4.0 Radiological Protection and Doses

This section provides information on the Hanford Site radiological program and doses as well as cleanup activities as DOE progresses toward site closure and the likely transfer of property to other entities.

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 up to 10 percent at any location due to changes in natural background radiation that can occur as a result of changes in annual cosmic and terrestrial radiation and from 15 percent to 25 percent because of shielding factors caused by changes in soil moisture and snow cover (NCRP 2009).

The Harshaw™[1] thermoluminescent dosimeter (TLD) system is used to measure external radiation on the Hanford Site. 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 (millirem per day) at each location were converted to annual dose equivalent rates (millirem per year) by averaging the daily dose rates and multiplying by 365 days per year. The TLDs were positioned approximately 3.3 feet (1 meter) above ground and were collected and read quarterly.

External radiation fields were monitored in 2014 at 115 locations near Hanford Site facilities and operations. The TLD results were used individually or averaged to determine dose rates in a given area for a specific sampling period. Table 4.1 compares 2013 and 2014 results for TLDs located near waste-handling facilities at the Hanford Site. Individual TLD results and detailed maps of monitoring locations are available upon request.

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

Table 4.1. Thermoluminescent Dosimeter Results

(millirem/year) [a]

Location	No. of Dosimeters	2013		2014		Percentage Change [e]
		Maximum[b]	Average[c, d]	Maximum[b]	Average[c, d]	
100-K	14	112 ± 12	86 ± 17	177 ± 140	89 ± 52	3
100-N	1	87 ± 13	84 ± 7	91 ± 14	82 ± 14	-2
200-East	42	230 ± 131	105 ± 56	217 ± 256	104 ± 57	0
200-West	24	158 ± 9	104 ± 41	157 ± 14	102 ± 42	-1
200-North	1	91 ± 14	86 ± 14	107 ± 16	91 ± 27	5
300 Area	8	124 ± 9	95 ± 26	114 ± 14	90 ± 20	-4
300 TEDF	6	93 ± 13	91 ± 4	91 ± 14	88 ± 8	-2
400 Area	7	100 ± 58	92 ± 9	98 ± 11	88 ± 11	-3
618-10	4	84 ± 11	83 ± 3	81 ± 8	80 ± 2	-2
CVDF	4	82 ± 13	80 ± 3	78 ± 9	77 ± 2	-2
ERDF	3	91 ± 11	88 ± 6	89 ± 22	84 ± 8	-4
IDF	1	102 ± 15	92 ± 16	97 ± 14	90 ± 13	-1

[a] To convert to international metric system units, multiply millirem/year by 0.01 to obtain millisievert/year.
[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 2013 mean.

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.

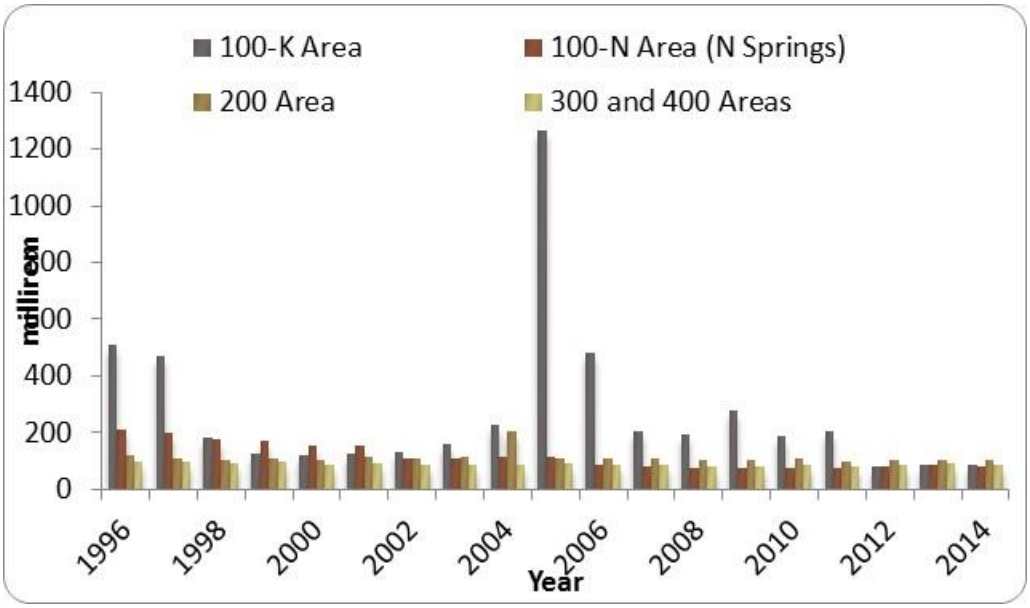
Radiation surveys with portable instruments are conducted at active and inactive waste disposal sites and the surrounding terrain to monitor and detect contamination and to provide a coarse screening for external radiation fields. The types of areas surveyed included underground radioactive material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

Additional information on radiation, dose rates, and dose terminology can be found in Appendix A, Glossary, and Appendix B, "Helpful Information."

4.1.1 External Radiation Measurements

100-K Area. The average dose rate levels seen in the 100-K Area during 2014 were, overall, slightly higher than 2013 levels (Figure 4.1). Dose rate levels in 2014 when compared to 2013 were 3 percent lower in the 100-K East Area and at the Cold Vacuum Drying Facility and were 11 percent higher in the 100-K West Area. This was due to elevated dose rate levels at the monitoring location 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 were transported.

Figure 4.1. Average Thermoluminescent Dosimeter Results



100-N Area Shoreline (N Springs). Dose rates were measured along the Columbia River shoreline in the 100-N Area (N Springs) to determine potential external radiation doses to onsite workers and to the public accessing the river. Cleanup activities at the retired 116-N-1 and 116-N-3 Trenches (located near the Columbia River) have decreased dose rates notably over the past few years (Figure 4.1). The 2014 average dose rate was 2 percent lower than in 2013, and was less than 100 millirem (1 millisievert) per year.

200 Area. Dose rate levels measured during 2014 in the 200 East and 200 West Areas were generally unchanged compared to 2013 (Figure 4.1, with the exception of ERDF where the average dose rates measured in 2014 (located near the 200 West Area) were approximately 4 percent lower than 2013 levels. Additional information on ERDF operations is provided in Section 5.3.3.8.

200-North Area. One TLD monitoring site, located in the 200 North Area at the formerly contaminated 212-R Railroad Car Disposition Area, continued to show reduced average dose rate levels in 2014. As in recent years, the 2014 levels were significantly lower than levels measured in 2011 and years previous. This TLD location was established in 2000 to monitor expected high radiation levels emitted from contaminated railroad cars. During the fourth quarter of 2010, dose rate levels began to fall as the radiologically contaminated railroad cars were dispositioned.

300 and 400 Areas. The average dose rates in 2014 in the 300 and 400 Areas and at the 300 Area TEDF were generally lower by approximately 5 percent compared to 2013 levels (Figure 4.1). Additional information about TEDF operations is provided in Section 5.3.4.3.

618-10 Burial Ground. TLD monitoring was initiated during late-February 2010 at four locations for this project. The average dose rates in 2014 were approximately 2 percent lower than 2013 levels. Additional information about the 618-10 Burial Ground cleanup project is provided in Section 5.1.4.

Integrated Disposal Facility (IDF). The average dose rates in 2014 at this facility were nearly unchanged from the 2013 levels. IDF is a new unused landfill that is not actively operating (see Section 5.3.3.7).

4.1.2 Waste Disposal Sites Radiological Surveys

JW Wilde

During 2014, 875 environmental radiological surveys were reported as performed at active and inactive waste disposal sites and the surrounding terrain to detect and characterize radioactive surface contamination. 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. Vehicles equipped with radiation detection devices and global positioning systems were used to measure accurately the extent of contamination. Area measurements were entered into the Hanford Geographical Information System, a computer database maintained by MSA. Routine radiological survey locations included 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 were posted as underground radioactive material areas, contamination areas, and soil contamination areas. The external dose rate at 80 percent of the outdoor contamination areas was estimated to be less than 1 millirem (0.01 millisievert) per hour, although direct dose-rate readings from isolated radioactive specks could have been higher.

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 inch [0.6 centimeter]). 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

R Perona and RT Ryti

Potential radiological doses to the public and biota from Hanford Site operations in 2014 were evaluated to determine compliance with pertinent regulations and limits. Potential sources of radionuclide contamination included gaseous emissions from stacks and ventilation exhausts, liquid effluent from operating wastewater treatment facilities, 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 radiological impacts of Hanford Site operations were assessed in terms of the following:

- Dose to a hypothetical, maximally exposed individual (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 miles (80 kilometers) of Hanford Site operation areas (Section 4.2.2)
- Doses for air pathways calculated using regulation-specified 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)
- Doses from recreational activities including hunting and fishing (Section 4.2.4.1)
- Dose to a worker consuming drinking water on the Hanford Site (Section 4.2.4.2)
- Doses 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 in 2014 from Hanford Site sources were too small to be measured in environmental media after they were 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 ambient air measurements of tritium at offsite locations near the 300 Area, radionuclide concentrations may be distinguishable from background levels, and these measurements are used to support the dose assessment.

