7. Dose

Activities on ORR have the potential to release small quantities of radionuclides and hazardous chemicals to the environment. These releases could expose members of the public to low concentrations of radionuclides or chemicals. Monitoring of materials released from the reservation and environmental monitoring and surveillance on and around the reservation provide data used to show that doses from released radionuclides and chemicals are in compliance with the law.

In 2014 a hypothetical maximally exposed individual could have received an ED of about 0.6 mrem from radionuclides emitted to the atmosphere from all ORR sources; this is well below the NESHAPs standard of 10 mrem for protection of the public.

A worst-case analysis of exposures to waterborne radionuclides for all pathways combined gives a maximum possible individual ED of about 1 mrem. This dose is based on a person eating 27 kg/year (60 lb/year) of the most contaminated fish accessible, drinking 680 L/year (180 gal/year) of the most contaminated drinking water, and using the shoreline near the most contaminated stretch of water for 60 h/year.

In addition, if a hypothetical person consumed one deer, one turkey, and two geese (containing the maximum ^{137}Cs concentration and maximum weights), that person could have received an ED of about 1 mrem. This calculation is conducted to provide an estimated upper-bound ED from consuming wildlife harvested from ORR.

Therefore, the annual dose to a maximally exposed individual from all these potential exposure pathways combined was estimated to be about 3 mrem. There are no known significant doses from discharges of radioactive constituents from ORR other than those reported. DOE O 458.1, *Radiation Protection of the Public and the Environment* (DOE 2011), limits the ED that an individual may receive from all exposure pathways from all radionuclides released from ORR during 1 year to no more than 100 mrem. The 2014 maximum ED was about 3% of the limit given in DOE O 458.1.

The potential doses to aquatic and terrestrial biota from contaminated soil and water were evaluated using a graded approach. Results of the screening calculations indicate that contaminants released from ORR site activities do not have an adverse impact on plants or animal populations.

7.1 Radiation Dose

Small quantities of radionuclides were released to the environment from operations at ORR facilities during 2014. Those releases were described, characterized, and quantified in previous chapters of this report. This chapter presents estimates of potential radiation doses to the public from the releases. The dose estimates were obtained using monitored and estimated release data, environmental monitoring and surveillance data, estimated exposure conditions that tend to maximize the calculated doses, and environmental transport and dosimetry codes that also tend to overestimate the calculated doses. Thus, the presented doses are likely overestimates of the doses received by actual people in the ORR vicinity.

7.1.1 Terminology

Exposures to radiation from nuclides located outside the body are called external exposures; exposures to radiation from nuclides deposited inside the body are called internal exposures. This distinction is important because external exposures occur only when a person is near or in a radionuclide-containing medium, whereas internal exposures continue as long as the radionuclides remain inside a person. Also, external exposures may result in uniform irradiation of the entire body, including all organs, while internal exposures usually result in nonuniform irradiation of the body and organs. When taken into the body, most radionuclides deposit preferentially in specific organs or tissues and thus do not irradiate the body uniformly.

A number of the specialized terms and units used to characterize exposures to ionizing radiation are defined in Appendix E. "Effective dose" or "ED" is an important term to understand. ED is a risk-based equivalent dose that can be used to estimate health effects or risks to exposed persons. It is a weighted sum of dose equivalents to specified organs and is expressed in rems or sieverts (1 rem = 0.01 Sv).

One rem of ED, regardless of radiation type or method of delivery, has the same total radiological (in this case, also biological) risk effect. Because the doses being considered here are very small, EDs are expressed in millirem (mrem), which is one one-thousandth of a rem. (See Appendix E, Sections E.5.1 and E.5.2, for a comparison and description of various dose levels.)

7.1.2 Methods of Evaluation

7.1.2.1 Airborne Radionuclides

The radiological consequences of radionuclides released to the atmosphere from ORR operations during 2014 were characterized by calculating, for each major facility and for the entire ORR, EDs to maximally exposed on- and off-site members of the public, and to the entire population residing within 80 km (50 miles) of the ORR center. The dose calculations were made with the CAP-88PC Version 3 software program (CAP-88) developed under EPA sponsorship to demonstrate compliance with 40 CFR 61, Subpart H, which governs the emissions of radionuclides other than radon from DOE facilities. CAP-88 implements a steady-state Gaussian plume atmospheric dispersion model to calculate concentrations of radionuclides in the air and on the ground and uses food-chain models to calculate radionuclide concentrations in foodstuffs (vegetables, meat, and milk) and subsequent intakes by humans.

CAP-88 PC Version 3 calculates EDs using radionuclide-specific dose coefficients (ED per unit intake) from Federal Guidance Report 13 (Eckerman et al. 1999). The dose coefficients were calculated by use of the methods in Publication 72 of the International Commission on Radiological Protection (ICRP 1995). These coefficients are weighted sums of equivalent doses to 12 specified tissues or organs plus a remainder term that accounts for the rest of the tissues and organs in the body.

A total of 37 emission points on ORR, each of which includes one or more individual sources, were modeled during 2014. The total includes 3 (two combined) points at Y-12, 28 points at ORNL, and 6 points at ETTP. Table 7.1 lists the emission-point parameter values and receptor locations used in the dose calculations.

Meteorological data used in the calculations for 2014 were in the form of joint frequency distributions of wind direction, wind speed class, and atmospheric stability category. (See Table 7.2 for a summary of tower locations used to model the various sources.) During 2014, rainfall, as averaged over the five rain gauges located on ORR, was 1,127 cm (50 in.). The average air temperature was 13.9°C (57.0°F), and the average mixing-layer height for ETTP and ORNL was 885.7 m (2,906 ft) and for Y-12 was 865.2 m (2,839 ft). The mixing height is the depth of the atmosphere adjacent to the surface within which air is mixed.

Table 7.1. Emission point parameters and receptor locations used in the dose calculations

Source	Stack height (m)	Stack diameter (m)	Effective exit gas velocity (m/s)	Distance (m) and direction to the maximally exposed individual[a]			
				Plant maximum		Oak Ridge Reservation maximum	
Oak Ridge National Laboratory							
X-2000 Lab Hoods	15	0.5	0	4,770	SW	4,770	SW
X-3000 Lab Hoods	15	0.5	0	5,100	SW	5,100	SW
X-4000 Lab Hoods	15	0.5	0	5,270	SW	5,270	SW
X-6000 Lab Hoods	15	0.5	0	5850	SW	5,850	SW
X-7000 Lab Hoods	15	0.5	0	5,290	WSW	5,290	WSW
X-2026	22.9	1.05	7.624	4,820	SW	4,820	SW
X-2099	3.66	0.178	21.9	4,810	SW	4,810	SW
X-3018	61	4.11	0.17	5,030	SW	5,030	SW
X-3020	61	1.22	16.526	4,970	SW	4,970	SW
X-3039	76.2	2.44	7.168	5,060	SW	5,060	SW
X-3544	9.53	0.279	14.38	4,810	SW	4,810	SW
X-3608 Air Stripper	10.97	2.44	0.57	4,930	SW	4,930	SW
X-3608 Filter Press	8.99	0.36	9.27	NA[a]		NA[a]	
X-5505M	11	0.305	4.11	NA[a]		NA[a]	
X-5505NS	11	0.96	0	5,550	SW	5,550	SW
X-7503	30.5	0.91	13.07	5,330	SW	5,330	SW
X-7830 Group	4.6	0.248	8.137	3,920	WSW	3,920	WSW
X-7856-CIP	18.29	0.483	11.725	3,970	WSW	3,970	WSW
X-7877	13.9	0.406	13.56	3,890	WSW	3,890	WSW
X-7880	27.7	1.52	14.92	3,970	WSW	3,970	WSW
X-7911	76.2	1.52	13.46	5,240	WSW	5,240	WSW
7935 Building Stack	18.29	0.6096	0	NA[a]		NA[a]	
7935 Glove Box	9.14	0.254	0	NA[a]		NA[a]	
X-7966	6.096	0.292	9.620	5,330	SW	5,330	SW
X-8915	24.38	1.219	6.838	8,070	SW	8,070	SW
X-Decon Areas	15	0.5	0	5,310	SW	5,310	SW
X-STP	7.6	0.203	7.39	4,590	SW	4,590	SW
East Tennessee Technology Park							
K-1200 South Bay	28	0.81	13.7	1,510	N	5,050	SE
K-1407-AL CWTS	2.74	0.15	0	740	NNW	5,710	SSE
K-2500-H-A	8.23	0.61	12.9	850	NE	6,350	SE
K-2500-H-B	8.23	0.61	12.9	820	NE	6,350	SE
K-2500-H-C	8.23	0.61	12.9	810	NE	6,340	SE
L-2500-H-D	8.23	0.61	12.9	800	NE	6,320	SE

Table 7.1 (continued)

Source ID	Stack height (m)	Stack diameter (m)	Effective exit gas velocity (m/s)	Distance (m) and direction to the maximally exposed individual[a]			
				Plant maximum		Oak Ridge Reservation maximum	
Y-12 National Security Complex							
Y-Monitored	20	0.5	0	2,270	NE	13,340	SW
Y-Unmonitored Processes	20	0.5	0	2,270	NE	13,340	SW
Y-Unmonitored Lab Hoods	20	0.5	0	2,270	NE	13,340	SW

Note: Exit gas temperatures are "ambient air" unless noted otherwise.
[a]NA: Effective doses were calculated to be zero; therefore, distance and direction to maximally exposed individuals could not be determined.

