2018 Highlight

External Monitoring
Overall, the average dose rate levels measured in the operational areas during 2018 were comparable to the previous years' levels. Individual thermoluminescent dosimeter results and detailed maps of monitoring locations are available upon request.

Dose to the Offsite Maximally Exposed Individual
The dose to the offsite maximally exposed individual was 0.28 mrem (2.8 µSv)/yr for air emissions releases and releases to Columbia River water combined, which is 0.28% of the 100 mrem/yr U.S. Department of Energy dose standard.

Recreationalist Dose
Wildlife sampling was conducted at the Hanford Site to measure radionuclide tissue concentrations in fish and game animals that could potentially be food sources. A fish ingestion dose of up to 0.43 mrem (4.3 µSv)/yr was calculated based on tissue samples of carp and bass. Site-related radionuclides were not detected at levels greater than analytical minimum detectable activities in muscle tissue samples of game animals (elk, mule deer, pheasant, and quail).

Clearance of Property with Potential for Residual Radioactivity
An estimated 36,000 items of personal property were cleared from the Hanford Site during 2018 for unrestricted use by members of the public. These items were considered to have minimal potential for residual radioactivity; they were verified to be free of residual radioactivity and to meet the DOE O 458.1 requirements. The Hanford Site did not release any real property (i.e., land or buildings) in 2018.

4.0 Radiological Protection and Doses

This section provides information on the Hanford Site radiological program and doses, as well as cleanup activities as the U.S. Department of Energy (DOE) progresses toward Hanford Site closure and the likely transfer of property to other entities. Additional information on radiation, dose rates, and dose terminology can be found in Appendices A and B.

4.1 External Radiation Monitoring

CJ Perkins

External radiation is defined as radiation originating from a source external to the human body. External radiation was monitored at the Hanford Site in relative proximity to known or potential radiation sources. Sources of external radiation at the Hanford Site include waste materials associated with the historical production of plutonium for defense; residual nuclear inventories in former production and processing facilities; radioactive waste handling, storage, and disposal activities; waste cleanup and remediation activities; atmospheric fallout from historical nuclear weapons testing; and natural sources

such as cosmic radiation. During any given year, external radiation levels can vary from 15 to 25% at any location because of changes in soil moisture and snow cover (NCRP 1975).

The Harshaw™ [1] thermoluminescent dosimeter (TLD) system is used to measure external radiation on the Hanford Site. This type of TLD measures very low dose rates only and is not suitable for use for personnel monitoring. This system includes the Harshaw 8800-series dosimeter and the Harshaw 8800 reader. The Harshaw 8800-series environmental dosimeter consists of two TLD-700 chips and two TLD-200 chips and provides both shallow- and deep-dose measurement capabilities using filters in the dosimeter. Data obtained from the two TLD-700 chips were used to determine the average total environmental dose at each location. The two TLD-200 chips were included to determine doses in the event of a radiological emergency and were not used in calculating average total environmental dose. The average daily dose rate was determined by dividing the average total environmental dose by the number of days the dosimeter was exposed. Daily dose equivalent rates (mrem/day) at each location were converted to annual dose equivalent rates (mrem/yr) by averaging the daily dose rates and multiplying by 365 days/yr. Reported values include background. The TLDs were positioned approximately 3.3 ft (1 m) above ground and were collected and read quarterly.

Radiation surveys with portable instruments are conducted to monitor and detect contamination and to provide a coarse screening for external radiation fields. The types of areas surveyed included underground radioactive material areas, contamination areas, soil contamination areas, high-contamination areas, roads, and fence lines.

4.1.1 External Radiation Measurements

External radiation fields were monitored in 2018 at 121 locations on and off the Hanford site The TLD results were used individually or averaged to determine dose rates in a given area for a specific sampling period (Table 4-1).

Table 4-1. Thermoluminescent Dosimeter Locations and Results (mrem/yr)[a] in 2017 and 2018. (2 Pages)

Locations	No. of Dosimeters	2017		2018		% Change[e]
		Maximum[b]	Average[c,d]	Maximum[b]	Average[c,d]	
100-Areas	5	86	82 ± 7	87	81 ± 10	-1%
100-K	14	196	87 ± 65	205	89 ± 69	2%
200-East	45	180	97 ± 49	178	98 ± 46	1%
200-West	24	212	98 ± 59	208	99 ± 56	1%
200-North (212-R)[f]	1	79	79 ± n/a	80	80 ± n/a	1%
300 Area	8	94	82 ± 11	88	82 ± 6	<1%
300 TEDF	6	83	82 ± 3	85	83 ± 3	1%
400 Area	7	91	81 ± 9	90	83 ± 7	2%
CVDF	4	75	74 ± 2	76	75 ± 2	1%
ERDF	3	87	84 ± 5	84	82 ± 3	-1%
IDF[f]	1	88	88 ± n/a	87	87 ± n/a	-1%

[1] Harshaw is a trademark of Thermo Fisher Scientific, Inc., Waltham, Massachusetts.

Table 4-1. Thermoluminescent Dosimeter Locations and Results (mrem/yr)[a] in 2017 and 2018. (2 Pages)

Locations	No. of Dosimeters	2017		2018		% Change[e]
		Maximum[b]	Average[c,d]	Maximum[b]	Average[c,d]	
WTP	14	159	94 ± 45	164	95 ± 44	1%
Perimeter (offsite)	3	91	89 ± 3	96	93 ± 4	4%
Reference (offsite)	1	70	70 ± n/a	74	74 ± n/a	5%

[a] To convert to international metric system units, multiply mrem/yr by 0.01 to obtain mSv/yr.
[b] Maximum values are ± analytical uncertainty.
[c] ± 2 standard deviations.
[d] Each dosimeter is collected and read quarterly.
[e] Numbers indicate a decrease (-) or increase from the 2009 mean.
[f] Maximum value represents highest quarterly value ± analytical uncertainty.
CVDF = Cold Vacuum Drying Facility (100 K Area).
ERDF = Environmental Restoration Disposal Facility (200 West Area).
IDF = Integrated Disposal Facility (200 East Area).
TEDF = 300 Area Treated Effluent Disposal Facility.
WTP = Waste Treatment Plant (includes 200-East Area and Permieter locations previously counted).

The average dose rate levels measured in the operational areas during 2018 were comparable to the previous years' levels (Figure 4-1).

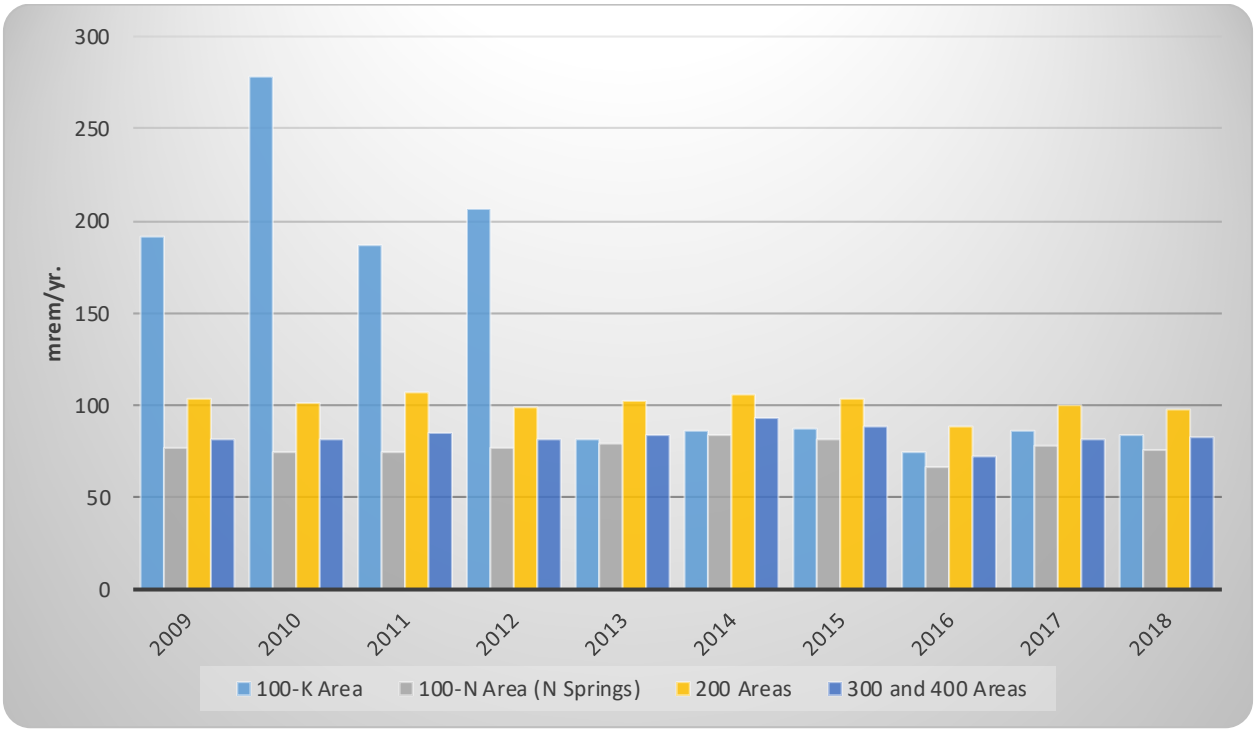

Figure 4-1. Average Thermoluminescent Dosimeter Results (mrem/year) in Selected Operational Areas.

4.1.1.1 100-K Area. The 2018 dose rate levels near the load-out area of the 105-KW (reactor) Building, where radioactive contaminated sludge and debris from the cleanout of the 100-K West Basin was transported, were noticeably higher than other TLD locations at the 100-K Area.

4.1.1.2 100 Areas. Dose rates measured along the Columbia River shoreline in the 100-N Area (N Springs) remained low during 2018. Locations established during 2016 along the River Corridor showed typical Hanford background dose rate levels during 2018. A new monitoring location was established during 2018 at the 105-B Reactor site. Dose rate levels measured were at/near typical Hanford Site background levels.

4.1.1.3 200-East Area. Dose rate levels measured during 2018 near the "A" and "C" Tank Farms were higher than other 200-East Area locations.

200-East Area – Plutonium Uranium Extraction Facility (PUREX) Tunnel Monitoring. Continued monitoring in 2018 at locations near the PUREX tunnels showed dose rates at/near typical Hanford background levels.

200-East Area - Waste Treatment Plant Baseline. During 2016, six new TLD monitoring locations were added in support of baseline monitoring for the Waste Treatment Plant: three locations at onsite air sampling locations and three locations at offsite (perimeter) air sampling locations. Data obtained during 2018 showed dose rate levels at each location comparable to typical Hanford Site background levels.

4.1.1.4 200-West Area. Dose rate levels measured during 2018 near the "S" and "T" Tank Farms and at the Solid Waste Operations Complex were higher than other 200-West Area locations.

200-West Area – Plutonium Finishing Plant Demolition. Demolition of the Plutonium Finishing Plant facility continued during 2018. the TLDs nearest the site showed dose rate levels at/near typical Hanford background throughout the year.

4.1.1.5 200-North. Dose rates measured in 2018 were low, and all four quarterly measurements were similar to each other and to recent years.

4.1.1.6 300 Area. Dose rate levels measured during 2018 at all locations in the 300 Area were at/near typical Hanford Site background levels.

4.1.1.7 400 Area. Dose rates measured in 2018 at all seven monitoring locations were low and similar to each other and to recent years.

4.1.1.8 Environmental Restoration Disposal Facility (ERDF). Dose rates measured in 2018 at all three monitoring locations were low and similar to each other and to recent years.

4.1.1.9 Integrated Disposal Facility. Dose rates measured in 2018 were low and all four quarterly measurements were similar to each other and to recent years.

4.1.1.10 Perimeter Locations. Three locations (i.e., Ringold, west end of Fir Road, and Dogwood Met Tower) established in January 2016 showed low dose rate levels in 2018 that were similar to each other and to onsite levels.

4.1.1.11 Reference Locations. A location at the Yakima airport was added during September 2016 to provide a reference (aka background) dose rate level monitoring station. Results obtained during 2018 were approximately 10% less than typical Hanford background dose rate levels.

4.1.2 Waste Disposal Sites Radiological Surveys

JE Cranna and JW Wilde

Radiological surveys are performed at active and inactive waste disposal sites and the surrounding terrain to detect and characterize radioactive surface contamination. Radiation surveys with portable instruments monitor and detect contamination and provide a coarse screening for external radiation fields. The types of areas surveyed include underground radioactive material areas, contamination areas, soil contamination areas, high-contamination areas, roads, and fence lines. Vehicles equipped with radiation detection devices and global positioning systems are used to accurately measure the extent of contamination along ERDF haul routes. Routine radiological survey locations include former waste disposal cribs and trenches, retention basin perimeters, ditch banks, solid waste disposal sites (e.g., burial grounds), unplanned release sites, tank farm perimeters, stabilized waste disposal sites, roads, and firebreaks in and around the Hanford Site operational areas. These sites are posted as underground radioactive material areas, contamination areas, and soil contamination areas.

Underground radioactive material areas are regions where radioactive materials occur below the soil surface. These areas are typically stabilized cribs, burial grounds, covered ponds, trenches, and ditches. Barriers have been placed over the contamination sources to inhibit radionuclide transport to the surface. These areas are surveyed at least annually to assess the effectiveness of the barriers.

Contamination areas and soil contamination areas may or may not be associated with an underground structure containing radioactive material. A breach in the surface barrier of a contaminated underground area may result in the growth of contaminated vegetation. Insects or animals may burrow into the soil and bring contamination to the surface. Vent pipes or risers from an underground structure may be sources of speck contamination (particles with a diameter less than 0.25 in. [0.6 cm]). Areas of contamination not related to subsurface structures can include sites contaminated with fallout from effluent stacks or with materials from unplanned releases (e.g., contaminated tumbleweeds and animal feces).

All contaminated areas may be susceptible to contaminant migration and are surveyed at least annually to assess their current radiological status. In addition, onsite paved roadways on which radioactive materials are transported to ERDF are surveyed annually.

