Appendix D. Dose Calculations

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D.0 Dose Calculations

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Dose calculations based on measured and/or estimated releases from stack emissions, liquid effluents, and contaminated soils were conducted for the public and biota. These dose calculations are summarized in Section 4.2. Details of the methods and assumptions used for modeling individual and population dose for the public are provided in Section D.1. Methods and assumptions related to the calculation of biota dose are provided in Section D.2.

The total annual dose to a hypothetical, maximally exposed individual (MEI) in 2017 at the offsite location where projected doses were highest (Horn Rapids Road) was 0.22 mrem (2.2 µSv). This dose is0.22% of the 100 mrem (1000 µSv)/yr public dose limit specified in DOE O 458.1, *Radiation Protection of the Public and the Environment*. For context, a 2009 National Council on Radiation Protection and Measurements report estimated that the overall annual exposure to ionizing radiation for the average American is 620 mrem (6,200 µSv), approximately half of which is related to natural sources and the other half attributable primarily to medical procedures.

D.1 Supporting Information for Calculation of Public Doses

The radiological dose that the public could have received in 2017 from the Hanford Site was calculated in terms of the total effective dose. The total effective dose is the sum of the effective dose equivalent from external sources and the committed effective dose equivalent for internal exposure, which are summarized here and described in more detail in 10 CFR 835, "Occupational Radiation Protection Program." The committed effective dose equivalent is the sum of doses to organs and tissues that is weighted to account for the sensitivity of the organ or tissue to the effects of radiation and for the biological effectiveness of the type of radiation causing the dose. It is expressed in units of rem (Sv), or more typically the sub-unit mrem (mSv)[1] for individuals, and in units of person-rem (person-Sv) for the collective dose received by the total population within a 50-mi (80-km) radius of Hanford Site operations areas. This appendix describes how the doses summarized in Section 4.2 of this report were calculated.

Calculation of the total effective dose accounts for the long-term (50 years) internal exposure from radionuclides absorbed into the body during the current year. The committed effective dose equivalent is the sum of individual committed (50 years) organ doses multiplied by tissue weighting factors (ICRP 1991) that represent the contribution of each organ or tissue to a person's internal radiation dose. Internal organs also may be irradiated from external sources of radiation. The external exposure received during the current year is added to the committed internal dose to obtain the total effective dose.

Releases of radionuclides from Hanford Site facilities are frequently too small for their concentrations to be accurately measured in many of the offsite environmental media of interest. Even when present in measureable amounts, it can be difficult to distinguish the small Hanford Site contributions from levels attributable to fallout from historical nuclear weapons testing and from naturally occurring radionuclides such as uranium and its decay products. Therefore, Hanford-related environmental radionuclide concentrations were estimated from stack effluent measurements (air pathway doses) or

[1] 1 rem (0.01 Sv) = 1,000 mrem (10 mSv).

river water measurements (water pathway doses) by using environmental transport models. The air dose calculations employ environmental transport modeling based on measurements made at the points of release (stacks and vents). The water pathway dose calculations are based on the difference in measurements of radionuclide concentrations in the Columbia River upstream and downstream of the Hanford Site.

The transport of radionuclides in the environment to points of exposure is predicted using mathematical models of the physical processes underlying the various exposure pathways. These models are used to calculate radionuclide levels in air, soil, and foods at offsite locations. Long-lived radionuclides deposited on the ground by irrigation or airborne depositions become possible sources of external exposure and uptake by agricultural products. Radionuclides taken into the body by inhalation or ingestion may be distributed among different organs and tissues and retained in the body for various lengths of times. Agricultural, behavioral, and dosimetric models were applied to calculate radionuclide intakes and radiological doses to the public from annual-average radionuclide concentrations in the exposure media. Computer programs were used to implement these mathematical models using Hanford Site-specific dispersion and uptake parameters. These programs are incorporated in a master code, *GENII - The Hanford Environmental Radiation Dosimetry Software System, Version 2.10.1* (PNNL-14583; PNNL-14584; PNNL-19168), which employs the internal dosimetry methodology described in ICRP 60 (ICRP 1991) and external dose coefficients described in Federal Guidance Report 12 (EPA 1993). GENII Version 1.485 (PNL-6584), which incorporated internal dosimetry methods of *International Commission on Radiological Protection Publication 30* (ICRP 1979a and 1979b) was used for dose calculations through 2008. GENII Version 2.10 is a Microsoft Windows®-based version that also incorporates some environmental modeling improvements (e.g., plume depletion during atmospheric transport) relative to Version 1.485. GENII Version 2.10.1 was used for dose calculations starting with 2016 data. The modeling assumptions and radionuclide release data used in the GENII calculations are the primary focus of Section D.1. The ingestion and inhalation dose coefficients (ICRP 1991) and external dose coefficients (EPA 1993) used for the pathway dose calculations are described further in PNNL-14584 and are not reproduced here.

In addition to the GENII calculations for assessing public doses, the computer program CAP-88PC (also known as CAP-88) was used to calculate an air pathway dose to an MEI for compliance with *Clean Air Act* standards, as required by the U.S. Environmental Protection Agency (EPA) through 40 CFR 61, "National Emission Standards for Hazardous Air Pollutants," Subpart H, from airborne radionuclide effluents (other than radon-220 and radon-222) released at the U.S. Department of Energy (DOE) facilities. Air pathway calculations performed with the CAP-88PC computer code differ slightly from those performed in GENII. Technical details of the CAP-88PC calculations are provided in DOE/RL-2017-17, *Radionuclide Air Emissions Report for the Hanford Site, Calendar Year 2016*.

Calculations of radiological doses to the public from radionuclides released into the environment are performed to demonstrate compliance with applicable standards and regulations. DOE O 458.1 provides requirements for demonstrating compliance with the public dose limit of 100-mrem (1,000-µSv) total effective dose in a year. Relevant requirements include the following:

- Compliance may be demonstrated by calculating dose to the representative person or to the MEI
- Collective dose for members of the public should be calculated, and may be truncated, by distance (e.g., 50 mi [80 km])

- The representative person or MEI must include members of the public outside of controlled areas on and off DOE sites

- Analytical models used to calculate dose must be codified or approved by DOE and must consider likely exposure pathways, including external radiation from air and soil, inhalation, and ingestion of water and terrestrial/aquatic foods

- Calculations of doses to the public from exposures resulting from both routine and unplanned activities must be performed using DOE-approved dose conversion factors

- Values of default or site-specific parameters used in the dose modeling must be included to document the calculations.