Acronyms
CIP = Capacity Increase Project
CWTS = Chromium Water Treatment System
STP = Sewer Treatment Plant

Table 7.2. Meteorological towers and heights used to model atmospheric dispersion from source emissions

Tower	Height (m)	Source
		Y-12 National Security Complex
MT6 (West Y-12)	30[a]	All Y-12 sources
	60	Spallation Neutron Source (ORNL)
		East Tennessee Technology Park
MT7 (K1209)	10	K-1407-AL CWTS, K-2500-H- A, B, C, and D
	30	K-1200 South Bay
		Oak Ridge National Laboratory
MT4 (Tow A)	10	X-7830, X-7966, X-7935 Glove Box
	30	X-7503, X-7856-CIP, X-7877, X-7880, X-7911, X-7935, and X-7000 Lab Hoods
MT3 (Tow B)	15	X-6000 Lab Hoods, X-5505
MT2 (Tow D)	15	X-2099, X-3026 D, X-3544, X-3608 FP, X-3608 AS, STP, X-Decon Hoods, X-2000, X-3000, and X-4000 Lab Hoods
	30	X-2026
	60	X-3018, X-3020, and X-3039

[a]Wind speeds adjusted to match conditions at a height of 30 m.

Acronyms
CIP = Capacity Increase Project
CWTS = Chromium Water Treatment System
ORNL = Oak Ridge National Laboratory
STP = Sewer Treatment Plant

For occupants of residences, the dose calculations assume that the occupant remained at home during the entire year and obtained food according to the rural pattern. This pattern specifies that 70% of the vegetables and produce, 44.2% of the meat, and 39.9% of the milk consumed are produced in the local area (e.g., a home garden). The remaining portion of each food is assumed to be produced within 80 km (50 miles) of ORR. The same assumptions are used for occupants of businesses, but the resulting doses are divided by 2 to compensate for the fact that businesses are occupied for less than half a year and less than half of a worker's food intake occurs at work. For collective ED estimates, production of beef, milk, and crops within 80 km (50 miles) of ORR was calculated using the production rates provided with CAP-88 PC Version 3.

7.1.2.1.1 Results

Calculated EDs from radionuclides emitted to the atmosphere from ORR are listed in Table 7.3 (maximum individual) and Table 7.4 (collective). The hypothetical maximally exposed individual for ORR was located about 13,340 m southwest of the main Y-12 release point, about 5,240 m west-southwest of the 7911 stack at ORNL, and about 5,710 m south-southeast of the K-1407-AL CWTS at ETTP. This individual could have received an ED of about 0.6 mrem, which is well below the NESHAPs standard of 10 mrem and is about 0.2% of the roughly 300 mrem that the average individual receives from natural sources of radiation. Based on the 2010 population census data, the calculated collective ED to the entire population within 80 km (50 miles) of ORR (about 1,172,530 persons) was about 52.8 person-rem, which is about 0.015% of the 363,484 person-rem that this population received from natural sources of radiation (based on an individual dose of about 300 mrem/year).

Table 7.3. Calculated radiation doses to maximally exposed off-site individuals from airborne releases, 2014

Plant	Effective dose, mrem (mSv)	
	At plant maximum	At Oak Ridge Reservation maximum
Oak Ridge National Laboratory	0.58 (0.0058)[a]	0.58 (0.0058)
East Tennessee Technology Park	0.006 (0.00006)[b]	5E-4 (5E-6)
Y-12 National Security Complex	0.17 (0.0017)[c]	0.015 (0.00015)
Entire Oak Ridge Reservation	*d*	0.6 (0.004)[e]

[a]The maximally exposed individual was located 5,060 m SW of X-3039 and 5,240 m WSW of X-7911.
[b]The maximally exposed individual was located 460 m W of K-1407-AL Chromium Water Treatment System.
[c]The maximally exposed individual was located 2,270 m NE of the Y-12 National Security Complex release point.
[d]Not applicable.
[e]The maximally exposed individual for the entire Oak Ridge Reservation is also the Oak Ridge National Laboratory maximally exposed individual.

Table 7.4. Calculated collective effective doses from airborne releases, 2014

Plant	Collective effective dose[a]	
	Person-rem	Person-Sv
Oak Ridge National Laboratory	43.8	0.438
East Tennessee Technology Park	0.045	4.5E-4
Y-12 National Security Complex	1.5	0.015
Entire Oak Ridge Reservation	52.8	0.53

[a]Collective effective dose to the 1,172,530 persons residing within 80 km (50 miles) of the Oak Ridge Reservation (based on 2010 census data).

The maximally exposed individual for the Y-12 Complex was located at a residence about 2,270 m (1.4 miles) northeast of the main Y-12 release point. This individual could have received an ED of about 0.17 mrem from Y-12 emissions. Inhalation and ingestion of uranium radioisotopes (i.e., ^{233}U, ^{234}U, ^{235}U, ^{236}U, and ^{238}U) accounted for about 99% and technicium-99 (^{99}Tc) accounted for about 0.9% of the dose (Fig. 7.1). The contribution of Y-12 emissions to the 50-year committed collective ED to the population residing within 80 km (50 miles) of ORR was calculated to be about 8.9 person-rem, which is about 17% of the collective ED for ORR.

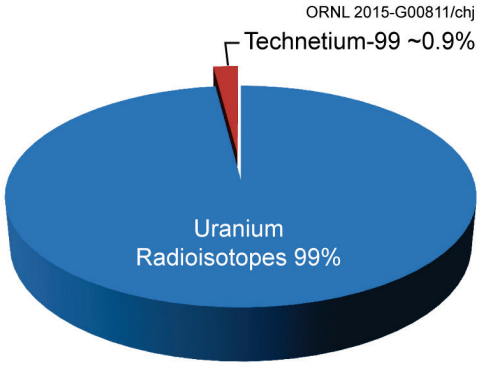

Fig. 7.1. Nuclides contributing to the effective dose at the Y-12 National Security Complex.

The maximally exposed individual for ORNL was located at a residence about 5,060 m (3.2 miles) southwest of the 3039 stack and 5,240 m (3.3 miles) west-southwest of the 7911 stack. This individual could have received an ED of about 0.58 mrem from ORNL emissions. Radionuclides contributing 5% or more to the dose include ^{11}C (59%), ^{212}Pb (14%), and ^{237}Np (7%) (Fig. 7.2). The contribution of ORNL emissions to the collective ED to the population residing within 80 km (50 miles) of ORR was calculated to be about 43.8 person-rem, about 83% of the collective ED for ORR.

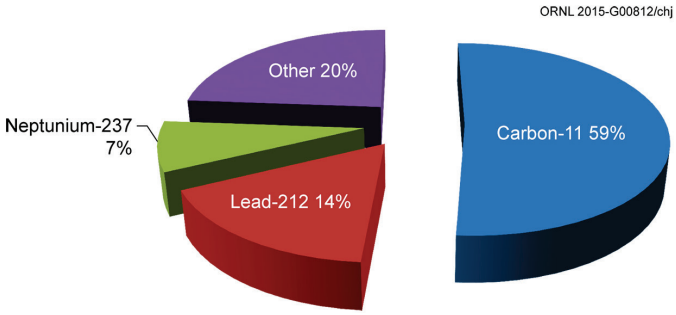

Fig. 7.2. Nuclides contributing to effective dose at Oak Ridge National Laboratory.

The maximally exposed individual for ETTP was located at a business about 800 m (0.5 miles) northeast of the K-2500-H-D. The ED received by this individual was calculated to be about 0.006 mrem. About 90% of the dose is from uranium radioisotopes (^{234}U, ^{235}U, ^{236}U, and ^{238}U) and 10% of the dose is from ^{99}Tc (Fig. 7.3). The contribution of ETTP emissions to the collective ED to the population residing within 80 km (50 miles) of ORR was calculated to be about 0.0045 person-rem, or about 0.09% of the collective ED for the reservation.

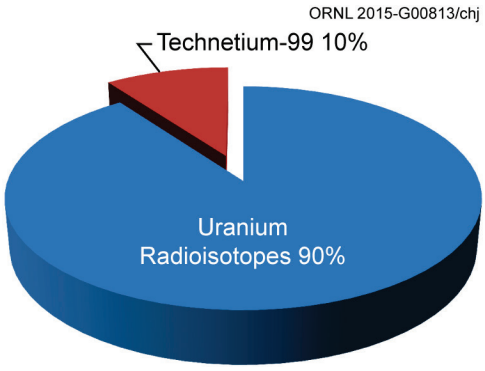

Fig. 7.3. Nuclides contributing to effective dose at East Tennessee Technology Park.