4.2 Potential Radiological Doses

AG Fleury, R Perona, C Schaupp

Potential radiological doses to the public and biota from Hanford Site operations in 2018 were evaluated to determine compliance with pertinent regulations and limits. Potential sources of radionuclide contamination included gaseous emissions from stacks and ventilation exhausts, contaminated

groundwater seeping into the Columbia River, and fugitive emissions from areas of contaminated soil and operating facilities. A summary of the methods and results of the public and biota dose assessments is provided here. Details of the methods used to calculate radiological doses are provided in Appendix D.

The total annual dose to a hypothetical, maximally exposed individual (MEI) in 2018 at the offsite location where projected doses were highest (Horn Rapids Road) was 0.28 mrem (2.8 µSv). This dose is 0.28% of the 100 mrem (1,000 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 (NCRP 2009) 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.

The offsite MEI dose is one of the following eight radiological impacts of Hanford Site operations that are assessed or summarized in this section:

- Dose to a hypothetical MEI at an offsite location, evaluated by using a multimedia pathway assessment DOE O 458.1 (Section 4.2.1)
- Collective dose to the population residing within 50 mi (80 km) of Hanford Site operations areas (Section 4.2.2)
- Dose for air pathways calculated using regulation-specified U.S. Environmental Protection Agency (EPA) methods for comparison to the *Clean Air Act* standards in 40 CFR 61, Subpart H, "National Emission Standards for Emissions of Radionuclides Other than Radon from Department of Energy Facilities" (Section 4.2.3)
- Dose from recreational activities (e.g., hunting and fishing) (Section 4.2.4.1)
- Dose to a worker consuming drinking water on the Hanford Site (Section 4.2.4.2)
- Dose to a visitor of the Manhattan Project National Historical Park (Section 4.2.4.3)
- Dose from non-DOE industrial sources on and near the Hanford Site (Section 4.2.5)
- Absorbed dose received by biota exposed to radionuclide releases to the Columbia River and to radionuclides in onsite surface water bodies (Section 4.2.6).

Radiological dose assessments related to environmental releases are ideally based on direct measurements of radionuclide concentrations in specific exposure media; however, amounts of many radioactive materials released to the Columbia River or the atmosphere from Hanford Site sources are too small to be measured in environmental media after they are dispersed in the offsite environment. For the radionuclides present in measurable amounts, it can be difficult to distinguish the small contribution of Hanford Site sources from contributions caused by fallout from historical nuclear weapons testing and naturally occurring radionuclides such as uranium and its decay products. As a result, computer models are employed to calculate offsite radionuclide concentrations based on measured and estimated releases. In specific instances, such as routine air measurements of tritium at

locations near the 300 Area, radionuclide concentrations may be distinguishable from background levels; these measurements are used to support interpretation of the dose assessment results.

Calculations of radiation dose require the use of biological and radiological models of the behavior of radioactive material in the human body. Scientific understanding of these processes has improved over time. In the 1960s, the annual environmental reporting at the Hanford Site used the recommendations and methodologies of the International Convention on Radiological Protection (ICRP) Publication 2 (*Permissible Dose for Internal Radiation* [ICRP 1959]). In the 1970s, the annual reports began to follow the newer recommendations in ICRP Publication 26 (ICRP 1977]) and Publication 30 (*Limits for Intakes of Radionuclides by Workers*, Part 1 [IRCP 1979a] and Supplement to Part 1 [IRCP 1979b]), which were incorporated in the dose factors from the EPA in Federal Guidance Reports 11 and 12 (EPA 1988 and EPA 1993, respectively). The GENII Version 1 computer code applied to dose assessments at the Hanford Site beginning in 1988 used ICRP Publications 26 and 30 as well as EPA dose factors. The GENII Version 2 computer code used for the annual report dose calculations beginning in 2009 uses ICRP Publication 60 methods (ICRP 1991) and updated EPA dose factors (EPA 1999).

Offsite dose for an MEI (Section 4.2.1) and collective dose for population residing within 50 mi (80 km) of Hanford Site operation areas (Section 4.2.2) are calculated separately for liquid releases to the Columbia River and stack air emissions. Radiological doses from the water pathways are calculated based on differences in radionuclide concentrations between upstream and downstream sampling points on the Columbia River. Although the downstream minus upstream radionuclide concentrations potentially include groundwater-related contributions from other operating areas, they have been assigned to the 200 Areas for tabulation of radiological dose. No direct permitted discharge of radioactive materials from the 100 or 300 Areas to the Columbia River has occurred since 2011. Radiological doses from the air pathways are calculated based on annual stack emissions measurements from approximately 60 emission points in the four Hanford Site operation areas.

Columbia River shoreline spring and seep water containing radionuclides is known to enter the river along the portion of the Hanford Site shoreline extending from the 100-BC Area downstream to the 300 Area. Tritium and isotopes of uranium were measured in the Columbia River downstream of the Hanford Site (Richland Pumphouse station, HRM 46.4) in 2018 at low concentrations that were nevertheless greater than upstream (Priest Rapids Dam station) levels (Appendix D). Radioactive air emissions are discussed in Section 6.1 and the specific radionuclides measured in 2018 are summarized in Table 6-2. For the GENII Version 2.10.2 (PNNL-14583) calculations supporting this dose assessment, ingrowth of short-lived radioactive progeny during environmental transport was calculated to develop a complete set of radionuclide release estimates. Details on the development of air pathway and water pathway radioactive release estimates and tables of water and air pathway dose calculation inputs are provided in Appendix D.

4.2.1 Maximally Exposed Individual Dose (Offsite Resident)

The MEI is a hypothetical person whose location and lifestyle are such that it is unlikely any actual member of the public would have received a higher radiological dose from Hanford Site releases during 2018. This individual's exposure pathways were chosen to maximize the combined doses from all potential environmental routes of exposure to radionuclides in Hanford Site liquid effluents and air emissions using a multimedia pathway assessment (DOE O 458.1, Section 4.e). In reality, such a combination of maximized exposures to radioactive materials is highly unlikely to apply to any single person. The individual pathway dose calculations themselves also incorporate conservative

assumptions intended to ensure that modeled concentrations of radionuclides in exposure media and resulting doses are protective. For these reasons, the dose assessment results for the MEI represent a hypothetical upper bound of potential individual dose rather than an anticipated dose to an actual individual.

The location of the hypothetical MEI varies depending on the relative contributions of radioactive air emissions and liquid effluent releases from Hanford Site operational areas. Four offsite locations were evaluated to determine the location of the offsite MEI (Figure 4-2). The Ringold location receives maximal air pathway impacts from the 200 Areas. Depending on annual differences in the prevailing wind direction, either the Sagemoor or Horn Rapids Road location may receive maximal air pathway impacts from the 300 Area. A population of West Pasco residents obtain their drinking water from the Riverview location via a community water system that draws water from the Columbia River; the domestic drinking water pathway for Columbia River water is, therefore, applied at this location. Residences in the vicinity of Horn Rapids Road receive drinking water from the City of Richland, which has an intake on the Columbia River downstream of the Hanford Site; the domestic drinking water pathway is, therefore, also applied here. Ringold, Riverview, and Horn Rapids Road are locations where Columbia River water is withdrawn for irrigation, and agricultural exposure pathways are applied at these locations.

Dose calculations for 2018 releases indicate that the MEI is located in the vicinity of the Pacific Northwest National Laboratory (PNNL) Laboratory Support Warehouse, an offsite business located at 3475 George Washington Way just to the south of the Hanford Site 300 Area and close to 638 Horn Rapids Road, which is the location used for the MEI receptor air modeling coordinates. For the Horn Rapids Road receptor dose calculations, the radiological dose was modeled using the aforementioned Columbia River and air emissions data for the following exposure routes:

- Inhalation and external radiation exposure related to airborne radionuclides
- External radiation exposure and inadvertent soil ingestion for radionuclides deposited on the ground
- Ingestion of domestic drinking water from the Columbia River
- Ingestion of locally grown food products grown on soil irrigated with Columbia River water and containing radionuclides deposited from the air
- External radiation exposure to radionuclides in Columbia River water and sediments near the Hanford Site during recreational activities (i.e., fishing, boating), and inadvertent ingestion of water while swimming
- Consumption of locally caught Columbia River nonmigratory fish.

A graphical depiction of the conceptual site model showing all potentially complete exposure pathways for the Horn Rapids Road MEI evaluated using GENII Version 2.10.2 (PNNL-14583) is provided in Figure 4-3. Additional information related to selection of the MEI location for releases is included in Appendix D. Exposure variable input values related to residency and recreational exposure times; intake rates for water, foods, and other media; and agricultural pathway assumptions for the MEI are provided in Appendix D.

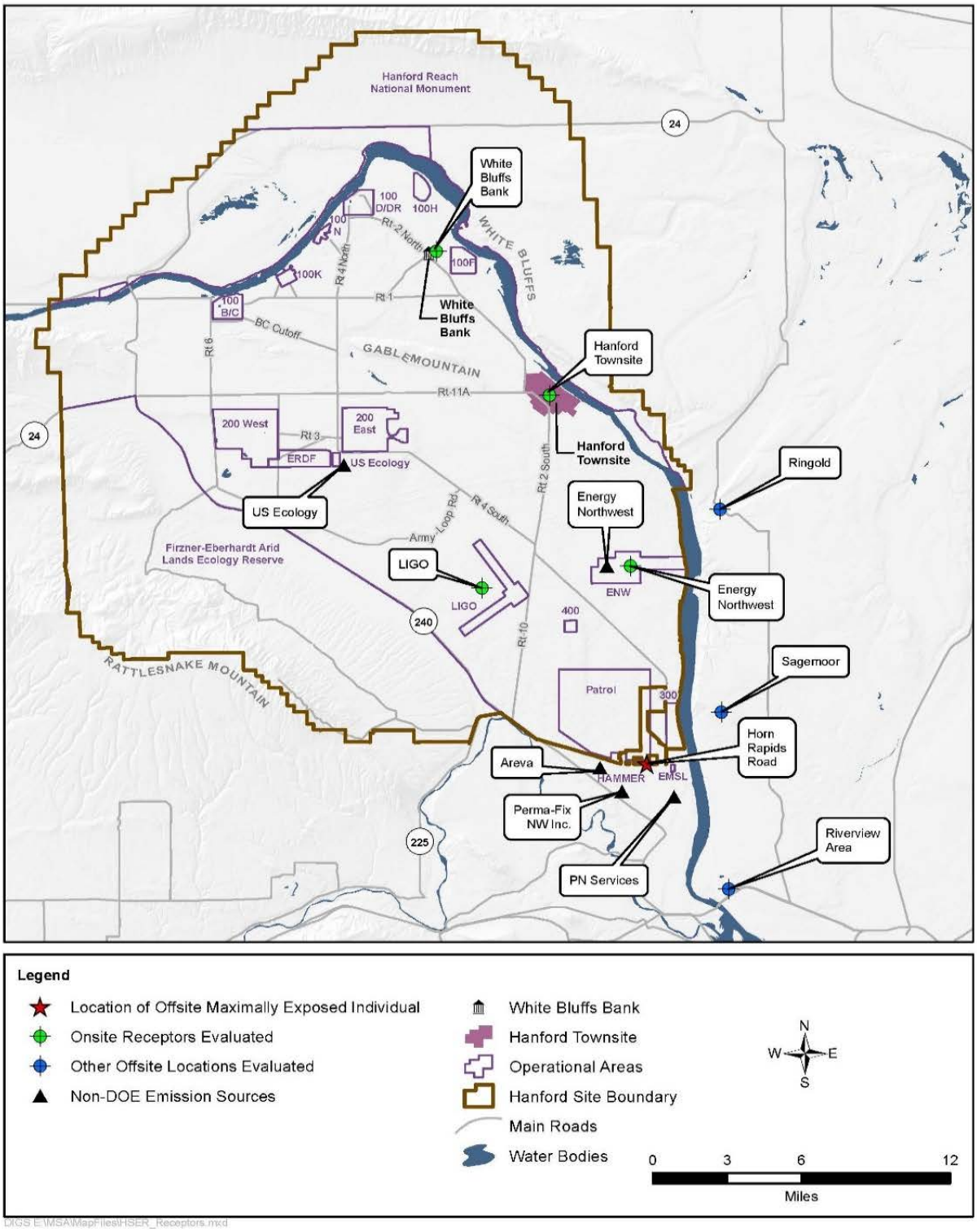

Figure 4-2. Locations Evaluated for Onsite and Offsite Receptors.

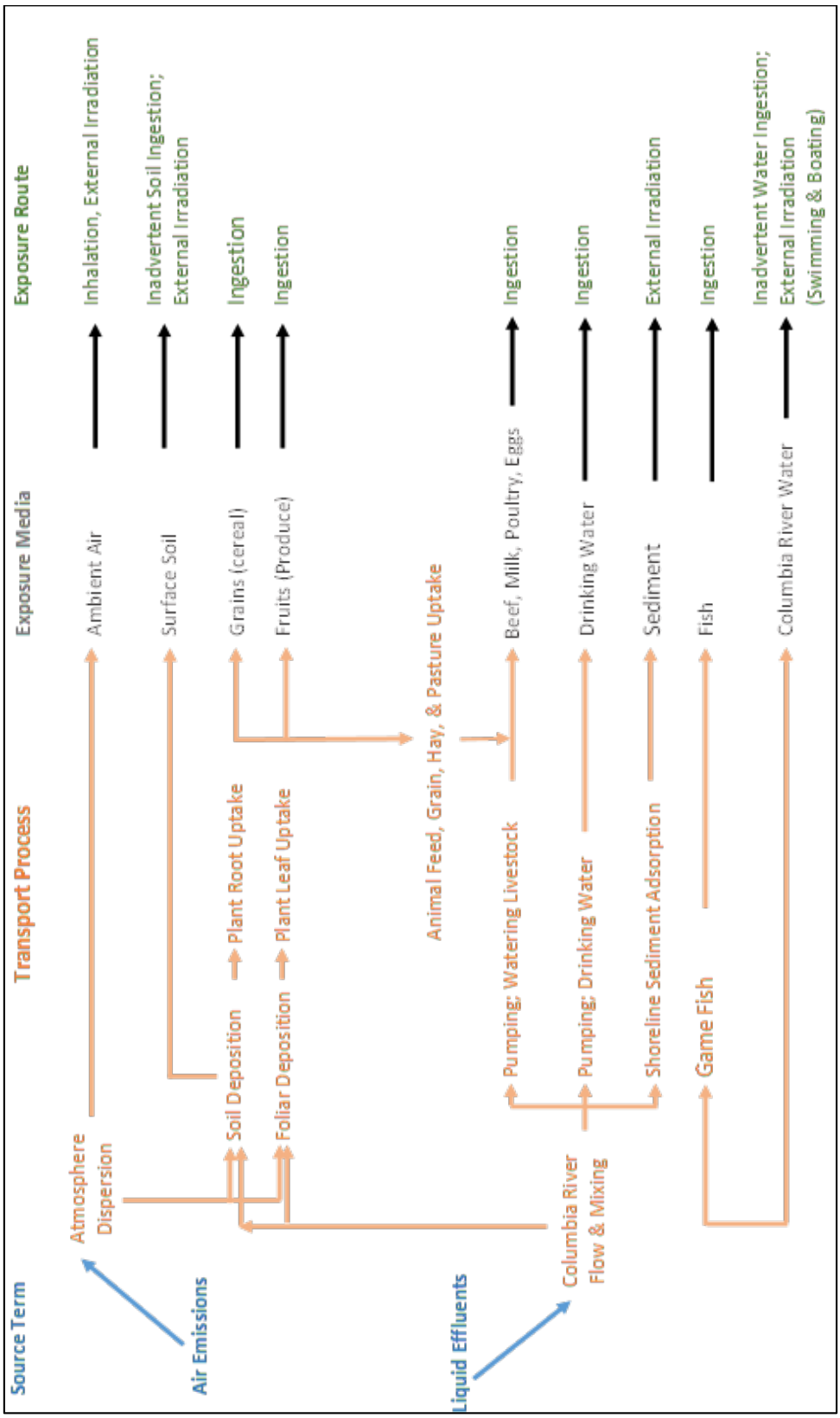

Figure 4-3. Conceptual Site Model of Exposure Pathways Evaluated in Dose Calculations (Horn Rapids Road MEI).