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 ICRP Report 2 (ICRP 1959, *Permissible Dose for Internal Radiation*). In the 1970s, the annual reports began to follow the newer recommendations in ICRP Reports 26 and 30 (ICRP 1977, *Recommendations of the ICRP*, and ICRP 1979a,b, *Limits for Intakes of Radionuclides by Workers*), incorporated in the dose factors from the EPA in Federal Guidance Reports 11 and 12 (EPA 520/1-88-020, *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion*; EPA-402-R-93-081, *External Exposure to Radionuclides in Air, Water, and Soil*). The GENII Version 1 computer code, used at the Hanford Site beginning in 1988, used ICRP 26/30 methods (ICRP 1977, 1979a, b) and EPA dose factors. The GENII Version 2 computer code, used for the annual report dose calculations beginning in 2009, uses ICRP Report 60 methods (ICRP 1991, *1990 Recommendations of the International Commission on Radiological Protection*) and updated EPA dose factors (EPA 402-R-99-001, *Cancer Risk Coefficients for Environmental Exposure to Radionuclides*).

Offsite dose for a MEI (Section 4.2.1) and collective dose for the population residing within 50 miles (80 kilometers) 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 Area for tabulation of radiological dose. No direct discharge of radioactive materials from the 100 or 300 Areas to the Columbia River was reported during 2014. Radiological doses from the air pathways are calculated based on stack emissions measurements from approximately 60 emission points in Hanford Site operation areas.

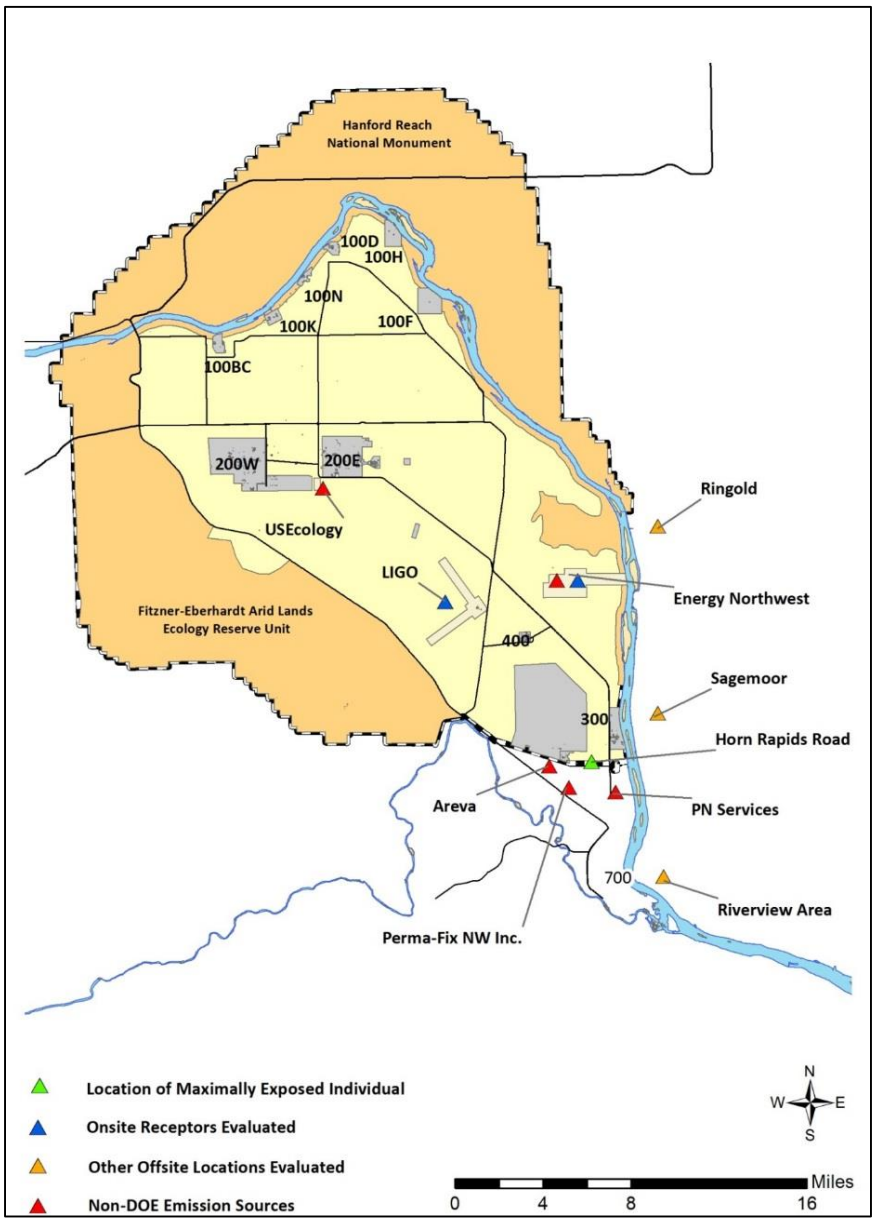
Columbia River shoreline spring and seep water-containing radionuclides is known to enter the river along the portion of the Hanford Site shoreline extending from the 100-BC Area downstream to the 300 Area. Tritium and uranium isotopes were found in the Columbia River downstream of the Hanford Site (Richland Pumphouse station, HRM 46.4) in 2014 at concentrations statistically greater than upstream (Priest Rapids Dam station) levels (Appendix D). Radioactive air emissions are discussed in Section 6.1 and summarized in Table 6.1. For the GENII Version 2.10 (PNNL-14583, Rev 3a) 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 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 2014. This individual's exposure pathways were chosen to maximize the combined doses from all reasonable 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 individual. 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 MEI (Figure 4.2). The Ringold locations receive maximal air pathway impacts from the 200 Area. Depending on year-to-year 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 small population of West Pasco residents obtains their drinking water from the Riverview location via a community water system, and the domestic drinking water pathway is applied to that location. Residences in the vicinity of Horn Rapids Road receive drinking water from the city of Richland, which has an intake downstream of the Hanford Site, so the domestic drinking water pathway is also applied here. Both Riverview and Horn Rapids Road are locations where Columbia River water is withdrawn for irrigation.

Figure 4.2. Locations Important to Hanford Site Dose Calculations



Dose calculations for 2014 releases indicate that the MEI is located at the PNNL Physical Sciences Facility, an offsite business just to the south of the Hanford Site 300 Area at 638 Horn Rapids Road. For the Horn Rapids Road receptor dose calculations, the following exposure routes were evaluated:

- 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 irrigated with Columbia River water and/or containing radionuclides deposited from the air
- External radiation exposure to radionuclides in Columbia River water and sediments near the Hanford Site during recreational activities, and inadvertent ingestion of water while swimming
- Consumption of locally caught Columbia River 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 (PNNL-14583, Rev 3a) is provided in Figure 4.3. Additional information related to the selection of the MEI location for releases is provided in Appendix D. Exposure variable input values related to residency and recreational exposure times, intake rates for water, foods, other media, and agricultural pathway assumptions for the MEI are provided in Appendix D.

The total dose to the MEI at Horn Rapids Road in 2014 was calculated to be 0.33 millirem (3.3 microsievert) per year (Table 4.2; Figure 4.4). This dose is 0.33 percent of the 100 millirem (1,000 microsievert) per year public dose limit specified in DOE O 458.1, Chg. 2 and 1.3 percent of the 25-millirem (250-microsievert)-per-year threshold where a supplemental assessment of dose to the lens of the eye, skin, and extremities is required. Water pathway contributions assigned to the 200 Areas contributed approximately two-thirds of the total dose of 0.33 millirem (3.3 microsievert) per year, with the remaining 33 percent related to air pathway exposures.

The primary radionuclides and exposure pathways contributing to the MEI dose are as follow:

- *Air Releases:* Consumption of food products containing tritium released from the 300 Area contributed approximately 84 percent of the total air pathways dose of 0.087 millirem (0.87 microsievert) per year. Inhalation of the radioactivity progeny of radon-220 released from the 300 Area contributed most of the remaining 8 percent, or 0.094 millirem (0.94 microsievert), of the of the total air pathways dose of 0.11 millirem (1.1 microsievert) per year. Inhalation of tritium and the radioactive progeny of radon-220 released from the 300 Area, which contributed most of the remaining 16 percent of the total air pathway dose.
- *Water Releases:* Consumption of fish from the Columbia River contributed 0.18 millirem (1.8 microsievert), or 81 percent of the total water pathways dose of 0.22 millirem (2.2 microsievert) per year. Consumption of food grown using Columbia River water withdrawn downstream from the Hanford Site contributed almost all of the remaining total water pathways dose of 0.037 millirem (0.37 microsievert), or 17 percent of the 0.22 millirem (2.2 microsievert) per year total. Potassium-40, a naturally occurring radionuclide not of Hanford origin, contributed approximately 77 percent (0.17 millirem 1.7 millisievert]) of the water pathways dose, with isotopes of uranium and their progeny, particularly uranium-234 and uranium-238, contributing most of the remainder.

The MEI dose in 2014 of 0.33 millirem (3.3 microsievert) is more than twice the 0.15 millirem (1.5 microsievert) MEI dose calculated in 2013 (DOE/RL-2013-47, *Hanford Site Environmental Report for Calendar Year 2013*). This large relative difference between the 2013 and 2014 dose estimates is almost entirely attributable to the inclusion of naturally occurring potassium-40 in the 2014 water pathways dose calculations. Potassium-40 was included in the 2014 dose calculations for water releases because average downstream river concentrations were statistically greater than upstream concentrations. In 2013, the downstream potassium-40 concentrations were not statistically different from those measured upstream. The 2014 MEI dose without the contribution of potassium-40 is 0.16 millirem (1.6 microsievert). This is approximately equivalent to the 2013 MEI dose of 0.154 millirem (1.5 microsievert). The relationship of the 2014 MEI dose to values calculated for the period of 2010 to 2013 is shown in Figure 4.4.