The reasonableness of the estimated doses can be inferred by comparing EDs calculated at the ORR PAM stations from measured air concentrations of radionuclides, excluding naturally occurring ^{7}Be and ^{40}K, with air concentrations calculated using CAP-88PC Version 3 and emissions data (Table 7.5). Based on measured air concentrations, hypothetical individuals assumed to reside at the PAM stations could have received EDs between 0.003 and 0.03 mrem/year. Based on calculated air concentrations using CAP-88PC Version 3, the above individuals could have received EDs between 0.09 and 0.8 mrem/year. As shown in Table 7.5, EDs calculated using CAP-88PC Version 3 and emissions data tend to be higher than or equivalent to EDs calculated using measured air concentrations.

Table 7.5. Hypothetical effective doses from living at the Oak Ridge Reservation and the East Tennessee Technology Park ambient air monitoring stations, 2014

Station	Calculated effective doses			
	Using air monitor data		Using CAP-88[a] and emission data	
	mrem/year	mSv/year	mrem/year	mSv/year
35	0.01	0.0001	0.2	0.002
37	0.006	0.00006	0.3	0.003
38	0.03	0.0003	0.09	0.0009
39	0.003	0.00003	0.5	0.005
40	0.006	0.00006	0.6	0.006
42	0.005	0.00005	0.1	0.001
46	0.03	0.0003	0.5	0.005
48	0.03	0.0003	0.8	0.008
52	0.005	0.00005	0.04	0.0004
K2	0.009	0.00009	0.2	0.002
K6	0.009	0.00009	0.1	0.001
K11	0.1	0.001	0.1	0.001

[a]CAP-88PC Version 3 software, developed under US Environmental Protection Agency sponsorship to demonstrate compliance with 40 CFR 61, Subpart H.

Station 52, located remotely from the ORR, gives an indication of potential EDs from background sources. Based on measured air concentrations, the ED was estimated to be 0.005 mrem/year (the isotopes ^{7}Be and ^{40}K also were not included in the background air monitoring station calculation), whereas the

estimated ED based on calculated air concentrations using CAP-88PC Version 3 was estimated to be 0.04 mrem/year. It should be noted that measured air concentrations of ^{7}Be were similar at the PAM stations and at the background air monitoring station.

Of particular interest is a comparison of EDs calculated using measured air concentrations of radionuclides at PAM stations located near the maximally exposed individuals for each plant and EDs calculated for those individuals using CAP-88PC Version 3 calculated air concentrations and emissions data. PAM station 46 is located near the maximally exposed individual for the Y-12 Complex. The ED calculated with measured air concentrations was 0.03 mrem/year, which is less than the ED of 0.5 mrem/year estimated using CAP-88PC Version 3 calculated air concentrations and emissions data. This year the maximally exposed individual location for ORR/ORNL was located off-site near the PAM station 39 air monitoring location; the ED calculated with measured air concentrations was 0.003 mrem/year, which was considerably less than the 0.5 mrem/year calculated using CAP-88PC Version 3 and emissions data.

7.1.2.2 Waterborne Radionuclides

Radionuclides discharged to surface waters from ORR enter the Tennessee River system by way of the Clinch River (see Section 1.3.4 for the surface water setting of ORR). Discharges from Y-12 enter the Clinch River via Bear Creek and EFPC, both of which enter Poplar Creek before it enters the Clinch River, and by discharges from Rogers Quarry into McCoy Branch and then into Melton Hill Lake. Discharges from ORNL enter the Clinch River via WOC and enter Melton Hill Lake via some small drainage creeks. Discharges from ETTP enter the Clinch River either directly or via Poplar Creek. This section discusses the potential radiological impacts of these discharges to persons who drink water; eat fish; and swim, boat, and use the shoreline at various locations along the Clinch and Tennessee Rivers.

For assessment purposes, surface waters potentially affected by ORR are divided into seven segments: (1) Melton Hill Lake above all possible ORR inputs, (2) Melton Hill Lake, (3) Upper Clinch River (from Melton Hill Dam to confluence with Poplar Creek), (4) Lower Clinch River (from confluence with Poplar Creek to confluence with the Tennessee River), (5) Upper Watts Bar Lake (from near the confluence of the Clinch and Tennessee rivers to below Kingston), (6) the lower system (the remainder of Watts Bar Lake and Chickamauga Lake to Chattanooga), and (7) Poplar Creek (including the confluence of EFPC).

Two methods are used to estimate potential radiation doses to the public. The first method uses radionuclide concentrations in the medium of interest (i.e., in water and fish) determined by laboratory analyses of water and fish samples (see Sections 6.4, 6.5, and 6.7). The second method calculates possible radionuclide concentrations in water and fish from measured radionuclide discharges and known or estimated stream flows. In both methods, reported concentrations of radionuclides were used if the reported value was statistically significant. The advantage of the first method is the use of radionuclide concentrations measured in water and fish; disadvantages are the inclusion of naturally occurring radionuclides (e.g., ^{40}K, uranium and its progeny, thorium and its progeny, and unidentified alpha and beta activities), the possible inclusion of radionuclides discharged from sources not part of ORR, and the possibility that some radionuclides of ORR origin might be present in quantities too low to be measured. The advantages of the second method are that most radionuclides discharged from ORR will be quantified and that naturally occurring radionuclides may not be considered or may be accounted for separately; the disadvantage is the use of models to estimate the concentrations of the radionuclides in water and fish. Both methods use the same models (Hamby 1991) to estimate radionuclide concentrations in media and at locations other than those that are sampled (e.g., downstream). However, combining the two methods allows the potential radiation doses to be bounded.

7.1.2.2.1 Drinking Water Consumption

Surface Water

Several water treatment plants that draw water from the Clinch and Tennessee river systems could be affected by discharges from ORR. No in-plant radionuclide concentration data are available for these plants; all of the dose estimates given below likely are high because they are based on radionuclide concentrations in water before it enters a processing plant. Based on a nationwide food consumption survey (EPA 2011) and weighted based on the combined population of Anderson, Knox, Loudon, and Roane counties, the drinking water consumption rate for the maximally exposed individual is 680 L/year (180 gal/year) and the drinking water consumption rate for the average person is 330 L/year (87 gal/year). The average drinking water consumption rate is used to estimate the collective ED. At all locations in 2014, estimated maximum EDs to a person drinking water were calculated using both measured radionuclide concentrations in and measured radionuclide discharges to off-site surface water, excluding naturally occurring radionuclides such as ^{40}K.

Upper Melton Hill Lake above all possible ORR inputs. Based on samples from Melton Hill Lake above possible ORR inputs [at Clinch River kilometer (CRK) 66], a maximally exposed individual drinking water at this location could have received an ED of about 0 mrem. The collective ED to the 46,676 persons who drink water from the city of Oak Ridge water plant would also be 0 person-rem.

Melton Hill Lake. The only water treatment plant located on Melton Hill Lake that could be affected by discharges from ORR is a Knox County plant. This plant is located near surface water sampling location CRK 58. A maximally exposed individual could have received an ED of about 5×10^{-9} mrem; the collective dose to the 62,812 persons who drink water from this plant could have been 2×10^{-7} person-rem.

Upper Clinch River. The ETTP (Gallaher) water plant draws water from the Clinch River near CRK 23. For assessment purposes, it is assumed that workers obtain half their annual water [340 L (90 gal)] intake at work. Such a worker could have received an ED of about 0.02 mrem; the collective dose to the 750 workers who drink water from this plant could have been about 0.008 person-rem.

Lower Clinch River. There are no known drinking water intakes in this river segment (from the confluence of Poplar Creek to the confluence of the Tennessee River).

Upper Watts Bar Lake. The Kingston and Rockwood municipal water plants draw water from the Tennessee River not very far from its confluence with the Clinch River. A maximally exposed individual could have received an ED of about 0.007 mrem; the collective dose to the 28,633 persons who drink water from these plants could have been about 0.1 person-rem.

Lower system. Several water treatment plants are located on tributaries of Watts Bar Lake and Chickamauga Lake. Persons drinking water from these plants could not have received EDs greater than the 0.006 mrem calculated for drinking Kingston and Rockwood water. The collective dose to the 294,591 persons who drink water within the lower system could have been about 0.7 person-rem.

Poplar Creek/Lower East Fork Poplar Creek. No drinking water intakes are located on Poplar Creek or lower EFPC.