The total dose to the MEI at Horn Rapids Road in 2018 was calculated to be 0.28 mrem (2.8 µSv)/yr (Table 4-2; Figure 4-4). This dose is 0.28% of the 100 mrem (1,000 µSv)/yr public dose limit specified in DOE O 458.1 and 1.12% of the 25-mrem (250-µSv)/yr threshold where a supplemental assessment of dose to the lens of the eye, skin, and extremities is required. Air pathway sources in the 300 Area contributed 0.20 mrem (2.0 µSv)/yr or approximately 71% of the total dose of 0.28 mrem (2.8 µSv)/yr. Water pathway sources in the Columbia River contributed 0.071 mrem (0.7 µSv)/yr or approximately 25% of the total dose (25%).

The primary radionuclides and exposure pathways contributing to the modeled MEI dose for air emission releases and Columbia River water releases are as follows:

- Air Releases. The inhalation exposure pathway in the 300 Area related to radon isotopes and their radioactive progeny accounted for 55% of the total air pathways dose of 0.20 mrem (2.0 µSv)/yr. Consumption of food products containing tritium released from the 300 Area contributed approximately 38% of the total air pathways dose.

- Water Releases. Consumption of fish from the Columbia River contributed approximately 55% of the total water pathways dose of 0.071 mrem (0.71 µSv)/yr, food grown using Columbia River water withdrawn downstream from the Hanford Site contributed approximately 31%, and drinking water ingestion contributed the remaining 14%. Uranium isotopes and their radioactive progeny contributed virtually 100% of the water-pathways dose. Potassium-40 was detected in both upstream and downstream water samples, however, it is a naturally occurring radionuclide and is not associated with releases from the reactors or any groundwater plumes entering the Columbia River. Therefore, to avoid masking of dose associated with potential Hanford Site releases, potassium-40 is not included in the MEI dose assessment. A sampling instrument failure may have affected identification of Hanford Site-related contaminants in Columbia River samples, as discussed in Section 4.2.1.1.

4.2.1.1 MEI Dose Discussion.

The 2018 MEI dose of 0.28 mrem (2.8 µSv)/yr is larger than the 0.22 mrem (2.2 µSv)/yr 2017 MEI dose (DOE/RL-2018-32), and more than double the 0.12 mrem (1.2 µSv)/yr MEI dose calculated for 2016 (DOE/RL-2017-24). The difference between the 2018 and 2017 dose estimates is mostly attributable to higher concentrations of uranium isotopes at the downstream Richland Pumphouse sampling location on the Columbia River in 2018, which may in part be attributable to the impact of the failed continuous water sampler in 2017, discussed below. Differences between the 2018 and 2016 MEI dose results are primarily attributable to higher inhalation doses in 2018 from radon isotopes.

In August 2017 the Richland Pumphouse sampling station continuous water sampler failed and a new continuous sampler was not put online until July 2018. Water samples for the period of January through June 2018 were instead collected as single 0.5-gal (2-L) grab samples. The continuous sampler collected 55-mL water samples at 1-hr intervals, which were composited bimonthly and then combined for a single monthly composite (DOE/RL-2018-32; Section 7.2.1).

There are several reasons why continuous samples are preferable in principle to grab samples for characterizing average river water concentrations. Water levels vary during the day due to impoundment and releases for power generation and other purposes. Having water samples collected each hour provides representation of this daily cycle, and collecting many sample increments over the

course of each month better captures seasonal changes in flow. Contaminant discharges along the Hanford Reach will be more or less diluted depending on river flow and elevation. For example, grab samples collected at a time of day with higher Hanford Reach river elevation could inadvertently create a low result in the measured downstream concentrations. For these reasons, there is a higher degree of uncertainty in the representativeness of the 2018 Richland Pumphouse sampling station water data than would be the case if all samples had been acquired with the continuous sampler. In the 2017 water data, the substitution of grab samples during the later summer and fall sampling events when downstream water concentrations are often highest due to lower flow may have contributed to uranium isotopes not being identified as Hanford Site-related contaminants in that year.

Table 4-2. Pathway Doses for the Hypothetical MEI Residing at Horn Rapids Road.

Release Type	Exposure Pathway	Dose Contributions from Operational Areas (mrem)[a]				
		100 Area	200 Areas	300 Area	400 Area	Pathway Total
Air	Food Ingestion	1.5E-06	1.9E-04	7.90E-02	9.1E-07	0.079
	Inhalation	1.1E-05	8.0E-06	1.19E-01	2.2E-06	0.12
	External, Soil Ingestion	2.0E-08	1.3E-07	5.98E-03	1.7E-08	0.006
	Subtotal Air	1.3E-05	2.0E-04	2.04E-01	3.1E-06	0.20
Water	Irrigation (food and soil ingestion; external)	NA[b, d]	0.022 [c]	NA[d]	NA[d]	0.022
	Drinking Water Ingestion	NA[b, d]	0.010 [c]	NA[d]	NA[d]	0.010
	Recreation (river water, sediments; external, ingestion)	NA[b, d]	2.3E-04 [c]	NA[d]	NA[d]	2.3E-04
	Fish Ingestion	NA[b, d]	0.039 [c]	NA[d]	NA[d]	0.039
	Subtotal Water	NA[d]	0.071	NA[d]	NA[d]	0.071
	Air + Water Total	**1.3E-05**	**0.071**	**0.20**	**3.1E-06**	**0.28**

[a] To convert mrem to International System dose units (μSv), multiply by 10.
[b] No measured releases; the last 100 Area NPDES-permitted outfall (1908-K Outfall) ceased releases in March 2011.
[c] Integrates releases from all operational areas based on difference between down and upstream Columbia River radionuclide concentrations.
[d] All liquid discharges reflected in the difference between upstream and downstream radionuclide concentrations are assigned to the 200 Areas.
NA = Not applicable.
NPDES = National Pollutant Discharge Elimination System

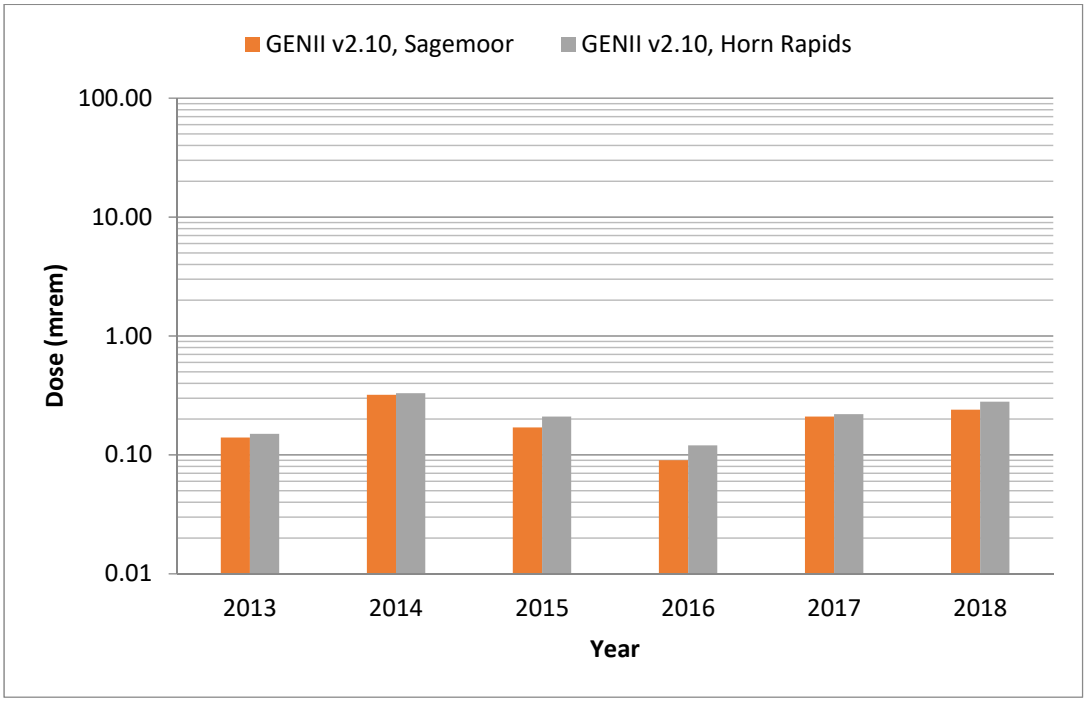

Figure 4-4. Total Dose for the Hypothetical MEI Over Time.

The MEI dose estimate incorporates a number of conservative assumptions to ensure that pathway doses are protective; therefore, calculated doses are likely to be overestimated. In the air pathways calculations, gross alpha and gross beta radiation measurements in stack emissions from the 100, 200, and 300 Areas were protectively added to the measured emissions of plutonium-239/240 (an alpha-emitting radionuclide related to Hanford Site operations) and cesium-137 (a beta-emitting radionuclide related to Hanford operations), respectively. The actual measured total air releases of plutonium-239/240 and cesium-137 in 2018 from all stacks are a small fraction (23% and 15%, respectively) of assumed releases that include the contribution of gross radioactivity values. Although gross alpha and gross beta levels in stack emissions are similar to air background levels, the addition of these values ensures that possible contributions from any unmeasured operations-related radionuclides are protectively incorporated in the estimated doses.

In the irrigation pathways calculations, all produce eaten by the MEI was protectively assumed to be locally grown and originate from areas irrigated with Columbia River water. For the fish consumption pathway, near-shore water samples were protectively used to represent Columbia River water generally. It was assumed that all fish consumed by the MEI are resident species rather than anadromous fish, such as salmon or steelhead. Because anadromous fish spend most of their lives in the ocean, they would have a much lesser exposure to contaminants associated with the Hanford Reach compared to species that spend their entire lives in the Hanford Reach (e.g., carp and bass).

Because tritium is measured in air samples from air monitoring station samples, and releases of tritium from the 300 Area are a significant source of calculated Hanford-related radiological dose for the hypothetical MEI, modeled annual-average tritium concentrations at locations near the 300 Area were compared to measured concentrations. Figure 4-5 shows the 2018 modeled annual average air concentrations of tritiated water vapor (HTO) at the Horn Rapids Road MEI location and 2018 annual averages based on measured values at locations near the Horn Rapids Road MEI location. Measured

monthly tritium concentrations vary substantially at each monitoring location. The 95% upper and lower confidence intervals of the annual average values are shown in Figure 4-5 in addition to the annual average.