The MEI dose estimate incorporates a number of conservative assumptions to ensure that pathway doses are protective and therefore calculated doses are likely to be overestimated. In the air pathways

calculations, measurements of gross alpha and gross beta radiation in stack emissions from the 100 Area, 200 Area, and 300 Area were protectively added to the measured emissions of plutonium-239/240 (an alpha-emitting radionuclide related to Hanford operations) and strontium-90 (a beta-emitting radionuclide related to Hanford operations), respectively. The actual measured air releases of plutonium-239/240 and strontium-90 are a small fraction (6 to 27 percent) of the assumed concentrations, including the contribution of the gross radioactivity values. Although gross alpha and gross beta levels in stack emissions are similar to ambient air background, this was done to ensure that contributions from any unmeasured operations-related radionuclides are incorporated in the estimated doses.

In the irrigation pathways calculations, all produce eaten by the MEI was assumed to 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, and 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, such as sturgeon.

Figure 4.3 Conceptual Site Model of Exposure Pathways Evaluated in Dose Calculations
(Horn Rapids Road MEI)

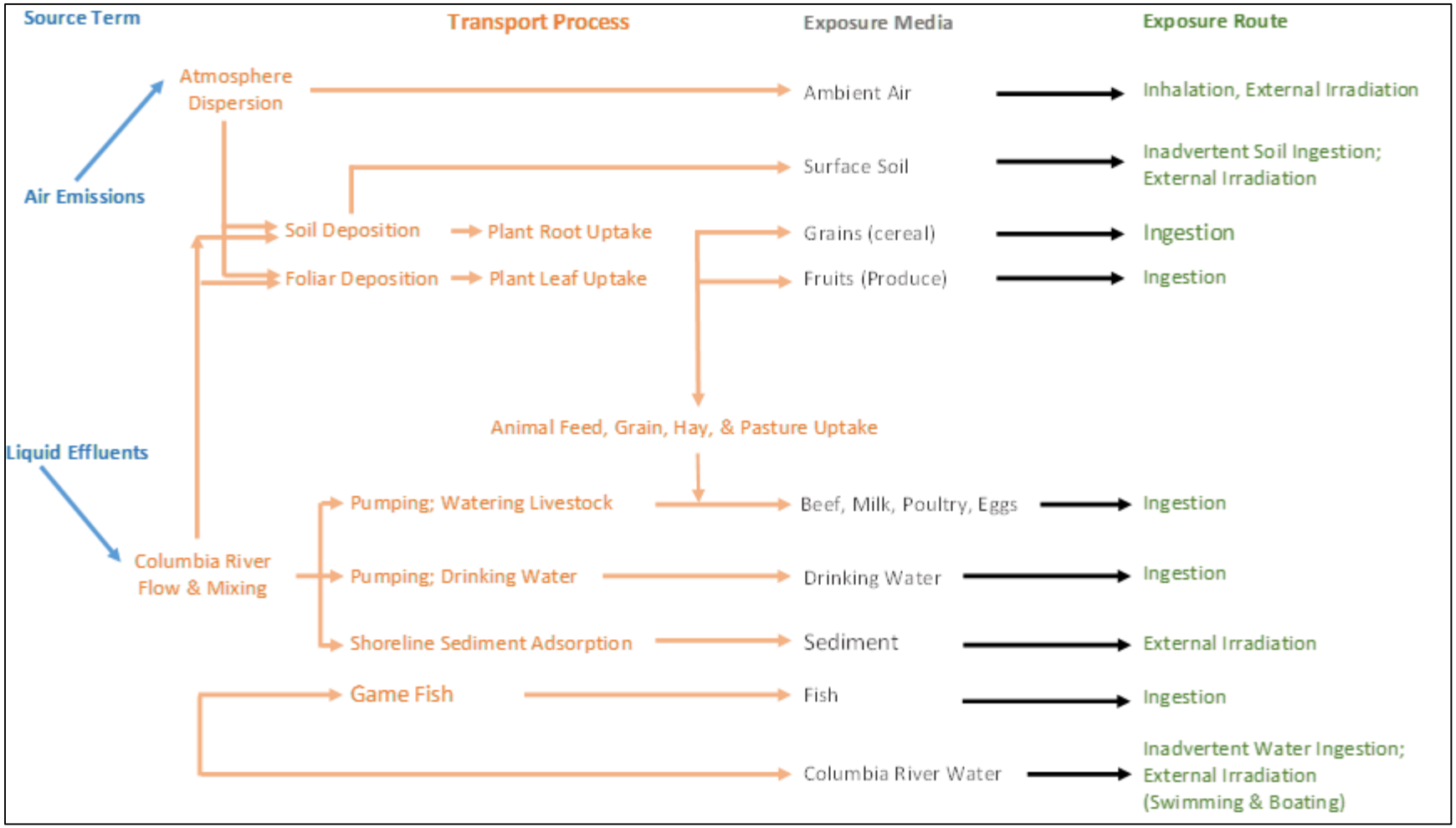


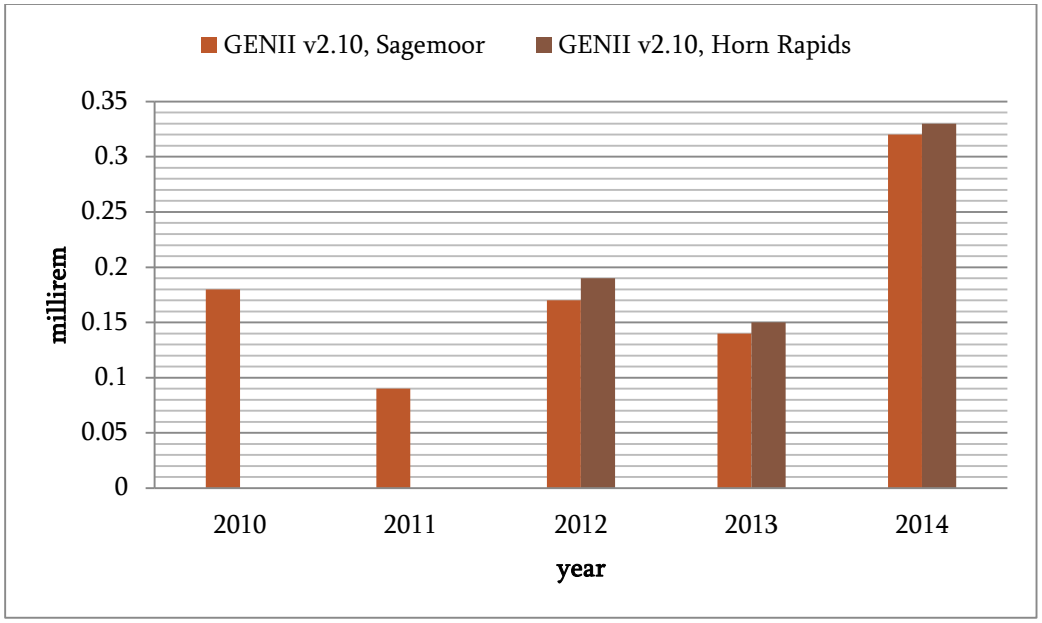
Table 4.2. Pathway Doses for the Hypothetical, Maximally Exposed Individual Residing at Horn Rapids Road

Release Type	Exposure Pathway	Dose Contributions from Operational Areas, mrem [a]				
		100 Areas	200 Areas [b]	300 Area[c]	400 Area	Pathway Total
Air	Food Ingestion	1.0E-07	1.2E-04	0.094	1.6E-07	0.095
	Inhalation	7.9E-07	5.7E-05	0.018	7.5E-07	0.018
	External, Soil Ingestion	5.3E-10	1.6E-07	0.00018	2.2E-09	0.00018
	Subtotal Air	8.9E-07	1.8E-04	0.11	8.9E-07	0.11
Water	Irrigation (food and soil ingestion; external)	NA[d]	0.037 [e]	NA	NA	0.037
	Drinking Water Ingestion	NA[d]	0.0077 [e]	NA	NA	0.0077
	Recreation (river water and sediments; external and ingestion)	NA[d]	0.0013[e]	NA	NA	0.0013
	Fish Ingestion	NA[d]	0.18 [e]	NA	NA	0.18
	Subtotal Water	NA	0.22	NA	NA	0.22
Air + Water Total		8.9E-07	0.22	0.11	8.9E-07	**0.33** [f]

[a] To convert millirem (mrem) to International System dose units (microsievert; µSv), multiply by 10.
[b] Integrates releases from all operational areas based on the difference between downstream and upstream Columbia River radionuclide concentrations.
[c] Measured tritium air concentrations at offsite locations near the 300 Area indicate modeled air pathways doses may be biased low by up to approximately 0.05 mrem; refer to text.
[d] No measured releases; the last 100 Areas NPDES-permitted outfall (1908-K Outfall) ceased releases in March 2011.
[e] Water pathways dose without potassium-40, a naturally occurring radionuclide not of Hanford origin, is 0.053 millirem.
[f] Air + Water pathways dose without potassium-40, a naturally occurring radionuclide not of Hanford origin, is approximately 0.16 millirem.

NA: Not applicable. All liquid discharges reflected in the difference between upstream and downstream radionuclide concentrations are assigned to the 200 Area.

Figure 4.4. Total Dose for the Hypothetical, Maximally Exposed Individual Over Time [a]



[a] The 2014 MEI Horn Rapids MEI total dose without the contribution of potassium-40, a naturally occurring radionuclide not of Hanford origin, is 0.16 millirem (1.6 microsievert).

Because releases of tritium from the 300 Area are the major 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 concentrations based on air monitoring station samples. Figure 4.5 shows the 2014 modeled annual average air concentrations of tritiated water vapor (HTO) at the Horn Rapids Road MEI location and 2014 annual averages based on measured values at three offsite locations south and east of the 300 Area. Measured monthly tritium concentrations vary substantially at each monitoring location. The 95 percent upper and lower confidence intervals of the annual average values are shown on Figure 4.5 in addition to the annual average.