A summary of how the location of the offsite MEI was identified and information on modeling assumptions and inputs to the GENII computer code used to conduct the MEI dose calculations is provided in Section D.1.1. Information supporting the calculation of collective offsite dose for members of the public using the GENII computer code is provided in Section D.1.2.

D.1.1 Maximally Exposed Individual Dose

The MEI is a hypothetical member of the public whose location and lifestyle make it unlikely that any actual individuals would receive higher doses. The location of the MEI can vary annually depending on the following:

- The relative contributions of the different operational areas to radioactive emissions released to the air

- The contribution of radionuclide releases to the Columbia River from Hanford Site facilities

- Variable differences in meteorology affecting wind dispersion

- The following potentially significant exposure pathways are considered for identifying the location of this hypothetical individual and calculating radiation dose:

  - Inhalation of airborne radionuclides

  - External exposure from submersion in airborne radionuclides

  - Ingestion of foodstuffs contaminated by radionuclides deposited on vegetation and the ground by airborne deposition and/or irrigation water drawn from the Columbia River downstream of the Hanford Site

  - Incidental ingestion of soil and external exposure to ground contaminated by airborne deposition and/or irrigation water

  - Ingestion of drinking water drawn from the Columbia River

- Consumption of fish from the Hanford Reach of the Columbia River

- Recreational activities along the Hanford Reach of the Columbia River (e.g., fishing, hunting, boating, swimming, and exposure to sediments during shoreline activities).

D.1.1.1 Determination of the Location of the MEI. Based on experience since 1990 from environmental transport modeling and environmental surveillance monitoring, four locations (Section 4, Figure 4.2) are considered for identifying the location of the MEI. The distinguishing characteristics of these locations are described in the following paragraphs.

Riverview MEI. The Riverview area is across the Columbia River from the City of Richland. Because of its location, an individual in the Riverview area has the potential to receive the maximum exposure to waterborne effluent from Hanford Site facilities, as well as some contribution from exposure to airborne emissions from the 300 Area. The Riverview location is where a small population of West Pasco residents obtain their drinking water from the river via a community water system; therefore, the domestic drinking water pathway is applied to this location. Columbia River water from just downstream of the Hanford Site is also withdrawn for irrigation of small gardens and farms at Riverview.

Ringold MEI. The Ringold area is along the eastern shoreline of the Columbia River, 16 mi (26 km) east of separations facilities in the 200 Areas. Because of its location, an individual in the Ringold area has the potential to receive the maximum exposure to airborne emissions from the 200 Areas. In addition, it is assumed that some individuals in the Ringold area may irrigate their crops with water from the Columbia River downstream of where contaminated groundwater originating from the 100 and 200-East Areas enters the river. For identifying the MEI, Hanford Site contributions to irrigation water at Ringold are protectively evaluated using the same downstream concentrations employed for Riverview. Domestic drinking water at Ringold is not obtained from the Columbia River, so this exposure pathway is incomplete.

Sagemoor MEI. An individual in the Sagemoor area, located 0.87 mi (1.4 km) directly across the Columbia River from the 300 Area, frequently receives maximum exposure to airborne emissions from the 300 Area. However, domestic water at this location comes from wells rather than from the river. As a result, wells on the eastern side of the Columbia River are not impacted by radionuclides of Hanford Site origin. Because the farms located across from the 300 Area obtain irrigation water from the Columbia River upstream of the Hanford Site, irrigation-related exposure pathways are likely incomplete at this location. However, because some individuals may obtain much of their food from local agriculture, Columbia River irrigation pathways agricultural dose has been historically assigned to the Sagemoor area MEI. This practice protectively but unrealistically sums the location-specific air deposition component of food-related dose with the irrigation component from another location. The added contribution of radionuclides in the Riverview area irrigation water maximizes the calculated dose from the air and water pathways combined.

Horn Rapids Road MEI. Meteorological conditions in 2012 through 2016 resulted in a more southerly direction of wind dispersion than has been observed in past years. As a result, air concentrations related to 300 Area emissions were modeled to be slightly higher at a location just to the south of the Hanford Site boundary than at the Sagemoor location across the Columbia River to the east. Buildings in this area historically have been associated with commercial and industrial activities. However, in recent years, residences also have been constructed near the southern boundary of the Hanford Site south of the

300 Area. Residences in this area obtain drinking water from the City of Richland, which has an intake on the Columbia River downstream of the Hanford Site; therefore, the domestic drinking water pathway is applied to this location. Additionally, some agriculture in this area occurs on leased property that receives irrigation water from the Battelle pumping station on the Columbia River just below the 300 Area.

During the period of plutonium production at the Hanford Site, Ringold was commonly the location of the MEI. Because of the shift in Hanford Site operations from nuclear weapons production to the current mission of managing waste products, cleaning up legacy waste, and researching new ideas and technologies for waste disposal and cleanup, the significance of air emissions from production facilities in the 200 Areas has decreased compared to emissions from research facilities in the 300 Area. For the past two decades, the hypothetical MEI has been associated with air emissions from the 300 Area.

Because the hypothetical MEI at all locations is assumed to potentially receive dose from consumption of foods raised using Columbia River irrigation water, the identification of the location of the MEI is based on the highest projected dose among the following air pathway receptor locations: at Ringold (200 Area air emissions sources), Sagemoor (300 Area air emissions sources), Horn Rapids Road (300 Area air emissions sources, plus drinking water pathway dose), and Riverview (300 Area air emissions sources, plus drinking water pathway dose).

For 2017, air pathway radiological dose calculations conducted using CAP-88PC in support of the *Clean Air Act* requirements and GENII Version 2.10.1 have identified the Horn Rapids Road as the location with the highest MEI dose. Air pathway calculations performed with the GENII computer code indicate that Sagemoor and Horn Rapids Road air pathway MEI doses in 2017 are almost identical (0.21 mrem at Sagemoor and 0.22 mrem at Horn Rapids Road). Unlike the Sagemoor receptor, the MEI at Horn Rapids Road receives additional dose from the drinking water pathway, but the contribution of water pathway doses in 2017 (0.0011 mrem) was negligible. A comparison of Sagemoor and Horn Rapids Road MEI GENII results are shown in Section 4.0, Figure 4.4.