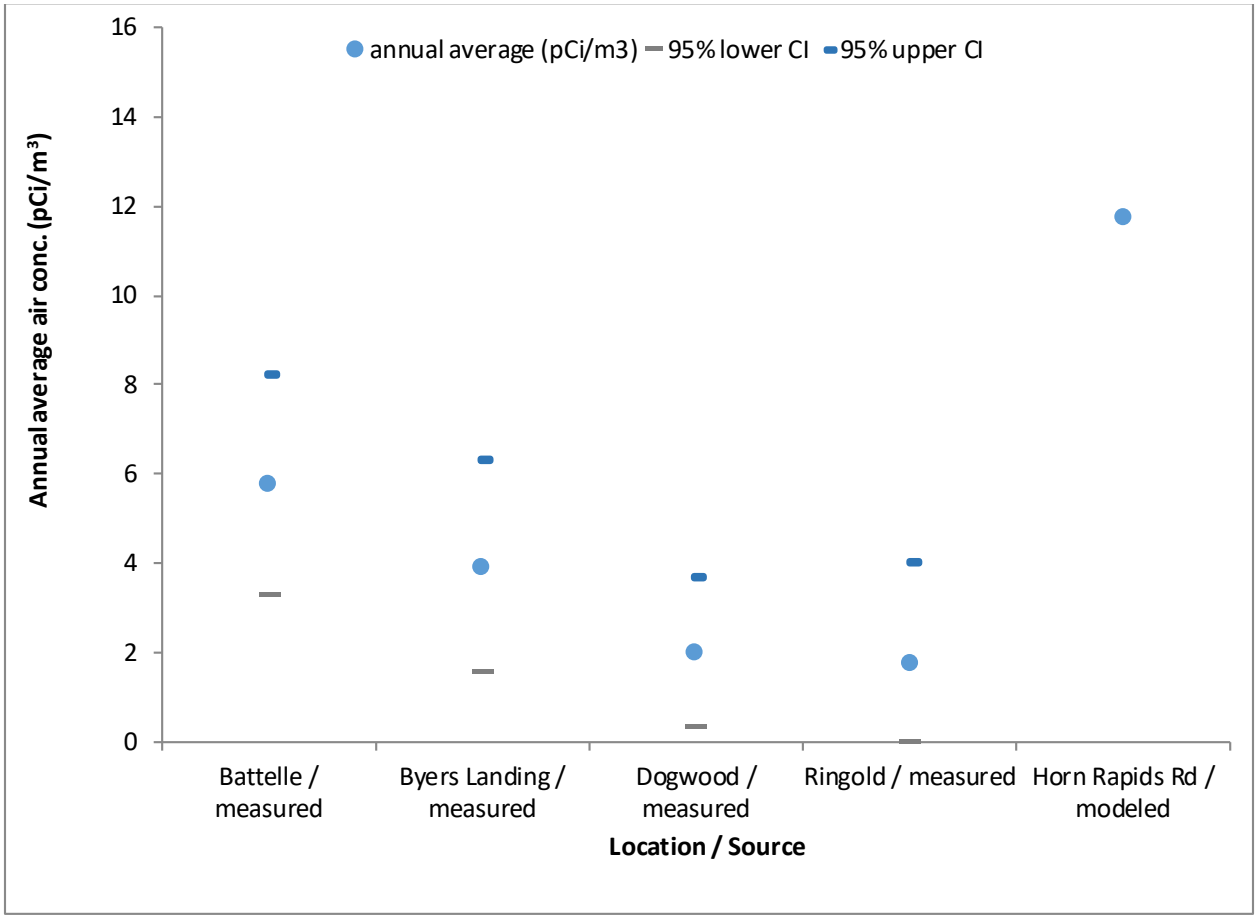

Figure 4-5. Comparison of Measured and Modeled Tritium Air Concentrations Near the 300 Area.
NOTE: Error bars are 95% confidence intervals of the mean

The modeled annual-average tritium concentration at the Horn Rapids Road MEI location is above the range of the 95% upper and lower confidence interval of the mean of the measured values at all four locations. The modeled MEI tritium air concentration is nearly double the largest measured annual-average tritium concentration, which was measured at the Battelle Complex air station, and about 1.5 times larger than the 95% upper confidence interval of the average at the Battelle Complex. That the modeled air concentration is outside the confidence intervals of measured annual-average concentrations reflects both a relatively large annual stack emission of tritium from the 300 Area (about 335 curies of tritiated water vapor and elemental hydrogen combined) and possibly relatively low natural background levels of atmospheric tritium in 2018. A relationship between 300 Area monthly tritium air emissions and onsite 300 Area ambient air concentrations in 2006 was shown by Barfuss (2007) but there was little correlation of monthly emissions and air concentrations for a combined group of four nearby offsite monitoring locations.

Note that exact correspondence between modeled and measured annual average values would not be expected because the episodic nature of HTO releases is not captured in the GENII air dispersion modeling, which assumes a constant rate of HTO emissions. Also, the modeled tritium values do not account for regional background levels of tritium, which would add between 1.5 and 4 pCi/m^3 to the modeled values (Figure 11 in Barfuss 2007).

Samples of locally raised foodstuffs were collected in 2018 from four locations including the Sagemoor, Riverview, Sunnyside, and East Wahluke areas. Sampled foodstuffs included fruits (apples, melons, and tomatoes), leafy vegetables, potatoes, corn, milk, and wine. With the exception of strontium-90 analyses for wine, gamma-emitting radionuclides and strontium-90 were analyzed in all foodstuffs, and tritium was analyzed in tomatoes, wine, and milk. Additionally, carbon-14 was analyzed in all foodstuffs. Reported results for the Hanford-related radionuclides carbon-14, strontium-90, and tritium in foods were compared to modeled concentrations calculated for the MEI receptor using the GENII computer code. These comparisons encompassed fruits, leafy vegetables, grain (corn), root vegetables (potatoes), and milk. Modeled concentrations of carbon-14, tritium, and strontium-90 are related to air emissions. Modeled concentrations of tritium are also related to irrigation with Columbia River water. The following observations are drawn from the comparisons:

- Carbon-14 was not detected in any of the 24 crop samples collected from the Sagemoor, Riverview, Sunnyside, and East Wahluke areas. The minimum detectable activities for these samples ranged from approximately 2.6 to 6.4 pCi/g. The modeled carbon-14 concentrations in crops grown at the MEI location of Horn Rapids Road are far below these activities, with a highest value of 0.00001 pCi/g, corresponding to a calculated annual dose of 1E-06 mrem (0.00001 µSv)/yr. Carbon-14 was detected in one of the nine milk samples collected from the East Wahluke area with a value of 263 pCi/L. The eight non-detect activities for milk ranged from -1,320 to 101 pCi/L. The modeled carbon-14 concentration in milk at the MEI location of Horn Rapids Road was far below these activities, with a highest value of 0.0022 pCi/L corresponding to a calculated annual dose of 2.2E-04 mrem (0.0022 µSv)/yr.

- Strontium-90 was analyzed in 24 crop samples and detected in 2 leafy vegetable samples (0.00562 pCi/g and 0.00418 pCi/g) from the East Wahluke area and 1 leafy vegetable sample (0.00613 pCi/g) from the Riverview area. Strontium-90 was not elevated in downstream Columbia River water samples in 2018 and, therefore, was not included in the water pathways dose calculations. Low levels of strontium-90 in the environment are widespread due to past above-ground weapons testing. The measured concentrations in these samples are consistent with trends based on observations in offsite vegetation samples (PNNL-20577, *Radionuclide Concentrations in Terrestrial Vegetation and Soil Samples On and Around the Hanford Site, 1971 Through 2008*). Strontium-90 was not detected in any of the nine milk samples collected from the Sagemoor and East Wahluke areas. The minimum detectable activities for these samples ranged from approximately -1.32 to 1.32 pCi/L. For comparison, modeled concentrations of strontium-90 in milk and crops grown at Horn Rapids Road are hundreds of thousands of times below these ambient levels.

- Tritium was analyzed in samples of tomatoes from the Sunnyside and Riverview areas but was not detected at either location with a minimum detectable activity of approximately 0.12 pCi/g. Tritium was detected in samples of milk at average concentrations of approximately 16 pCi/L (Sagemoor)

and 24 pCi/L (East Wahluke). These concentrations are about 20 times below the modeled worst-case tritium concentration in milk for cows grazing at the MEI location of Horn Rapids Road (approximately 500 pCi/L) and far less than the environmental surveillance project dose-based reporting limit of 17,000 pCi/L (DOE/RL-91-50).

4.2.2 Collective Dose

Collective dose is defined as the sum of doses to all individual members of the public within a defined distance of a specific release location. The regional collective dose from 2018 Hanford Site operations was estimated by calculating the radiological dose to the population residing within a 50-mi (80-km) radius of onsite operating areas (DOE O 458.1). The collective doses reported are based on regional population data from the 2010 census, as described in Appendix D.

The conceptual site model of potentially complete exposure pathways for the Horn Rapids Road MEI shown in Figure 4-3 is also applicable to the collective dose calculations. Like the Horn Rapids Road MEI, the collective dose calculation also incorporates the drinking water exposure pathway because the cities of Richland and Pasco obtain all or part of their municipal water directly from the Columbia River downstream from the Hanford Site, and the City of Kennewick obtains its municipal water indirectly from wells adjacent to the river. A primary distinction between the MEI and collective dose calculations is the use of population-average values for certain exposure variables in place of reasonable upper bound values. Exposure variable input values related to residency and recreational exposure times, intake rates for foods and other media, and agricultural pathway assumptions for the collective dose calculations are provided in Appendix D. The air pathways collective dose calculations employ population data from the 2010 census broken out according to direction and distance to coincide with air dispersion and deposition modeling conducted within the GENII Version 2.10.2 computer code (PNNL-14583).

The annual collective dose is reported in units of person-rem (person-sievert), which is the sum of doses to all individual members of the exposed population. The total collective dose calculated for this population in 2018 was 2.5 person-rem (0.025 person-Sv)/yr (Table 4-3), which is the largest collective dose calculated in the past several years (Figure 4-6). Air pathway contributions from releases in the 300 Area contributed effectively 50% of the population dose, with water pathway releases contributing the other 50% of the population dose in 2018.

The primary radionuclides and exposure pathways contributing to the collective dose are as follows.

- Air Releases. Inhalation exposure contributed approximately 60% of the of the air pathways collective dose of 1.3 person-rem (0.013 person-Sv). The remaining air pathways collective dose is primarily related to consumption of food products grown downwind of the 300 Area. About 53% of the air pathways doses are due to inhalation of the radioactive progeny of radon-220 released from the 300 Area. Approximately another 46% of the total air pathways collective dose is associated with releases of tritium from the 300 Area. Air releases from the 100, 200, and 400 Areas had negligible contributions to the air pathways collective dose.

- Water Releases. Consumption of drinking water drawn from the Columbia River downstream of the Hanford Site contributed approximately 92% of the total water pathways collective dose of 1.2 person-rem (0.012 person-Sv). Uranium isotopes and their progeny contributed 92% of the water

pathways dose. Tritium was the only other contaminant identified in Columbia River samples in 2018 and contributed the remaining 8% of the water-pathways dose.

The collective dose in 2018 of 2.5 person-rem (0.025 person-Sv) is the largest collective dose calculated in the past several years (Figure 4-6). This could be attributable to the fact that in 2018 the air and water pathway calculations were based on relatively large estimated releases of radon and uranium isotopes, respectively. The air dispersion patterns in 2018 could also have contributed to the relatively large collective dose result. There is no specific collective dose metric analogous to the 100 mrem (1,000 mSv)/yr public dose limit for individual exposures described in Section 4.2.

Table 4-3. Collective Pathway Doses within a 50-mi (80-km) Radius.

Release Type	Exposure Pathway	Dose Contributions from Operational Areas, person-rem[a]				
		100 Areas	200 Areas	300 Area	400 Area	Pathway Total
Air	Food Ingestion	2.58E-04	9.44E-03	5.14E-01	3.62E-05	0.52
	Inhalation	3.86E-03	1.25E-03	7.82E-01	1.31E-04	0.79
	External, Soil Ingestion	4.09E-06	1.09E-05	1.45E-02	6.08E-07	0.015
	Subtotal Air	*4.12E-03*	*1.07E-02*	*1.31E+00*	*1.68E-04*	*1.3*
Water	Irrigation (food and soil ingestion; external)	NA[b, d]	0.023 [c]	NA[d]	NA[d]	0.023
	Drinking Water Ingestion	NA[b, d]	1.1 [c]	NA[d]	NA[d]	1.1
	Recreation (river water, sediments; external, ingestion)	NA[b, d]	0.0019 [c]	NA[d]	NA[d]	0.0019
	Fish Ingestion	NA[b, d]	0.014 [c]	NA[d]	NA[d]	0.015
	Subtotal Water	*NA[d]*	*1.2*	*NA[d]*	*NA[d]*	*1.2*
Air + Water Total		**0.0041**	**1.2**	**1.3**	**1.7E-04**	**2.5**

[a] To convert person-rem to International System dose units (person-Sv), divide by 100.
[b] No measured releases; the last 100 Area NPDES-permitted outfall (1908-K Outfall) ceased releases in March 2011.
[c] Integrates releases from all operational areas based on difference between down- and upstream Columbia River radionuclide concentrations.
[d] All liquid discharges reflected in difference between up- and downstream radionuclide concentrations assigned to 200 Areas.
NA = not applicable
NPDES = National Pollutant Discharge Elimination System

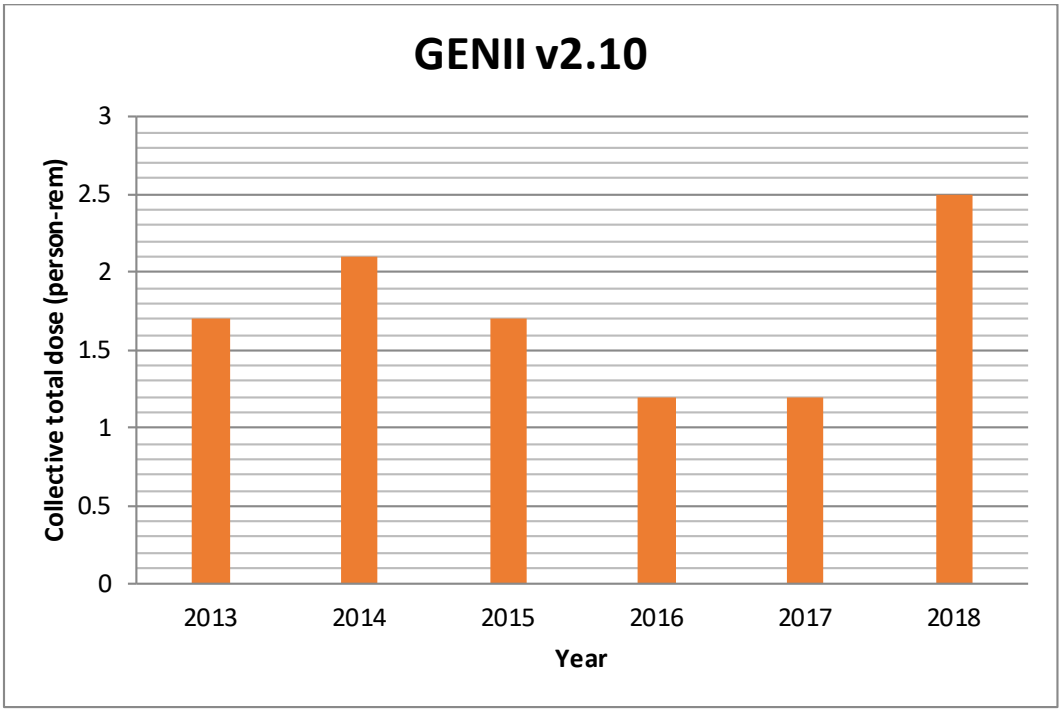

Figure 4-6. Collective Total Dose within a 50-mi (80-km) Radius.