Groundwater

In 2004, six groundwater monitoring wells were installed in the western end of Melton Valley as sentinel wells to detect site-related contaminants that might seep toward the Clinch River. In FY 2010, off-site

monitoring was initiated west of the Clinch River across from the Melton Valley waste management areas. This action was taken in response to detection of site-related contaminants in some of the on-site sentinel well monitoring zones in FY 2007 through FY 2009. As a precaution, DOE funded installation of potable water lines to the residential area near Jones Road on the west side of the Clinch River to provide utility water to residents in the area. Sampling of the off-site wells occurred semiannually from FY 2010 through FY 2014. During FY 2014, EPA drinking water MCLs for alpha activity (15 pCi/L) were exceeded in two off-site wells (both of which produce highly saline groundwater samples, and high dissolved solids samples are known to cause high bias in the analytical result). The MCL for total radium alpha activity (5 pCi/L) was exceeded in one deep off-site well. Beta activity exceeded the 50 pCi/L screening level during FY 2014 in one deep off-site well. Similar to alpha activity, high dissolved solids content in the saline zone contributed to elevated beta analysis in the analyses. Strontium-90 was not detected in any of the off-site monitoring wells in FY 2014. Although ^{99}Tc was detected in one off-site well early in the monitoring program, it was not detected in any of the on-site sentinel wells or in the off-site monitoring wells during FY 2012 through FY 2014. Currently no water is consumed from these groundwater wells. A revised sampling was agreed upon in FY 2013 by DOE, EPA, and TDEC (DOE 2015).

7.1.2.2.2 Fish Consumption

Fishing is quite common on the Clinch and Tennessee River systems. Based on a nationwide food consumption survey (EPA 2011) and weighted based on the combined population of Anderson, Knox, Loudon, and Roane counties, it was assumed that avid fish consumers would have eaten 27 kg (60 lb) of fish during 2014. For the average person used for collective dose calculations, it was assumed that 11 kg (24 lb) of fish was consumed in 2014. The estimated maximum ED will be based on either the first method, measured radionuclide concentrations in fish, or by the second method, which calculates possible radionuclide concentrations in fish from measured radionuclide discharges and known or estimated stream flows. The EDs estimated by both methods, in each of the surface water segments, are provided in Appendix E. The number of individuals who could have eaten fish is based on lake creel surveys conducted annually by TWRA. The 2012 Melton Hill and Chickamauga creel surveys and 2013 Watts Bar creel survey data (creel survey data for Melton Hill and Chickamauga were not collected in 2013) are used to estimate the numbers of individuals who harvested fish from these water bodies.

Upper Melton Hill Lake above All Possible ORR Inputs. For reference purposes, a hypothetical avid fish consumer who ate fish caught at CRK 66, which is above all possible ORR inputs, could have received an ED of about 0.7 mrem. This dose was estimated from a composite fish sample collected near CRK 70 and ^{90}Sr was the primary dose contributor. The collective ED to the 28 persons who could have eaten such fish was about 0.008 person-mrem.

Melton Hill Lake. An avid fish consumer who ate fish from Melton Hill Lake could have received an ED of about 3×10^{-9} mrem. The collective ED to the 248 persons who could have eaten such fish could be about 3×10^{-10} person-rem.

Upper Clinch River. An avid fish consumer who ate fish from the upper Clinch River could have received an ED of about 0.4 mrem. This dose was estimated from a composite fish sample collected near CRK 32 and ^{90}Sr was the primary dose contributor. The collective ED to the 124 persons who could have eaten such fish could have been about 0.02 person-rem.

Lower Clinch River. An avid fish consumer who ate fish from the lower Clinch River (CRK 16) could have received an ED of about 1.2 mrem. The collective ED to the 290 persons who could have eaten such fish could have been about 0.1 person-rem.

Upper Watts Bar Lake. An avid fish consumer who ate fish from upper Watts Bar Lake could have received an ED of about 0.003 mrem. The collective ED to the 827 persons who could have eaten such fish could be about 0.001 person-rem.

Lower System. An avid fish consumer who ate fish from the lower system could have received an ED of about 0.003 mrem. The collective ED to the 40,437 persons who could have eaten such fish could have been about 0.03 person-rem.

Poplar Creek/Lower East Fork Poplar Creek. An avid fish consumer who ate fish from lower EFPC above its confluence with Poplar Creek could have received an ED of about 0.4 mrem. Assuming that 100 people could have eaten fish from lower EFPC and 100 from Poplar Creek, the collective ED could have been about 0.02 person-rem.

7.1.2.2.3 Other Uses

Other uses of ORR area waterways include swimming or wading, boating, and use of the shoreline. A highly exposed "other user" was assumed to swim or wade for 30 h/year, boat for 63 h/year, and use the shoreline for 60 h/year. The average individual, who is used for collective dose estimates, was assumed to swim or wade for 10 h/year, boat for 21 h/year, and use the shoreline for 20 h/year. Measured and calculated concentrations of radionuclides in water and equations used in the LADTAP XL code (Hamby 1991) were used to estimate potential EDs from these activities. At all locations in 2014, the estimated maximally exposed individual EDs were based on measured off-site surface water radionuclide concentrations and excluded naturally occurring radionuclides such as ^{7}Be and ^{40}K.

The number of individuals who could have been other users is different for each section of water because the data sources differ. For Watts Bar parts (upper Clinch River through lower Watts Bar), the assumption for other users is five times the number of people who harvest fish. For Chickamauga and Melton Hill, the number for other users is based on surveys conducted by TVA.

Upper Melton Hill Lake Above All Possible ORR Inputs. A hypothetical maximally exposed other user of upper Melton Hill Lake above possible ORR inputs (CRK 66) could have received an ED of about 0 mrem. The collective ED to the 10,412 other users could have been 0 person-rem.

Melton Hill Lake. An individual other user of Melton Hill Lake could have received an ED of about 8×10^{-11} mrem. The collective ED to the 24,294 other users could have been about 5×10^{-10} person-rem.

Upper Clinch River. An individual other user of the upper Clinch River could have received an ED of about 5×10^{-4} mrem. The collective ED to the 866 other users could have been about 8×10^{-5} person-rem.

Lower Clinch River. An individual other user of the lower Clinch River could have received an ED of about 3×10^{-4} mrem. The collective ED to the 2,026 other users could have been about 2×10^{-4} person-rem.

Upper Watts Bar Lake. An individual other user of upper Watts Bar Lake could have received an ED of about 1×10^{-5} mrem. The collective ED to the 5,778 other users could have been about 2×10^{-5} person-rem.

Lower system. An individual other user of the lower system could have received an ED of about 8×10^{-6} mrem. The collective ED to the 286,737 other users could have been about 4×10^{-4} person-rem.

Poplar Creek/Lower East Fork Poplar Creek. An individual other user of Lower East Fork Poplar Creek, above its confluence with Poplar Creek, could have received an ED of about 0.01 mrem. The

collective ED to the 200 other users of Poplar Creek and Lower East Fork Poplar Creek could have been about 4×10^{-4} person-rem.

7.1.2.2.4 Summary

Table 7.6 is a summary of potential EDs from identified waterborne radionuclides around ORR. Adding worst-case EDs for all pathways in a water-body segment gives a maximum individual ED of about 2 mrem to a person obtaining his or her full annual complement of fish from, and participating in other water uses on, Lower East Fork Poplar Creek. The maximum collective ED to the 80 km (50 miles) population could be as high as 6 person-rem. These are small percentages of individual and collective doses attributable to natural background radiation, about 0.7% of the average individual background dose of roughly 300 mrem/year and 0.002% of the 363,484 person-rem that this population received from natural sources of radiation.

7.1.2.2.5 Irrigation

Although there are no known locations that used water from water bodies around ORR to irrigate food or feed crops, it was decided to determine whether irrigation could contribute to radiation doses to one or more members of the public. To make this determination, the method described by the Nuclear Regulatory Commission (NRC 1977) was used. As shown in Table 7.6, the water body associated with the highest individual dose from waterborne radionuclides was CRK 16. Based on measured and calculated concentrations of radionuclides at that location the maximum potential dose to an individual ranged from 0 to 0.1 mrem in 2014. The individual was assumed to consume 24 kg of leafy vegetables, 90 kg of produce, 321 L of milk and 671 kg of meat (beef) during the year.