MEI location coordinates relative to Hanford Site operating areas are entered in the GENII computer code to specify the location for the air pathway dose calculations. For Sagemoor, these coordinates are:

100 Area: 26.874 km Easting, 30.064 km Northing	300 Area: 1.35 km Easting, 0.26 km Northing
200 Areas: 24.954 km Easting, 20.814 km Northing	400 Area: 7.909 km Easting, 6.739 km Northing

For Horn Rapids Road, these coordinates are:

100 Area: 29.1 km Easting, –29.1 km Northing	300 Area: 0 km Easting, –1.80 km Northing
200 Areas: 22.6 km Easting, –22.6 km Northing	400 Area: 7.92 km Easting, –7.92 km Northing

D.1.1.2 Water and Air Release Inputs Used In GENII Version 2.10.1. As discussed in Section 4.2, the environmental data needed to perform the GENII Version 2.10.1 dose calculations for the water pathway are the measured upstream and downstream radionuclide concentrations in the Columbia River. As discussed below, radionuclide releases to the Columbia River that are calculated as the difference between annual-average downstream and upstream concentrations. The source of these differences are assigned to the 200 Areas but area assignment does not affect the dose results. Measured emissions of radionuclides in stack releases are used in the GENII air pathway dose calculations. These air and water pathway data must be processed for input to the GENII computer code. GENII accepts inputs for environmental releases using dimensions of activity (e.g., curie or becquerel) per time for both water and air pathways.

Direct liquid effluent releases from outfalls in the 100 Area were historically used to characterize contributions from the 100 Area. The last operating outfall, 1908-K in the 100-K Area, ceased operations at the end of March 2011; therefore, no annual releases were identified from the 100 Area in 2017. Liquid effluent discharges related to historical Hanford operations are known to enter the Columbia River by groundwater discharge at certain locations along the site shoreline from the 100-B/C Area downstream to the 300 Area. The impact of these discharges was evaluated as the difference between near-shore riverwater radionuclide concentrations downstream of the Hanford Site (samples collected at the Richland Pumphouse, sampling location label RICH.PMPHS HRM46.4) and upstream of the Hanford Site (samples collected at a location below the Priest Rapids Dam, sampling location label PRIEST RAPIDS-RIVER). Radionuclides are measured in both filtered samples (in solution) and in samples that capture suspended particulates (adhered to a resin). These data for dissolved and particle-bound radionuclides were evaluated both separately and summed.

The river water samples used in the GENII dose assessment are based on continuous sampling of river water. A continuous sampler collects 55-mL water samples at 1-hr intervals. These samples are composited bimonthly and then combined for a single monthly composite that is submitted for laboratory analysis (DOE/RL-2017-24). In August 2017, the Richland Pumphouse sampling station continuous water sampler failed, and these samples were not collected. In their stead, 0.5-gal (2-L) grab water samples were collected once per month for the period of August through December 2017. River flow varies seasonally and in response to operations of upstream dams, which can produce a change of up to 10 ft (3 m) in Hanford Reach river elevation within a few hours (DOE/RL-2017-24). Changes in river flow and elevation can lead to changes in river water concentrations of Hanford-related radionuclides. Ideally, downstream and upstream water would be sampled using the same method to eliminate artificial differences related to sample collection method. The continuous (hourly) increments better represent the full range of monthly water quality conditions. Therefore, the substitution of once a month grab samples for continuous (hourly) samples at RICH.PMPHS HRM46.4 in the latter part of the year affected the ability to accurately measure monthly average downstream concentrations.

Specifically, as discussed in Section 4.2.1.1, it is possible that dose from the water pathways has been underestimated in 2017 when, unlike in previous years, neither uranium-234 nor uranium-238 were identified at higher levels in Columbia River samples downgradient of the Hanford Site relative to upstream levels. The difference in downstream versus upstream contaminant concentrations is commonly larger during the fall when river flow is lowest and effluent discharges from the Hanford Site are less diluted. A single grab sample cannot be representative of an entire month. If, for example, the grab was collected at a time with relatively high river flow or elevation, then this would have inadvertently created a low result in the measured downstream concentrations. As shown in Figure 4-5,

from 2002 through 2016 annual-average downstream concentrations of uranium have generally been larger than upstream concentrations, but there is also an increasing trend in uranium concentrations from 2012 through 2017 at both upstream and downstream locations. The change to grab samples at the Richland Pumphouse beginning August 2017, and/or the trend of increasing uranium concentrations at both upstream and downstream locations, could be factors in explaining why uranium releases to the Columbia River were not identified in 2017.

One-tailed paired t-tests and nonparametric Wilcoxon Rank Sum (WRS) tests were used to determine whether average downstream sample concentrations were statistically greater than upstream average concentrations. The results of statistical tests were used in conjunction with supporting information such as known releases from groundwater plumes to the river and historical observations in river water to identify Hanford-related contaminants. The paired t-test is more powerful than the ordinary t-test when the values in the pairs correlate or when the concentrations measured downstream tend to correlate to those upstream. The WRS test has less power than the t-test when the data originate from a normal distribution, but the assumptions under which the statistical results are valid are not as restrictive. A p-value of 0.05 is commonly used as the threshold of statistical significance but a larger, less restrictive value may be used when other factors support evidence of a release. Likewise, when a contaminant does not have any known Hanford Site sources, a smaller threshold could be appropriate to identify radionuclides for the dose assessment.

Both statistical tests identified tritium as a potentially Hanford-related contaminant to include in the 2017 water pathway dose assessment using a p-value of 0.05. As discussed above, concentrations of uranium isotopes in downstream samples were not greater than upstream concentrations in 2017. Statistical tests could not be conducted for gamma-emitting radionuclides and isotopic plutonium, analytes that are commonly present in forms that are relatively insoluble (antimony-125, beryllium-7, cesium-134, cesium-137, cobalt-60, isotopic europium, isotopic plutonium, potassium-40, and ruthenium-106). With the continuous flow sampler, these radionuclides are sampled by passing water through a filter to trap particulates and subsequently through a resin column to trap radionuclides in solution. The minimum detectable activity of plutonium isotopes in the grab samples was about 100-times larger than that of the continuous samples; for the gamma-emitting analytes this difference ranged from several hundred to approximately 1,000-times larger. However, with the exception of beryllium-7 and potassium-40, these radionuclides were not measured at levels above minimum detectable activities in any sample including those collected with the continuous sampler at the Richland Pumphouse through July 2017. Beryllium-7 is a naturally occurring radionuclide of cosmogenic origin with a half-life of approximately 53 days. Because of its short half-life, it is not plausibly present today due to historical Hanford operations. Potassium-40 is a primordial radionuclide (half-life of approximately 1.25E+09 years) that is naturally occurring and has no known Hanford-related sources.

Table D-1 summarizes the mean annual differences in downstream and upstream concentrations, and calculated annual releases for the 2017 GENII water pathway dose calculations.