4.2.3 Compliance with *Clean Air Act* Standards

Historically at the Hanford Site, there has been one primary expression of radiological risk to an offsite individual; however, the MEI dose is currently calculated by two different methods in response to two different requirements. One MEI dose computation is required by DOE O 458.1 and is calculated using the GENII computer code as described in Section 4.2.1 of this report. This calculation considers all potential environmental exposure pathways (e.g., from releases to both air and water) that maximize a hypothetical offsite individual's exposure to the Hanford Site's radiological liquid effluents and air emissions. A second estimate of MEI air pathways dose is required by the *Clean Air Act* and must be calculated using an EPA air dispersion and dose modeling computer code (such as the Clean Air Act Assessment Package 1988-Personal Computer program, CAP-88-PC v4.0 [EPA 2013]) or other methods accepted by the EPA under the *Clean Air Act* to demonstrate compliance with 40 CFR 61, Subpart H requirements. This regulation specifies that no member of the public shall receive a dose greater than 10 mrem (100 µSv)/yr from exposure to airborne radionuclide emissions (other than radon) released at DOE facilities. The Hanford Site stack emissions and emissions from diffuse and unmonitored sources (e.g., windblown dust) are considered in the calculation of offsite dose for the *Clean Air Act* based solely on an airborne radionuclide emissions pathway.

The assumptions embodied in the CAP88-PC v4.0 computer code differ slightly from the air pathways assumptions used with the GENII computer code; therefore, air-pathway doses calculated by the two codes may differ somewhat. In principle, the MEI for air pathways assessed under 40 CFR 61, Subpart H may be evaluated at a different location from the DOE O 458.1 all-pathways MEI if dose from the water pathways is significant (Appendix D).

The *Clean Air Act* regulation also requires that an annual report for each DOE facility be submitted to EPA that supplies information about atmospheric emissions for the preceding year and any potential

contributions to offsite dose. For more detailed information about 40 CFR 61, Subpart H, modeling of dose from 2018 air emissions at the Hanford Site, refer to DOE's report to EPA (DOE/RL-2019-09).

4.2.3.1 Dose from Stack Emissions to an Offsite Maximally Exposed Individual. Using CAP88PC, the offsite MEI for air pathways in 2018 was at the PNNL Richland Campus' Laboratory Supply Warehouse, an offsite business located in north Richland, Benton County, Washington, directly south of the Hanford Site 300 Area and proximal to the Horn Rapids Road MEI location evaluated with GENII (Figure 4-2). The potential air pathway dose from stack emissions to an MEI at that location calculated using the CAP88PC computer code was determined to be 0.058 mrem (0.58 µSv)/yr, less than 1% of the EPA standard of 10 mrem (100 µSv)/yr. The CAP88PC result is approximately one-fifth of the all-pathways dose of 0.28 mrem (2.8 µSv) calculated with GENII (Table 4-2).

Dose related to radon-222 and radon-220 is not included in the dose calculated for EPA compliance in 40 CFR 61, Subpart H but is regulated by the 10-mrem (100-µSv)/yr standard established in WAC 246-247, "Radiation Protection – Air Emissions." A release of 885 curies of radon-220 was calculated from engineering estimates for stack emissions from the 325 Building in the 300 Area. No radon-222 operational releases were reported in 2018. A radon-220 dose of 0.14 mrem (1.4 µSv)/yr was calculated using the CAP88PC computer code for the Laboratory Supply Warehouse MEI, far below the WAC 246-247 standard. The sum of MEI dose for radon-220 (0.14 mrem), radon-222 (0 mrem), and dose calculated for compliance with 40 CFR 61, Subpart H using the CAP88PC computer code (0.058 mrem [0.58 µSv]/yr) is approximately 0.20 mrem (2.0 µSv), which is the same as the Horn Rapids Road air pathways MEI dose of 0.20 mrem (2.0 µSv) calculated using the GENII computer code.

4.2.3.2 Dose from Diffuse and Fugitive Radionuclide Emissions to an Offsite Maximally Exposed Individual. The December 15, 1989, revisions to 40 CFR 61, Subpart H required DOE facilities to estimate the dose to a member of the public for radionuclides released from all potential sources of airborne radionuclides. DOE and EPA interpreted the regulation to include diffuse and fugitive (nonpoint source) emissions, as well as emissions from monitored point sources (i.e., stacks) described in Section 4.2.3.1. EPA has not specified or approved standardized methods to estimate diffuse airborne emissions because of the wide variety of sources at DOE sites. The method developed at the Hanford Site to estimate potential diffuse emissions is based on environmental monitoring measurements of airborne radionuclides at the site perimeter (DOE/RL-2019-09). Modeled contributions from monitored stack emissions and contributions from background levels of radionuclides are subtracted from perimeter ambient air concentrations measured for each radionuclide. Positive differences are attributed to a virtual fugitive source located near the center of the Hanford Site.

The Laboratory Supply Warehouse location immediately south of the 300 Area, the MEI location determined from Hanford Site stack emissions, was also used for reporting dose from diffuse and fugitive emissions (DOE/RL-2019-09). The estimated dose from diffuse emissions to this MEI was calculated using the CAP88PC computer code to be 0.019 mrem (0.19 µSv)/yr. Therefore, the potential combined dose from stack emissions, radon-220 and radon-222 emissions, and diffuse emissions during 2018 at the Laboratory Supply Warehouse location was 0.22 mrem (2.2 µSv)/yr, far below the 10 mrem (100 µSv)/yr federal and state standards described above.

4.2.3.3 Maximum Dose to Non-U.S. Department of Energy Workers at the Hanford Site.

DOE allows private businesses to locate their activities and personnel on some regions of the Hanford Site. The EPA Region 10 Office and the Washington State Department of Health provided guidance to the U.S. Department of Energy, Richland Operations Office that when demonstrating compliance with 40 CFR 61 standards it should evaluate potential doses to non-DOE employees who work at facilities within the Hanford Site but who are not under direct DOE control. This situation has created the need to calculate a maximum dose for an onsite individual employed by a non-DOE business who works within the boundary of the Hanford Site.

Doses to members of the public employed at non-DOE facilities at locations outside access-controlled areas on the Hanford Site (those requiring DOE-access authorization for entry) were evaluated in the 2018 EPA air emissions report (DOE/RL-2019-09) as possible MEI locations. Included in these locations were the Columbia Generating Station operated by Energy Northwest and the Laser Interferometer Gravitational Wave Observatory (LIGO) operated by the University of California (Figure 4-2). The non-DOE worker dose due to stack emissions at these facilities was calculated using the CAP88PC computer code assuming full-time occupancy because Washington State Department of Health guidance does not allow for adjustment of such doses to account for less than full-time occupancy. The highest estimated dose to a member of the public from fugitive emissions (0.067 mrem [0.67 µSv]) was at LIGO. The total dose attributable to 2018 stack emissions, fugitive source emissions, and radon-220 and radon-222 at LIGO was calculated using CAP88PC to be 0.082 mrem (0.82 µSv) (DOE/RL-2019-09). Even assuming that a LIGO employee is continuously present, the estimated total dose to non-DOE onsite workers in 2018 was lower than the 0.22 mrem (2.2 µSv)/yr total dose calculated with CAP88PC to an offsite MEI at the Laboratory Supply Warehouse.

4.2.4 Special Case Dose Estimates

The exposure assumptions used to calculate the dose to the MEI were selected to provide a scenario yielding a reasonable upper-bound dose estimate. The MEI dose calculations are based on measurements of radionuclide releases from stack emissions (air pathways) and differences between downstream and upstream radionuclide concentrations in the Columbia River (water pathways) followed by modeling of environmental transport related to a number of different exposure pathways (Figure 4-3). Exposure pathways using other radionuclide measurements also exist that could have resulted in radiological exposures. Three such scenarios include an outdoor recreationalist who consumed meat from contaminated wildlife that migrated from the Hanford Site, an individual who drank water from one of four DOE-owned water treatment facilities at the Hanford Site, and a visitor to the Manhattan Project National Historical Park. The potential doses resulting from these scenarios are examined in the following sections.

4.2.4.1 Outdoor Recreationalist Dose.

Wildlife has access to Hanford Site areas that are contaminated with radioactive materials and have the potential to acquire radioactive contamination and migrate offsite. Wildlife sampling was conducted at the Hanford Site to estimate radionuclide tissue concentrations in animals from the site that could potentially have been hunted offsite. An outdoor recreationalist is also potentially exposed to contaminated soil and sediment along the river corridor if they access this area from the Columbia River.

Concentrations of radionuclides measured in soil (cesium-137, plutonium-238, plutonium-239/240, and strontium-90) at far-field sampling locations are not readily distinguishable from background levels, and soil concentrations are less susceptible to yearly variation than sediment and wildlife. An evaluation of

radionuclide soil concentrations and trends over time is provided in PNNL-20577. Review of the 2018 sediment data indicates that concentrations of key radionuclides frequently detected in sediment (including cesium-137, plutonium-239/240, and uranium isotopes) have approximately equal or larger concentrations in upstream (Priest Rapids Dam) samples in comparison to samples from downstream (McNary Dam) locations and samples at slough locations along the Hanford Site near White Bluff and the Hanford Townsite. The 2018 sediment data do not indicate the presence of a Hanford contribution to sediment radionuclide concentrations. Therefore, the screening assessment of outdoor recreationalist dose will focus on wildlife samples.

Gamma-emitting radionuclides were analyzed in muscle tissue samples collected in 2018 from mule deer, pheasant, quail, and elk. In addition to muscle tissue, samples of bone tissue were obtained from these animals and analyzed for strontium-90, a radionuclide that accumulates in bone. For estimating dose from ingestion of game meat, radionuclide concentrations in muscle tissue are most applicable. However, the only radionuclide detected in the muscle tissue of any animal was potassium-40, a naturally occurring primordial radioisotope that is not of Hanford Site origin. Because site-related radionuclides were not detected at levels greater than analytical minimum detectable activities, calculations of dose related to ingestion of game meat were not performed.

Fillet tissue and carcass samples were obtained from bass and carp in two river sections of the Hanford Reach and reference locations in 2018. Fillet samples were analyzed for gamma-emitting radionuclides, tritium, strontium-90, and isotopes of plutonium and uranium. Carcass samples were only analyzed for strontium-90. Detected radionuclides in fillet samples were limited to potassium-40, uranium-234, uranium-235, and uranium-238. Potassium-40 is a naturally occurring radionuclide that is not of Hanford Site origin. However, uranium isotopes are associated with Hanford Site operations and dose calculations were performed for these analytes.

Uranium-234 was detected in two carp fillet samples from the 100 Area. Uranium-235 was detected in two carp fillet samples and one bass fillet sample from the 100 Area. Uranium-235 was also detected in one bass fillet in the 300 Area. Uranium-238 was detected in three carp fillet samples from the 100 Area. Only carp fillet samples were captured in the upstream reference area. All fillet samples in the reference area were non-detects; the maximum non-detect for uranium-234 was 0.021 pCi/g, for uranium-235 was 0.0109 pCi/g, and for uranium-238 was 0.00521 pCi/g. The carp fillet uranium-234 maximum concentrations measured in the 100 Area (0.0228 pCi/g and 0.0199 pCi/g) were larger and essentially identical to the maximum non-detect for uranium-234 in the reference area. The carp fillet uranium-234 maximum concentrations measured in the 100 Area (0.0193 pCi/g and 0.0112 pCi/g) were both larger than the maximum non-detect for uranium-234 in the reference area. The carp fillet uranium-235 maximum concentrations measured in the 100 Area (0.016, 0.017, and 0.02 pCi/g) are all larger than the maximum non-detect for uranium-235 in the reference area. These uranium-234, uranium-235, and uranium-238 results for carp fillets in 2018 are larger than the values measured in carp fillets in the reference and 100 Areas in 2016 (0.00189 to 0.00315 pCi/g).

The uranium-235 results for bass fillets in 2018 (0.0999 and 0.104 pCi/g) are similar to the values measured in bass fillets in the reference and 100 Areas in 2016 (0.003 to 0.0111 pCi/g), which is the last year when bass fillets were acquired in the 100 and reference Areas. In 2018, it is possible the data indicated that uranium isotope concentrations are higher in carp fillets from fish collected in the 100 or 300 Areas than in reference area fish; however, detected data in the reference area are not available for comparison. Nevertheless, potential radiation dose received from consumption of fish fillets with

isotopic uranium concentrations measured in 2018 was calculated to provide a measure of the significance of these levels.

The potential radiation dose received from consumption of fish fillets with the largest isotopic uranium concentrations measured in 2018 would be negligible. Assuming annual fish consumption of 88 lb (40 kg) for an MEI (Table D-4), the annual radiation dose related to fish ingestion for fish with tissue concentrations of 0.0228 pCi/g of uranium-234, 0.0193 pCi/g of uranium-235, and 0.02 pCi/g of uranium-238 is estimated to be 0.431 mrem (4.31 µSv). The annual dose estimate for fish ingestion was derived using an ingestion dose factor of 1.8×10^{-4} mrem/pCi (4.9×10^{-2} µSv/Bq) for uranium-234, 1.7×10^{-4} mrem/pCi (4.6×10^{-2} µSv/Bq) for uranium-235, and 1.7×10^{-4} mrem/pCi (4.6×10^{-2} µSv/Bq) for uranium-238 from ICRP Publication 72 (ICRP 1995) in the following manner:

((0.0228 pCi uranium-234/g × 1.8×10^{-4} mrem/pCi) +(0.0193 pCi uranium-235/g × 1.7×10^{-4} mrem/pCi) + (0.02 pCi uranium-238/g × 1.7×10^{-4} mrem/pCi)) × 40 kg/yr × 1,000 g/kg = 0.431 mrem (4.31 µSv)/yr

4.2.4.2 Hanford Site Drinking Water Dose. Drinking water was sampled and analyzed for tritium, gross alpha radiation, and gross beta radiation during 2018 in accordance with applicable regulations (40 CFR 141); water samples were collected from the 100-K Area, 200-West Area, and two sources in the 400 Area (primary well P-14 and emergency backup well P-15). The water supply for the 100-K and 200-West Areas is the Columbia River, whereas the primary and backup water supplies for the 400 Area are groundwater wells (see Section 7.1).

