7. Dose

Activities on Oak Ridge Reservation (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 2015, a hypothetical maximally exposed individual could have received an effective dose (ED) of about 0.4 mrem from radionuclides emitted to the atmosphere from all ORR sources; this is well below the National Emission Standards for Hazardous Air Pollutants for Radionuclides 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. US Department of Energy (DOE) Order 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 2015 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.

Because of differing permit-reporting requirements and instrument capabilities, various units of measurement are used in this report. The information found in "Units of Measure and Conversion Factors" is intended to help readers convert numeric values presented here as needed for specific calculations and comparisons.

7.1 Radiation Dose

Small quantities of radionuclides were released to the environment from operations at Oak Ridge Reservation (ORR) facilities during 2015. 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" (ED) is a risk-based equivalent dose that is 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 rem 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 discussed here are very small, EDs are expressed in millirem (mrem), which is one one-thousandth of a rem. (See Appendix E 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 2015 were characterized by calculating 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 calculations were performed for each major facility and for the entire ORR. The dose calculations were made using the Clean Air Act Assessment Package—1988 (CAP-88 PC) Version 4 (EPA 2015), a software program developed under sponsorship of the US Environmental Protection Agency (EPA) to demonstrate compliance with 40 CFR 61, Subpart H, which governs the emissions of radionuclides other than radon from US Department of Energy (DOE) facilities. CAP-88 PC 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 4 was used for the first time in 2015 to estimate doses from airborne emissions. Version 4 differs significantly from Version 3 in three areas:

- incorporation of age-dependent radionuclide dose and risk factors for ingestion and inhalation,
- increase in the number of radionuclides included in the database, and
- a change in the file management system used by the program (EPA 2015).

In this assessment, adult dose coefficients were used to estimate doses. 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 35 emission points on ORR were modeled during 2015. The total includes 3 (two combined) points at the Y-12 National Security Complex (Y-12), 27 points at Oak Ridge National Laboratory (ORNL), and 5 points at the East Tennessee Technology Park (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 2015 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 2015, rainfall, as averaged over the five rain gauges located on ORR, was 152.6 cm (60.1 in.). The average air temperature was 15.1°C (59.2°F) at the 10 to 15 m levels, and the average mixing-layer height for ETTP and ORNL was 811.9 m (2,664 ft) and for Y-12 was 796.5 m (2,613 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) [a]	Distance (m) and direction to the maximally exposed individual			
				Plant maximum		Oak Ridge Reservation maximum	
Oak Ridge National Laboratory							
X-2000 Lab Hoods	15	0.5	0	5,482	E	5482	E
X-3000 Lab Hoods	15	0.5	0	4,949	E	4,949	E
X-4000 Lab Hoods	15	0.5	0	4,729	E	4,729	E
X-6000 Lab Hoods	15	0.5	0	4,208	E	4,208	E
X-7000 Lab Hoods	15	0.5	0	4,176	E	4,176	E
X-2026	22.9	1.05	7.09	5,295	E	5,295	E
X-2099	3.66	0.18	19.03	5,283	E	5,283	E
X-3018	61	4.11	0.17	5,115	E	5,115	E
X-3020	61	1.22	16.10	5,155	E	5,155	E
X-3039	76.2	2.44	5.96	5,002	E	5,002	E
X-3544	9.53	0.279	21.98	5,043	ENE	5,043	ENE
X-3608 Air Stripper	10.97	2.44	0.57	4,883	ENE	4,883	ENE
X-3608 Filter Press	8.99	0.36	9.27	4,883	ENE	4,883	ENE
X-5505M	11	0.305	2.53	4,369	E	4,369	E
X-5505NS	11	0.96	0	4,342	E	4,342	E
X-7503	30.5	0.91	12.55	4,183	ENE	4,183	ENE
X-7830 Group	4.6	0.248	7.58	5,524	ENE	5,524	ENE
X-7856-CIP	18.29	0.483	11.58	5,478	ENE	5,478	ENE
X-7877	13.9	0.406	13.56	5,553	ENE	5,553	ENE
X-7880	27.7	1.52	14.92	5,588	ENE	5,588	ENE
X-7911	76.2	1.52	14.12	4,218	ENE	4,218	ENE
X-7935 Building Stack	18.29	0.6096	0	4,230	ENE	4,230	ENE
X-7935 Glove Box	9.14	0.25	0	4,230	ENE	4,230	ENE