Table D-1. Liquid Effluent Radionuclide Releases for GENII Dose Calculations.

Radionuclide	Upstream	Downstream	Difference
Columbia River Annual-Average Radionuclide Concentrations (pCi/L)[a]			
Tritium	1.5E+01	2.4E+01	9.6E+00
Calculated Radionuclide Releases (Ci/year) [b]			
Tritium	NA [d]	NA [d]	1.18E+03

[a] 1 pCi=0.037 Bq
[b] Calculated as the product of the difference in downstream and upstream radionuclide concentrations and the 2017 annual-average river flow rate of 1.24E+14 L/yr at Priest Rapids Dam.
[d] Radionuclide releases calculated based on difference between annual-average downstream and upstream concentrations.
NA = not applicable

Radioactive air emissions based on monitoring of stacks in the 100, 200, 300, and 400 Areas were used as the basis for the GENII air pathway dose calculations. Stack emissions are measured for specific radionuclides related to the operations at each emissions point. During the dispersion time from the stack to an offsite exposure location, there is opportunity for ingrowth of short-lived radioactive progeny that are included in the GENII radionuclide inventory. A protective upper-bound dispersion time of 15 hours was estimated based on the longest dispersion distance in the collective dose calculations (50 mi [80 km]) and an assumed (4.9 ft/sec [1.5 m/sec]) average wind speed. The highest short-term (15-hr ingrowth period) concentrations of short-lived progeny that have a separate dose conversion factor were included in the GENII air emissions inventory to address their potential contribution to the inhalation dose. Ingrowth of longer-lived progeny in soil and other environmental media is accounted for within GENII.

In addition to measurement of specific radionuclides, gross alpha and gross beta measurements were also made on emissions from each operating area. Following the precedent of DOE/RL-2018-5, measurements of gross alpha and gross beta radiation in stack emissions were protectively added to the measured emissions of plutonium-239/240 and cesium-137, respectively, to ensure that contributions from any unmeasured operations-related radionuclides were incorporated in the estimated doses. These specific radionuclides were selected based on their historical association with releases in these operating areas and because air pathway calculations indicate dose is highest for these radionuclides among the group of plausible candidates of alpha- and beta-emitting radionuclides. Annual radionuclide air releases used in the GENII air pathway dose calculations are summarized in Table D-2.

Table D-2. Air Pathway Radionuclide Stack Emissions for GENII Modeling. (3 Pages)

Radionuclide	100 Area	200 Areas	300 Area	400 Area
	(Curies)			
Hydrogen-3 (elemental tritium)	NA [a]	NA [a]	16	NA [a]
Hydrogen-3 (tritiated water vapor)	NA [a]	NA [a]	160	0.016
Carbon-14	NA [a]	NA [a]	1.2E-04	NA [a]
Sodium-22	NA [a]	NA [a]	NA	2.1E-10

Table D-2. Air Pathway Radionuclide Stack Emissions for GENII Modeling. (3 Pages)

Radionuclide	100 Area	200 Areas	300 Area	400 Area
	(Curies)			
Cobalt-60	NA [a]	NA [a]	7.7E-08	NA [a]
Krypton-85	NA [a]	NA [a]	5.2E-07	NA [a]
Stontium-90	5.5E-06	5.9E-06	1.9E-07	NA [a]
Yttrium-90 [a]	8.2E-07	8.8E-06	2.8E-08	NA [a]
Technetium-99	NA [a]	NA [a]	4.1E-06	NA [a]
Ruthenium-106	NA [a]	NA [a]	1.3E-09	NA [a]
Iodine-129	NA [a]	9.3E-04	NA [a]	NA [a]
Cesium-134	NA [a]	NA [a]	NA [a]	NA [a]
Cesium-137 [b]	2.0E-05	2.2E-05	1.4E-05	1.9E-06
Barium-137m [b, c]	2.0E-05	2.2E-05	1.4E-05	1.9E-06
Europium-152	NA [a]	NA [a]	2.2E-09	NA [a]
Europium-154	NA [a]	NA [a]	1.1E-08	NA [a]
Gadolinium-153	NA [a]	NA [a]	9.0E-11	NA [a]
Radon-219	NA [a]	NA [a]	3560	NA [a]
Lead-211 [c]	NA [a]	NA [a]	6.4	NA [a]
Bismuth-211 [c]	NA [a]	NA [a]	1.1	NA [a]
Thallium-207 [c]	NA [a]	NA [a]	5.0E-02	NA [a]
Radon-220	NA [a]	NA [a]	885	NA [a]
Lead-212 [c]	-- [d]	-- [d]	1.3E+00	NA [a]
Bismuth-212 [c]	-- [d]	-- [d]	1.1E+00	NA [a]
Radon-222	NA [a]	NA [a]	3.6E-05	NA [a]
Polonium-218 [c]	NA [a]	NA [a]	3.6E-05	NA [a]
Lead-214 [c]	NA [a]	NA [a]	3.4E-05	NA [a]
Bismuth-214 [c]	NA [a]	NA [a]	3.2E-05	NA [a]
Radium-226	NA [a]	NA [a]	3.7E-10	NA [a]
Actinium-227	NA [a]	NA [a]	3.1E-10	NA [a]
Uranium-232	NA [a]	NA [a]	8.6E-09	NA [a]
Uranium-233	NA [a]	NA [a]	2.3E-08	NA [a]
Neptunium-237	NA [a]	NA [a]	1.4E-08	NA [a]
Plutonium-238	4.1E-07	1.8E-07	3.6E-08	NA [a]
Plutonium-239/240 [e]	1.1E-05	3.1E-05	4.6E-06	2.9E-07
Plutonium-241	1.4E-05	3.3E-06	NA	NA [a]
Americium-241	3.9E-06	2.2E-06	1.6E-08	NA [a]
Americium-243	NA [a]	NA [a]	4.3E-08	NA [a]
Neptunium-239 [e]	-- [d]	-- [d]	7.3E-09	NA [a]
(gross alpha)	8.2E-06	2.1E-05	4.6E-06	2.9E-07
(gross beta)	1.5E-05	1.9E-05	1.4E-05	1.9E-06

Table D-2. Air Pathway Radionuclide Stack Emissions for GENII Modeling. (3 Pages)

Radionuclide	100 Area	200 Areas	300 Area	400 Area
	(Curies)			

[a] No stack emissions reported for this radionuclide.
[b] Values include the addition of gross beta activity.
[c] These short-lived radionuclides will ingrow during air dispersion to offsite locations and contribute to inhalation dose. Values are the highest activity calculated within an upper bound 15-hr dispersion time period to any exposure point within a 50-mi (80-km) distance.
[d] Separate stack emission estimates were not reported for this short-lived radionuclide.
[e] Values include the addition of gross alpha activity.