Table 7.6. Summary of annual maximum individual (mrem) and collective (person-rem) effective doses (EDs) from waterborne radionuclides, 2014[a,b]

	Drinking water	Eating fish	Other uses	Total[c]
Upstream of all Oak Ridge Reservation discharge locations (CRK 66, City of Oak Ridge Water Plant)				
Individual ED	0	0.7	0	0.7
Collective ED	0	0.008	0	0.008
Melton Hill Lake (CRK 58, Knox County Water Plant)				
Individual ED	5E-9	3E-9	8E-11	9E-9
Collective ED	2E-7	3E-10	5E-10	2E-7
Upper Clinch River (CRK 23, Gallaher Water Plant, CRK 32)				
Individual ED	0.02	0.4	5E-4	0.4
Collective ED	0.008	0.02	8E-5	0.03
Lower Clinch River (CRK 16)				
Individual ED	NA[d]	1.2	3E-4	1.2
Collective ED	NA[d]	0.1	2E-4	0.1
Upper Watts Bar Lake, Kingston Municipal Water Plant				
Individual ED	0.007	0.003	1E-5	0.01
Collective ED	0.1	0.001	2E-5	0.1

Table 7.6 (continued)

	Drinking water	Eating fish	Other uses	Total[c]
Lower system (Lower Watts Bar Lake and Chickamauga Lake)				
Individual ED	0.006	0.003	8E-6	0.009
Collective ED	0.7	0.03	4E-4	0.8
Lower East Fork Poplar Creek and Poplar Creek				
Individual ED	NA[d]	0.4	0.01	0.4
Collective ED	NA[d]	0.02	0.0004	0.02

[a]1 mrem = 0.01 mSv.
[b]Doses based on measured radionuclide concentrations in water or estimated from measured discharges and known or estimated stream flows.
[c]Total doses and apparent sums over individual pathway doses may differ because of rounding.
[d]Not at or near drinking water supply locations.

Acronyms
CRK = Clinch River kilometer.

7.1.2.3 Radionuclides in Other Environmental Media

The CAP-88 computer codes are used to calculate radiation doses from ingestion of meat, milk, and vegetables that contain radionuclides released to the atmosphere. These doses are included in the dose calculations for airborne radionuclides. However, some environmental media, including milk and vegetables, are sampled as part of the surveillance program. The following dose estimates are based on environmental sampling results and may include contributions from radionuclides occurring in the natural environment, released from ORR, or both.

7.1.2.3.1 Milk

During 2014, milk samples were collected from a nearby dairy, and milk samples were composited from several reference locations. Based on a nationwide food consumption survey (EPA 2011), a hypothetical person (weighted based on the combined population of Anderson, Knox, Loudon, and Roane counties) who drank milk was assumed to have consumed a maximum of about 321 L (85 gal) of milk annually. Statistically significant concentrations of ^{40}K, tritium and radioactive strontium were detected in all samples from both the nearby dairy and the composite of several reference locations. Potential EDs attributable to ^{40}K at both "locations" were about 5 mrem/year. Excluding ^{40}K, a naturally occurring radionuclide, the doses associated with tritium and strontium were estimated to be 0.03 mrem for the Claxton dairy and 0.02 mrem for the composite of several reference locations.

7.1.2.3.2 Food Crops

The food-crop sampling program is described in Section 6.6. Samples of tomatoes, lettuce, and turnips were obtained from six gardens, five local and one distant. These vegetables represent fruit-bearing, leafy, and root vegetables. All radionuclides detected in the food crops are found in the natural environment and in commercial fertilizers, and all but ^{7}Be and ^{40}K also are emitted from ORR. Dose estimates are based on hypothetical consumption rates of vegetables that contain statistically significant amounts of detected radionuclides that could have come from ORR. Based on a nationwide food consumption survey (EPA 2011), a hypothetical home gardener (weighted based on the combined population of Anderson, Knox, Loudon, and Roane counties) was assumed to have eaten a maximum of about 72 kg (158 lb) of homegrown tomatoes, 24 kg (53 lb) of homegrown lettuce, and 90 kg (198 lb) of homegrown turnips. The hypothetical gardener could have received a 50-year committed ED of between 0.05 and 0.2 mrem, depending on garden location. Of this total, between 0 and 0.06 mrem could have come from eating

tomatoes, between 0.02 and 0.08 mrem from eating lettuce, and between 0 and 0.06mrem from eating turnips. The highest dose to a gardener could have been about 0.2 mrem from consuming all three types of homegrown vegetables. A person eating food from the distant (background) garden also could have received a committed ED of 0.1 mrem from consumption of all three vegetables.

An example of a naturally occurring and fertilizer-introduced radionuclide is ^{40}K, which is specifically identified in the samples and accounts for most of the beta activity found in them. The presence of ^{40}K in the samples adds, on average, about 14 mrem to the hypothetical home gardener's ED. In 2014, each gardener was asked about water sources and fertilizers used. One gardener (background location) irrigated via Little River and the other five reported that they did not use fertilizers and did not irrigate. It is believed ^{40}K and most of the excess unidentified alpha activities are due to naturally occurring or fertilizer-introduced radionuclides, not radionuclides discharged from ORR.

7.1.2.3.3 White-Tailed Deer

TWRA conducted two 3-day deer hunts during 2014 on the Oak Ridge Wildlife Management Area, which is part of ORR (see Section 6.8). During the hunts, 416 deer were harvested and were brought to the TWRA checking station. At the station, a bone sample and a tissue sample were taken from each deer; these samples were field counted for radioactivity to ensure that the deer met wildlife release criteria (less than 20 pCi/g of beta-particle activity in bone or 5 pCi/g of ^{137}Cs in edible tissue). Three deer exceeded the limit for beta-particle activity in bone and were retained. The remaining 413 deer were released to the hunters.

The average ^{137}Cs concentration in tissue of the 413 released deer, as determined by field counting, was 0.46 pCi/g; the maximum ^{137}Cs concentration in a released deer was 0.68 pCi/g. Most of the ^{137}Cs concentrations were less than minimum detectable levels. Of the released deer, the average weight was about 40 kg (89 lb) and the maximum weight was 71 kg (156 lb). The EDs attributed to field-measured ^{137}Cs concentrations and actual field weights of the released deer ranged from about 0 to 1.1 mrem, with an average of 0.5 mrem.

Potential doses attributed to deer that might have moved off ORR and been harvested elsewhere were also evaluated. In this scenario, an individual who consumed one hypothetical average-weight 40 kg (89 lb) deer (assuming 55% field weight is edible meat) containing the 2014 average field-measured concentration of ^{137}Cs (0.46 pCi/g) could have received an ED of about 0.5 mrem. The maximum field-measured ^{137}Cs concentration was 0.68 pCi/g, and the maximum deer weight was 71 kg (156 lb). A hunter who consumed a hypothetical deer of maximum weight and ^{137}Cs content could have received an ED of about 1 mrem.

Tissue samples collected in 2014 from 15 deer (12 released and 3 retained) were subjected to laboratory analysis. Requested radioisotopic analyses included ^{137}Cs, ^{90}Sr, and ^{40}K radionuclides. Comparison of the released deer field results to analytical ^{137}Cs concentrations found that the field concentrations were all greater than the analytical results and all were less than the administrative limit of 5 pCi/g. Using analytically measured ^{137}Cs and ^{90}Sr and excluding ^{40}K (a naturally occurring radionuclide) and actual deer weights, the estimated doses for the 15 deer (both retained and released) ranged between less than 0 and 0.5 mrem**.**

The maximum ED to individual consuming venison from two or three deer was also evaluated. About 48 hunters each harvested two deer (one hunter harvested three) from ORR. Based on ^{137}Cs concentrations determined by field counting and actual field weight, the ED range to a hunter who consumed two or more harvested deer was estimated to be between 0.05 and 1.4 mrem**.**

The collective ED from eating all the harvested venison from ORR with a 2014 average field-derived ^{137}Cs concentration of 0.46 pCi/g and an average weight of 40 kg (89 lb) is estimated to be about 0.2 person-rem.

7.1.2.3.4 Canada Geese

During the 2014 goose roundup, 17 geese were weighed and subjected to whole-body gamma scans. The geese were field counted for radioactivity to ensure that they met wildlife release criteria (<5 pCi/g of ^{137}Cs in tissue). The average ^{137}Cs concentration was 0.3 pCi/g, with a maximum ^{137}Cs concentration in the released geese of 0.4 pCi/g. All of the ^{137}Cs concentrations were below MDA levels. The average weight of the geese screened during the roundup was about 3.2 kg (7 lb), and the maximum weight was about 4.9 kg (10.7 lb).

The EDs attributed to field-measured ^{137}Cs concentrations and actual field weights of the geese ranged from 0.01 to 0.02 mrem. However, for bounding purposes, if a person consumed a released goose with an average weight of 3.2 kg (7 lb) and an average ^{137}Cs concentration of 0.3 pCi/g, the estimated ED would be about 0.02 mrem. It is assumed that about half the weight of a Canada goose is edible. The maximum estimated ED to an individual who consumed a hypothetical released goose with the maximum ^{137}Cs concentration of 0.4 pCi/g and the maximum weight of 4.9 kg (10.7 lb) was about 0.05 mrem.

It is possible that a person could eat more than one goose that spent time on ORR. The average seasonal goose bag per active hunter from Tennessee in the Mississippi Flyway has ranged from 1.9 to 3.0 geese per hunting season between 1999 and 2010 (TWRA 2010). If one person consumed two hypothetical geese of maximum weight with the highest measured concentration of ^{137}Cs, that person could have received an ED of about 0.1 mrem.