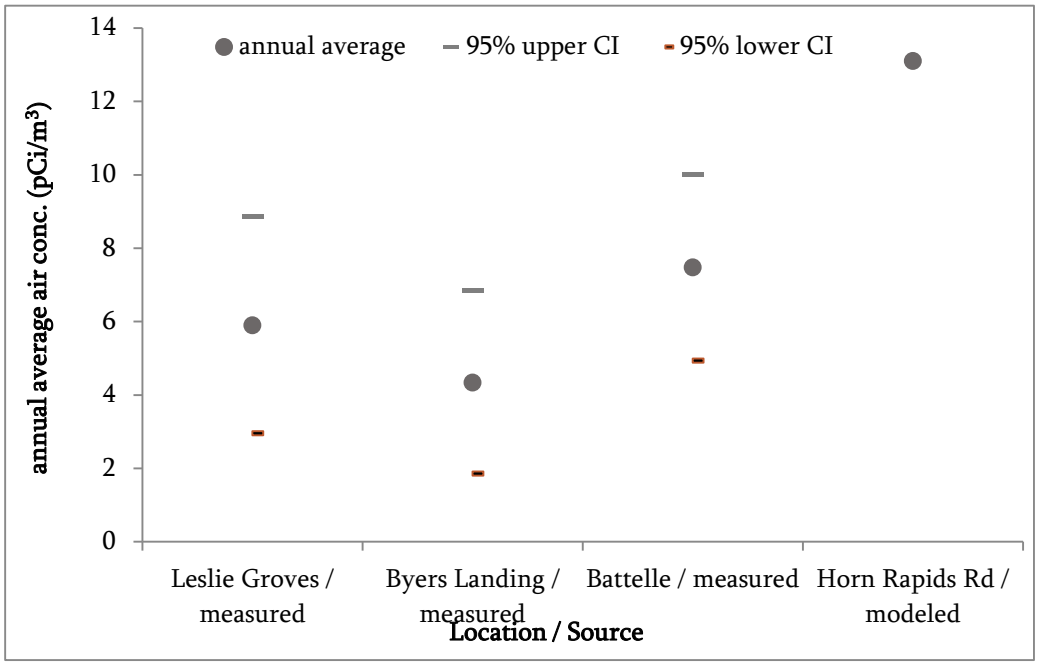
The modeled annual-average tritium concentration at the Horn Rapids Road MEI location is above the range of the 95 percent upper and lower confidence intervals of the mean of the measured values at the three nearby offsite monitoring locations. The potential significance of the lower mean values for the measured concentrations of tritium at the nearby offsite monitoring stations depends on their having a relationship to Hanford Site 300 Area annual tritium emissions. A relationship between 300 Area monthly tritium air emissions and onsite 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. GENII air dispersion calculations from Building 325 in the 300 Area were performed to compare annual average modeled and measured HTO air concentrations for two specific locations at approximately the same distance from Building 325 as the Horn Rapids Road MEI with the following results:

Monitoring Location	HTO Measured Concentration (pCi/m^3)	HTO Modeled Concentration (pCi/m^3)
Battelle Complex	7.5	6.0
Byers Landing	4.3	4.3

The relationship of modeled and measured annual average air concentrations at these two nearby onsite monitoring stations in the 300 Area is relatively good. This suggests that the modeled HTO air concentration of 13.1 pCi/m^3 used for the 2014 MEI air pathways dose calculations is also reasonable. 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. Note also that 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 (Barfuss 2007, Figure 11).

Figure 4.5 Comparison of Measured and Modeled Tritium Air Concentrations near the 300 Area

(Error bars are 95% confidence intervals of the mean)



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 2014 Hanford Site operations was estimated by calculating the radiological dose to the population residing within a 50-mile (80-kilometer) radius of onsite operating areas (DOE O 458.1, Chg. 2; Section 4.e(d). 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 in order to coincide with air dispersion and deposition modeling conducted within the GENII Version 2.10 computer code (PNNL-14583, Rev 3a).

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 2014 was 2.1 person-rem (0.021 person-sievert) per year (Table 4.3), which is higher than the collective doses calculated between 2010 and 2013 (Figure 4.6). Water pathway contributions assigned to the 200 Area contributed approximately 60 percent, and air pathway contributions from releases in the 300 Area contributed approximately 40 percent to the total collective dose of 2.1 person-rem (0.021 person-sievert) in 2014.

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

- *Air Releases:* Consumption of food products grown downwind of the 300 Area contributed slightly less than 80 percent of the of the air pathways collective dose of 0.86 person-rem (0.0086 person-sievert). The remaining air pathways collective dose is primarily related to inhalation. About 90 percent of these food and inhalation air pathways doses, which combined account for approximately 97 percent of the total air pathways collective dose, are due to releases of tritium from the 300 Area. The remaining 10 percent of the total air pathways collective dose of 0.86 person-rem (0.0086 person-sievert) is largely associated with inhalation of the radioactive progeny of radon-220 released from the 300 Area. Air releases from the 100 Area, 200 Area, and 400 Area had negligible contributions to the air pathways collective dose.
- *Water Releases*: Consumption of drinking water withdrawn from the Columbia River downstream of the Hanford Site contributed approximately 90 percent of the total water pathways collective dose of 1.3 person-rem (0.013 person-sievert). Consumption of Columbia River fish, and ingestion of food products grown with Columbia River irrigation water, contributed approximately 60 percent and 40 percent of the remaining total water pathways dose, respectively. Naturally occurring isotopes of uranium (uranium-234, uranium-235, and uranium-238) and their progeny from releases assigned to the 200 Area were the largest contributors (approximately 70 percent) to the drinking water collective dose. Potassium-40, a naturally occurring radionuclide not of Hanford origin, contributed most of the remaining 30 percent of the water pathways collective dose.

Table 4.3. Collective Pathway Doses
(Within a 50-mile [80-Kilometer] Radius)

		Dose Contributions from Operational Areas, person-rem [a]				
Release Type	**Exposure Pathway**	**100 Areas**	**200 Areas**	**300 Area**	**400 Area**	**Pathway Total**
Air	Food Ingestion	1.3E-05	0.013	0.66	5.8E-06	0.67
	Inhalation	0.00020	0.012	0.17	4.3E-05	0.18
	External, Soil Ingestion	8.7E-08	1.5E-05	0.0012	7.8E-08	0.0012
	Subtotal Air	0.00022	0.025	0.83	4.9E-05	0.86
Water	Irrigation (food and soil ingestion; external)	NA [b]	0.048 [c]	NA	NA	0.048
	Recreation (river water and sediments; external and ingestion)	NA [b]	0.0088 [c]	NA	NA	0.0088
	Fish Ingestion	NA [b]	0.066 [c]	NA	NA	0.066
	Drinking Water	NA [b]	1.1 [c]	NA	NA	1.1
	Subtotal Water	NA	1.3	NA	NA	1.3

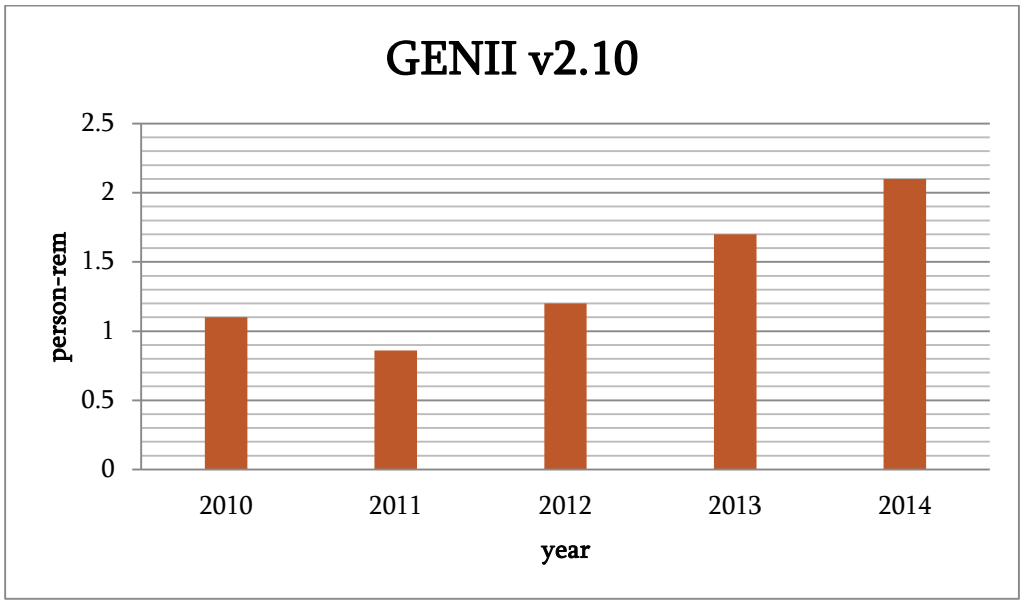
Table 4.3. Collective Pathway Doses
(Within a 50-mile [80-Kilometer] Radius)

Release Type	Exposure Pathway	Dose Contributions from Operational Areas, person-rem [a] 100 Areas	200 Areas	300 Area	400 Area	Pathway Total
	Air + Water Total	0.00022	1.3	0.83	4.9E-05	2.1

[a] To convert person-rem to International System dose units (person-Sievert), divide by 100.
[b] No measured releases; the last 100 Areas NPDES-permitted outfall (1908-K Outfall) ceased releases in March 2011.
[c] Integrates releases from all operational areas, based on the difference between downstream and upstream Columbia River radionuclide concentrations.