Table 7.1 (continued)

Source ID	Stack height (m)	Stack diameter (m)	Effective exit gas velocity (m/s) [a]	Distance (m) and direction to the maximally exposed individual			
				Plant maximum		Oak Ridge Reservation maximum	
Oak Ridge National Laboratory (continued)							
X-7966	6.096	0.292	9.62	4,162	ENE	4,162	ENE
X-8915	24.38	1.219	6.6	4,242	ESE	4,242	ESE
X-Decon Areas	15	0.5	0	4,703	E	4,703	E
X-STP	7.6	0.203	7.39	5,240	ENE	5,240	ENE
East Tennessee Technology Park							
K-1200 South Bay	28	0.81	13.7	753	NW	11,315	E
K-1407-AL CWTS	2.74	0.15	0	455	WSW	11,339	E
K-2500-H-B	8.23	0.61	12.9	553	SE	12,181	E
K-2500-H-C	8.23	0.61	12.9	547	SE	12,173	E
L-2500-H-D	8.23	0.61	12.9	524	SE	12,149	E
Y-12 National Security Complex							
Y-Monitored	20	0.5	0	2,272	NE	5,800	S
Y-Unmonitored Processes	20	0.5	0	2,272	NE	5,800	S
Y-Unmonitored Lab Hoods	20	0.5	0	2,272	NE	5,800	S

[a] Exit gas temperatures are "ambient air" unless noted otherwise.

Acronyms
CIP = Capacity Increase Project
CWTS = Chromium Water Treatment System
STP = Sewage 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 category 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 4.

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	All Y-12 sources
	60	X-8915 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)	30	X-7503, X-7856-CIP, X-7877, X-7830,X-7880, X-7911, X-7935, X 7966,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

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

7.1.2.1.1 Results

Calculated EDs from radionuclides emitted to the atmosphere from the ORR are listed in Table 7.3 (maximum individual) and Table 7.4 (collective). The hypothetical maximally exposed individual for ORR was located about 5,800 m south of the main Y-12 release point, about 4,218 m east-northeast of the 7911 stack at ORNL, and about 11,339 m east of the K-1407-AL Chromium Water Treatment System (CWTS) at ETTP. This individual could have received an ED of about 0.4 mrem, which is well below the National Emission Standards for Hazardous Air Pollutants for Radionuclides standard of 10 mrem and is about 0.1% 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 10.8 person-rem, which is about 0.003% of the 351,759 person-rem that this population received from natural sources of radiation (based on an individual dose of about 300 mrem/year). As mentioned, CAP-88 PC Version 4 was used in 2015 to calculate both individual and collective doses. Due to improved time-in-flight calculations (implementation of full chain decay of isotopes in flight for each sector), collective doses associated with short-lived radionuclides are lower than would have been calculated using CAP-88 PC Version 3 (EPA 2015).

Table 7.3. Calculated radiation doses to maximally exposed off-site individuals from airborne releases, 2015

Plant	Effective dose, mrem (mSv)	
	At plant maximum	At Oak Ridge Reservation maximum
Oak Ridge National Laboratory	0.4 (0.004)[a]	0.4 (0.004)
East Tennessee Technology Park	0.0004 (0.000004)[b]	1E-5 (1E-7)
Y-12 National Security Complex	0.1 (0.0011)[c]	0.007 (0.00007)
Entire Oak Ridge Reservation	*d*	0.4 (0.004)[e]

[a]The maximally exposed individual was located 5,002 m E of X-3039 and 4,218 m ENE of X-7911.
[b]The maximally exposed individual was located 460 m WSW 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.

