents the time dependence of a layer of surface soil that is initially contaminated at some uniform concentration (C_0). The formula for the fractional loss rate from the surface layer as a function of time is shown below.

$$\lambda_v = \frac{J_s}{\rho d C_0} = \frac{1}{d} \sqrt{\frac{D_E}{\pi T}} \left[1 - \text{Exp}\left(\frac{-d^2}{4 D_E T}\right) \right] \text{Exp}(-\lambda_R T)$$

$$D_E = \frac{\theta^{10/3} D_w + (\theta_A)^{10/3} D_A H'}{(\rho K_d + \theta + \theta_A H') \phi^2}$$

where,

- C_0 = initial soil concentration, in g/kg
 d = thickness of the surface layer that holds the contaminants, 15 cm (5.9 inches) assumed
 D_A = diffusion coefficient for the chemical vapor in air from Table A41, cm²/s
 D_E = effective diffusion coefficient for contaminant motion from the soil and soil water into the soil air, cm²/y
 D_w = diffusion coefficient for the chemical dissolved in water from Table A41, cm²/s
 T = time at which the chemical loss rate is calculated, in years
 H' = unitless Henry's Law Constant for the chemical from Table A3
 J_s = mass flux of the chemical out of the soil surface, in g/cm² per year
 K_d = distribution coefficient for the chemical in surface soil, in ml/g. Values for chemicals are shown on Table A38.
 ϕ = total soil porosity, in ml/cm³. $\phi = 1 - \rho/\rho_p = 0.40$ ml/cm³

- λ_V = volatile emanation constant for the chemical, or fractional loss rate from the surface soil layer into the air above the soil, per year
 λ_R = decomposition constant for the chemical, per year (assumed zero)
 ρ = bulk density of the surface soil layer, 1.5 g/cm³ assumed
 ρ_p = particle density of the surface soil layer, 2.5 g/cm³ assumed
 θ = volumetric water content of the surface soil, milliliters of water per cubic centimeter of soil. A value of 0.2 ml/cm³ is assumed.
 θ_A = volumetric air content of the surface soil, milliliters of air per cubic centimeter of soil. $\theta_A = \phi - \theta$

The loss rate decreases with time. Thus, an average loss rate is calculated by performing the time integral of the above formula divided by the averaging time (T_{AVE}). The average loss rate (or emanation constant) assuming no decomposition ($\lambda_R=0$) is shown in the equation below.

$$\lambda_V = \frac{2}{d} \sqrt{\frac{D_E}{\pi T_{AVE}}} \left[1 - \text{Exp}\left(\frac{-d^2}{4 D_E T_{AVE}}\right) \right] + \frac{1}{T_{AVE}} \text{ERFC}\left(\frac{d}{2\sqrt{D_A T_{AVE}}}\right)$$

Values for the diffusion coefficients (D_A and D_w) are from the ORNL RAIS data base. Several chemicals did not have numbers, so values were imputed from a fit to the diffusivity versus molecular weight (MW) data. The diffusion coefficients (D_A and D_w) are shown in Table A41, while the molecular weights are listed in Table A3. The fitting functions for the air and water diffusion coefficients are shown below. The data and fitting functions are graphed in Figures A1 and A2. The points on the curve are the imputed numbers.

$$D_A = \frac{0.4 \text{ cm}^2/\text{s}}{1 + 0.04 * \text{MW}} \quad \text{and} \quad D_w = \frac{2.1 \times 10^{-5} \text{ cm}^2/\text{s}}{1 + 0.01 * \text{MW}}$$

Numbers for diffusion coefficients are shown in Table A41 along with the emanation constants (λ_V). Irrigated fields are represented as a series of contamination events. Active watering of the soil lasts less than an hour. The averaging period is taken to be the time between irrigation additions to the soil. Because the emanation constant decreases with time, the longest averaging time possible was used, namely, 168 hours (1 week). During the non-irrigation period, the emanation constants are calculated using an averaging period of 0.5 year.