-- = Not included;
NA = Not available or not detected.

D.1.1.3 Exposure Parameter Values Used in GENII Version 2.10.1. GENII Version 2.10.1 requires input values for numerous parameters used in the environmental transport and human exposure models. Important parameters affecting the movement of radionuclides within agricultural exposure pathways such as animal dietary parameters, irrigation rates, crop yield, growing periods, and holdup periods are listed in Table D-3. The plant, animal, and aquatic foods transfer factors used for the pathway dose calculations are documented in PNNL-14584 and are not reproduced here.

The offsite radiological dose is related to the extent of external exposure to or intake of radionuclides released from Hanford Site operations that become incorporated in exposure media such as air, water, soil, sediment, and various foodstuffs. Tables D-4 through D-6 provide the values for the diet, residency, and river recreation parameters for the MEI and collective dose (average individual) calculations.

D.1.1.4 Meteorological Data Used in GENII Version 2.10.1. GENII Version 2.10.1 employs an atmospheric dispersion model to calculate annual-average air concentrations and deposition rates at downwind locations based on site-specific radionuclide air emissions measurements and meteorological data (PNNL-14583). The 2017 meteorological data used in the GENII air dispersion modeling were gathered at monitoring stations in the 100 Area (station 29 100-K), 200 Areas (station 21; Hanford Meteorological Station), 300 Area (Station 11; 300 Area), and 400 Area (station 9; Fast Flux Test Facility). With the exception of the 100 and 200 Areas, all meteorological data were obtained at a height of 33 ft (10 m). In the 100-K Area, the temporary tower was implemented at 10 ft (3 m) in height. In the 200 Areas, where some active stacks are 200 ft (61 m) in height, the meteorological data used were collected at 200 ft (61 m).

Table D-3. Agricultural Pathway Parameters for Hanford Site Dose Calculations.

Medium	Vegetables		Fruits	Cereals	Eggs	Poultry	Beef	Milk	Hay (beef cattle, milk cows)	Pasture (milk cows)	Grains (beef cattle, poultry)
	Leafy	Root									
Holdup time[a]; day (MEI)	1	5	5	180	1	1	15	1	100	0	180
Holdup time[a]; day (population)	14	14	14	180	18	34	34	4	100	0	180
Growing period; day	90	90	90	90	NA	NA	NA	NA	45	30	90
Yield; kg/m[b]	1.5	4	2	0.8	NA	NA	NA	NA	2	1.5	0.8
Irrigation rate; cm/yr	77	88	77	NA[c]	NA	NA	NA	NA	103	103	NA[c]
Irrigation period; month	6	6	6	NA[c]	NA	NA	NA	NA	6	6	NA[c]
Water intake; L/year	NA	NA	NA	NA	0.3	0.3	50	60	NA	NA	NA
Food intake; kg/day	NA	NA	NA	NA	0.12	0.12	68/68[d]	55/55[e]	NA	NA	NA
Contaminated fraction of diet[b]	NA	NA	NA	NA	1.0	1.0	0.25/0.75[d]	0.25/0.75[e]	NA	NA	NA
Livestock soil intake; kg/day	NA	NA	NA	NA	0.0	0.0	0.0	0.375[f]	NA	NA	NA

[a] Holdup time is the time between harvest and consumption
[b] Pertains to animal feed; 100% of animal water is assumed contaminated surface water.
[c] No irrigation is assumed to occur for cereal crops or grains.
[d] First value pertains to grains, and second value pertains to hay.
[e] First value pertains to hay, and second value pertains to pasture grass.
[f] Calculated as 0.5 kg soil/day while grazing × 0.75 diet fraction of pasture grass.

MEI=maximally exposed individual
NA=not applicable

Table D-4. Consumption Parameters for Hanford Site Dose Calculations.

Medium	Consumption Rate[a]	
	Maximally Exposed Individual	Average Individual (Collective Dose)
Leafy vegetables	66 lbs (30 kg)/yr	33 lbs (15 kg)/yr
Root vegetables	485 lbs (220 kg)/yr	310 lbs (140 kg)/yr
Fruits	728 lbs (330 kg)/yr	140 lbs (64 kg)/yr
Cereals	180 lbs (80 kg)/yr	160 lbs (72 kg)/yr
Milk	71 gal (270 L)/yr	61 gal (230 L)/yr
Beef	180 lbs (80 kg)/yr	150 lbs (70 kg)/yr
Poultry	40 lbs (18 kg)/yr	19 lbs (8.5 kg)/yr
Eggs	66 lbs (30 kg)/yr	44 lbs (20 kg)/yr
Fish[b]	88 lbs (40 kg)/yr	--[c]
Drinking water[d]	193 gal (730 L)/yr	116 gal (440 L)/yr
Inadvertent soil ingestion	1.17 oz (36.5 g)/yr	0.59 oz (18.3 g)/yr

[a] A transit time of 11 hours from the release to receptor locations is assumed.
[b] A holdup time of 1 day is used for both MEI and population calculations.
[c] Average individual consumption not identified; see text of Section D.1.2.
[d] A holdup time of 1 day is used for the Riverview calculations for identification of the location of the MEI.
MEI = maximally exposed individual

Table D-5. Residency Parameters for Hanford Site Dose Calculations.

Pathway	Exposure	
	Maximally Exposed Individual	Average Individual (Collective Dose)
Air: Inhalation[a, b]	24 hrs/day, 365 days/yr	24 hrs/day, 365 days/yr
Air: external (submersion)[b]	24 hrs/day, 365 days/yr	24 hrs/day, 365 days/yr
Soil: external (groundshine)	12 hrs/day, 365 days/yr	8 hrs/day, 365 days/yr

[a] Inhalation rate, adult 1.0 m^3/hr (35 ft^3/hr).
[b] Dispersion time of 15 hours is protectively assumed for ingrowth of short-lived progeny during transport (50 mi [80 km]) population dose radius and 4.9 ft/sec (1.5 m/sec) wind speed.

Table D-6. Columbia River Parameters for Hanford Site Dose Calculations.