Between 2000 and 2009, 22 geese tissue samples were analyzed. An evaluation of potential doses was made based on laboratory-determined concentrations of the following radionuclides: ^{40}K, ^{137}Cs, ^{90}Sr, thorium (^{228}Th, ^{230}Th, ^{232}Th), uranium ($^{233/234}$U, ^{235}U, ^{238}U), and TRUs (^{241}Am, $^{243/244}$Cm, ^{238}Pu, $^{239/240}$Pu). The total dose, less the contribution of ^{40}K, ranged from 0.01 to 0.5 mrem, with an average of 0.2 mrem (EP&WSD 2010).

7.1.2.3.5 Eastern Wild Turkey

Participating hunters are allowed to harvest one turkey from the reservation in a given season unless a harvested turkey is retained, in which case, the hunter is allowed to hunt for another turkey. Two wild turkey hunts took place on the reservation in 2014: April 5–6 and April 12–13. In addition, one turkey harvested during the 2014 fall hunt season was brought in to the checking station on November 1. Twenty-four birds were harvested (including the off-site turkey), and none were retained. The average ^{137}Cs concentration measured in the released turkeys was 0.09 pCi/g, and the maximum ^{137}Cs concentration was 0.15 pCi/g. The average weight of the turkeys released was about 8.6 kg (18.9 lb). The maximum turkey weight was about 10.7 kg (23.6 lb).

The EDs attributed to the field-measured ^{137}Cs concentrations and the actual field weights of the released turkeys ranged from about 0.004 to 0.02 mrem with an average dose of 0.02 mrem. Potential doses were also evaluated for turkeys that might have moved off ORR and were then harvested elsewhere. In this scenario, if a person consumed a wild turkey with an average weight of 8.6 kg (18.9 lb) and an average ^{137}Cs concentration of 0.09 pCi/g, the estimated ED would be about 0.02 mrem. The maximum estimated ED to an individual who consumed a hypothetical released turkey with the maximum ^{137}Cs concentration of 0.15 pCi/g and the maximum weight of 10.7 kg (23.6 lb) was about 0.04 mrem. It is assumed that approximately half the weight of a wild turkey is edible. No tissue samples were analyzed in 2014.

The collective ED from consuming all the harvested wild turkey meat (24 birds) with an average field-derived ^{137}Cs concentration of 0.09 pCi/g and average weight of 8.6 kg (18.9 lb) is estimated to be about 0.0005 person-rem.

Earlier evaluations of doses based on laboratory-determined concentrations of radionuclides included ^{40}K, ^{137}Cs, ^{90}Sr, ^{230}Th, ^{3}H, ^{234}U, ^{235}U, ^{238}U, and TRUs (^{241}Am, ^{244}Cm, ^{237}Np, ^{239}Pu). The total dose, less the contribution of ^{40}K, ranged from 0.06 to 0.2 mrem (EP&WSD 2010).

7.1.2.3.6 Direct Radiation

The principal sources of natural external exposure are the penetrating gamma radiations emitted by ^{40}K and the series originating from ^{238}U and ^{232}Th (NCRP 2009). External exposure rates due to natural external background sources in the state of Tennessee average about 6.4 μR/h and range from 2.9 to 11 μR/h (Myrick 1981). These exposure rates correspond to ED rates between 18 and 69 mrem/year, with an average of 40 mrem/year.

External radiation exposure rates are measured at numerous locations on and off ORR. During 2014, HPIC detectors, which have been used since the early 1990s to measure external radiation exposure rates, were replaced with GM-based detectors. Exposure rates measured with the HPICs at five PAM stations around ORR during 2014 averaged about 8.2 μR/h and ranged from 7.2 to 9.1 μR/h. These exposure rates correspond to an annual average ED of about 49 mrem and a range of 44 to 56 mrem. Exposure rates measured by the new GM-type detectors, in 2014 averaged about 10.9 μR/h and ranged from 9.6 to 11.9 μR/h. These exposure rates correspond to an annual average ED of about 65 mrem and a range of 59 to 73 mrem. The variation in exposure rates and therefore doses between the two systems are due primarily to different detector and efficiencies. At the remote PAM station, the exposure rate, measured with the HPIC, averaged 6.9 μR/h (annual ED of 42 mrem). With the new GM instrument, the exposure rate measured at the remote PAM station averaged about 9.6 μR/h (annual ED of 59 mrem). All measured exposure rates at or near the ORR boundaries fall within the range of statewide background levels.

7.1.3 Current-Year Summary

A summary of the maximum EDs to individuals by pathway of exposure is given in Table 7.7. In the unlikely event that any person was irradiated by all of those sources and pathways for the duration of 2014, that person could have received a total ED of about 3 mrem. Of that total, 0.6 mrem would have come from airborne emissions and 1 mrem from waterborne emissions (0.02 mrem from drinking water, 1 mrem from consuming fish along the lower Clinch River and 0.01 mrem from other water uses along Lower East Fork Popular Creek), and no appreciable dose above background from external radiation. There are no known significant doses from discharges of radioactive constituents from ORR other than those reported.

The dose of 3 mrem is about 1% of the annual dose (roughly 300 mrem) from background radiation. The ED of 3 mrem includes the person who received the highest EDs from eating wildlife harvested on ORR. If the maximally exposed individual did not consume wildlife harvested from ORR, the estimated dose would be about 2 mrem.

DOE O 458.1 limits the ED that an individual may receive from all exposure pathways from all radionuclides released from ORR during 1 year to no more than 100 mrem. The 2014 maximum ED should not have exceeded about 3 mrem, or about 3% of the limit given in DOE O 458.1. (For further information, see Sections E.5.1 and E.5.2 in Appendix E, which summarize dose levels associated with a wide range of activities.)

The total collective ED to the population living within an 80 km (50-mile) radius of ORR was estimated to be about 53 person-rem. This dose is about 0.01% of the 363,484 person-rem that this population received from natural sources during 2014.

Table 7.7. Summary of maximum estimated effective doses to an adult by exposure pathway

Pathway	Dose to maximally exposed individual		Percentage of DOE mrem/year limit (%)	Estimated population dose		Population within 80 km	Estimated background radiation population dose (person-rem)[a]
	Mrem	mSv		person-rem	person-Sv		
				Airborne effluents			
All pathways	0.6	0.006	0.6	52.8	0.53	1,172,530[b]	
				Liquid effluents			
Drinking water	0.02	0.0002	0.02	0.008	0.00008	433,462[c]	
Eating fish	1	0.01	1	0.1	0.001	42,154[d]	
Other activities	0.01	0.0001	0.01	0.0004	0.000004	330,313[d]	
Irrigation	0.1	0.1	0.1				
				Other Pathways			
Eating deer	1[e]	0.01	1	0.2	0.002	413	
Eating geese	0.1[f]	0.001	0.1	[g]	[g]		
Eating turkey	0.04[h]	0.0004	0.04	0.0005	0.000005	24	
Direct radiation	NA[i]	NA					
All pathways	**3**	**0.003**	**3**	**53**	**0.53**	**1,172,530**	**363,484**

[a]Estimated background population dose is based on the roughly 300 mrem/year individual dose and the population within 80 km (50 miles) of the Oak Ridge Reservation.
[b]Population based on 2010 census data.
[c]Population estimates based on community and non-community drinking water supply data from the Tennessee Department of Environment and Conservation, Division of Water.
[d]Population estimates based on population within 80 km (50 miles) and fraction of fish harvested from Melton Hill, Watts Bar, and Chickamauga reservoirs. Melton Hill and Chickamauga recreational use information was obtained from the Tennessee Valley Authority (Stephens et al. 2006 and Stephens et al. 2007).
[e]From consuming one hypothetical worst-case deer, a combination of the heaviest deer harvested and the highest measured concentrations of ^{137}Cs in released deer on ORR; population dose based on number of hunters that harvested deer.
[f]From consuming two hypothetical worst-case geese, each a combination of the heaviest goose harvested and the highest measured concentrations of ^{137}Cs in released geese.
[g]Population doses were not estimated for the consumption of geese since no geese were brought to the checking station during the goose hunt.
[h]From consuming one hypothetical worst-case turkey, a combination of the heaviest turkey harvested and the highest measured concentrations of ^{137}Cs in released turkey. The population dose is based on the number of hunters who harvested turkey.
[i]Direct radiation dose estimates were conducted, although exposure rates near the Clinch River were near background levels. In addition, direct radiation monitoring is no longer conducted for locations that were formerly the UF_6 cylinder storage yards and the K-770 Scrap Yard. Direct dose measurements have been taken and have confirmed that there is no longer a source of potential dose to the public above the background levels.

7.1.4 Five-Year Trends

EDs associated with selected exposure pathways for the years 2010 to 2014 are given in Table 7.8. In 2014, the air pathway dose increased primarily due to an increase in SNS power. In addition, the dose from fish consumption was less than the dose in 2013 though greater than doses from 2010 through 2012.