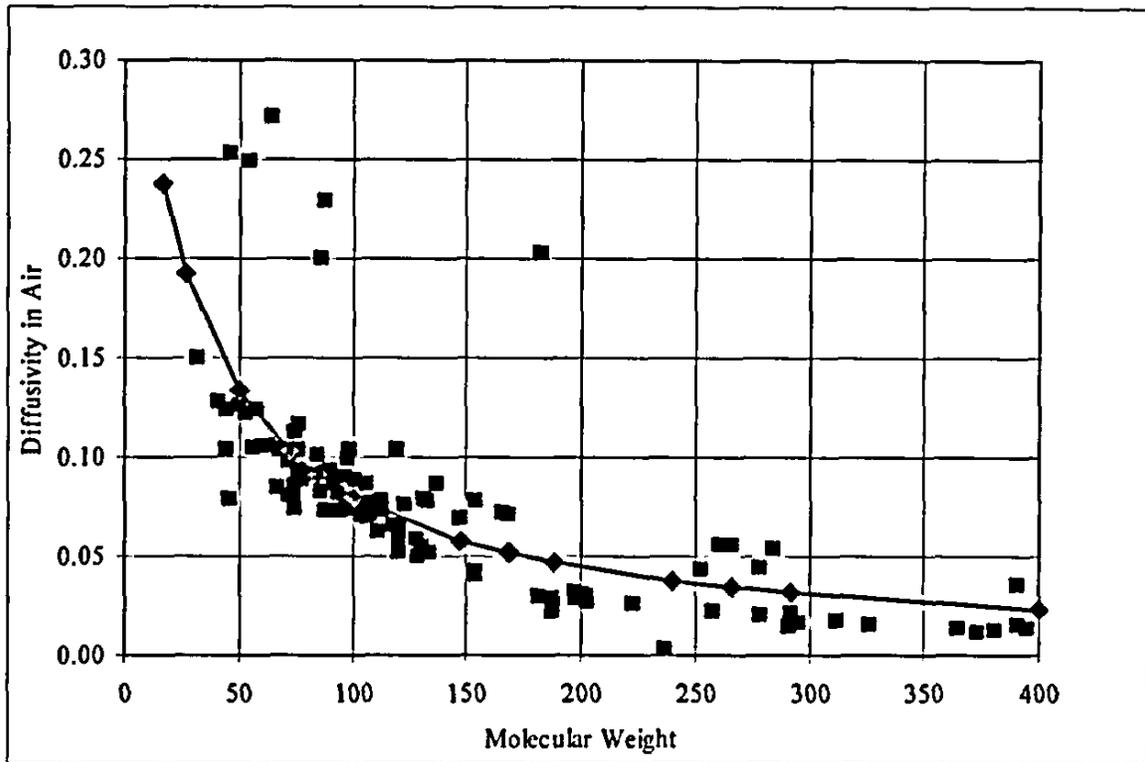


Figure A1. Diffusivity in Air as a Function of Molecular Weight

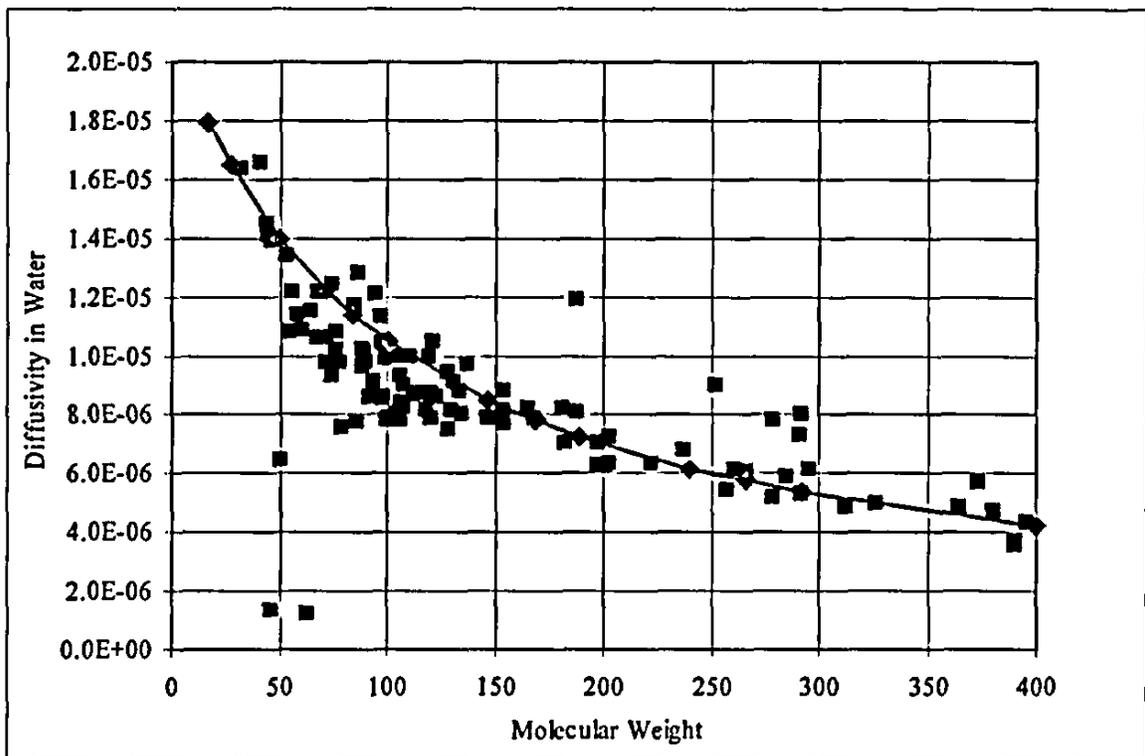


Figure A2. Diffusivity in Water as a Function of Molecular Weight

Table A41. Diffusion Coefficients and Emanation Constants

CASRN	Chemical	Diffusion Coefficients (cm ² /sec)		Emanation Constants (per year)	
		Air	Water	Active Irrigation	No Irrigation
50-32-8	Benzo[a]pyrene	4.30E-02	9.00E-06	8.68E-03	1.70E-03
53-70-3	Dibenz[a,h]anthracene	2.02E-02	5.18E-06	3.49E-03	6.83E-04
56-23-5	Carbon tetrachloride	7.80E-02	8.80E-06	4.32E+01	1.93E+00
57-12-5	Cyanide, free	*1.92E-01*	*1.65E-05*	4.38E+00	8.32E-01
57-14-7	1,1-Dimethylhydrazine	1.06E-01	1.09E-05	1.67E+00	3.27E-01
57-55-6	Propylene glycol (1,2-Propanediol)	9.30E-02	1.02E-05	3.37E+00	6.55E-01
58-89-9	gamma-Benzene hexachloride (gamma-Lindane)	1.42E-02	7.34E-06	1.36E-01	2.66E-02
60-29-7	Ethyl ether (Diethyl ether)	7.40E-02	9.30E-06	3.57E+01	1.87E+00
60-34-4	Methylhydrazine	2.53E-01	1.39E-05	1.96E+00	3.85E-01
60-57-1	Dieldrin	1.25E-02	4.74E-06	7.49E-02	1.47E-02
62-75-9	N-Nitrosodimethylamine	1.13E-01	1.24E-05	1.72E+00	3.36E-01
64-18-6	Formic acid	7.90E-02	1.37E-06	1.46E+00	2.85E-01
67-56-1	Methanol (Methyl alcohol)	1.50E-01	1.64E-05	7.01E+00	1.16E+00
67-64-1	Acetone (2-Propanone)	1.24E-01	1.14E-05	1.41E+01	1.55E+00
67-66-3	Chloroform	1.04E-01	1.00E-05	3.53E+01	1.87E+00
67-72-1	Hexachloroethane	2.50E-03	6.80E-06	3.26E+00	6.35E-01
71-36-3	n-Butyl alcohol (n-Butanol)	8.00E-02	9.30E-06	5.78E+00	1.03E+00
71-43-2	Benzene	8.80E-02	9.80E-06	2.49E+01	1.76E+00
71-55-6	1,1,1-Trichloroethane (Methyl chloroform)	7.80E-02	8.80E-06	4.11E+01	1.92E+00
72-20-8	Endrin	1.25E-02	4.74E-06	6.75E-02	1.32E-02
74-83-9	Bromomethane	7.28E-02	1.21E-05	4.09E+01	1.91E+00
74-87-3	Methyl chloride (Chloromethane)	1.26E-01	6.50E-06	4.48E+01	1.94E+00
75-00-3	Ethyl Chloride	2.71E-01	1.15E-05	4.67E+01	1.96E+00
75-01-4	Vinyl chloride (Chloroethene)	1.06E-01	1.23E-06	4.63E+01	1.96E+00
75-05-8	Acetonitrile	1.28E-01	1.66E-05	1.15E+01	1.46E+00
75-07-0	Acetaldehyde	1.24E-01	1.41E-05	1.87E+01	1.66E+00
75-09-2	Dichloromethane (Methylene chloride)	1.01E-01	1.17E-05	3.66E+01	1.88E+00
75-15-0	Carbon disulfide	1.04E-01	1.00E-05	4.81E+01	1.97E+00
75-21-8	Ethylene Oxide (Oxirane)	1.04E-01	1.45E-05	2.42E+01	1.75E+00
75-34-3	1,1-Dichloroethane (Ethylidene chloride)	7.42E-02	1.05E-05	3.59E+01	1.87E+00
75-35-4	1,1-Dichloroethylene	9.00E-02	1.04E-05	4.47E+01	1.94E+00
75-45-6	Chlorodifluoromethane	8.30E-02	1.28E-05	4.57E+01	1.95E+00
75-68-3	Chloro-1,1-difluoroethane, 1-	*7.97E-02*	*1.05E-05*	4.58E+01	1.95E+00
75-69-4	Trichlorofluoromethane	8.70E-02	9.70E-06	4.71E+01	1.96E+00
75-71-8	Dichlorodifluoromethane	5.20E-02	1.05E-05	4.77E+01	1.97E+00
76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane (CFC-113)	2.88E-02	8.07E-06	4.42E+01	1.94E+00
76-44-8	Heptachlor	1.12E-02	5.69E-06	1.27E-01	2.49E-02
78-83-1	Isobutanol	8.60E-02	9.30E-06	6.38E+00	1.10E+00
78-87-5	1,2-Dichloropropane	7.82E-02	8.73E-06	2.55E+01	1.76E+00
78-93-3	Methyl ethyl ketone (2-Butanone)	8.08E-02	9.80E-06	1.20E+01	1.48E+00
79-00-5	1,1,2-Trichloroethane	7.80E-02	8.80E-06	1.48E+01	1.57E+00