A comparison of analytical results for the 100-K, 200, and 400 Areas drinking water samples to state and federal standards is provided in Section 7.1. Tritium, an isotope of hydrogen with 2 neutrons, is a man-made beta radiation emitter; there are also naturally occurring beta emitters found in groundwater in the uranium, actinium, and thorium decay series. Potential onsite drinking water dose from Hanford-related beta-emitting radionuclides is addressed in this section by evaluating drinking water data for tritium. Drinking water concentrations for tritium range from 4,450 to 5,110 pCi/L, and for gross beta from only 0 to 12 pCi/L.

Tritium was measured in four quarterly samples from backup well P-15 in the 400 Area. Tritium was detected in all four drinking water samples collected from the backup drinking water sources for the 400 Area (well P-15), and was not analyzed in samples from primary well P-14 in the 400 Area or in samples from 100-K and 200-West areas. Based on the average of the four 400 Area samples, the annual average 400 Area drinking water tritium concentration was 4695 pCi/L (173 Bq/L). Assuming a consumption rate of 0.26 gal (1 L)/day for 250 working days at the Fast Flux Test Facility in the 400 Area, the potential annual worker dose in 2018 would be approximately 0.079 mrem (0.79 µSv). This estimate is well below EPA's drinking water dose limit of 4 mrem (40 µSv)/yr for beta-emitting radionuclides in public drinking water supplies.

The dose estimate for the 400 Area drinking water sources was derived using a tritium ingestion dose factor of 6.7×10^{-8} mrem/pCi (1.8×10^{-5} µSv/Bq) from ICRP Publication 72 (ICRP 1995) in the following manner:

4695 pCi tritium/L × 1 L/day × 250 d/year × 6.7×10^{-8} mrem/pCi = 0.079 mrem (0.79 µSv)/yr

4.2.4.3 Manhattan Project National Historical Park Visitor Dose.

The Manhattan Project National Historical Park at the Hanford Site includes guided tours of the B Reactor as well as access to several pre-Manhattan Project locations, two of which (Hanford Townsite and White Bluffs Bank) are situated to the east of the 100-K and 200 Areas. These historical locations are geographically closer to these air emissions sources than the offsite MEI locations evaluated in Section 4.2.1. However, unlike an offsite residential MEI receptor, visitors to these locations would not be exposed from agricultural and drinking water exposure pathways, nor would they be continually exposed over the course of a year, as might be anticipated for some residents. For these reasons, potential doses at these locations are likely to be considerably below those calculated for the hypothetical offsite MEI.

Inhalation dose related to 100-K and 200 Areas stack emissions was calculated for a hypothetical individual at the Hanford Townsite and White Bluffs Bank locations using the GENII Version 2.10.2 computer code. Although Historical Park visitors would be present only briefly and on a single occasion at these locations, individuals conducting tours could be present for greater lengths of time. Additionally, these locations are adjacent to the Columbia River where recreationalists might be exposed while boating, fishing, or engaging in other activities. For this screening calculation, continuous exposure (24 hrs/day, 365 days per year) at the Hanford Townsite and White Bluffs Bank locations was assumed. The results of these dose calculations are presented in Table 4-4.

Table 4-4. Annual Doses for a Hypothetical Individual at the Hanford Townsite and White Bluffs Bank Locations (2018).

Release Type	Exposure Pathway	Location	Dose Contributions from Operational Areas, mrem[a]		
			100 Area	200 Areas	Pathway Total
Air	Inhalation	Hanford Townsite	1.4E-04	1.5E-05	1.6E-04
		White Bluffs Bank	3.5E-04	1.2E-05	3.6E-04

[a] To convert mrem to International System dose units (µSv), multiply by 10.

Radiological doses assuming continuous inhalation exposure at either the Hanford Townsite or White Bluffs Bank locations are far below the hypothetical offsite MEI air pathways annual dose of 0.20 mrem (2.0 µSv; Table 4-2) at Horn Rapids Road.

4.2.5 Doses from Non-U.S. Department of Energy Sources

Doses from non-DOE sources were not quantified in 2018 because the MEI dose of 0.28 mrem (2.8 µSv)/yr from DOE-related sources (Section 4.2.1) was far below the threshold of 25 mrem (250 µSv)/yr at which the contribution of non-DOE sources must be included. DOE O 458.1 paragraph 4.e(1)(c) states::

> *The dose to members of the public from DOE-related exposure sources only, if the projected DOE-related dose to the representative person or MEI is 25 mrem (250 µSv) in a year or less. If the DOE-related dose is greater than 25 mrem in a year, the dose to members of the public must include both major non-DOE sources of exposure . . . and dose from DOE-related sources.*

4.2.6 Dose to Non-Human Biota

Dose assessments for non-human biota evaluate the potential for exposures from Columbia River sediment and water, soils (near facilities), and exposures associated with West Lake. Upper estimates of the radiological dose to aquatic organisms were made in accordance with the DOE O 458.1 requirement for management and control of liquid discharges and air emissions. The current dose limit for aquatic animal organisms is 1 rad (10 milligray [mGy])/day (DOE-STD-1153-2019). Rad is a unit of absorbed dose of ionizing radiation equal to an energy of 100 ergs/g of irradiated material. In addition to the dose limit for aquatic organisms, DOE-STD-1153-2019 provides a dose limit for terrestrial plants of 1 rad (10 milligray [mGy])/day and a dose limit for riparian or terrestrial wildlife of 0.1 rad (1 mGy)/day.

Concentration guides for assessing doses to biota are very different from the DOE-derived concentration standards used to assess radiological doses to humans. A tiered approach is used to estimate radiological doses to aquatic and terrestrial biota. This method uses the RESidual RADioactive (RESRAD)-BIOTA computer code (DOE/EH-0676) to compare radionuclide concentrations measured by routine monitoring programs to a set of biota concentration guides (BCG).

Biota concentration guides are the soil, water, or sediment concentrations of a radionuclide that would result in a 1 rad (10 mGy)/day dose for aquatic biota or terrestrial plants, or 0.1 rad (1 mGy)/day dose for riparian or terrestrial wildlife. For samples containing multiple radionuclides, a sum of fractions is calculated to account for the contribution to dose from each radionuclide relative to the dose limit. If the sum of fractions exceeds 1.0, then the dose limit has been exceeded. If the initial estimated screening value (Tier 1) exceeds the guideline (sum of fractions more than 1.0), additional screening calculations are performed (Tier 2 or Tier 3) to evaluate, more accurately, exposure of the biota to the radionuclides. The process may culminate in a site-specific assessment requiring additional sampling and study of exposure. Biota-dose screening assessments were conducted using surveillance data collected in 2018 from on and around the Hanford Site.

Researchers used the RESRAD-BIOTA computer code to evaluate potential effects on biota from the maximum concentrations of radionuclides measured in Columbia River sediment and water as tabulated in Appendix C. The detected radionuclides evaluated across all locations in the Columbia River sediment and water biota dose assessment are carbon-14, cesium-137, plutonium-238, plutonium-239/240, strontium-90, technetium-99, tritium, uranium-234, uranium-235, uranium-236, and uranium-238. RESRAD-BIOTA v1.8 lacks uranium-236 BCGs for estimating radiological dose. As a result, uranium-236 values were added to uranium-235 values due to similar radiological decay emissions between the isotopes and assessed using the uranium-235 BCG from RESRAD-BIOTA v1.8. Beryllium-7 was detected but is of cosmogenic origin and is not associated with the Hanford Site. Potassium-40 was also detected in sediments upstream, onsite, and downstream of the Hanford Site. Potassium-40 is a naturally occurring radionuclide and is not associated with releases from the reactors or any groundwater plumes entering the Columbia River. Therefore, dose associated with potassium-40 is not included in the biota dose assessment.

Most of the locations located on the Columbia River had samples collected from riverbank springs or seeps that carry groundwater contaminants into the Columbia River. Concentrations in springs or seeps are generally greater than those observed in the river water; therefore, the dose assessment results for these discrete areas of elevated concentrations are protective relative to the potential for impacts on populations of biota in the Columbia River. For an initial screen of ecological populations, the sediment and water data were split into five subareas (i.e., upstream, 100 Area, Hanford Townsite, 300 Area, and

downstream) and the maximum measured concentrations in these locations were evaluated. If risks to biota were identified in the initial screen, then further assessments using average concentration over smaller spatial units would be evaluated.

The results of the screening calculations listed in Table 4-5 showed the concentrations in all Columbia River sediment and water samples passed the Tier 1 screen and indicated that the calculated doses were below dose limits (sum of fractions less than one). Most of the estimated dose in the 100 Area is from strontium-90 (55%) and carbon-14 (41%); dose in the 300 Area is basically entirely associated with uranium isotopes. Biota doses upstream of the Hanford Townsite and downstream were all similar and likely related to background concentrations in water and sediment. Further documentation of the Columbia River biota dose calculations is provided in Appendix D.

Biota dose calculations also were completed for West Lake, located on the Central Plateau of the Hanford Site. West Lake is a vernal pool or ephemeral wetland that fills with water during the winter and generally becomes smaller or dries up entirely in other seasons. West Lake is part of the 200 Areas Unplanned Release Waste Group Operable Unit (200-UR-1 Operable Unit) and is a location of planned supplemental characterization (DOE/RL-2009-121). The results of these planned investigations will be presented in the appropriate *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) remedial action document for the 216-N-8 waste site. In parallel with these planned CERCLA studies, this program has been collecting sediment data annually. In addition, other media (water and biota) have been evaluated at West Lake on a less regular schedule. Both sediment and water samples were collected in 2018 and data are tabulated in Appendix C, Tables C-1, C-2.

The results of the 2018 screening calculations listed in Table 4-6 show the West Lake sediment and water concentrations failed the Tier 1 and 2 screens. The Tier 1 screen was based on the maximum concentration, and the Tier 2 screen was based on the average concentrations of six water and seven sediment samples. The estimated biota dose for Tiers 1 and 2 was almost entirely due to the measured concentration of uranium in water and the assumed potential for uptake from water to aquatic biota using a default bioaccumulation factor. The variability in the sum of fractions may be due to the water in the pool drying up in non-winter seasons, thus, increasing water concentrations in those seasons.

The RESRAD-BIOTA default bioaccumulation factor for uranium isotopes from water to aquatic biota is 1,000. This means that the concentration in tissues would be 1,000 times that measured in water. Hanford Site-specific data from West Lake are indicative of a much lower uranium bioaccumulation factor. Aquatic biota (only brine flies have been sampled, and they are also the most relevant organisms) and water were sampled concurrently in 2000 and 2007 (PNNL-13487; DOE/RL-2007-50). Brine flies are the most relevant organisms as they are continually present during the period of time when West Lake contains water (late fall, winter, spring, and early summer), therefore, they have a higher potential for bioaccumulation at West Lake compared to birds (avocets), which are not continually present during the period of time when West Lake contains water.. The maximum concentration of any of the uranium isotopes in brine flies was 0.77 pCi/g for uranium-233/234 in 2007. The minimum uranium-233/234 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); therefore, the maximum bioaccumulation factor for uranium would be less than one. A bioaccumulation factor of one was used for the Tier 3 biota dose calculation as a somewhat protective measure of site-specific uranium uptake into the food chain.

Table 4-5. Estimated Sum of Fractions to Biota Associated with Columbia River Sediment and Water[a].

Location	Media Sampled for Key Radionuclides[b]	Tier 1 Screen Sum of Fractions[c]			Pass or Fail (2018)
		2016	2017	2018	
Upstream	Sediment, Water	0.018	0.018	0.015	Pass
100 Area	Sediment, Water	0.71	0.46	0.53	Pass
Hanford Townsite	Sediment, Water	0.014	0.014	0.013	Pass
300 Area	Sediment, Water	0.25	0.27	0.17	Pass
Downstream	Sediment, Water	0.015	0.016	0.014	Pass

[a] Using RESRAD-BIOTA 1.8 computer code, a screening method to estimate radiological doses to aquatic and riparian biota.
[b] A sum of fractions is calculated to account for the contribution to dose from each radionuclide. If the sum of fractions exceeds 1.0, then the dose guideline has been exceeded and further screening (Tier 2 or 3) is required. The sum of fractions has been rounded to two figures with a maximum of three decimal points. Maximum concentrations and the Biota Concentration Guides are presented in Appendix D.
[c] The biota dose assessment requires concentration data for both sediment and water. If one of these media is not measured then it is estimated by using the default water to sediment partition coefficient. If water was measured, then sediment was estimated from water and if sediment was measured then water was estimated from sediment. In some cases where both sediment and water were measured a radionuclide was only measured in one medium (e.g., tritium in water), and the concentration for that radionuclide in the other medium was estimated. See Appendix D for details on what was measured.

Table 4-6. Estimated Sum of Fractions to Biota Associated with West Lake[a].

Tier	Exposure Assumptions	Sum of Fractions[b]			Pass or Fail (2018)
		2016	2017	2018	
1	Maximum Sediment, Water Concentration and Default Bioaccumulation	120	6.3	5.2	Fail
2	Average Sediment, Water Concentration and Default Bioaccumulation	41	4.3	3.8	Fail
3	Average Sediment, Water Concentration and Site-specific Bioaccumulation	0.49	0.095	0.11	Pass

[a] Using RESRAD-BIOTA 1.8 computer code, a screening method to estimate radiological doses to aquatic and riparian biota.
[b] A sum of fractions is calculated to account for the contribution to dose from each radionuclide. If the sum of fractions exceeds 1.0, then the dose guideline has been exceeded and further screening (Tier 2 or 3) is required.

The Tier 3 biota dose calculations resulted in sum of fractions less than one, indicating that the calculated doses were below dose limits related to the biota concentration guides. This result was similar to those calculated for 2017; however, the 2018 doses were about 3 times less than those calculated for 2016 (Table 4-6). The reason for the change is that the maximum isotopic uranium concentrations in West Lake pond water samples varied quite widely from year to year and isotopic uranium is typically detected in West Lake pond water. The isotopic ratios of uranium indicate a natural source (PNL-7662). The last 3 years of concentrations were: 2016 (uranium-234 at 10,700 pCi/L, uranium-235 at 43.5 pCi/L, uranium-238 at 13,700 pCi/L), 2017 (uranium-234 at 658 pCi/L, uranium-235 at 34.7 pCi/L, uranium-238 at 623 pCi/L), and 2018 (uranium-234 at 546 pCi/L, uranium-235 at 27.6 pCi/L, uranium-238 at 500 pCi/L). The maximum concentrations measured in 2018 were

approximately 20 to 30 times less than those measured in 2016. Further documentation of the West Lake biota dose calculations, including the Tier 3 Biota Concentration Guides, is provided in Appendix D.