WSW

Table 7.4. Calculated collective effective doses from airborne releases, 2015

Plant	Collective effective dose[a]	
	Person-rem	Person-Sv
Oak Ridge National Laboratory	9.4	0.094
East Tennessee Technology Park	0.0007	7E-6
Y-12 National Security Complex	1.4	0.014
Entire Oak Ridge Reservation	10.8	0.108

[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 2,272 m (1.4 miles) northeast of the main Y-12 release point. This individual could have received an ED of about 0.1 mrem from Y-12 airborne emissions. Inhalation and ingestion of uranium radioisotopes (i.e., 233U, 234U, 235U, 236U, and 238U) accounted for about 94% and technicium-99 (99Tc) accounted for about 0.6% 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 1.4 person-rem, which is about 13% of the collective ED for ORR.

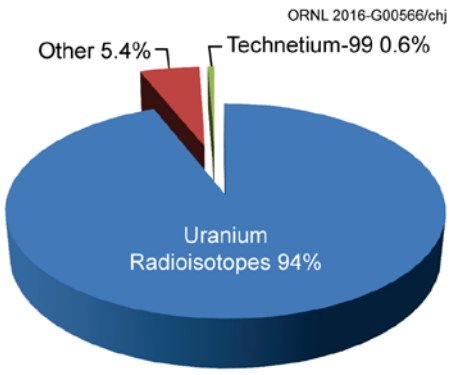

Fig. 7.1. Nuclides contributing to the effective dose at the Y-12 National Security Complex.

The maximally exposed individual for ORNL was located at a residence about 5,002 m (3.1 miles) east of the 3039 stack and 4,218 m (2.6 miles) east-northeast of the 7911 stack. This individual could have received an ED of about 0.4 mrem from ORNL airborne emissions. Radionuclides contributing 5% or more to the dose include ^{234}U (26%), ^{11}C (25%), ^{238}Pu (12%), ^{237}Np (6%), and ^{212}Pb (5%) (Fig. 7.2). The total contribution from uranium radioisotopes (i.e., ^{233}U, ^{234}U, ^{235}U, ^{236}U, and ^{238}U) accounted for about 29% of the dose, and ^{234}U contributed about 26% of the dose. 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 9.4 person-rem or about 87% of the collective ED for ORR.

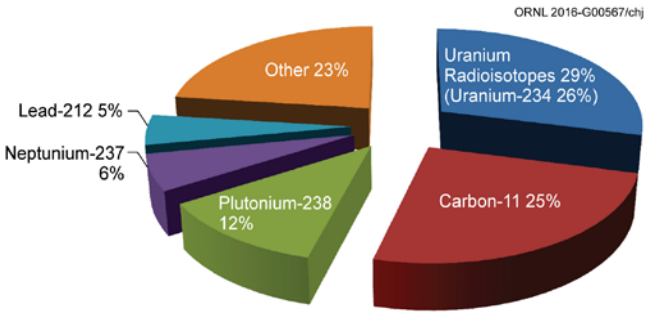

Fig. 7.2. Nuclides contributing to effective dose at Oak Ridge National Laboratory.

The maximally exposed individual for ETTP was located at a business about 455 m (0.3 miles) west southwest of the K-1407-AL Chromium Water Treatment System. The ED received by this individual from airborne emissions was calculated to be about 0.0004 mrem. About 88% of the dose is from uranium radioisotopes (^{234}U, ^{235}U, ^{236}U, and ^{238}U) and 8% 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 0.0007 person-rem, or about 0.006% of the collective ED for the reservation.