Activity and Pathway	Exposure[a]	
	Maximally Exposed Individual	Average Individual (Collective Dose)
Shoreline: sediment; external	5.0 hrs/day, 100 days/yr[b]	1.7 hrs/day, 10 days/yr[b]
Boating: river water; external	2.0 hrs/day, 50 days/yr[c]	0.1 hr/day, 50 days/yr[c]
Swimming: river water; inadvertent ingestion[d], external	2.0 hrs/day, 50 days/yr	0.2 hr/day, 50 days/yr

[a] A transit time of 11 hours from the release to receptor locations is assumed.
[b] A shoreline width factor of 0.2 is used.
[c] No shielding by the boat is assumed.
[d] Ingestion rate of 0.68 oz (0.02 L)/hr.

Hourly meteorological data from the monitoring stations described above were formatted for use in the GENII computer code. Four meteorological files were created, one for each of the Hanford Site operating areas and stations described above. These files were referenced in the GENII Chronic Plume

Air Module. A radial grid consisting of 16 directional sectors and 10 downwind distances was specified in the air module. The downwind distances were varied for each operating area to coincide with the distance to the MEI location, as defined by the Easting and Northing coordinates described in Section D.1.1.1. For example, the finest resolution was entered for the distance from the 300 Area to the MEI location.

D.1.2 Fifty-Mile (Eighty-Kilometer) Collective Population Dose

Regulatory limits have not been established for collective doses to a population; however, evaluation of the collective population doses to all residents within a 50-mi (80-km) radius of Hanford Site operations is required by DOE O 458.1. The radiological dose received by the total population within 50 mi (80 km) of site operation areas was calculated to conform to DOE environmental protection policies and to provide information to the public. The 50-mi (80-km) collective dose is the sum of doses to all individual members of the public within 50 mi (80 km) of the four Hanford Site operations areas (100, 200, 300, and 400 Areas).

The same exposure pathways evaluated for the MEI (Section D.1.1) were used to calculate doses to the offsite population. The primary difference between the MEI and collective dose calculations is in the values selected for certain exposure parameters. As shown in Tables D-4, D-5, and D-6, exposure parameter values for the collective dose calculations reflect an average individual rather than an MEI.

In calculating the collective dose related to water-mediated exposure pathways (drinking water, irrigated foods, Columbia River recreation, and fish consumption), estimates were made of the offsite population size expected to be affected by each pathway. The assumptions of population size and the calculation of collective dose for each of these four exposure pathways are described in the following paragraphs.

D.1.2.1 Drinking Water. The cities of Richland and Pasco obtain all or part of their municipal water directly from the Columbia River downstream from the Hanford Site; the City of Kennewick obtains its municipal water indirectly from wells adjacent to the river. Approximately 182,000 people residing in the Tri-Cities[2] are assumed to obtain all of their drinking water directly from the Columbia River or from impacted wells near the river that are assumed to have the same radionuclide concentrations as were measured in near-shore river water. Annual drinking water dose for an average individual is multiplied by the Tri-Cities population to calculate the collective drinking water dose.

D.1.2.2 Irrigated Food. Columbia River water is withdrawn for irrigation of small vegetable gardens and farms in the Riverview area of Pasco in Franklin County. It is assumed enough food is grown in this area to feed an estimated 2,000 people. Commercial crops are also irrigated by the Columbia River in the Horn Rapids area of Benton County. Because these crops are widely distributed, any individual in the Tri-Cities is likely to receive only negligible potential exposure. An annual irrigated foods dose for an average individual is protectively multiplied by the estimate population of 2,000 individuals to calculate the collective irrigated foods dose.

[2] The Cities of Pasco, Kennewick, and Richland—known as the Tri-Cities—are located in southeastern Washington State. Population estimates are based on the 2010 census, from https://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml.

D.1.2.3 Columbia River Recreation. As described in Section 4.2 and Section D.1.1, recreational activities on the Columbia River include fishing, swimming, boating, and shoreline recreation. It was protectively assumed that all 182,000 individuals in the Tri-Cities participated in these recreational activities. Annual recreational dose for an average individual is multiplied by the Tri-Cities population to calculate the collective recreational dose.

D.1.2.4 Fish Consumption. Population doses from consuming fish obtained locally from the Columbia River were calculated from an estimated total annual catch of 33,000 lb (15,000 kg)/yr. It was protectively assumed that 100% of the annual catch was consumed by individuals in the Tri-Cities area and that tissue concentrations in the fish were in equilibrium with concentrations of radionuclides in river water, which is likely to introduce a protective bias for anadromous fish such as salmon and steelhead. Population dose related to fish consumption was calculated as follows:

Population dose (person-rem) = MEI dose (mrem) × 0.001 rem/mrem × (annual catch [kg/yr]/IR_fish [kg/yr/person]), where MEI dose=fish ingestion dose for the MEI; annual catch=15,000 kg fish/yr; IR_fish=individual fish ingestion rate used in the MEI calculation (40 kg/yr/person)

Collective dose related to air-mediated exposure pathways was calculated based on the geographic distribution of the population residing within a 50-mi (80-km) radius of the Hanford Site operating areas (PNNL-20631, *Hanford Site Regional Population—2010 Census*). These distributions are based on 2010 United States Census Bureau data and influence the population dose by providing estimates of the number of people exposed to radioactive air emissions and their proximity to the points of release.

The air pathway collective dose calculations are based on modeled radionuclide air concentrations and deposition rates downwind of the Hanford Site operating areas coupled with the geographic population distribution in these areas. Both meteorological and population distribution data are organized according to 16 directional sectors based on the 4 cardinal, 4 ordinal, and 8 cross-wind directions (e.g., N, NNE, NE, ENE). These sectors were transformed into grids using concentric circles with radii of 1, 2, 3, 4, 5, 10, 20, 30, 40, and 50 mi (1.6, 3.2, 4.8, 6.4, 8, 16, 32.1, 48.2, 64.3 and 80.4 km). These radii correspond to the downwind distances specified in the GENII Chronic Plume Air Module. Population files were created based on the number of individuals located in each of the 160-grid segments centered on the 100, 200, 300, and 400 Areas (PNNL-20631). These files were identified in the GENII Air Dose Report Module.