This increase was due to a composite fish sample collected at CRK 16 in which ^{90}Sr was a primary dose contributor. In 2013, an increase in the dose from fish consumption was observed as compared to earlier years and this increase in dose was because of a composite fish sample collected near CRK 32 in which ^{137}Cs was the primary dose contributor. Recent measurements along the Clinch River indicate doses near background levels. There was a decrease in drinking water dose in 2014. Doses from consumption of wildlife have been similar the last 5 years.

Table 7.8. Trends in effective dose (mrem)[a] for selected pathways

Pathway	2010	2011	2012	2013	2014
Air pathway (all routes)	0.4	0.3	0.3	0.4	0.6
Surface water pathway					
Fish consumption (Clinch River)	0.3	0.3	0.08	1.5	1.2
Drinking water (Kingston)	0.03	0.02	0.02	0.01	0.003
Direct radiation pathway					
Clinch River	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]
Wildlife					
Deer	2	2	2	2	2
Geese	0.2	0.1	0.1	0.1	0.1
Turkey	0.05	0.1	0.06	0.08	0.04

[a]1 mrem = 0.01 mSv.
[b]Direct radiation dose estimates were conducted, although exposure rates near the Clinch River were near background levels.

7.1.5 Potential Contributions from Non-DOE Sources

DOE O 458.1 requires that if the DOE-related annual dose is greater than 25 mrem, the dose to members of the public must include major non-DOE sources of exposure as well as doses from DOE-related sources. In 2014, the DOE-related source doses were considerably below the 25 mrem criteria. However, DOE requested information from non-DOE facilities pertaining to potential radiation doses to members of the public. There are several non-DOE facilities on or near ORR that could contribute radiation doses to the public. These facilities submit annual reports to demonstrate compliance with NESHAPs regulations and the terms of their operating licenses. Nine facilities responded to the DOE request. Three facilities, using the COMPLY screening tool for evaluating radiation exposure from atmospheric releases of radionuclides, reported annual doses from airborne emissions ranging from 8×10^{-6} mrem to 0.2 mrem and one facility reported <10 mrem (COMPLY, level 1). Non-DOE facility doses from water discharges ranged from zero emissions to sewer discharges less than the sum of ratios. Doses from direct radiation ranged from none to an annual dose of 45 mrem based on area monitors location within one of the facilities. Therefore, annual doses from air and water emissions and external radiation from both non-DOE and DOE sources should be less than the DOE O 458.1 requirement of 100 mrem.

7.1.6 Doses to Aquatic and Terrestrial Biota

7.1.6.1 Aquatic Biota

DOE O 458.1 sets an absorbed dose rate limit of 1 rad/day to native aquatic organisms from exposure to radioactive material in liquid wastes discharged to natural waterways (see Appendix E for definitions of absorbed dose and rad). To demonstrate compliance with this limit, the aquatic organism assessment was

conducted using the RESRAD-Biota code (1.5), a companion tool for implementing the DOE technical standard, *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota* (DOE 2002). The code serves as DOE's biota dose evaluation tool and uses the screening [i.e., biota concentration guides (BCGs)] and analysis methods in the technical standard. The BCG is the limiting concentration of a radionuclide in sediment or water that would not cause dose limits for protection of aquatic biota populations to be exceeded.

The intent of the graded approach is to protect populations of aquatic organisms from the effects of exposure to anthropogenic ionizing radiation. Certain organisms are more sensitive to ionizing radiation than others. Therefore, it is generally assumed that protecting the more-sensitive organisms will adequately protect other less-sensitive organisms. Depending on the radionuclide, either aquatic organisms (e.g., crustaceans) or riparian organisms (e.g., raccoons) may be considered to be the more sensitive and are typically the limiting organisms for the general screening phase of the graded approach for aquatic organisms.

At ORNL, doses to aquatic organisms are based on surface water concentrations at the following 11 different instream sampling locations.

- Melton Branch [Melton Branch Weir and Melton Branch (X13)]
- WOC [White Oak headwaters (X14) and WOD (X15) First Creek]
- Fifth Creek
- Northwest Tributary
- Clinch River (CRK 23, CRK 32, and CRK 66)

All locations, except WOC (X14) and WOD (X15), passed the general screening phase (comparison of maximum radionuclide water concentrations to default BCGs). Both WOC (X14) and WOD (X15) passed when comparing average radionuclide water concentrations to default BCGs. This resulted in absorbed dose rates to aquatic organisms below the DOE aquatic dose limit of 1 rad/day at all 11 sampling locations.

At Y-12, doses to aquatic organisms were estimated from surface water concentrations at the following four different instream sampling locations.

- Surface Water Hydrological Information Support System Station 9422-1 (also known as station 17)
- Discharge Point S24, Bear Creek at Bear Creek kilometer 9.4
- Discharge Point S17 (unnamed tributary to the Clinch River)
- Discharge Point S19 (Rogers Quarry)

All locations passed the general screening phase (maximum water concentrations and default parameters for BCGs). This resulted in absorbed dose rates to aquatic organisms below the DOE aquatic dose limit of 1 rad/day at all four Y-12 locations.

At ETTP, doses to aquatic organisms were estimated from surface water concentrations at the following 13 different instream sampling locations.

- Mitchell Branch at K1700; MIKs 0.45, 0.59, 0.71, 0.82, and 1.4 (upstream location)
- Poplar Creek at K-716 (downstream)
- K1007-B and K-1710 (upstream location)
- K-702A and K901-A (downstream of ETTP operations)
- Clinch River (CRK 16 and CRK 23)

All of these locations passed the initial general screening (using maximum concentrations and default parameters for BCGs). This resulted in absorbed dose rates to aquatic organisms below the DOE aquatic dose limit of 1 rad/day at all 13 sampling locations.

7.1.6.2 Terrestrial Biota

To evaluate impacts on biota, in accordance with requirements in DOE O 458.1, a terrestrial organism assessment was conducted. An absorbed dose rate of 0.1 rad/day is recommended as the limit for terrestrial animal exposure to radioactive material in soils. As for aquatic and riparian biota, certain terrestrial organisms are more sensitive to ionizing radiation than others, and it is generally assumed that protecting the more sensitive organisms will adequately protect other less-sensitive organisms. Initial soil sampling for terrestrial dose assessment was initiated in 2007 and reassessed in 2014. This biota sampling strategy was developed by taking into account guidance provided in *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota* (DOE 2002) and existing radiological information on the concentrations and distribution of radiological contaminants on ORR. As in 2007, the soil sampling focused on unremediated areas, such as floodplains and some upland areas. Floodplains are often downstream of contaminant source areas and are dynamic systems where soils are eroding in some places and being deposited in others. Soil sampling locations are identified as follows.

- WOC floodplain and upland location
- Bear Creek Valley floodplain
- Mitchell Branch floodplain
- Two background locations: Gum Hollow and near Bearden Creek

The soil samples were collected in similar locations as in 2007. With the exception of samples collected on the WOC floodplain (collected on the WOC floodplain upstream from WOD), samples taken at all other soil sampling locations passed either the initial-level screening (comparison of maximum radionuclide soil concentrations to default BCGs) or second-level screening, for which BCG default parameters and average soil concentrations were used. Cesium-137 is the primary dose contributor in the soil samples collected on the WOC floodplain.

Biota sampling in the WOC floodplain was conducted in 2009. White-footed mice (*Peromyscus leucopus*), deer mice (*Peromyscus maniculatus*), and hispid cotton rats (*Sigmodon hispidus)* were selected for sampling because they live and forage in these areas, are food for other mammals, and have relatively small home ranges. The biota sampling locations were at the confluence of Melton Branch and WOC and in the floodplain upstream of White Oak Lake. Based on the current measured concentrations in soil and tissue concentrations collected, the absorbed doses to the terrestrial organisms collected along the confluence of Melton Branch and WOC and in the floodplain upstream of White Oak Lake were less than 0.1 rad/day.

The next evaluation of exposure to terrestrial organisms would be within the next 5 years or if an abnormal event occurs that could have adverse impacts on terrestrial organisms.

7.2 Chemical Dose

7.2.1 Drinking Water Consumption

Surface Water

To evaluate the drinking water pathway, hazard quotients (HQs) were estimated downstream of ORNL and downstream of ORR discharge points (Table 7.9). The HQ is a ratio that compares the estimated

exposure dose or intake to the reference dose. (See Appendix F for a detailed description of the chemical dose methodology.) Based on a nationwide food consumption survey (EPA 2011) and weighted based on the combined population of Anderson, Knox, Loudon, and Roane counties, it was assumed that the drinking water consumption rate for the maximally exposed individual is 680 L/year (180 gal/year). This is the same drinking water consumption rate used in the estimation of the maximum exposed radiological dose from consumption of drinking water. Chemical analytes were measured in surface water samples collected at CRK 23 and CRK 16. CRK 23 is located near the water intake for ETTP; CRK 16 is located downstream of all DOE discharge points. As shown in Table 7.9, HQs were less than 1 for detected chemical analytes for which there are reference doses or maximum contaminant levels.