Table A41. Diffusion Coefficients and Emanation Constants

CASRN	Chemical	Diffusion Coefficients (cm ² /sec)		Emanation Constants (per year)	
		Air	Water	Active Irrigation	No Irrigation
79-01-6	Trichloroethylene	7.90E-02	9.10E-06	3.61E+01	1.87E+00
79-10-7	2-Propenoic acid (Acrylic acid)	9.80E-02	1.06E-05	3.60E+00	6.97E-01
79-34-5	1,1,2,2-Tetrachloroethane (Acetylene tetrachloride)	7.10E-02	7.90E-06	7.63E+00	1.22E+00
79-46-9	2-Nitropropane	9.23E-02	1.01E-05	9.71E+00	1.37E+00
82-68-8	Pentachloronitrobenzene (PCNB)	1.59E-02	6.14E-06	2.96E-01	5.79E-02
83-32-9	Acenaphthene	4.21E-02	7.69E-06	5.63E-01	1.10E-01
84-66-2	Diethyl phthalate	2.56E-02	6.35E-06	5.69E-01	1.11E-01
84-74-2	Dibutyl phthalate	4.38E-02	7.86E-06	2.14E-01	4.19E-02
85-68-7	Butyl benzyl phthalate	1.74E-02	4.83E-06	6.08E-02	1.19E-02
87-68-3	Hexachlorobutadiene	5.61E-02	6.16E-06	1.20E+01	1.48E+00
87-86-5	Pentachlorophenol	5.60E-02	6.10E-06	1.05E-01	2.05E-02
88-06-2	2,4,6-Trichlorophenol	3.18E-02	6.25E-06	2.21E-01	4.33E-02
88-85-7	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)	*3.77E-02*	*6.17E-06*	1.08E-01	2.12E-02
91-20-3	Naphthalene	5.90E-02	7.50E-06	1.87E+00	3.67E-01
92-52-4	1,1'-Biphenyl	4.04E-02	8.15E-06	7.07E-01	1.38E-01
95-47-6	o-Xylene	8.70E-02	1.00E-05	1.57E+01	1.60E+00
95-48-7	2-Methylphenol (o-Cresol)	7.40E-02	8.30E-06	4.01E-01	7.86E-02
95-50-1	1,2-Dichlorobenzene (ortho-)	6.90E-02	7.90E-06	8.56E+00	1.29E+00
95-57-8	2-Chlorophenol	5.01E-02	9.46E-06	6.62E-01	1.30E-01
95-63-6	1,2,4-Trimethylbenzene	6.44E-02	7.92E-06	1.16E+01	1.46E+00
95-95-4	2,4,5-Trichlorophenol	2.91E-02	7.03E-06	2.13E-01	4.18E-02
98-86-2	Acetophenone	6.00E-02	8.73E-06	2.02E+00	3.96E-01
98-95-3	Nitrobenzene	7.60E-02	8.60E-06	1.60E+00	3.14E-01
100-25-4	1,4-Dinitrobenzene (para-)	*5.18E-02*	*7.83E-06*	4.82E-01	9.43E-02
100-41-4	Ethyl benzene	7.50E-02	7.80E-06	1.66E+01	1.62E+00
100-42-5	Styrene	7.10E-02	8.00E-06	9.61E+00	1.36E+00
100-51-6	Benzyl alcohol	7.12E-02	8.97E-06	1.73E+00	3.39E-01
106-42-3	p-Xylene	7.69E-02	8.44E-06	1.72E+01	1.63E+00
106-44-5	4-Methylphenol (p-Cresol)	7.40E-02	1.00E-05	4.24E-01	8.30E-02
106-46-7	1,4-Dichlorobenzene (para-)	6.90E-02	7.90E-06	9.68E+00	1.37E+00
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	2.17E-02	1.19E-05	8.69E+00	1.30E+00
106-99-0	1,3-Butadiene	2.49E-01	1.08E-05	4.90E+01	1.98E+00
107-02-8	2-Propenal (Acrolein)	1.05E-01	1.22E-05	2.07E+01	1.70E+00
107-05-1	3-Chloropropene (Allyl chloride)	1.17E-01	1.08E-05	4.15E+01	1.92E+00
107-06-2	1,2-Dichloroethane (Ethylene chloride)	1.04E-01	9.90E-06	2.38E+01	1.74E+00
107-13-1	Acrylonitrile	1.22E-01	1.34E-05	1.81E+01	1.65E+00
108-10-1	Methyl isobutyl ketone (4-Methyl-2-pentanone)	7.50E-02	7.80E-06	1.30E+01	1.52E+00
108-38-3	m-Xylene	7.00E-02	7.80E-06	1.67E+01	1.62E+00
108-39-4	3-Methylphenol (m-Cresol)	7.40E-02	1.00E-05	4.17E-01	8.16E-02
108-67-8	1,3,5-Trimethylbenzene	6.02E-02	8.67E-06	1.36E+01	1.53E+00
108-87-2	Methyl cyclohexane	9.86E-02	8.52E-06	4.72E+01	1.96E+00