NA: Not applicable. All liquid discharges reflected in the difference between upstream and downstream radionuclide concentrations are assigned to the 200 Area.

Figure 4.6. Collective Total Dose
(Within 50-mile [80-kilometer] radius)



The dose for the MEI in 2014 was 0.33 millirem (3.3 microsievert) (Section 4.2.1). The average individual dose from Hanford Site operations in 2014, based on the 50-mile (80-kilometer) radius population exposed to air emissions and the Tri-Cities populations exposed to water pathways releases to the Columbia River, was approximately 0.0089 millirem (0.089 microsievert). 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 (NCRP) issued Report 160 in March 2009 that estimated the overall average exposure to ionizing radiation for the average American to be 620 millirem (6,200 microsievert) per year (NCRP 2009). Approximately 50 percent of the 620 millirem (6,200 microsievert) per year average annual dose is related to natural sources, with the remaining 50 percent 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 millirem [190 microsievert]), cosmic background radiation (30 millirem [300 microsievert]), and radon (radon-222)

and thoron (radon-220) gases (230 millirem [2,300 microsievert]) are shown relative to Hanford Site operational doses in Figure 4.8. The calculated radiological doses from Hanford Site operations in 2014 were a small percentage of national average annual doses from these natural background sources. Note that annual dose is shown on a logarithmic scale in Figure 4.8, where each increment represents a factor of 10. For example, the national annual average terrestrial radiation dose (approximately 19 millirem [190 microsievert]) is approximately 60 times larger than the 2014 Hanford Operations dose to the MEI (0.33 millirem [3.3 microsievert]).

Figure 4.7. United States Annual Average Radiological Doses from Various Sources (2009 National Council on Radiation Protection and Measurement)

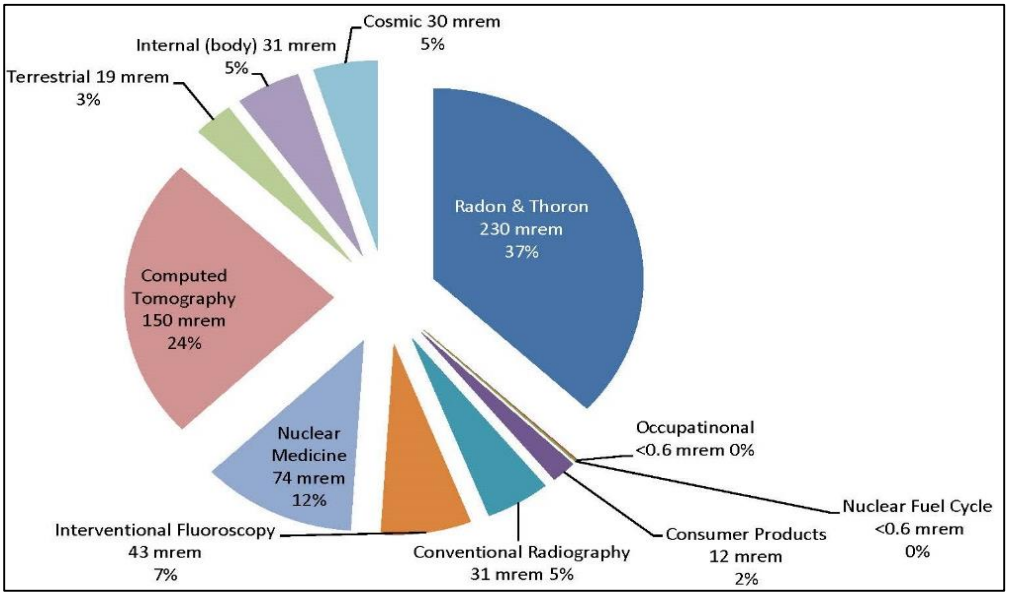
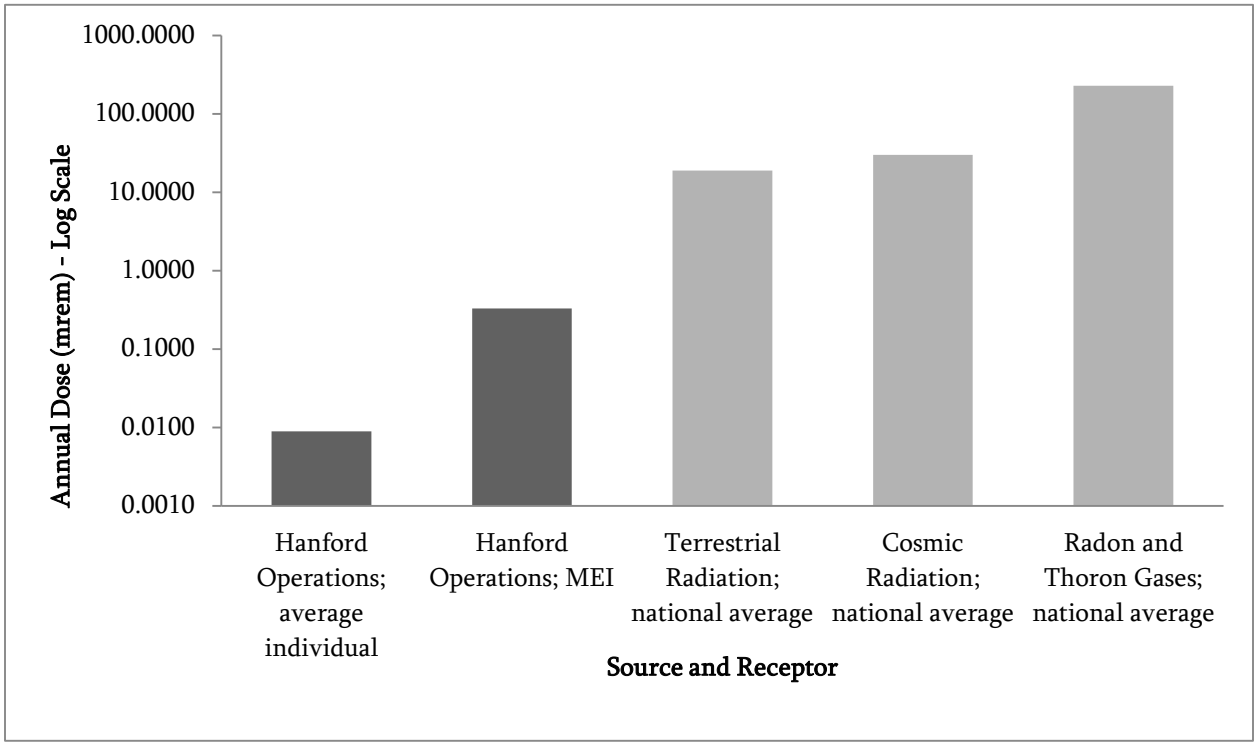


Figure 4.8. Radiological Doses from Hanford Site Operations Compared with Annual Average from Natural Sources



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—this is the MEI dose; 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, Chg. 2 and is calculated using the GENII computer code as described in Section 4.2.1. This calculation considers all reasonable environmental pathways (e.g., from releases to both air and water) that maximize a hypothetical individual's offsite exposure to the Hanford Site's radiological liquid effluents and air emissions. A second estimate of MEI dose is required by the *Clean Air Act* and must be calculated using an EPA dose modeling computer code (CAP-88) or other methods accepted by the EPA under the *Clean Air Act* for estimating offsite exposure. The Hanford Site stack emissions and emissions from diffuse and unmonitored sources (e.g., windblown dust) are considered in the offsite dose for the *Clean Air Act*, and are based solely on an airborne radionuclide emissions pathway.

In addition to complying with the all-pathways dose limits established by DOE O 458.1, Chg. 2, (100-millirem [1,000-microsievert] per year), officials managing DOE facilities are required to demonstrate their facilities comply with standards established by EPA for airborne radionuclide emissions under the *Clean Air Act* in 40 CFR 61, Subpart H. This regulation specifies that no member of the public shall receive a dose greater than 10 millirem (100 microsievert) per year from exposure to airborne radionuclide emissions (other than radon) released at DOE facilities. Whereas DOE uses the GENII computer code at the Hanford Site to determine dose to the all-pathways MEI, EPA requires the use of the CAP-88 computer code (EPA 402-R-00-004, *Updated User's Guide for CAP88-PC*) or other EPA-approved computer models to demonstrate compliance with the requirements in 40 CFR 61, Subpart H.
The assumptions embodied in the CAP-88 computer code differ slightly from standard 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 all-pathways MEI if dose from the water pathways exceeds that from air pathways (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 2014 air emissions at the Hanford Site, refer to DOE's report to EPA (DOE/RL-2015-12, *Radionuclide Air Emissions Report for the Hanford Site, Calendar Year 2014*.

4.2.3.1 Dose from Stack Emissions to an Offsite Maximally Exposed Individual

Using CAP-88, the maximally exposed offsite individual for air pathways in 2014 was at PNNL's Physical Sciences Facility, an offsite business located at 638 Horn Rapids Road in north Richland, Benton County, Washington, directly south of the Hanford Site 300 Area (Figure 4.2). The potential air pathway dose from stack emissions to a MEI at that location calculated using the CAP-88 computer code was determined to be 0.28 millirem (2.8 microsievert) per year, which is less than 3 percent of the EPA standard of 10 millirem (100 microsievert) per year. The CAP-88 result is approximately 2.5 times higher than the air pathway dose for stack emissions calculated with GENII (Table 4.2).

Dose related to radon-220 and radon-222 is not included in the dose calculated for compliance with the EPA standard in 40 CFR 61, Subpart H, but is regulated by the 10-millirem (100-microsievert) per year standard established by Ecology in WAC 246-247. A release of 75.2 curies of radon-220 and 0.024 curies of radon-222 was calculated from engineering estimates for stack emissions from Building 325 in the 300 Area. A total radon-220 and radon-222 dose of 0.019 millirem (0.19 microsievert) per year was calculated for the MEI at Horn Rapids Road, far below the WAC 246-247 standard.