Acceptable risk levels for carcinogens typically range in magnitude from 10^{-4} to 10^{-6}. A risk value slightly greater than or equal to 10^{-5} was calculated for the intake of arsenic in water collected at both locations.

Table 7.9. Chemical hazard quotients and estimated risks for drinking water, 2014

Chemical	Hazard quotient	
	CRK 23[a]	CRK 16[b]
Arsenic	0.08	0.05
Mercury	0.00009	0.0003
Nickel	0.004	
Uranium	0.002	0.003
Zinc	0.005	
Risk for carcinogens		
Arsenic	3×10^{-5}	1×10^{-5}

[a]Clinch River near the water intake for East Tennessee Technology Park.
[b]Clinch River downstream of all US Department of Energy inputs.

Acronyms
CRK = Clinch River kilometer.

Groundwater

As mentioned in Section 7.1.2.2.1, a series of off-site monitoring wells was installed across the Clinch River from ORNL west of the Melton Valley waste management areas in 2010. Sampling of the off-site wells occurred semiannually during FY 2012 and FY 2013, and results were compared to EPA maximum contaminant levels (DOE 2015). A trend evaluation of monitoring data from two off-site monitoring wells (2012 through 2013) indicates that fluoride and barium concentrations were increasing, antimony levels were decreasing, and arsenic concentrations were stable (DOE 2015). Reviews of shallow groundwater monitoring data near the Melton Valley waste disposal areas do not show fluoride plumes emanating from the buried waste. Fluoride has natural and potential human-made sources in Melton Valley. Barium is a common constituent of geologic brines (DOE 2014). VOCs have not been detected in off-site wells since September 2010 (DOE 2015). Currently, no water is consumed from these off-site groundwater wells.

7.2.2 Fish Consumption

Chemicals in water can be accumulated by aquatic organisms that may be consumed by humans. To evaluate the potential health effects from the fish consumption pathway, HQs were estimated for the consumption of noncarcinogens, and risk values were estimated for the consumption of carcinogens

detected in sunfish and catfish collected both upstream and downstream of the ORR discharge points. Based on a nationwide food consumption survey (EPA 2011) and weighted based on the combined population of Anderson, Knox, Loudon, and Roane counties, it was assumed that avid fish consumers would have eaten 27 kg (60 lb) of fish during 2014. This fish consumption rate of 74 g/day (27 kg/year) is assumed for both the noncarcinogenic and carcinogenic pollutants. This is the same fish consumption rate used in the estimation of the radiological dose from consumption of fish. (See Appendix F for a detailed description of the chemical dose methodology.)

As shown in Table 7.10, for consumption of sunfish and catfish, HQ values of less than 1 were calculated for all detected analytes except for Aroclor-1260 (which are PCBs, also referred to as PCB-1260) and for mercury for catfish at CRK 32. An HQ greater than 1 for Aroclor-1260 was estimated in sunfish and catfish at all three locations (CRKs 16, 32, and 70).

For carcinogens, risk values at or greater than 10^{-5} were calculated for the intake of Aroclor-1260 in sunfish and catfish collected at all three locations. TDEC has issued a fish advisory that states that catfish should not be consumed from Melton Hill Reservoir (in its entirety) because of PCB contamination and has issued a precautionary fish consumption advisory for catfish in the Clinch River arm of Watts Bar Reservoir (TWRA 2012). The risk values for Aroclor-1260 for sunfish and catfish were similar to risk values estimated in 2012 and roughly an order of magnitude less than the values estimated in 2013.

Table 7.10. Chemical hazard quotients and estimated risks for carcinogens in fish, 2014[a]

Carcinogen	Sunfish			Catfish		
	CRK 70[b]	CRK 32[c]	CRK 16[d]	CRK 70[b]	CRK 32[c]	CRK 16[d]
Hazard quotients for metals						
Antimony			0.3	0.2		0.3
Arsenic		0.3				
Barium	0.002	0.003	0.002	0.00004	0.00007	0.0005
Cadmium				0.2		
Chromium	0.09	0.05	0.05	0.02	0.02	0.03
Copper	0.008	0.01	0.01	0.006	0.007	0.009
Manganese	0.01	0.03	0.02	0.001	0.001	0.003
Mercury	0.1	0.2	0.4	0.3	1.3	0.6
Nickel				0.002		0.001
Selenium	0.3	0.3	0.2	0.2	0.2	0.2
Strontium	0.004	0.006	0.005	0.00007	0.00008	0.0005
Thallium	0.1	0.1	0.09	0.04	0.2	0.08
Uranium	0.0003		0.0004			
Vanadium	0.003					
Zinc	0.04	0.05	0.05	0.1	0.02	0.02
Hazard quotients for pesticides and Aroclors						
Aroclor-1260	1	2	2	6	4	5

Table 7.10 (continued)

Carcinogen	Sunfish			Catfish		
	CRK 70[b]	CRK 32[c]	CRK 16[d]	CRK 70[b]	CRK 32[c]	CRK 16[d]
Risks for carcinogens						
Arsenic		5E-5				
Aroclor-1260	2E-5	3E-5	3E-5	1E-4	7E-5	9E-5
PCBs (mixed)[e]	2E-5	3E-5	3E-5	1E-4	7E-5	9E-5

[a]A blank space for a particular location indicates that the parameter was undetected.
[b]Melton Hill Reservoir, above the city of Oak Ridge Water Plant.
[c]Clinch River downstream of Oak Ridge National Laboratory.
[d]Clinch River downstream of all US Department of Energy inputs.
[e]Mixed polychlorinated biphenyls (PCBs) consist of the summation of Aroclors detected or estimated.

Acronyms
CRK = Clinch River kilometer

7.3 References

DOE. 2002. DOE Standard: *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota*. DOE-STD-1153-2002. US Department of Energy, Washington, DC.

DOE. 2011. *Radiation Protection of the Public and the Environment,* DOE O 458.1. Approved 2-11-2011 (Admin. Chg. 3 dated 1-15-2013). US Department of Energy, Washington, DC.

DOE. 2014. *2014 Remediation Effectiveness Report for the U.S. Department of Energy Oak Ridge Reservation, Oak Ridge, Tennessee, Data and Evaluations.* DOE/OR/01-2640&D1, March 2014.

DOE. 2015. *2015 Remediation Effectiveness Report for the U.S. Department of Energy Oak Ridge Reservation, Oak Ridge, Tennessee, Data and Evaluations.* DOE/OR/01-2675&D1. US Department of Energy, Oak Ridge, Tennessee.

Eckerman, Keith F., et al. 1999. *Cancer Risk Coefficients for Environmental Exposure to Radionuclides*, Federal Guidance Report 13, EPA 402-R-99-001. US Environmental Protection Agency, Washington, DC.

EP&WSD. 2010. *Radiological Monitoring and Dose Report for Selected Wildlife Populations Oak Ridge Reservation*. EPWSD-EPS-TP-01. Oak Ridge National Laboratory, Environmental Protection and Waste Services Division, Oak Ridge, Tennessee.

EPA. 2011. *Exposure Factors Handbook.* EPA/600/R-090/052F. US Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment.

Hamby, D. M. 1991. "LADTAP XL: An Improved Electronic Spreadsheet Version of LADTAP II." DE93003179. Westinghouse Savannah River Company, Aiken, South Carolina.

ICRP. 1995. *Age-Dependent Doses to the Members of the Public from Intake of Radionuclides: Part 5, Compilation of Ingestion and Inhalation Coefficients*. Publication 72, Ann. ICRP 26(1). International Commission on Radiological Protection, Ottawa, Ontario, Canada.

Myrick, T. E., et al. 1981. *State Background Radiation Levels: Results of Measurements Taken during 1975–1979*. ORNL/TM-7343. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

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

NRC. 1977. *Regulatory Guide 1.109, Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I.* US Nuclear Regulatory Commission, Washington, DC.

Stephens, B., et al. 2006. *Recreation Use on Norris Reservoir*. October. Human Dimensions Research Lab, University of Tennessee Agriculture Institute.

Stephens, B., et al. 2007. *Recreation Use on Chickamauga Reservoir*. December. Human Dimensions Research Lab, University of Tennessee Agriculture Institute.

TWRA. 2010. *Tennessee Waterfowl Report 2010–2011*, Tennessee Wildlife Resources Agency Technical Report No. 11-XX, 2011. Available online at http://www.state.tn.us/twra/pdfs /waterfowlreport1011.pdf.

TWRA. 2012. TWRA Region 4—Reservoir Fisheries Management Program, "Fish Consumption Advisory," updated August, 2012. Available online at http://www.tnfish.org/ ContaminantsInFishAdvisories_TWRA/ FishFleshConsumptionAdvisories_TWRA.htm.