Table A41. Diffusion Coefficients and Emanation Constants

CASRN	Chemical	Diffusion Coefficients (cm ² /sec)		Emanation Constants (per year)	
		Air	Water	Active Irrigation	No Irrigation
108-88-3	Toluene (Methyl benzene)	8.70E-02	8.60E-06	2.21E+01	1.72E+00
108-90-7	Chlorobenzene	7.30E-02	8.70E-06	1.43E+01	1.56E+00
108-94-1	Cyclohexanone	7.84E-02	8.62E-06	3.40E+00	6.61E-01
108-95-2	Phenol (Carbolic acid)	8.20E-02	9.10E-06	4.76E-01	9.33E-02
109-99-9	Tetrahydrofuran	*1.03E-01*	*1.22E-05*	1.41E+01	1.55E+00
110-00-9	Furan (Oxacyclopentadiene)	1.04E-01	1.22E-05	3.15E+01	1.83E+00
110-54-3	n-Hexane	2.00E-01	7.77E-06	5.01E+01	1.98E+00
110-80-5	2-Ethoxyethanol	9.32E-02	9.76E-06	3.58E+00	6.95E-01
110-82-7	Cyclohexane	*9.16E-02*	*1.14E-05*	4.56E+01	1.95E+00
110-86-1	Pyridine	9.10E-02	7.60E-06	2.80E+00	5.47E-01
111-76-2	2-Butoxyethanol (Ethylene Glycol Monobutyl Ether)	6.51E-02	8.15E-06	3.71E+00	7.18E-01
111-90-0	2-(2-Ethoxyethoxy)-ethanol (Diethylene Glycol Monoethyl Ether)	5.24E-02	8.02E-06	2.98E+00	5.83E-01
117-81-7	Di (2-ethylhexyl) phthalate (DEHP)	3.51E-02	3.66E-06	1.22E-02	2.38E-03
117-84-0	Di-n-octylphthalate	1.51E-02	3.58E-06	1.26E-02	2.48E-03
118-74-1	Hexachlorobenzene	5.42E-02	5.91E-06	2.60E+00	5.08E-01
120-82-1	1,2,4-Trichlorobenzene	3.00E-02	8.23E-06	3.83E+00	7.38E-01
121-14-2	2,4-Dinitrotoluene	2.03E-01	7.06E-06	3.51E-01	6.88E-02
121-44-8	Triethylamine	8.81E-02	7.88E-06	5.43E+00	9.85E-01
122-39-4	Diphenylamine	*5.15E-02*	*7.80E-06*	2.18E-01	4.28E-02
123-91-1	1,4-Dioxane (Diethylene oxide)	2.29E-01	1.02E-05	7.82E+00	1.24E+00
126-73-8	Tributyl Phosphate	*3.43E-02*	*5.73E-06*	1.38E-01	2.70E-02
126-98-7	2-Methyl-2-propenenitrile (Methacrylonitrile)	8.45E-02	1.06E-05	1.72E+01	1.63E+00
127-18-4	Tetrachloroethylene	7.20E-02	8.20E-06	3.65E+01	1.88E+00
129-00-0	Pyrene	2.72E-02	7.24E-06	4.22E-02	8.27E-03
141-78-6	Ethyl acetate (Acetic acid, ethyl ester)	7.32E-02	9.66E-06	1.53E+01	1.58E+00
156-59-2	cis-1,2-Dichloroethylene	7.36E-02	1.13E-05	3.18E+01	1.83E+00
206-44-0	Fluoranthene (1,2-Benzacenaphthene)	3.02E-02	6.35E-06	3.84E-02	7.52E-03
309-00-2	Aldrin	1.32E-02	4.86E-06	4.05E-02	7.93E-03
319-84-6	alpha-Benzene hexachloride (alpha-Lindane)	1.42E-02	7.34E-06	1.61E-01	3.14E-02
319-85-7	beta-Benzene hexachloride (beta-Lindane)	1.42E-02	7.34E-06	1.16E-01	2.28E-02
541-73-1	1,3-Dichlorobenzene	*5.81E-02*	*8.50E-06*	9.29E+00	1.34E+00
542-75-6	1,3-Dichloropropene (cis & trans)	6.26E-02	1.00E-05	2.40E+01	1.75E+00
621-64-7	N-Nitrosodi-N-propylamine	5.45E-02	8.17E-06	4.99E-01	9.77E-02
1314-62-1	Vanadium pentoxide	na	na	0.00E+00	0.00E+00
1330-20-7	Xylenes (mixtures)	7.14E-02	9.34E-06	1.61E+01	1.61E+00
1336-36-3	Polychlorinated Biphenyls	1.75E-02	8.00E-06	1.85E-01	3.62E-02
1336-36-3	Polychlorinated Biphenyls (lowest risk)	1.75E-02	8.00E-06	1.85E-01	3.62E-02
6533-73-9	Thallium carbonate	na	na	0.00E+00	0.00E+00
7429-90-5	Aluminum	na	na	0.00E+00	0.00E+00
7439-89-6	Iron	na	na	0.00E+00	0.00E+00
7439-93-2	Lithium	na	na	0.00E+00	0.00E+00