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-2015-12).

The Horn Rapids Road location immediately south of the 300 Area was chosen for purposes of demonstrating compliance with the MEI dose standard for diffuse and fugitive emissions (DOE/RL-2015-12). The estimated dose from diffuse emissions to a MEI at Horn Rapids Road in was calculated using the CAP-88 computer code to be 0.17 millirem (1.7 microsievert) per year. Therefore, the potential combined dose from stack emissions and diffuse emissions (excluding radon) during 2014 at the Horn Rapids Road location was 0.45 millirem (4.5 microsievert) per year, which is less than 5 percent of 10 millirem (100-microsievert) per year standard in 40 CFR 61, Subpart H.

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

DOE has recently allowed private businesses to locate their activities and personnel on some regions of the Hanford Site. The EPA Region 10 Office and the WDOH provided guidance to RL 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 has created the need to calculate a maximum dose for an onsite individual who is employed by a non-DOE business and 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 2014 EPA air emissions report (DOE/RL-2013-12) as possible MEIs. These locations included the Columbia Generating Station operated by Energy Northwest and the Laser Interferometer Gravitational Wave Observatory operated by the University of California (Figure 4.2). The non-DOE worker dose due to stack emissions from these facilities was calculated using the CAP-88 computer code assuming full-time occupancy because EPA guidance does not currently allow for adjustment of such doses to account for less than full-time occupancy. Even assuming an employee is continuously present, the estimated doses to non-DOE onsite workers in 2014 were lower than the 0.28 millirem (2.8 microsievert) per year dose calculated with CAP-88 to an offsite MEI at Horn Rapids Road. Combined stack emissions and diffuse/fugitive emissions dose for the Columbia Generating Station was 0.26 millirem (2.6 microsievert) per year, and for the Laser Interferometer Gravitational Wave Observatory was 0.36 millirem (3.6 microsievert) per year (DOE/RL-2015-12).

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. Two such scenarios include 1) an outdoor recreationalist who consumed meat from contaminated wildlife that migrated from the Hanford Site, and 2) an individual who drank water from one of four DOE-owned water treatment facilities at the Hanford Site. 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.

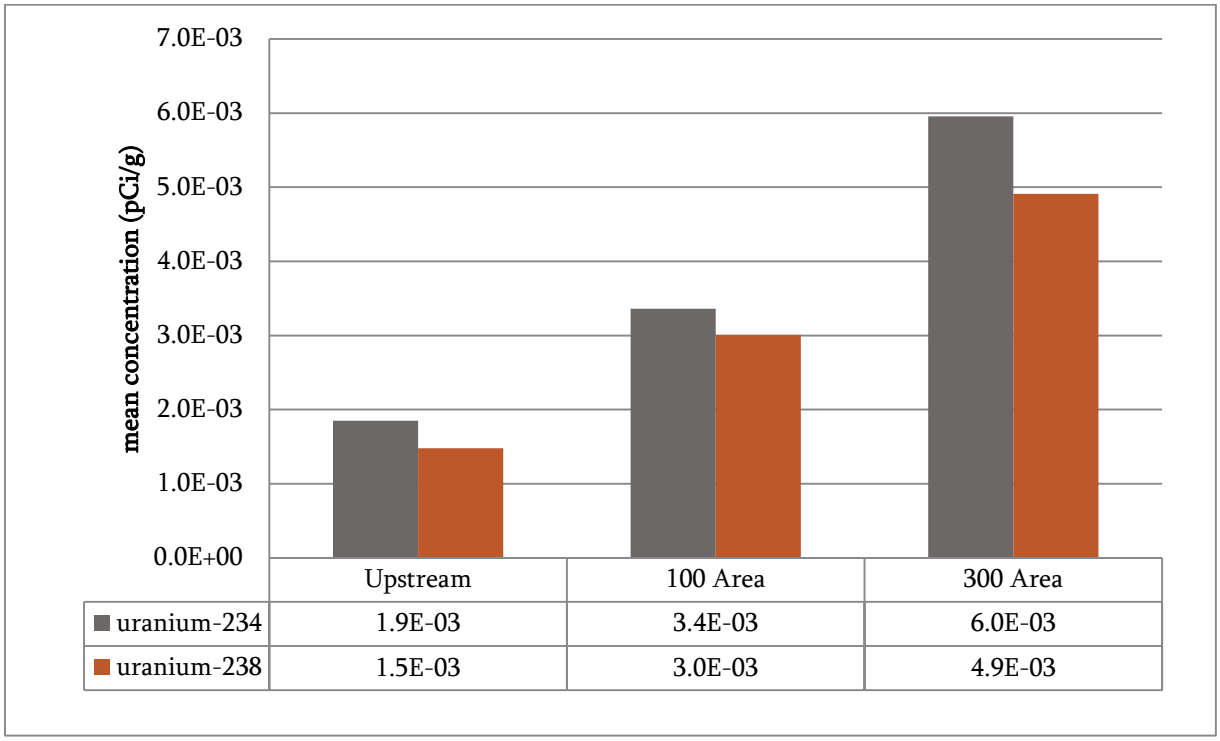
Gamma-emitting radionuclides were analyzed in muscle tissue samples collected in 2014 from mule deer, elk, and quail. In addition to muscle tissue, bone samples were collected from these three animals, and liver samples were collected from mule deer and elk. For estimating dose from ingestion of game meat, radionuclide concentrations in muscle tissue are most applicable. Five muscle tissue samples were available in 2014 for mule deer, two for elk, and nine for quail. The only radionuclide detected in the muscle tissue of mule deer, elk, or quail was potassium-40, a naturally occurring primordial radioisotope

not of Hanford Site origin. Both isotopic plutonium and gamma-emitting radionuclides were analyzed in five liver samples from mule deer and two liver samples from elk. Again, potassium-40 was the only radionuclide detected.

Fillet tissue samples were obtained from bass and carp in the 100 Area, 300 Area, and Desert Aire/Vantage (upstream) regions of the Columbia River and analyzed for gamma-emitting radionuclides, tritium, strontium-90, and isotopes of uranium. Additionally, fillet tissue samples from bass were collected in the Hanford Slough/Townsite (downstream) region. A total of 28 fillet samples were collected in July and August 2014. Detected radionuclides in fillet samples were limited to potassium-40, uranium-234, uranium-235, and uranium-238. Although, naturally occurring radionuclides like potassium-40 and uranium isotopes are associated with Hanford Site operations.

Only a single sample with isotopic uranium results is available at each location for bass fillets from the Desert Aire/Vantage (upstream) region, 100 Area, and 300 Area of the Columbia River. Although uranium isotopes were not detected in upstream and 100 Area bass fillet samples, both uranium-234 and uranium-238 were detected in the 300 Area sample. Three to four carp fillet samples were also available from these three regions. Uranium-234 and uranium-238 were detected in all these samples, and as shown in Figure 4.9, concentrations of both isotopes increase in carp fillet samples from upstream through the 100 Area and 300 Area.

Figure 4.9 Isotopic Uranium Concentrations in Carp Fillets from Upstream, 100 Area and 300 Areas



	Upstream	100 Area	300 Area
uranium-234	1.9E-03	3.4E-03	6.0E-03
uranium-238	1.5E-03	3.0E-03	4.9E-03

The average measured fillet concentrations of uranium-234 in the 300 Area samples is approximately 3.5 times higher than the uranium-234 fish tissue concentration of 0.0017 pCi/g (6.3×10^{-5} Bq/g) modeled in GENII Version 2.10 (PNNL-14583) from the difference in upstream and downstream uranium-234 concentrations. Similarly, the average measured fillet concentrations of uranium-238 in the 300 Area samples is approximately 2.5 times higher than the modeled uranium-238 fish tissue concentration of 0.0020 pCi/g (7.5×10^{-5} Bq/g).

Although the measured uranium-234 and uranium-238 values in the carp fillet samples are higher than the levels modeled to be attributable to Hanford Site releases, the radiation dose received from consumption of fish fillets with these isotopic uranium concentrations would be negligible. Assuming annual fish consumption of 88 pounds (40 kilograms) for a MEI (see Table D.4), the annual radiation dose related to fish ingestion for fish that contains 0.0060 pCi/g [2.2×10^{-4} Bq/g] of uranium-234 and 0.0049 pCi/g [1.8×10^{-4} Bq/g] of uranium-238 is estimated to be 0.078 millirem (0.78 microsievert) per year.

This dose estimate was derived using a uranium-234 ingestion dose factor of 1.8×10^{-4} millirem/pCi (4.9×10^{-2} microsievert/Bq) and a uranium-238 ingestion dose factor of 1.8×10^{-4} millirem/pCi (4.9×10^{-2} microsievert/Bq) from ICRP Publication 72 (ICRP 1996, *Age-dependent Doses to the Members of the Public from Intake of Radionuclides – Part 5 Compilation of Ingestion and Inhalation Coefficients*) in the following manner using uranium-234 as an example:

0.0060 pCi uranium-234/g × 40 kg × 1,000 g/kg × 1.8×10^{-4} millirem/pCi =
0.043 millirem (0.43 microsievert) per year.

4.2.4.2 Hanford Site Drinking Water Dose

Drinking water was sampled and analyzed for tritium, strontium-90, gross alpha radiation, and gross beta radiation during 2014 in accordance with applicable regulations (40 CFR 141, "National Primary Drinking Water Regulations"); water samples were collected from the 100-K Area, 200-West Area, and two sources in the 400 Area. 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).