Biota dose calculations were implemented for terrestrial biota based on exposures to soils collected on the Hanford Site. The RESRAD-BIOTA computer code was used to evaluate potential effects on biota using the maximum concentrations of radionuclides measured in onsite soil samples, as tabulated in Appendix C. The radionuclides evaluated in soil are cesium-137, plutonium-238, plutonium-239/240, strontium-90, uranium-234, uranium-235, uranium-238, and americium-241. The results of 2018 screening calculations listed in Table 4-7 show the onsite soil concentrations passed the Tier 1 screen based on the maximum concentration. Nearly the entire estimated 2018 dose for onsite locations results from cesium-137 (89.5%) and strontium-90 (10.3%). See PNNL-20577 for a long-term trend analysis of soil concentrations and associated biota doses on and off the Hanford Site.

Table 4-7. Estimated Sum of Fractions to Terrestrial Biota Associated with On- and Offsite Soil[a].

Location	Tier 1 Screen Sum of Fractions [b]			Pass or Fail (2018)
	2016	2017	2018	
Onsite	0.57	0.86	0.95	Pass
Offsite	Not measured[c]	Not measured[c]	Not measured[c]	--

[a] Using RESRAD-BIOTA 1.8 computer code, a screening method to estimate radiological doses to aquatic and riparian biota.
[b] A sum of fractions is calculated to account for the contribution to dose from each radionuclide. If the sum of fractions exceeds 1.0, then the dose guideline has been exceeded and further screening (Tier 2 or 3) is required. The sum of fractions has been rounded to two figures with a maximum of three decimal points. Maximum concentrations and the Biota Concentration Guides are presented in Appendix D.
[c] Offsite soil samples are collected approximately every 3 to 5 years and are planned for collection in 2019.

In addition to the dose assessments related to soils, sediments, and water, there are also fish and wildlife tissue samples collected from the Hanford Site and reference locations. Although none of the biota dose assessments (except for West Lake) required any additional tiers of analysis, supplemental calculations using these tissue samples were made to characterize more realistic doses based on measured concentrations. Dose to aquatic animals based on the maximum concentrations of uranium-234 (0.0228 pCi/g), uranium-235 (0.0193 pCi/g), and uranium-238 (0.02 pCi/g) in fish was 0.0003 rad/day. Internal dose to terrestrial plants based on the maximum concentrations of plutonium-238 (0.0446 pCi/g), plutonium-239/240 (0.626 pCi/g), strontium-90 (1.76 pCi/g), uranium-234 (0.0176 pCi/g), uranium-235 (0.0228 pCi/g), and uranium-238 (0.0304 pCi/g) in plants was 0.0006 rad/day. Dose to terrestrial animals based on the maximum concentrations of plutonium-238 (0.0152 pCi/g) and strontium-90 (0.0853 pCi/g) in mule deer liver was 0.00009 rad/day. Using the measured tissue data leads to lower doses than using the default bioaccumulation information assumed in the Tier 1 RESRAD-BIOTA calculations.

4.2.7 Radiological Dose in Perspective

The hypothetical annual dose for the MEI in 2018 was 0.28 mrem (2.8 µSv; Section 4.2.1). The annual dose for an average individual from Hanford Site operations in 2018, based on the 50-mi (80-km) radius population exposed to air emissions and the Tri-Cities populations exposed to water pathways releases to the Columbia River, was approximately 0.0095 mrem (0.095 µSv). To place the MEI and average individual estimated doses into perspective, the estimated doses may be compared with doses received from other routinely encountered sources of radiation. The National Council on Radiation Protection

and Measurement report *Ionizing Radiation Exposure of the Population of the United States* (NCRP 2009) estimated that the overall average exposure to ionizing radiation for the average American is 620 mrem (6,200 µSv)/yr. Approximately 50% of the 620 mrem (6,200 µSv)/yr average annual dose is related to natural sources, with the remaining 50% attributable primarily to medical procedures.

The most relevant radiation sources for comparison to doses received from environmental media include natural terrestrial and cosmic background radiation, and inhalation of naturally occurring radon (Figure 4-7). Average annual individual background dose related to terrestrial radiation (19 mrem [190 µSv]), cosmic background radiation (30 mrem [300 µSv]), and radon (radon-222) and thoron (radon-220) gases (230 mrem [2,300 µSv]) are shown relative to Hanford Site operational doses in Figure 4-8. The calculated radiological doses from Hanford Site operations in 2018 were a small percentage of national average annual doses from these natural background sources. Note that annual dose is shown on a linear scale in Figure 4-8 and Hanford-related doses are too small to be observed. For example, the national annual average radiation dose from natural terrestrial sources (approximately 19 mrem [190 µSv]) is approximately 70 times larger than the 2018 Hanford Operations dose to the MEI receptor (0.28 mrem [2.8 µSv]).

Scientific studies (*Health Risks from Exposure to Low Levels of Ionizing Radiation, BEIR VII Phase 2* [National Research Council 2006]) have been performed to estimate the possible risk from exposure to low levels of radiation. These studies provide information to government and scientific organizations for use in recommending radiological dose limits and standards for public and occupational safety.

Although no increase in the incidence of health effects from low doses of radiation actually has been confirmed by the scientific community, regulatory agencies cautiously assume that the probability of these types of health effects occurring due to exposure to low doses (down to zero dose) is the same per unit dose as the health effects observed after an exposure to much higher doses (e.g., in atomic bomb survivors; individuals receiving medical exposure; or, historically, painters of radium dials). This concept is known as the linear no-threshold hypothesis. Under these assumptions, public exposure to radiation from current Hanford Site releases; exposure to natural background radiation, which is hundreds of times greater; and exposure to very high levels of radiation each increases an individual's probability or chance of developing a detrimental health effect (primarily cancer) proportional to the dose received.

Scientists do not fully agree on how to translate the available epidemiological data on health effects from high radiological doses into the numerical probability (risk) of detrimental effects from low radiological doses (UNSCEAR 2012). Some scientific studies have indicated that low radiological doses may result in beneficial rather than adverse effects (Calabrese 2009). Because cancer is a common disease in the general population and may be attributable to many other causes besides radiation (e.g., genetic defects, natural and man-made chemicals, natural biochemical body reactions), some scientists doubt that the risk from low-level radiation exposure can be proven conclusively. In developing *Clean Air Act* regulations, EPA used a probability of approximately 4 per 10 million (4×10^{-7}) for the risk of developing a fatal cancer after receiving a dose of 1 mrem (10 µSv; EPA 1989). Additional data support the reduction of even this small risk value, possibly to zero, for certain types of radiation when the dose is spread over an extended time (National Research Council 2006). Guidance from the Interagency Steering Committee on Radiation Standards (ISCORS 2002) recommends that agencies assign a risk factor of 6 per 10 million (6×10^{-7}) for developing a fatal cancer after receiving a dose of 1 mrem (10 µSv).

One approach for providing perspective on calculated risks related to low-dose radiation exposures is to compare them to risks involved in other typical activities. Table 4-8 compares the estimated risks from various radiological doses to the risks of some activities encountered in everyday life.

The hypothetical annual dose from 2018 Hanford Operations for the MEI in 2018 was 0.28 mrem (2.8 µSv [Section 4.2.1]) and 0.0095 mrem (0.095 µSv) for an average individual. The dose to the MEI calculated in 2018 from Hanford Site operations was 0.28 mrem (2.8 µSv), which is 0.28% of the 100 mrem (1,000 µSv) annual public dose limit specified in DOE O 458.1. Furthermore, the calculated radiological doses from Hanford Site operations in 2018 were a small percentage of the national average annual doses from natural background sources (Figure 4-8). For example, the national annual average radiation dose from natural terrestrial sources (approximately 19 mrem [190 µSv]) is approximately 70 times larger than the 2018 Hanford Operations dose to the MEI receptor (0.28 mrem [2.8 µSv]) and 2,000 times larger than the 2018 Hanford Operations dose to the average individual (0.0095 mrem [0.095 µSv]). Thus, the dose to the MEI receptor from 2018 Hanford Site Operations is very small compared to natural background sources and the acceptable public dose limit.

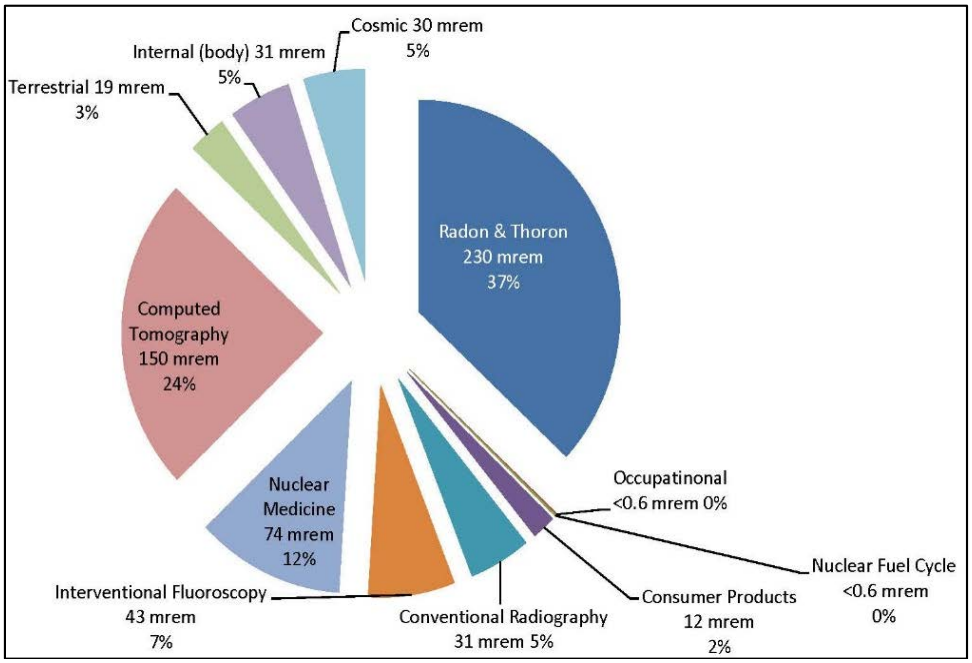

Figure 4-7. U.S. Annual Average Radiological Doses from Various Sources (2009 National Council on Radiation Protection and Measurements).

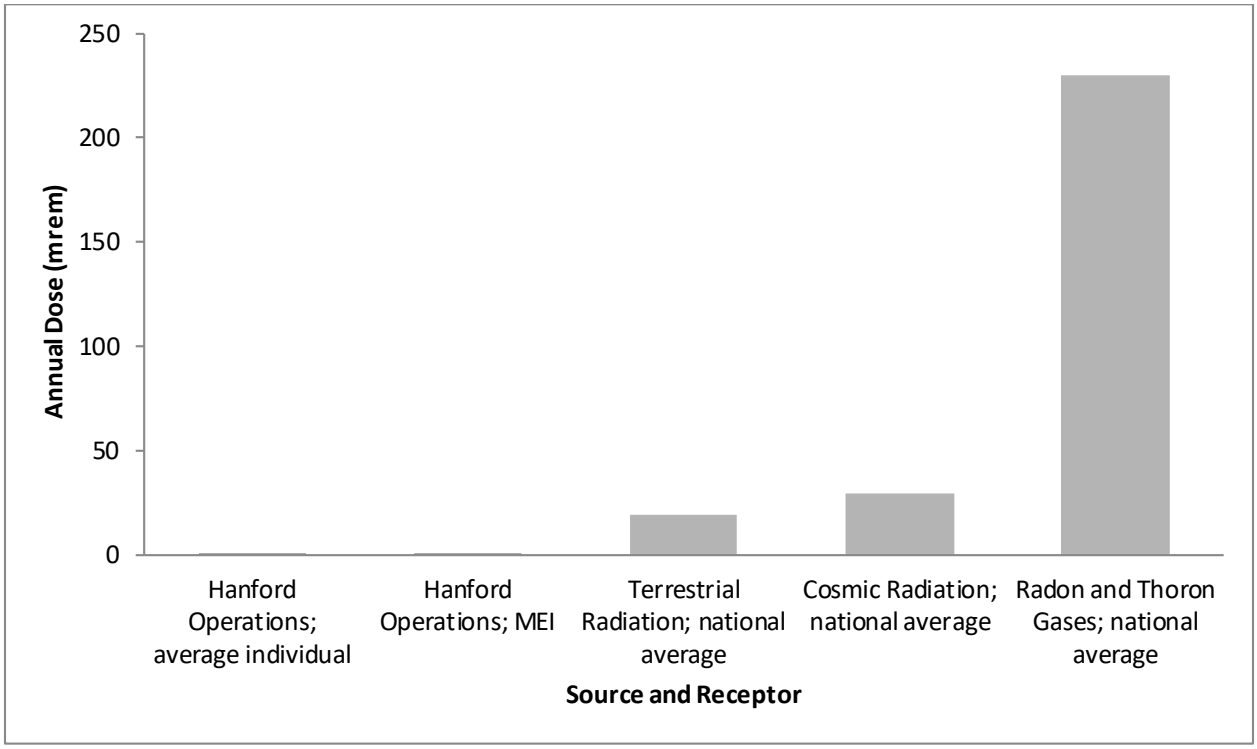

Figure 4-8. Radiological Doses from Hanford Site Operations Compared to Annual Average from Natural Sources.

Table 4-8. Estimated Risk from Various Activities and Exposures.