Table A41. Diffusion Coefficients and Emanation Constants

CASRN	Chemical	Diffusion Coefficients (cm ² /sec)		Emanation Constants (per year)	
		Air	Water	Active Irrigation	No Irrigation
7439-96-5	Manganese	na	na	0.00E+00	0.00E+00
7439-97-6	Mercury metal vapor	3.07E-02	6.30E-06	3.36E-01	6.58E-02
7439-98-7	Molybdenum	na	na	0.00E+00	0.00E+00
7440-02-0	Nickel (soluble salts)	na	na	0.00E+00	0.00E+00
7440-22-4	Silver	na	na	0.00E+00	0.00E+00
7440-24-6	Strontium, Stable	na	na	0.00E+00	0.00E+00
7440-28-0	Thallium metal	na	na	0.00E+00	0.00E+00
7440-31-5	Tin	na	na	0.00E+00	0.00E+00
7440-36-0	Antimony	na	na	0.00E+00	0.00E+00
7440-38-2	Arsenic (inorganic)	na	na	0.00E+00	0.00E+00
7440-39-3	Barium	na	na	0.00E+00	0.00E+00
7440-41-7	Beryllium and compounds	na	na	0.00E+00	0.00E+00
7440-42-8	Boron and borates only	na	na	0.00E+00	0.00E+00
7440-43-9	Cadmium	na	na	0.00E+00	0.00E+00
7440-45-1	Cerium (Ceric oxide 1306-38-3)	na	na	0.00E+00	0.00E+00
7440-48-4	Cobalt	na	na	0.00E+00	0.00E+00
7440-50-8	Copper	na	na	0.00E+00	0.00E+00
7440-62-2	Vanadium metal	na	na	0.00E+00	0.00E+00
7440-66-6	Zinc and compounds	na	na	0.00E+00	0.00E+00
7487-94-7	Mercuric chloride	na	na	0.00E+00	0.00E+00
7664-41-7	Ammonia	*2.38E-01*	*1.79E-05*	4.08E+00	7.81E-01
7723-14-0	Phosphorus, white	na	na	0.00E+00	0.00E+00
7782-41-4	Fluorine (soluble fluoride)	na	na	0.00E+00	0.00E+00
7782-49-2	Selenium and compounds	na	na	0.00E+00	0.00E+00
8001-35-2	Toxaphene	1.16E-02	4.34E-06	2.09E-02	4.10E-03
11096-82-5	Aroclor 1260	1.38E-02	4.32E-06	7.53E-02	1.47E-02
11097-69-1	Aroclor 1254	1.56E-02	5.00E-06	1.22E-01	2.38E-02
11104-28-2	Aroclor 1221	*4.68E-02*	*7.27E-06*	5.09E-01	9.98E-02
11141-16-5	Aroclor 1232	*4.68E-02*	*7.27E-06*	5.09E-01	9.98E-02
12672-29-6	Aroclor 1248	*3.15E-02*	*5.36E-06*	2.81E-01	5.50E-02
12674-11-2	Aroclor 1016	2.22E-02	5.42E-06	2.04E-01	4.00E-02
14797-55-8	Nitrate	na	na	0.00E+00	0.00E+00
14797-65-0	Nitrite	na	na	0.00E+00	0.00E+00
16065-83-1	Chromium (III) (insoluble salts)	na	na	0.00E+00	0.00E+00
16984-48-8	Fluorine anion	na	na	0.00E+00	0.00E+00
18540-29-9	Chromium (VI) (soluble salts)	na	na	0.00E+00	0.00E+00
53469-21-9	Aroclor 1242	2.14E-02	5.31E-06	2.03E-01	3.97E-02
na	Uranium (soluble salts)	na	na	0.00E+00	0.00E+00

Notes:

- CASRN = Chemical Abstract Service Reference Number
- The averaging times for the "Active" and "No" irrigation cases are 1 week (168 hours) and 0.5 year.
- Diffusion Coefficients marked with an asterisk were estimated from a fit to the Diffusivity versus Molecular Weight data. Missing values are indicated with "na", which means "not available".

A7.0 DIAMETER OF TYPICAL WATER WELLS

The State of Washington Department of Ecology, Water Resources has placed a database of well reports on their web site. The address is "<http://apps.ecy.wa.gov/wellog/>". These reports summarize the location, dimensions, and geologic information collected at each well. The well report viewer enables one to retrieve and examine individual well reports generated from 1960 to the present (January 2004).

To obtain a picture of the typical water well in the area surrounding the Hanford Site, well records for Adams, Benton, Franklin, and Grant county were obtained for well depths ranging from 200 ft to 400 ft. These were then sorted by well diameter and totaled. The results are shown in Table A42.

Table A42. Number of Wells of Each Diameter

Diameter	Number	% of Total
1 in	1	0.033%
3 in	1	0.033%
4 in	51	1.689%
5 in	10	0.331%
6 in	1952	64.636%
8 in	529	17.517%
9 in	2	0.066%
10 in	105	3.477%
11 in	2	0.066%
12 in	123	4.073%
12.25 in	1	0.033%
14 in	13	0.430%
15 in	18	0.596%
16 in	129	4.272%
17 in	1	0.033%
18 in	11	0.364%
20 in	12	0.397%
22 in	2	0.066%
26 in	4	0.132%
30 in	3	0.099%
blank	50	1.656%
Totals	3020	99.999%

The database does not distinguish between domestic and industrial or irrigation use for the well. Hence, a second list of wells was created whose owner name was an individual's name. This removed government entities, farms, ranches, orchards and various businesses.

In addition, the Water Well Reports for the larger diameters (10 inches and above) were examined to obtain any well use information. For the past 25 years, the form submitted to the Department of Ecology has a "Proposed Use" check box. It was found that none of the wells greater than 16 inches had the "Domestic" box checked. Most were listed as "Irrigation". Wells with the "Domestic" use were retained along with wells for which no proposed use was stated. The large number of wells with diameters less than 10 inches was not examined in detail. Samples of the Water Well Reports show that most of the smaller diameters are domestic use wells. The subtotals for the second list are shown in Table A43.

Table A43. Number of Individual Wells of Each Diameter

Diameter	Number	% of Total
1 in	1	0.042%
4 in	1	0.042%
5 in	10	0.424%
6 in	1792	75.964%
8 in	405	17.168%
9 in	2	0.085%
10 in	55	2.331%
11 in	1	0.042%
12 in	56	2.374%
14 in	2	0.085%
15 in	2	0.085%
blank	32	1.357%
Totals	2359	99.999%

The list of all wells summarized in Table A42 shows that 64% have a diameter of 6 inches. The modified list summarized in Table A43 shows that 76% have a diameter of 6 inches. Since the 6 and 8 inch well counts in Table A43 were not adjusted for proposed use, their percentage is exaggerated. Nevertheless, it is apparent that the typical well drilled for domestic use is 6 inches in diameter. Comparing the two tables, the most likely large diameter commercial irrigation well is 16 inches.

The diameter of a well that might be used in the rural pasture scenario ranges from 6 to 16 inches. A diameter of 10 inches is recommended as an intermediate size suitable for the larger water flow rate needed to supply irrigation water for a cow pasture.