D.2 Calculation of Biota Doses

The RESidual RADioactivity (RESRAD)-BIOTA 1.8 computer code was used to screen the 2017 radionuclide concentrations in water, sediment, soil, and tissues to see if they exceeded the established biota concentration guides. Biota concentration guides (BCGs) are concentrations published in DOE-STD-1153-2002, *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota*, that could result in a dose rate of 1 rad/day for aquatic biota or 0.1 rad/day for terrestrial organisms. Table D-7 presents water and sediment Tier 1 biota concentration guides for the radionuclides evaluated. Table D-8 presents the soil Tier 1 biota concentration guides for the radionuclides evaluated. Both internal and external doses to aquatic, riparian, and terrestrial animals and plants are included in the screening process. For with multiple media and radionuclides analyses, a sum of fractions is calculated to account for the contribution to dose from each radionuclide relative to its corresponding biota concentration guide. If the sum of fractions exceeds 1.0, then the dose guideline has been

exceeded. If the initial estimated screening value (Tier 1) exceeds the dose limit (sum of fractions more than 1.0), additional screening calculations are performed (Tiers 2 or 3) to evaluate accurate exposure of biota to radionuclides. The process may culminate in a site-specific assessment requiring additional sampling and study of exposure.

Table D-7. Biota Concentration Guides and Sediment to Water Distribution Coefficients.

Radionuclide	Water (pCi/L)[a]	Limiting Organism	Sediment (pCi/g)[a]	Limiting Organism	Default K_d (mL/g)[b]
Hydrogen-3	2.65E+08	Riparian animal	3.74E+05	Riparian animal	0.001
Carbon-14	6.09E+02	Riparian animal	5.90E+04	Riparian animal	0.001
Strontium-90	2.78E+02	Riparian animal	5.82E+02	Riparian animal	30
Technetium-99	6.67E+05	Riparian animal	4.22E+04	Riparian animal	5
Cesium-137	4.26E+01	Riparian animal	3.12E+03	Riparian animal	500
Plutonium-238	1.76E+02	Aquatic animal	5.73E+03	Riparian animal	2000
Plutonium-239/240	1.87E+02	Aquatic animal	5.86E+03	Riparian animal	2000
Uranium-234	2.02E+02	Aquatic animal	5.27E+03	Riparian animal	50
Uranium-235	2.17E+02	Aquatic animal	3.73E+03	Riparian animal	50
Uranium-238	2.23E+02	Aquatic animal	2.49E+03	Riparian animal	50

[a] 1 pCi=0.037 Bq. Biota concentration guides (pCi/g or pCi/L) from RESRAD-BIOTA v1.8.
[b] K_d=Sediment to Water Distribution Coefficients (mL/g) from RESRAD-BIOTA v1.8.
RESRAD = RESidual RADioactivity

Table D-8. Tier 1 Soil Biota Concentration Guides.

Radionuclide	Soil (pCi/g)[a]	Limiting Organism
Strontium-90	2.25E+01	Terrestrial animal
Cesium-137	2.08E+01	Terrestrial animal
Plutonium-238	5.27E+03	Terrestrial animal
Plutonium-239/240	6.11E+03	Terrestrial animal
Uranium-234	5.13E+03	Terrestrial animal
Uranium-235	2.77E+03	Terrestrial animal
Uranium-238	1.58E+03	Terrestrial animal
Americium-241	3.89E+03	Terrestrial animal

[a] 1 pCi=0.037 Bq.
Biota concentration guides (pCi/g) from RESRAD-BIOTA v1.8.
RESRAD = RESidual RADioactivity

In the initial (Tier 1) screening assessment, researchers compare maximum measured concentrations to the biota concentration guides. The maximum detected concentrations evaluated for aquatic biota dose assessment are presented in Table D-9. If the sum of fractions does not exceed one, no further analysis is required. However, if the sum of fractions does exceed one, a second analysis (Tier 2) is performed using average concentrations and the same Tier 1 biota concentration guides. For the aquatic biota dose assessment, paired sediment and water data are required. In the event that only one of these media was sampled, the other was calculated using an element-specific sediment to water distribution coefficient. These coefficients are tabulated in Table D-7.

The sites for the aquatic biota dose assessment were grouped into the following:

- Upstream (Vernita sediment and Priest Rapids Dam river water samples)
- The 100 Area (sediments from 100-K, 100-D, 100-H, 100-F and White Bluff; river water from 100-N; and seeps from 100-BC, 100-K, 100-N, 100-D, 100-H, 100-F)
- The Hanford Town Site (sediments from Hanford slough, Savage Island, and Locke Island; river water; and seep water from Hanford Spring)
- The 300 Area (river water and springs)
- Downstream (sediments from McNary Dam and river water from the Richland Pumphouse station).

Table D-9. Maximum Detected Concentrations Evaluated for Aquatic Biota Dose Assessment. (2 Pages)

Location Group	Radionuclide	Maximum Sediment (pCi/g) [a]	Maximum Water (pCi/L) [a]
Upstream	Hydrogen-3	—	20.2
	Cesium-137	0.295	—
	Plutonium-239/240	0.0117	—
	Uranium-234	1.63	0.393
	Uranium-235	0.127	0.0765
	Uranium-238	1.43	0.267
100 Area	Hydrogen-3	—	3370
	Carbon-14	—	216
	Strontium-90	—	22.5
	Technetium-99	—	8.54
	Cesium-137	0.285	—
	Plutonium-238	0.00064	—
	Plutonium-239/240	0.00218	—
	Uranium-234	1.07	1.09
	Uranium-235	0.0958	0.101
	Uranium-238	0.932	0.859
Hanford Townsite	Hydrogen-3	—	15900
	Cesium-137	0.21	—
	Plutonium-238	0.0458	—
	Uranium-234	1.19	0.323
	Uranium-235	0.11	0.0644
	Uranium-238	1.03	0.232
300 Area	Hydrogen-3	—	4590
	Cesium-137	0.163	—
	Uranium-234	0.886	26.7
	Uranium-235	0.125	3.14[b]
	Uranium-238	0.958	24.8
Downstream	Hydrogen-3	—	26.5
	Cesium-137	0.239	—
	Uranium-234	1.69	0.404
	Uranium-235	0.18	0.0671
	Uranium-238	1.29	0.313

Table D-9. Maximum Detected Concentrations Evaluated for Aquatic Biota Dose Assessment. (2 Pages)

[a] 1 pCi = 0.037 Bq
[b] Uranium-236 was added to the uranium-235 value due to the lack of available BCGs for uranium-236 in RESRAD-BIOTA v1.8. These radionuclides have similar K_d values and emissions and thus would have similar calculated BCGs.
— = Not detected or not measured
K_d = Water to Sediment Distribution Coefficients (mL/g) from RESRAD-BIOTA v1.8
BCG = Biota Concentration Guide
RESRAD = RESidual RADioactivity

Radionuclides were selected for the aquatic biota dose assessment based primarily on their detection in sediment or water. In addition, having known or suspected sources from DOE operations, the results for tissue samples compared to reference (i.e., upstream, generally at Vernita Bridge), and the known potential for bioaccumulation was also used to identify which radionuclides should be included in the dose assessment. Most of the detected radionuclides in water (hydrogen-3 (tritium), carbon-14, strontium-90, technetium-99, and isotopic uranium) could readily be associated with known groundwater plumes. Most of the remainder of the detected radionuclides could have sources from DOE operations; however, due to relatively high soil-water distribution coefficients, these radionuclides would most likely be associated with sediments instead of water. Cesium-137 and isotopic plutonium were detected in sediments and may have sources from DOE operations. Although the magnitude of the sediment concentrations onsite is sometimes no greater than upstream, these radionuclides are included in the aquatic biota dose assessment. This is likely protective, as these radionuclides are not elevated above reference in tissues. Potassium-40 has no groundwater plumes or other known DOE sources; therefore, potassium-40 was not included in the aquatic biota dose assessment.