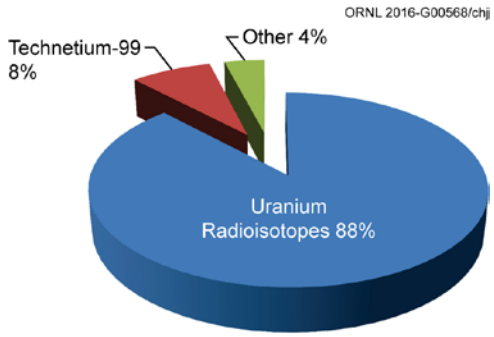

Fig. 7.3. Nuclides contributing to effective dose at East Tennessee Technology Park.

The reasonableness of the estimated doses can be inferred by comparing EDs calculated at the ORR perimeter area monitoring (PAM) stations from measured air concentrations of radionuclides, excluding naturally occurring ^{7}Be and ^{40}K, with air concentrations calculated using CAP-88 PC Version 3 and emissions data (Table 7.5). Based on measured air concentrations, hypothetical individuals assumed to reside at PAM stations 35–48 could have received EDs between 0.008 and 0.04 mrem/year. Based on emissions data using CAP-88 PC Version 4, the above individuals could have received EDs between 0.03 and 0.5 mrem/year. As shown in Table 7.5, EDs calculated using CAP-88 PC Version 4 and emissions data tend to be greater than or equivalent to EDs calculated using measured air concentrations.

Table 7.5. Hypothetical effective doses from living near the Oak Ridge Reservation, Oak Ridge National Laboratory, and the East Tennessee Technology Park ambient air monitoring stations, 2015

Station	Calculated effective doses			
	Using air monitor data		Using CAP-88[a] and emission data	
	mrem/year	mSv/year	mrem/year	mSv/year
1	0.01	0.0001	0.5	0.005
35	0.02	0.0002	0.07	0.0007
37	0.009	0.00009	0.2	0.002
38	0.008	0.00008	0.03	0.0003
39	0.04	0.0004	0.4	0.004
40	0.009	0.00009	0.3	0.003
42	0.01	0.0001	0.04	0.0004
46	0.01	0.0001	0.3	0.003
48	0.009	0.00009	0.5	0.005
52	0.03	0.0003	0.01	0.0001
K2	0.03	0.0003	0.06	0.0006
K6	0.03	0.0003	0.03	0.0003
K11	0.03	0.0003	0.04	0.0004
K12	0.02	0.0002	0.04	0.0004

[a]CAP-88 PC Version 4 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 0.03 mrem/year (the isotopes 7Be and 40K also were not included in the background air monitoring station calculation), whereas the estimated ED based on calculated air concentrations using CAP-88 PC Version 4 was estimated to be 0.01 mrem/year, the only case where the dose calculated with measured concentration was greater than the dose calculated using emission data. The measured air concentrations of 7Be 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 source emissions data. K11 station is located near the on-site maximally exposed individual for ETTP. The ED calculated with measured air concentrations was 0.03 mrem/year, which is comparable to the ED of 0.04 mrem/year estimated using source emissions data. PAM station 46 is located near the off-site maximally exposed individual for the Y-12 Complex. The ED calculated with measured air concentrations was 0.01 mrem/year, which is considerably less than the ED of 0.3 mrem/year estimated using source emissions data. This year PAM Station 1 was located near the ORR/ORNL off-site maximally exposed individual location; the ED calculated with measured air concentrations was 0.01 mrem/year, which was considerably less than the 0.5 mrem/year calculated using source 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 East Fork Poplar Creek (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 White Oak Creek (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 (1) that most radionuclides discharged from ORR will be quantified and (2) 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, utilizing the two methods to estimate potential doses takes into account both field measurements and discharge measurements.

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 2015, 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 40K.

- **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 near the City of Oak Ridge Water Intake Plant], a maximally exposed individual drinking water at this location could have received an ED of about 0.001 mrem. The collective ED to the 46,676 persons who drink water from the City of Oak Ridge water plant would also be 0.03 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 0.001 mrem; the collective dose to the 62,812 persons who drink water from this plant could have been 0.04 person-rem.