All 100-K, 200 Area, and 400 Area drinking water gross alpha radiation concentrations measured during 2014 were below the applicable drinking water standard of 15 pCi/L. Gross beta radiation groundwater standards are published as dose-based levels (millirem or microsievert per year) rather than radiation concentrations. Tritium and strontium-90 are both man-made soluble beta radiation emitters; there are also naturally occurring beta emitters in the uranium, actinium, and thorium decay series. Potential onsite drinking water dose from Hanford-related beta-emitting radionuclides is addressed by evaluating the drinking water data for tritium and strontium-90.

Strontium-90 was analyzed in one sample from each of the four drinking water sources in 2014, and was not identified above detection limits in any drinking water sample. Tritium was analyzed in one sample from both the 100-K and 200-West Areas and was not detected in either sample. Tritium was detected in all four drinking water samples collected from the primary drinking water sources for the 400 Area (well P-16) and in the single sample from backup well P-14. Based on the four quarterly samples from the primary well, the annual average 400 Area drinking water tritium concentration was 1,130 pCi/L (42 Bq/L). Assuming a consumption rate of 0.26 gallon (1 liter) per day for 250 working days at the FFTF in the 400 Area, the potential annual worker dose in 2014 would be approximately 0.019 millirem (0.19 microsievert). A single tritium sample was also collected from Well P-14 in the 400 Area, where a value of 11,500 pCi/L was reported. Based on this single measurement, an annual worker drinking water dose for water from this backup supply well would be 0.19 millirem (1.9 microsievert). These estimates are well below EPA's drinking water dose limit of 4 millirem (40 microsievert) per year for beta-emitting radionuclides in public drinking water supplies.

The dose estimates were derived using a tritium ingestion dose factor of 6.7×10^{-8} millirem/pCi (1.8×10^{-5} microsievert/Bq) from ICRP Report 72 (ICRP 1996) in the following manner:

1,130 pCi tritium/L × 1 L/day × 250 d/year × 6.7×10^{-8} millirem/pCi = 0.019 millirem/year.

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

Doses from non-DOE sources were not quantified in 2014 because the MEI dose of 0.33 millirem (3.3 microsievert) per year from DOE-related sources (Section 4.2.1) was far below the threshold of 25 millirem (250 microsievert) per year at which the contribution of non-DOE sources must be included. DOE O 458.1, Chg. 2; paragraph 4.e.(1)(c) states that dose evaluations to demonstrate compliance with the public dose limit must include:

- 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 millirem (250 millisievert) in a year or less. If the DOE-related dose is greater than 25 millirem (250 millisievert) in a year, the dose to members of the public must include major non-DOE sources of exposure and dose from DOE-related sources.

Before it was superseded by the release of DOE O 458.1 in 2011, DOE O 5400.5, Chg 2, provided the applicable requirements for radiation protection of members of the public. Chapter II, Paragraph 7, of DOE O 5400.5, Chg 2, has a reporting requirement for a combined dose due to DOE and other manmade sources. Therefore, Hanford Site environmental reports prior to 2011 routinely evaluated dose contributions from various non-DOE industrial sources of radiation exposure on or near the Hanford Site. These included a commercial, low-level radioactive waste burial ground at the Hanford Site operated by US Ecology; a nuclear power-generating station at the Hanford Site operated by Energy Northwest; a nuclear-fuel production plant operated near the site by AREVA NP, Inc.; a commercial, low-level radioactive waste treatment facility operated near the site by Perma-Fix Northwest, Inc.; and a commercial decontamination facility operated near the site by PN Services (Figure 4.2). The total individual dose from non-DOE source activities in 2010 was conservatively estimated at about 0.004 millirem (0.04 microsievert) per year. PNNL-20548, *Hanford Site Environmental Report for Calendar Year 2010* is online at http://msa.hanford.gov/files.cfm/2010_pnnl-20548_env-report.pdf.

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 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, Chg. 2, interim requirement for management and control of liquid discharges. The current dose limit for aquatic animal organisms is 1 rad (10 milligray) per day. Rad is a unit of absorbed dose of ionizing radiation equal to an energy of 100 ergs per gram of irradiated material. In addition to the dose limit for aquatic organisms there is a proposed dose limit for riparian or terrestrial wildlife is 0.1 rad (1 milligray) per 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, *User's Guide, Version 1. RESRAD-BIOTA: A Tool for Implementing a Graded Approach to Biota Dose Evaluation*; DOE/STD-1153-2002, *A Graded Approach for Evaluating*

Radiation Doses to Aquatic and Terrestrial Biota) to compare radionuclide concentrations measured by routine monitoring programs to a set of biota concentration guides.

Biota concentration guides are the water or sediment concentrations of a radionuclide that would produce 1 rad (10 milligray) per day for aquatic biota or 0.1 rad (1 milligray) per day 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 2014 from on and around the Hanford Site. The results from 2013 are provided for comparison.

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-239/240, strontium-90, technetium-99, tritium, uranium-234, uranium-235, and uranium-238. 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 greater than those observed in the river water, and 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. The results of the screening calculations listed in Table 4.4 show the concentrations in all Columbia River sediment and water samples passed the Tier 1 screen and indicate that the calculated doses were below dose limits (sum of fractions less than one). Except for the 100-K Area most of the estimated dose is associated with uranium isotopes, which are the key radionuclides for the biota dose assessment. The sum of fractions tends to be greater at locations where uranium water concentrations were estimated from sediment (and not measured). In general, the dose estimates for 2014 were similar to those calculated in 2013.

At the 100-K Area, the estimated biota dose in 2014 was less than the acceptable limit. In contrast, the estimated biota dose in 2013 was about 3.5 times the acceptable limit. Nearly 100 percent of these estimated doses were from carbon-14 to the riparian animal through the water pathway. Carbon-14 has been detected at the 100-K Area springs in 2012 (57.3 pCi/L), 2013 (2,150 pCi/L), and 2014 (414 pCi/L). The maximum concentration measured in 2013 was nearly 40 times greater than that measured in 2012. Further documentation of the Columbia River biota dose calculations is provided in Appendix D.

Table 4.4. Estimated Doses to Biota associated with Columbia River Sediment and Water (Using RESRAD-BIOTA[a] Computer Code)

Location	Media Sampled for Key Radionuclides [c]	Tier 1 Screen Sum of Fractions [b]		2014 Pass or Fail
		2013	2014	
Priest Rapids Dam	Sediment	0.25	0.26	Pass
100-B Area	Water	<0.01	<0.01	Pass
100-K Area	Water	3.5	0.68	Pass
100-N Area	Water	0.16	0.05	Pass
100-D Area	Sediment, Water	0.03	0.02	Pass
Locke Island	Sediment	0.26	0.27	Pass
White Bluffs Slough	Sediment	0.16	0.23	Pass
100-F Area	Sediment, Water	0.11	0.10	Pass
Hanford Townsite	Sediment, Water	0.54	0.17	Pass
Savage Island	Sediment	0.15	0.13	Pass
300 Area Spring	Water	0.47	0.36	Pass
McNary Dam	Sediment	0.28	0.28	Pass

[a] A screening method to estimate radiological doses to aquatic and riparian biota.
[b] 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 would be estimated. Please see Appendix D for the details on what was measured.
[c] 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 Tier 3) is required. The sum of fractions has been rounded to two figures with a maximum of two decimal points. Maximum concentrations and the Biota Concentration Guides are presented in Appendix D.

Biota dose calculations also were completed for West Lake, which is 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 Area Unplanned Release Waste Group Operable Unit (200-UR-1 Operable Unit), and is planned for supplemental characterization (DOE/RL-2009-121, *Sampling and Analysis Plan for the West Lake Site*). The results of these planned investigations will be presented in the appropriate 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 collected from West Lake on a less regular schedule. Both sediment and water samples were collected in 2014 and data tabulated (Appendix C, Tables C.2, C.3, and C.4).

The results of the 2014 screening calculations listed in Table 4.5 show the West Lake sediment and water concentrations failed the Tier 1 and Tier 2 screens. The Tier 1 screen was based on the maximum concentration, and the Tier 2 screen was based on the average concentrations of two water 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 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. Site-specific data from West Lake support 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, *Hanford Site Environmental Report for Calendar Year 2000*; DOE/RL-2007-50, *Central Plateau Ecological Risk Assessment Data Package Report*). 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. 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 is similar to those calculated for 2012, but the 2014 doses are about 10 times greater than those calculated for 2013 (Table 4.5). The reason is that the maximum concentrations in West Lake pond water samples have also varied quite widely. Isotopic uranium is typically detected in West Lake pond water. The last three years of concentrations were—2012 (uranium-234 at 3,850 pCi/L, uranium-235 at 147 pCi/L, uranium-238 at 3650 pCi/L); 2013 (uranium-234 at 256 pCi/L, uranium-235 at 13.8 pCi/L, uranium-238 at 250 pCi/L); and 2014 (uranium-234 at 6,580 pCi/L, uranium-235 at 248 pCi/L, uranium-238 at 6,380 pCi/L). The maximum concentration measured in 2014 was about 25 times greater than that measured in 2013. Further documentation of the West Lake biota dose calculations, including the Tier 3 Biota Concentration Guides, is provided in Appendix D.

Table 4.5. Estimated Doses to Biota Associated with West Lake (Using RESRAD-BIOTA[a] Computer Code)

Tier	Exposure Assumptions	Sum of Fractions [b]		2014
		2013[c]	2014	Pass or Fail
1	Maximum Sediment, Water Concentration and Default Bioaccumulation	2.5	62	Fail
2	Average Sediment, Water Concentration and Default Bioaccumulation	1.3	31	Fail
3	Average Sediment, Water Concentration and Site-specific Bioaccumulation	0.05	0.34	Pass

[a] 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 Tier 3) is required.
[c] Doses presented in the 2013 annual report incorrectly omitted the maximum concentrations of isotopic uranium from pond water. The doses presented in this column reflect the corrected 2013 biota dose.