A8.0 REFERENCES

- ANL/EAD/LD-2, Yu, C., et al., 1993, *Manual for Implementing Residual Radioactive Material Guidelines Using RESAD, Version 5.0*, Argonne National Laboratory, Argonne, Illinois.
- BNWL-1754, Soldat, J. K., N. M. Robinson, and D. A. Baker, 1974, *Models and Computer Codes for Evaluating Environmental Radiation Doses*, Pacific Northwest National Laboratory, Richland, WA.
- Chu, S. Y. F., L. P. Ekstrom, and R. B. Firestone, 1998, "The LUND/LBNL Nuclear Data Search Preliminary Version 7 April 1998", Lawrence Berkeley National Laboratory, University of California.
- Chunseng, L., J. Guo, and L. Daming, 1997, "A Procedure for the Separation of ⁷⁹Se from Fission Products and Application to the Determination of ⁷⁹Se Half Life", *Journal of Radioanalytical and Nuclear Chemistry*, Volume 220, Number 1.
- Confederated Tribes of the Umatilla Indian Reservation (CTUIR), *Scoping Report: Nuclear Risks in Tribal Communities*, Pendleton, Oregon, March 1995.
- DOE/EH-0071 (DE88-014297), 1988, *Internal Dose Conversion Factors for Calculation of Dose to the Public*, U.S. Department of Energy, Washington, D.C.
- DOE/EH-0070 (DE88-014297), 1988, *External Dose-Rate Conversion Factors for Calculation of Dose to the Public*, U.S. Department of Energy, Washington, D.C.
- DOE/EIS-0189, 1996, *Tank Waste Remediation System, Hanford Site, Richland, Washington, Final Environmental Impact Statement*, U.S. Department of Energy, Washington, D.C.
- DOE-HDBK-3010-94, 1994, *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities, Volume 1 - Analysis of Experimental Data*, U.S. Department of Energy, Washington, D.C.
- DOE/LLW-93, 1991, *Performance Assessment Review Guide for DOE Low-Level Radioactive Waste Disposal Facilities*, U.S. Department of Energy, Washington, D.C.
- DOE M 435.1-1, 1999, *Radioactive Waste Management Manual, Chapter IV, Low Level Waste Requirements*, U.S. Department of Energy, Washington, D.C.
- DOE/ORP-2000-24 Revision 0, (formerly DOE/RL-97-69 Revision 0), 2001, *Hanford Immobilized Low-Activity Tank Waste Performance Assessment: 2001 Version*, U.S. Department of Energy - Richland, Richland, WA.
- DOE/RL-91-45 Revision 3, 1995, *Hanford Site Risk Assessment Methodology*, U.S. Department of Energy - Richland, Richland, WA.

DOE/RL-96-16 Revision 0, 1997, *Screening Assessment and Requirements for a Comprehensive Assessment: Columbia River Comprehensive Impact Assessment*, U.S. Department of Energy - Richland, Richland, WA.

ENDF/B-VI, Evaluated Nuclear Data File, Release VI. This nuclear data library is maintained by the Cross Section Evaluation Working Group. Data and documentation is available from the National Nuclear Data Center, Brookhaven National Laboratory, Upton, New York. www.nndc.bnl.gov.

EPA-402-R-93-081, Federal Guidance Report Number 12, 1993, *External Exposure to Radionuclides in Air, Water and Soil*, U.S. Environmental Protection Agency, Washington, DC.

EPA-402-R-99-001, Federal Guidance Report Number 13, 1999, *Cancer Risk Coefficients for Environmental Exposure to Radionuclides*, U.S. Environmental Protection Agency, Washington, DC.

EPA-454/B-95-003a, 1995, *User's Guide for the Industrial Source Complex (ISC3) Dispersion Models, Volume I -- User Instructions*, U.S. Environmental Protection Agency, Washington, DC.

EPA-454/B-95-003b, 1995, *User's Guide for the Industrial Source Complex (ISC3) Dispersion Models, Volume II -- Description of Model Algorithms*, U.S. Environmental Protection Agency, Washington, DC.

EPA-520/1-88-020, Federal Guidance Report Number 11, 1988, *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion*, U.S. Environmental Protection Agency, Washington, DC.

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

EPA-540/R-96/018, 1996, *Soil Screening Guidances: User's Guide*, U.S. Environmental Protection Agency, Washington, DC.

EPA-540/R-97/036, 1997, *Health Effects Assessment Summary Tables (HEAST) FY 1997 Update*, U.S. Environmental Protection Agency, Washington, DC.

EPA/600/8-89/043, 1989, *Exposure Factors Handbook*, U.S. Environmental Protection Agency, Washington, D.C.

Harris, S. G., and B. L. Harper, 1997, *A Native American Exposure Scenario*, in *Risk Analysis*, Vol. 17, pp 789-795, Society for Risk Analysis.

Hinds, W. C., 1982, *Aerosol Technology: Properties, Behavior, and Measurement of Airborne Particles*, John Wiley & Sons, New York, New York.

- HNF-EP-0826, Revision 3, Mann, F. M., 1999, *Performance Objectives for the Hanford Immobilized Low-Activity Waste (ILAW) Performance Assessment*, Fluor Daniel Hanford, Inc., Richland, WA.
- HNF-EP-0828, Revision 2, Mann, F. M., 1999, *Scenarios for the Hanford Immobilized Low-Activity Waste (ILAW) Performance Assessment*, Fluor Daniel Hanford, Inc., Richland, WA.
- IAEA Technical Report 364, 1994, *Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments*, International Atomic Energy Agency, Vienna.
- ICRP Publication 23, 1975, International Commission on Radiological Protection (ICRP), *Report of the Task Group on Reference Man*, Pergamon Press, New York, New York.
- ICRP Publication 26, 1977, International Commission on Radiological Protection (ICRP), *Recommendations of the International Commission on Radiological Protection*, Pergamon Press, New York, New York.
- ICRP Publication 71, 1996a, International Commission on Radiological Protection, *Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 4. Inhalation Dose Coefficients*, Pergamon Press, New York, New York.
- ICRP Publication 72, 1996b, International Commission on Radiological Protection, *Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 5. Compilation of Ingestion and Inhalation Dose Coefficients*, Pergamon Press, New York, New York.
- Jury, W. A., W. F. Spencer, and W. J. Farmer, 1983, "Behaviour Assessment Model for Trace Organics in Soil: I. Model Description", *J. Environ. Qual.*, 12(4):558-564.
- Jury, W. A., W. F. Spencer, and W. J. Farmer, 1984, "Behaviour Assessment Model for Trace Organics in Soil: II. Chemical Classification and Parameter Sensitivity", *J. Environ. Qual.*, 13(4):567-572.
- Jury, W. A., D. Russo, G. Streile, and H. E. Abd, 1990, "Evaluation of Volatilization by Organic Chemicals Residing Below the Soil Surface", *Water Resources Research*, 26(1):13-20.
- McKone, T. E., 1994, "Uncertainty and Variability in Human Exposures to Soil Contaminants Through Home-Grown Food: a Monte Carlo Assessment", *Risk Anal.*, 14(4):449-463.
- Miller, D. W., *Waste Disposal Effects on Ground Water*, Premier Press, Berkeley, CA, 1980.
- NCRP Report Number 76, 1984, National Council on Radiological Protection and Measurements, *Radiological Assessment: Predicting the Transport, Bioaccumulation, and Uptake by Man of Radionuclides Released to the Environment*, Bethesda, Maryland.