As discussed in Section 4.2.6, biota doses were evaluated for Columbia River water and sediment and West Lake water, sediment, and soils (onsite and offsite). For West Lake, Tier 1 sum of fractions exceeded 1.0; therefore, Tiers 2 and 3 calculations were implemented using the mean water concentrations presented in Table D-10. The tiered screening process is further described in DOE-STD-1153-2002.

Table D-10. West Lake 2017 Water and Sediment Samples.

Radionuclide	Water Concentration (pCi/L)[a]		Sediment Concentration (pCi/g)[a]	
	Maximum	Average	Maximum	Average
Hydrogen-3	305	305	—	
Strontium-90	—	—	0.368	0.182
Cesium-137	—	—	1.34	0.637
Uranium-234	658	447	3.62	1.29
Uranium-235	34.7	22.1	0.241	0.116
Uranium-238	623	421	3.38	1.23

[a] pCi=0.037 Bq

— = Not detected or not measured.

The Tier 1 and 2 West Lake biota dose assessments were driven by the potential for dose from uranium isotopes in water and the assumed potential for these isotopes to accumulate in biota. The isotopic ratios of uranium indicate a natural source (granitic erratic's from the Missoula floods) and no uranium-236 was detected, albeit some minor amounts of depleted uranium may be present (PNL-7662). Therefore, the Tier 3 West Lake biota dose calculations utilized site-specific information on bioaccumulation. As defined in DOE-STD-1153-2002, bioaccumulation is the ratio of the contaminant concentration in the organism relative to the contaminant concentration in an environmental medium resulting from the uptake of the contaminant from one or more routes of exposure. The more relevant biota data collected from West Lake are the brine flies sampled in 2000 and 2007 (PNNL-13487; DOE/RL-2007-50). Birds (avocets) were also sampled in 2000 and had lower concentrations than the brine flies (PNNL-13487). These birds are not year-round residents and, thus, have lower exposure and less potential for bioaccumulation at West Lake (DOE/RL-2007-50, Appendix K).

The maximum concentration of any of the uranium isotopes in brine flies was 0.88 pCi/g for uranium-233/234 in 2007. The minimum uranium-233/234 West Lake pond water concentration was 940 pCi/L in 2007. The bioaccumulation factor is calculated by dividing the biota concentration (in pCi/g) by the water concentration (in pCi/mL), because RESRAD-BIOTA assumes that aquatic bioaccumulation occurs from water to biota. Therefore, the maximum bioaccumulation factor for uranium would be less than one (0.88 divided by 0.94). Also, as presented in Table D-10 of DOE/RL-2011-119, *Hanford Site Environmental Report for Calendar Year 2011*, bioaccumulation factors for uranium isotopes based on the mean concentrations in flies and water were between 0.2 and 0.5. A bioaccumulation factor of one was used for the West Lake Tier 3 biota dose calculation as a somewhat protective measure of site-specific uranium uptake into the food chain. This same approach was used in the 2011 (DOE/RL-2011-119) and in annual reports since that date. The data supporting the site-specific bioaccumulation factor are presented in those reports. Table D-11 presents the Tier 3 biota concentration guides for isotopic uranium for both aquatic and riparian animals. These site-specific values were used in the RESRAD-BIOTA Tier 3 screening discussed in Section 4.2.6.

Table D-11. Tier 3 Biota Concentration Guides Calculated Using RESRAD-BIOTA v1.8.

Radionuclide	Water BCG (pCi/L) [a]		Sediment BCG (pCi/g) [a]	
	Aquatic Animal	Riparian Animal	Aquatic Animal	Riparian Animal
Uranium-234	202000	20200	3030000	5270
Uranium-235	217000	21700	110000	3790
Uranium-238	222000	22200	42900	2490

[a] 1 pCi=0.037 Bq

RESRAD = RESidual RADioactivity

Dose to terrestrial biota were evaluated using the onsite soil sample results. Note that offsite soil samples are collected every 3 to 5 years and are scheduled for collection in 2018. Table D-12 lists the maximum concentrations of strontium-90, cesium-137, plutonium-238, plutonium-239/240, uranium-234, uranium-235, uranium-238, and americium-241. These radionuclides were selected for the terrestrial biota dose assessment based on their detection in soil. In addition, having known or suspected sources from DOE operations, vegetation sample compared to soil results and the known potential for bioaccumulation were used to include or exclude radionuclides for the biota dose assessment.

The biota dose assessment also included supplemental calculations using measured concentrations in tissues. Presented in Section 4.2.6, these supplemental calculations provide a more realistic estimate of biota dose compared to doses calculated using the protective bioaccumulation assumptions made in the Tier 1 dose assessments. Section 4.2.6 lists the detected tissue concentrations evaluated in these supplemental dose calculations. The tissue concentrations are used for the internal dose calculations, whereas external dose is estimated from the relevant soil, sediment, and water concentrations. Maxima were used in the supplemental internal dose calculations, which is more protective than the mean recommended by DOE guidance for these Tier 3 dose calculations. However, the detections were infrequent for tissues and, therefore, the maximum detected values and mean detected values would be similar.

Table D-12. Maximum Detected Concentrations Evaluated for Terrestrial Biota Dose Assessment.

Location Group	Radionuclide	Maximum Soil Concentration (pCi/g) [a]
Onsite	Strontium-90	1.87
	Cesium-137	16
	Uranium-234	2.23
	Uranium-235	0.114
	Uranium-238	1.93
	Plutonium-238	0.127
	Plutonium-239/240	1.6
	Americium-241	0.042

[a] 1 pCi=0.037 Bq.

D.3 References

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