4.2.7 Radiological Dose in Perspective

Scientific studies (National Research Council 2006, *Health Risks from Exposure to Low Levels of Ionizing Radiation, 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, *Biological Mechanisms of Radiation Actions at Low Doses*). Some scientific studies have indicated that low radiological doses may result in beneficial rather than adverse effects (Calabrese 2009, "The road to linearity: why linearity at low doses became the basis for carcinogen risk assessment"). 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, and natural biochemical reactions in the body), some scientists doubt that the risk from low-level radiation exposure can ever be conclusively proven. 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 millirem (10 microsievert) (EPA/520/1-89-005, *Risk Assessments Methodology Environmental Impact Statement NESHAPS for Radionuclides Background Information Document – Volume 1*). Additional data (National Research Council 2006) 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. Guidance from the Interagency Steering Committee on Radiation Standards (*A Method for Estimating Radiation Risk from TEDE*, 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 millirem (10 microsievert).

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 4.6 compares the estimated risks from various radiological doses to the risks of some activities encountered in everyday life.

Table 4.6. 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 miles (483 kilometers) in a passenger vehicle	2×10^{-6} [a]
Natural background radiological dose (310 millirem [3,100 µSv]) for 70 year	0 to $13{,}000 \times 10^{-6}$ [a]
Dose of 1 millirem (10 microsievert) for 70 years	0 to 40×10^{-6} [a]
Flying as an airline passenger (cross-country roundtrip – radiation)	0 to 6×10^{-6} [b]
Dose to the hypothetical, maximally exposed individual (2014 dose rate) of 0.33 millirem (3.3 microsievert) per year living near the Hanford Site for 70 years	0 to 2×10^{-7} [b]

[a] Real actuarial values.
[b] Upper bound calculated using 6×10^{-7} risk of developing a fatal cancer after receiving a dose of 1 millirem (10 microsievert) (ISCORS 2002).

4.3 Radiological Clearance of Hanford Site Property

JW DeMers

Principal requirements for the control and clearance of DOE property containing residual radioactivity are found in DOE O 458.1, Chg. 2. These requirements are designed to ensure the following:

- Property is evaluated, radiologically characterized—and where appropriate—decontaminated before release
- Residual radioactivity level in property to be released is as near background levels as reasonably practicable, as determined through DOE's as low as reasonably achievable (ALARA) process requirements, and authorized limits
- All property releases are appropriately certified, verified, documented, and reported; public participation needs are addressed; and processes are in place to maintain appropriate records.

The site contractors transitioned from DOE O 5400.5, Chg. 2, to the new order, DOE O 458.1, Chg. 2.

4.3.1 Radiological Clearance for Potentially Contaminated Personal Property with Hard-to-Detect Radionuclides

In the process of performing environmental remediation or related support activities, Hanford Site contractors encounter a wide variety of contaminated personal property, including consumables, office items, tools and equipment, and debris. Over 10,000 items of personal property were unconditionally released from radiological areas on the Hanford Site; however, the majority of the items did not leave the Hanford Site. The personal property items primarily consisted of small items such as flashlights, hard hats, radios, cameras, pens, pencils, respiratory protection, radiological control instruments, and industrial hygiene instruments. All of these items met DOE O 458.1 release criteria, and therefore, did not require additional radiological controls post-survey.

DOE issued a moratorium in January 2000 prohibiting the release of volume-contaminated metals, and subsequently suspended the release of metals for recycling purposes from DOE radiological areas in July 2000. As a result, no volume of contaminated metals or metals for recycling purposes were released from Hanford in 2014.

Final disposition of potentially contaminated personal property with hard-to-detect radionuclides depends on whether the property is considered radiologically contaminated, and whether the disposal of such

property is subject to CERCLA requirements. Radiologically contaminated property is disposed at ERDF if subject to CERCLA requirements, and if not, at the CWC in the 200-West Area. Personal property that has contamination levels below approved DOE control and release guidelines (DOE O 458.1) are considered for release if the property can be reused. Hanford Site contractors routinely encounter a wide variety of radionuclide mixtures ranging from essentially pure plutonium to fission and activation products. Included in these fission and activation products are low-energy beta emitters, such as carbon-14, iron-55, nickel-59, nickel-63, selenium-79, technetium-99, palladium-107, and europium-155 that are difficult or impossible to detect with routine field-survey methods (i.e., hard-to-detect radionuclides).

Traditionally, field detectable or easy-to-detect radionuclides have been used as an analog for the entire mixture of radionuclides encountered during work activities. The control and release criteria (DOE O 458.1) have been adjusted downward to account for the portion of the activity that is not detectable by field survey methods. As the ratio of hard-to-detect radionuclides to easy-to-detect radionuclides increases, the criteria are reduced to a point where the adjusted limits are difficult or impossible to verify with field survey instruments. Decades of radioactive decay have reduced the contributions of easy-to-detect radionuclides to such low levels that current control and release methodologies are no longer sufficient for verifying that contaminant levels comply with the existing, approved DOE property release guidelines in DOE O 458.1.

Accordingly, in May 2006, a request to DOE was submitted by WCH (DOE contractor for the River Corridor Closure Contract) to increase the release criteria (authorized limits) for hard-to-detect radionuclides. The requested authorized limits would apply only to beta-gamma surface contamination on potentially contaminated equipment and materials, and exclude volumetric contamination (contamination that is distributed throughout the volume of the property), contamination in or on persons, unrestricted release of metals, and alpha-surface contamination. Detailed radiological analyses were performed to demonstrate these authorized limits would be protective of human health and the environment. Based on these analyses, the authorized limits would result in a dose of less than 1 millirem (10 microsievert) in any year to the MEI and a collective dose of less than 10 person-rem (0.1 person-sievert) to any exposed population. These authorized limits (Table 4.7) were reviewed by RL and HQ personnel and approved for use by WCH in May 2007. In 2008, RL provided conditional approval to CHPRC and Fluor Hanford, Inc., to use these hard-to-detect authorized limits. In addition to this request, in 2013 CHPRC requested and was approved an authorized limit to apply the general beta-gamma limits to the low energy beta emitter, plutonium-241, (1,000 dpm/100 cm^2 removable limit and 5,000 dpm/100 cm^2total contamination limit). In June 2009, WRPS submitted a request to ORP for approval to use these hard-to-detect authorized limits. ORP provided conditional approval for this request in June 2009. MSA submitted a request to RL in October 2009 for approval to use these hard-to-detect authorized limits. RL provided conditional approval for this request in November 2009.

Table 4.7. Approved Release Criteria (Authorized Limits) for Select Hard-to-Detect Radionuclides[a] for Residual Beta-Gamma Surface Contamination

Average	Maximum	Removable
50,000 dpm/100 cm^2	150,000 dpm/100 cm^2	10,000 dpm/100 cm^2

[a] Carbon-14, iron-55, nickel-59, nickel-63, selenium-79, technetium-99, palladium-107, and europium-155.
DPM = disintegrations per minute.

4.3.2 Granular Activated Carbon for Offsite Shipment and Regeneration Radiological Clearance

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, in the 200 West Area. The 200-PW-1 Operable Unit soil-vapor extraction system includes vapor-phase granular activated carbon canisters to remove carbon tetrachloride from the extracted vapors prior to discharge. This facility was in full operation by 1995.

Workers installed a groundwater pump-and-treat system in 1996 in a second operable unit (200-ZP-1 Operable Unit) 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 granular activated carbon canisters that are identical to the large, carbon-steel granular activated carbon canisters in the 200-PW-1 Operable Unit soil-vapor extraction system.

Each of these systems uses granular activated carbon canisters to capture the volatile organic compounds removed during the extraction process. When a granular activated carbon canister has reached volatile organic compound saturation, it is removed from the system, and the granular activated carbon is prepared for shipment to an offsite facility for regeneration and reuse. Regeneration of the granular activated carbon 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, this granular activated carbon could contain residual radioactivity. Characterization sampling results were used to determine specific radionuclides of concern for this residual radioactivity. For any potential residual radioactivity, DOE O 458.1, Chg. 2 requires that the residual radioactivity not exceed established guidelines or that radiological release criteria (i.e., authorized limits) be developed and submitted to the applicable DOE field office. Following review by RL and HQ personnel in October 2008, approved authorized limits for offsite shipment and regeneration of granular activated carbon was approved for use by CHPRC.

In anticipation of placing the new 200-West Area Pump and Treat facility online, increasing the volume of spent granular activated carbon being sent offsite, a request to modify the authorized limits was made by CHPRC and approved by DOE in October 2010 (Table 4.8). This modification to the authorized limits does not change the expected dose to the public.

Approximately 196,577 pounds (89,166 kilograms) of granular activated carbon was shipped offsite in 2014 for regeneration under these approved modified authorized limits.

Table 4.8. Approved Modified 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

Table 4.8. Approved Modified Authorized Limits for Offsite Shipment and Regeneration of Granular Activated Carbon

Radionuclide	Authorized Limit (pCi/g)
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

4.3.3 Tri-Cities Development Council (TRIDEC) Land Conveyance

The DOE O 458.1, Authorized Limits for the radiological release of the proposed land conveyance to TRIDEC were approved in December 2013. In 2014, field work was completed, and sample and survey results determined that the authorized limits were met. An Independent Verification contractor, Oak Ridge Associated Universities, has completed independent verification field and close out activities.