- NCRP Report Number 123, 1996, National Council on Radiological Protection and Measurements, *Screening Models for Releases of Radionuclides to Atmosphere, surface Water, and Ground*, Bethesda, Maryland.
- NRC Regulatory Guide 1.109, 1977, *Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50 Appendix I*, Bethesda, Maryland.
- NUREG/CR-5512, Kennedy, W. E., and D. L. Strenge, 1992, *Residual Radioactive Contamination from Decommissioning, Volume 1*, Pacific Northwest National Laboratory, Richland, WA.
- ORNL-5785, Baes III, C. F., et al., 1984, *TERRA: A Computer Code for Simulating the Transport of Environmentally Released Radionuclides through Agriculture*, Oak Ridge National Laboratory, Oak Ridge, TN.
- ORNL-5786, Baes III, C. F., et al., 1994, *A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides through Agriculture*, Oak Ridge National Laboratory, Oak Ridge, TN.
- ORNL-TM/13401, *Performance Assessment for the Class L-II Disposal Facility*, Oak Ridge National Laboratory, Oak Ridge, Tennessee, 1997.
- Paustenbach, D. J., 1989, *The Risk Assessment of Environmental and Human Health Hazards: A Textbook of Case Studies*, John Wiley & Sons, Inc., New York, New York.
- PNNL-6312, Aaberg, R. L. and W. E. Kennedy, Jr., 1990, *Definition of Intrusion Scenarios and Example Concentration Ranges for the Disposal of Near-Surface Waste at the Hanford Site*, Pacific Northwest National Laboratory, Richland, WA.
- PNNL-6415, Revision 15, D. A. Neitzel, Ed., 2003, *Hanford Site National Environmental Policy Act (NEPA) Characterization*, Pacific Northwest National Laboratory, Richland, WA.
- PNNL-6584, Napier, B. A., R. A. Peloquin, D. L. Strenge and J. V. Ramsdell, 1988, *GENII - The Hanford Environmental Radiation Dosimetry Software System*, Pacific Northwest National Laboratory, Richland, WA.
- PNNL-7493, Revision 1, Strenge, D. L., R. A. Kennedy, M. J. Sula, and J. R. Johnson, 1992, *Code for Internal Dosimetry (CINDY Version 1.2)*, Pacific Northwest National Laboratory, Richland, WA.
- PNNL-9823, Dirkes, R. L., R. W. Hanf, R. K. Woodruff and R. E. Lundgren, 1994, *Hanford Site Environmental Report for 1993*, Pacific Northwest National Laboratory, Richland, WA.
- PNNL-10190, Strenge, D. L. and P. J. Chamberlain, 1994, *Evaluation of Unit Risk Factors in Support of the Hanford Remedial Action Environmental Impact Statement*, Pacific Northwest National Laboratory, Richland, WA.

- PNNL-10523, Strenge, D. L. and P. J. Chamberlain, 1995, *Multimedia Environmental Pollutant Assessment System (MEPAS): Exposure Pathway and Human Health Impact Assessment Models*, Pacific Northwest National Laboratory, Richland, WA.
- PNNL-12040, Weimers, K. D., M. E. Lerchen, M. Miller, and K. Meier, 1998, *Regulatory Data Quality Objectives Supporting Tank Waste Remediation System Privatization Project*, Pacific Northwest National Laboratory, Richland, WA.
- PNNL-13859, Hoitink, D. J., K. W. Burk, J. V. Ramsdell, and W. J. Shaw, 2002, *Hanford Site Climatological Data Summary 2001 with Historical Data*, Pacific Northwest National Laboratory, Richland, WA.
- PNNL-14041, Napier, B. A., and S. F. Snyder, 2002, *Recommendations for User Supplied Parameters for the RESRAD Computer Code for Application to the Hanford Reach National Monument*, Pacific Northwest National Laboratory, Richland, WA.
- Putnam, J. J. and J. E. Allshouse, 1999, *Food Consumption, Prices, and Expenditures, 1970-97*, Statistical Bulletin No. 965, U.S. Department of Agriculture.
- PNWD-2023, Revision 1, Snyder, S. F., W. T. Farris, B. A. Napier, T. A. Ikenberry and R. O. Gilbert, 1994, *Parameters Used in the Environmental Pathways and Radiological Dose Modules (DESCARTES, CIDER, and CRD Codes) of the Hanford Environmental Dose Reconstruction Integrated Codes (HEDRIC)*, Pacific Northwest National Laboratory, Richland, WA.
- Roseberry, A. M., and D. E. Burmaster, "Lognormal Distributions for Water Intake by Children and Adults", *Risk Analysis*, Volume 12, Number 1, pp 99-104, 1992.
- SAND2001-2977, Cochran, J. R., W. E. Beyeler, D. E. Brosseau, 2001, *Compliance Assessment Document for the Transuranic Waste in the Greater Confinement Disposal Boreholes at the Nevada Test Site, Volume 2: Performance Assessment*, Sandia National Laboratories, Albuquerque, New Mexico.
- U.S. Environmental Protection Agency, 1991, *Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Factors*, OSWER Directive 9285.6-03 (March 25, 1991), Interim Final, EPA Office of Emergency and Remedial Response, Washington, D.C.
- U.S. EPA-10, 1991, *Supplemental Risk Assessment Guidance for Superfund*, U.S. Environmental Protection Agency, Region X, Seattle, Washington.
- Washington State Department of Agriculture, *Washington Agricultural Statistics 1993-1994*, 1994.
- Washington State University Cooperative Extension, *Home Gardens*, EB-422, 1980.

WHC-SD-WM-EE-004, Revision 1, Kincaid, C. T., et al., 1995, *Performance Assessment of Grouted Double-Shell Tank Waste Disposal at Hanford*, Pacific Northwest National Laboratory and Westinghouse Hanford Company, Richland, WA.

WHC-EP-0645, Wood, M.I., et al., 1994, *Performance Assessment for the Disposal of Low-Level Waste in the 200 West Area Burial Grounds*, Westinghouse Hanford Company, Richland, WA.

WHC-SD-WM-TI-596, Rittmann, P. D., 1993, *Verification Tests for the July 1993 Revision to the GENII Radionuclide and Dose Increment Libraries*, Westinghouse Hanford Company, Richland, WA.

WHC-SD-WM-TI-616, Rittmann, P. D., 1994, *Dose Estimates for the Solid Waste Performance Assessment*, Westinghouse Hanford Company, Richland, WA.

WHC-SD-WM-TI-707, Revision 0, 1995, Rittmann, P. D., *Data and Assumptions for Estimates of Radiation Doses for the Glass Low Level Waste Interim Performance Assessment*, Westinghouse Hanford Company, Richland, WA.