Activity or Exposure Per Year	Risk of Fatality
Home accidents	100×10^{-6} [a]
Firearms (sporting accidents)	10×10^{-6} [a]
Flying as an airline passenger (cross-country roundtrip – accidents)	8×10^{-6} [a]
Recreational boating (accidents)	6×10^{-6} [a]
Riding or driving 300 mi (483 km) in a passenger vehicle	2×10^{-6} [a]
Dose of 1 mrem (10 µSv) for 70 yrs	0 to 0.6×10^{-6} [b]
Natural background radiological dose (310 mrem [3,100 µSv]) for 70 yrs	0 to 200×10^{-6} [b]
Dose to hypothetical MEI (2018 rate) of 0.28 mrem (2.8 µSv)/yr living near Hanford Site for 70 yrs	0 to 0.3×10^{-6} [b]

[a] Real actuarial values.
[b] Upper bound calculated using 6×10^{-7} risk of developing a fatal cancer after receiving a 1 mrem (10 µSv) dose (ISCORS 2002).
MEI = maximally exposed individual

4.3 Radiological Clearance of Hanford Site Property

TA Ikenberry

Radiological clearance is a process where property with the potential to contain residual radioactive material is released from DOE control. It may be conducted for personal property (e.g., materials and equipment) or for real property (i.e., land and buildings). After clearance, property is considered suitable

for unrestricted use by members of the public, although in some cases restrictions on some types of use may be included. The requirements for release and clearance of DOE property are found in DOE O 458.1. Key aspects of these requirements are as follows:

- Demonstrate property does not contain residual radioactive material. This accounts for most of the property released from the Hanford Site.

- Evaluate property for the potential presence of residual radioactive material. As determined necessary, appropriately monitor and survey to determine presence (if any), type, and quantity of residual radioactive material. Most surveyed property has no detectable radioactivity above background levels and is considered to be free of residual radioactivity.

- Do not exceed the dose constraints for clearance (Table 4-9) and keep residual radioactivity as near background levels as reasonably practicable, as determined through DOE's as low as reasonably achievable process requirements and authorized limits. In addition to pre-approved authorized limits, Hanford Site-specific authorized limits have been approved for use by Hanford Site contractors.

- Document radiological clearance of property, independently verify clearance of real property, and properly report; address public participation needs; and provide processes to maintain appropriate records.

Table 4-9. Dose Constraints for Release and Clearance of Property, DOE O 458.1.

Exposure from release of real (land and buildings) and personal property shall be controlled to be ALARA and meet dose constraints.	**Total Effective Dose**	
	mrem/year	***mSv/year***
Public dose constraint from real property	25	*0.25*
Public dose constraint from personal property	1	*0.01*

NOTE: International dose units shown in italics are not in the order but are provided for information.
ALARA = as low as reasonably achievable
Mrem = millirem
mSv = millisievert

4.3.1 Personal Property

Personal property is considered to be everything except real property, namely material and equipment. Surveys are performed to verify common items cleared from the Hanford Site do not have residual radioactivity (e.g., electronics, pallets, batteries, office items, respiratory protection equipment, compressed gas cylinders, vehicles, tools, and physical security items). Some types of debris may be cleared to go to sanitary waste disposal sites. Formal clearance surveys may also be conducted on property such as power poles, transformers, miscellaneous electrical equipment, air conditioning units, industrial vehicles, excavation equipment, man lifts, scaffolding, and any of the common items as determined necessary and prudent. During 2018 an estimated 36,000 items of personal property were surveyed. Ninety-nine percent were small items, and 1% were large items; less than 10% had any real potential for residual radioactivity. The items were verified to meet the authorized limits for clearance under DOE O 458.1 and able to undergo unrestricted release from the Hanford Site.

Scrap metal that has been confirmed as not being in radiological areas can be verified to be free of residual radioactivity and cleared for release from the Hanford Site. All DOE sites are currently (since 2000) under a moratorium prohibiting the release of volume-contaminated metals for recycling from DOE radiological areas. No scrap metal is released from radiological areas.

4.3.2 Real Property

Real property is land and buildings. There was no radiological clearance of real property in 2018.

4.3.3 Granular-Activated Carbon for Offsite Shipment and Regeneration

Another important area of radiological clearance from the Hanford Site is that of granular-activated carbon (GAC), used to remove carbon tetrachloride from groundwater. Carbon tetrachloride was found in the unconfined aquifer beneath the 200-West Area in the mid-1980s. Groundwater monitoring indicated the carbon tetrachloride plume was widespread and concentrations were increasing. An expedited response action was initiated in 1992 to extract carbon tetrachloride from the vadose zone in the 200-ZP-2 Operable Unit, currently designated as the 200-PW-1 Operable Unit. This action continued during 2018 in the 200-West Area.

Since 2012, the 200-West Area Pump-and-Treat facility has used GAC to treat contaminated groundwater in the unconfined aquifer. The system includes an air-stripping unit that volatilizes carbon tetrachloride in the groundwater and then discharges the carbon tetrachloride vapors through large GAC canisters. The GAC captures the volatile organic compounds removed during the extraction process. When a GAC canister has reached volatile organic compound saturation, it is removed from the system and the GAC is prepared for shipment to an offsite facility for regeneration and reuse. Regeneration of the GAC requires heating it in a hearth furnace to remove the captured volatile organic compounds.

Based on past Hanford Site activities, and the results of characterization sampling, it was determined the GAC could potentially contain residual radioactivity. Characterization sampling results were used to determine radionuclides that could be present and of potential concern. Authorized limits for these radionuclides were established under DOE O 458.1 to allow radiological clearance for offsite shipment and regeneration of GAC. The current authorized limits (Table 4-10) resulted from modifications in 2010 because of an increase in volume of GAC from the 200-West Area Pump-and-Treat facility compared to the predecessor treatment systems. This modification did not change the expected dose to the public, which is expected to remain negligible. Approximately 120,000 lb (54,400 kg) of GAC was shipped offsite in 2018 for regeneration.

The predecessor treatment systems are no longer operable. The 200-ZP-1 Operable Unit groundwater pump-and-treat system was installed in 1996 and operated until 2009. The 200-PW-1 Operable Unit soil-vapor extraction system was in full operation by 1995 and operated until 2014. These systems also used GAC to remove organic vapors from groundwater and soil.

Table 4-10. Authorized Limits for Offsite Shipment and Regeneration of Granular-Activated Carbon.

Radionuclide	Authorized Limit (pCi/g)
Americium-241	29
Carbon-14	3,000
Cesium-137	80
Cobalt-60	21
Europium-152	40
Europium-154	40
Europium-155	700
Iodine-129	50
Neptunium-237	50
Nickel-63	100
Plutonium-238	26
Plutonium-239	24
Plutonium-240	24
Protactinium-231	10
Selenium-79	2,000
Strontium-90	100
Technetium-99	500
Thorium-232 plus progeny	6
Tritium	300,000
Uranium-234	100
Uranium-235	100
Uranium-238 plus short-lived progeny	100

4.4 References

40 CFR 61, Subpart H, "National Emission Standards for Emissions of Radionuclides Other than Radon from Department of Energy Facilities." *Code of Federal Regulations*, as amended.

Barfuss, B. C. 2007. *Development of a Tritium Dilution Factor from Measured Laboratory Emissions and Localized Ambient Air Sampling Measurements*. Master's thesis, Washington State University, Pullman, Washington

Calabrese, E.J. 2009. "The Road to Linearity: Why Linearity at Low Doses Became the Basis for Carcinogen Risk Assessment." *Archives of Toxicology* 83(3):203-225.

Clean Air Act of 1963. 42 U.S.C. 7401 et seq., Public Law 88-206, as amended. Online at https://www.epa.gov/laws-regulations/summary-clean-air-act.

Comprehensive Environmental Response, Compensation, and Liability Act of 1980, 42 U.S.C. 9601 et seq., Public Law 107-377. Online at https://www.govinfo.gov/content/pkg/USCODE-2017-title42/pdf/USCODE-2017-title42-chap103.pdf.

DOE O 458.1, Chg. 3. 2013. *Radiation Protection of the Public and the Environment*. U.S. Department of Energy, Washington, D.C. Online at https://www.directives.doe.gov/directives-documents/400-series/0458-1-border-admc3.

DOE/EH-0676. 2004, *User's Guide, Version 1, RESRAD-BIOTA: A Tool for Implementing a Graded Approach to Biota Dose Evaluation*. U.S. Department of Energy, Springfield, Virginia. Online at http://resrad.evs.anl.gov/docs/RESRAD-BIOTA_Manual_Version_1.pdf.

DOE/RL-91-50. 2018. *Hanford Site Environmental Monitoring Plan*. Rev. 8. U.S. Department of Energy, Richland Operations Office, Richland, Washington. Online at https://www.hanford.gov/files.cfm/2018_EMP_estars.pdf.

DOE/RL-2007-50, Revision1, 2011, *Central Plateau Ecological Risk Assessment Data Package Report.* U.S. Department of Energy, Richland Operations Office, Richland, Washington. Online at https://pdw.hanford.gov/document/1108100554.

DOE/RL-2009-121, 2011, *Sampling and Analysis Plan for the West Lake Site.* U.S. Department of Energy, Richland Operations Office, Richland, Washington. Online at https://pdw.hanford.gov/document/0084064.

DOE/RL-2017-24, 2017, *Hanford Annual Site Environmental Report for Calendar Year 2016.* U.S. Department of Energy, Richland Operations Office, Richland, Washington. Online at https://msa.hanford.gov/files.cfm/DOE-RL-2017-24_Rev0_9-26-171.pdf

DOE/RL-2018-032, 2018, *Hanford Annual Site Environmental Report for Calendar Year 2017.* U.S. Department of Energy, Richland Operations Office, Richland, Washington. Online at: https://msa.hanford.gov/files.cfm/DOE-RL-2018-32_Rev0_UPDATED.pdf.

DOE/RL-2019-09, Revision 0, 2019, Radionuclide Air Emissions Report for the Hanford Site, Calendar Year 2018. U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE-STD-1153-2019. *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota.* U.S. Department of Energy, Richland Operations Office, Washington D.C. Online at https://www.standards.doe.gov/standards-documents/1100/1153-astd-2019/.

EPA. 1988. *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion*. Federal Guidance Report No. 11, EPA-520/1-88-020. U.S. Environmental Protection Agency, Washington, D.C. Online at https://nepis.epa.gov/Exe/ZyPDF.cgi/100009SV.PDF?Dockey=100009SV.PDF.

EPA. 1989. *Risk Assessments Methodology Environmental Impact Statement NESHAPS for Radionuclides Background Information Document – Volume 1*. EPA/520/1-89-005. U.S. Environmental Protection Agency, Washington, D.C. Online at https://nepis.epa.gov/Exe/ZyPDF.cgi/10000AI7.PDF?Dockey=10000AI7.PDF.

EPA. 1993. *External Exposure to Radionuclides in Air, Water, and Soil*. Federal Guidance Report No. 12, EPA-402-R-93-081. U.S. Environmental Protection Agency, Washington, D.C. Online at https://nepis.epa.gov/Exe/ZyPDF.cgi/00000AA1.PDF?Dockey=00000AA1.PDF.

EPA. 1999. *Cancer Risk Coefficients for Environmental Exposure to Radionuclides*. Federal Guidance Report No. 13, EPA-402-R-99-001. Office of Radiation and Indoor Air, U.S. Environmental Protection Agency, Washington, D.C. Online at https://nepis.epa.gov/Exe/ZyPDF.cgi/00000C9E.PDF?Dockey=00000C9E.PDF.

EPA. 2000. *Updated User's Guide for CAP88-PC, Version 2.0*. EPA-402-R-00-004. Office of Radiation and Indoor Air, U.S. Environmental Protection Agency, Washington, D.C. Online at https://nepis.epa.gov/Exe/ZyPDF.cgi/0000045B.PDF?Dockey=0000045B.PDF.

EPA. 2013. CAP88-PC Version 4 Testing Report. United States Environmental Protection Agency, Office of Radiation Programs, Radiation Protection Division, Office of Radiation and Indoor Air, Washington, D.C.

ICRP. 1959. *Report of Committee II for Permissible Dose on Internal Radiation*. International Commission on Radiological Protection Publication 2. Pergamon Press, London, England. Online at http://www.icrp.org/publication.asp?id=ICRP Publication 2.

ICRP. 1977. *Recommendations of the International Commission on Radiological Protection*. International Commission on Radiological Protection Publication 26. Pergamon Press, Oxford, England. Online at http://www.icrp.org/publication.asp?id=ICRP Publication 26.

ICRP. 1979a. *Limits for Intakes of Radionuclides by Workers*. International Commission on Radiological Protection Publication 30 (Part 1). Pergamon Press, Oxford, England. Online at http://www.icrp.org/publication.asp?id=ICRP%20Publication%2030%20(Part%201).

ICRP. 1979b. *Limits for Intakes of Radionuclides by Workers*. International Commission on Radiological Protection Publication 30 (Supplement to Part 1). Pergamon Press, Oxford, England.

ICRP. 1991. *1990 Recommendations of the International Commission on Radiological Protection*. International Commission on Radiological Protection Publication 60. Pergamon Press, Oxford, England.

ICRP. 1995. *Age-dependent Doses to the Members of the Public from Intake of Radionuclides: Part 5, Compilation of Ingestion and Inhalation Coefficients*. International Commission on Radiological Protection Publication 72. Pergamon Press, Oxford, England.

ISCORS. 2002. *A Method for Estimating Radiation Risk from TEDE*. Interagency Steering Committee on Radiation Standards Technical Report No. 1. Washington, D.C.

National Research Council. 2006. *Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2*. National Academy Press, Washington, D.C.

NCRP. 1975. *Natural Background Radiation in the United States: Recommendations of the National Council on Radiation Protection and Measurements*. Report No. 45. National Council on Radiation Protection and Measurements, Washington, D.C.

NCRP. 2009. *Ionizing Radiation Exposure of the Population of the United States*. Report No. 160. National Council on Radiation Protection and Measurements, Washington, D.C.

PNL-7662. 1991. *An Evaluation of the Chemical, Radiological, and Ecological Conditions of West Lake on the Hanford Site.* Pacific Northwest Laboratory, Richland, Washington.

PNNL-13487. 2001. *Hanford Site Environmental Report for Calendar Year 2000*. Pacific Northwest National Laboratory, Richland, Washington.

PNNL-14583. 2012. *GENII Version 2 Users' Guide*. Rev. 4. Pacific Northwest National Laboratory, Richland, Washington.

PNNL-20577. 2011. *Radionuclide Concentrations in Terrestrial Vegetation and Soil Samples On and Around the Hanford Site, 1971 Through 2008*. Pacific Northwest National Laboratory, Richland, Washington. Online at http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-20577.pdf.

UNSCEAR. 2012. *Biological Mechanisms of Radiation Actions at Low Doses*. United Nations Scientific Committee on the Effects of Atomic Radiation, United Nations, New York, New York.