WHC-SD-WM-UM-018, Rittmann, P. D., 1993, *GRTPA - A Program to Calculate Human Dose from PORFLOW Output*, Westinghouse Hanford Company, Richland, WA.

WHC-SD-WM-UM-030, Rittmann, P. D., 1995, *ISO-PC Version 1.98 - User's Guide*, Westinghouse Hanford Company, Richland, WA.

Yang, Y. and C. B. Nelson, "An Estimation of Daily Food Usage Factors for Assessing Radionuclide Intakes in the U.S. Population", *Health Physics*, Volume 50, Number 2, pp 245-257, 1986.

Yu, R., J. Guo, and A. Cui, 1993, *Chinese Journal of Nuclear Radiochemistry*, Volume 15, page 240.

Zhang, S., J. Guo, A. Cui, D. Li, and D. Liu, 1996, "Measurement of the Half Life of ^{126}Sn Using a Radiochemical Method", *Journal of Radioanalytical and Nuclear Chemistry, Letters*, Volume 212, Number 2, page 93.

Attachment A1. ISCST3 Input Files for the 100 m² Source

First Case -- Zero Elevation Receptors

```

CO STARTING
  TITLEONE Area Sources --- 100 sq.m
  MODELOPT MSGPRO CONC RURAL
  AVERTIME ANNUAL
  TERRHGTS ELEV
  FLAGPOLE 0.0
  POLLUTID OTHER
  RUNORNOT RUN
  ERRORFIL ERRORS.LST
CO FINISHED

SO STARTING
**          SRCID  SRCTYP   XS      YS      ZS
**          -----  -----  -----  -----  -----
  LOCATION  A100    AREA    -5.0   -5.0   .0000

**          SRCID   QS      HS      XINIT   YINIT
**          -----  -----  -----  -----  -----
  SRCPARAM  A100    1.0     0.0     10.     10.

  EMISUNIT   1.00 (GRAMS/(SEC-M**2))          grams/cubic-meter

  SRCGROUP   AREA1   A100
SO FINISHED

RE STARTING
  GRIDPOLR POL1 STA
          DIST  1.  1.5  2.  2.5  3.  5.  10.  15.  20.
          GDIR  36  0.0  10.0
  GRIDPOLR POL1 END
  DISCCART  0.   0.   0.   0.
  DISCCART  0.   0.   0.   1.
  DISCCART  0.  10.   0.   0.
  DISCCART  0.  10.   0.   1.
  DISCCART 10.  10.   0.   0.
  DISCCART 10.  10.   0.   1.
  DISCCART 10.   0.   0.   0.
  DISCCART 10.   0.   0.   1.
  DISCCART 10. -10.   0.   0.
  DISCCART 10. -10.   0.   1.
  DISCCART  0. -10.   0.   0.
  DISCCART  0. -10.   0.   1.
  DISCCART -10. -10.   0.   0.
  DISCCART -10. -10.   0.   1.
  DISCCART -10.  0.   0.   0.
  DISCCART -10.  0.   0.   1.
  DISCCART -10. 10.   0.   0.
  DISCCART -10. 10.   0.   1.
RE FINISHED

ME STARTING
  INPUTFIL  MET\EPA92-96.2E
  ANEMHGHT 10.0
  
```

SURFDATA 67656 1992 Hanford-200
 UAIRDATA 67656 1992 Hanford-200
 ME FINISHED

OU STARTING
 RECTABLE ALLAVE FIRST SECOND
 MAXTABLE ALLAVE 50
 OU FINISHED

Second Case -- 0.5 m Elevation Receptors

CO STARTING
 TITLEONE Area Sources --- 100 sq.m
 MODELOPT MSGPRO CONC RURAL
 AVERTIME ANNUAL
 TERRHGTS ELEV
 FLAGPOLE 0.5
 POLLUTID OTHER
 RUNORNOT RUN
 ERRORFIL ERRORS.LST
 CO FINISHED

SO STARTING
 ** SRCID SRCTYP XS YS ZS
 ** -----
 LOCATION A100 AREA -5.0 -5.0 .0000
 ** SRCID QS HS XINIT YINIT
 ** -----

SRCPARAM A100 1.0 0.0 10. 10.
 EMISUNIT 1.00 (GRAMS/(SEC-M**2)) grams/cubic-meter

SRCGROUP AREA1 A100
 SO FINISHED

RE STARTING
 GRIDPOLR POL1 STA
 DIST 3. 5. 6. 7. 8. 9. 10. 12. 15.
 GDIR 36 0.0 10.0
 GRIDPOLR POL1 END
 RE FINISHED

ME STARTING
 INPUTFIL MET\EPA92-96.2E
 ANEMHGHT 10.0
 SURFDATA 67656 1992 Hanford-200
 UAIRDATA 67656 1992 Hanford-200
 ME FINISHED

OU STARTING
 RECTABLE ALLAVE FIRST SECOND
 MAXTABLE ALLAVE 50
 OU FINISHED

Third Case -- 1 m Elevation Receptors

```

CO STARTING
  TITLEONE Area Sources --- 100 sq.m
  MODELOPT MSGPRO CONC RURAL
  AVERTIME ANNUAL
  TERRHGTS ELEV
  FLAGPOLE 1.0
  POLLUTID OTHER
  RUNORNOT RUN
  ERRORFIL ERRORS.LST
CO FINISHED

SO STARTING
**          SRCID  SRCTYP   XS      YS      ZS
**          -----  -----  -----  -----  -----
  LOCATION  A100    AREA    -5.0   -5.0   .0000

**          SRCID   QS      HS      XINIT   YINIT
**          -----  -----  -----  -----  -----
  SRCPARAM  A100    1.0     0.0    10.    10.

  EMISUNIT   1.00 (GRAMS/(SEC-M**2))          grams/cubic-meter

  SRCGROUP   AREA1  A100
SO FINISHED

RE STARTING
  GRIDPOLR  POL1 STA
              DIST  8.  12.  13.  14.  15.  16.  17.  20.  25.
              GDIR  36  0.0  10.0
  GRIDPOLR  POL1 END
RE FINISHED

ME STARTING
  INPUTFIL  MET\EPA92-96.2E
  ANEMHGHT  10.0
  SURFDATA  67656  1992  Hanford-200
  UAIRDATA  67656  1992  Hanford-200
ME FINISHED

OU STARTING
  RECTABLE  ALLAVE FIRST SECOND
  MAXTABLE  ALLAVE 50
OU FINISHED
    
```

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