- **Upper Clinch River.** The ETTP (Gallaher) water plant that drew water from the Clinch River near CRK 23 was deactivated; therefore doses from drinking water are no longer calculated. ETTP and the Rarity Ridge community receive drinking water from the City of Oak Ridge water plant, which is located near CRK 66.

- **Lower Clinch River.** There are no known drinking water intakes in this river segment (from the confluence of Poplar Creek with the lower Clinch River to the confluence of the lower Clinch River with 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 0.02 mrem. The collective dose to the 25,871 persons who drink water from these plants could have been about 0.2 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 0.01 mrem calculated for drinking water from the Kingston or Rockwood municipal water plants. The collective dose to the 311,622 persons who drink water within the lower system could have been about 1.5 person-rem.

- **Poplar Creek/Lower EFPC.** 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 fiscal year (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 maximum contaminant levels (MCLs) for alpha activity (15 pCi/L) were exceeded in two off-site wells (both of which produce highly saline groundwater samples; samples containing high levels of dissolved solids 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 the Tennessee Department of Environment and Conservation (TDEC) (DOE 2015).

Two off-site groundwater sampling events were completed in 2015 to implement key recommendations from the Oak Ridge Reservation groundwater strategy report that was approved in 2014 (DOE 2014a). Samples were collected at 34 wells and 15 springs located west and north of the Clinch River at the western boundary of the ORR. Ongoing evaluation of results includes comparison to screening levels for protection of human health and the environment and review of data for indicators of potential contaminant sources and pathways (e.g., potential ORR contaminants, potential migration beyond the Clinch River, potential naturally occurring substances.). The project is a cooperative DOE, EPA, and TDEC effort. A report on the study is planned for November 2016.

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 2015. For the average person used for collective dose calculations, it was assumed that 11 kg (24 lb) of fish was consumed in 2015. 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 the Tennessee Wildlife Resources Agency (TWRA 2015). 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 5×10^{-5} mrem. This dose was estimated from a composite fish sample collected near CRK 70, and major contributor to dose was ^{3}H. The collective ED to the 25 persons who could have eaten such fish was about 6×10^{-7} person-rem.

- **Melton Hill Lake.** An avid fish consumer who ate fish from Melton Hill Lake could have received an ED of about 5×10^{-5} mrem. The collective ED to the 222 persons who could have eaten such fish could be about 5×10^{-6} person-rem.

- **Upper Clinch River.** An avid fish consumer who ate fish from the upper Clinch River could have received an ED of about 0.03 mrem. The collective ED to the 127 persons who could have eaten such fish could have been about 0.001 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 0.03 mrem. The collective ED to the 297 persons who could have eaten such fish could have been about 0.003 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 0.006 mrem. The collective ED to the 849 persons who could have eaten such fish could be about 0.002 person-rem.

- **Lower System.** An avid fish consumer who ate fish from the lower system could have received an ED of about 0.005 mrem. The collective ED to the about 9,997 persons who could have eaten such fish could have been about 0.02 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 0.8 mrem. Assuming that 100 people could have eaten fish from lower EFPC and 100 from Poplar Creek, the collective ED could have been about 0.04 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 2015, 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 2×10^{-6} mrem. The collective ED to the 10,412 other users could have been 7×10^{-7} person-rem.

- **Melton Hill Lake.** An individual other user of Melton Hill Lake could have received an ED of about 2×10^{-6} mrem. The collective ED to the 24,294 other users could have been about 6×10^{-6} person-rem.

- **Upper Clinch River.** An individual other user of the upper Clinch River could have received an ED of about 0.002 mrem. The collective ED to the 3,232 other users could have been about 0.002 person-rem.

- **Lower Clinch River.** An individual other user of the lower Clinch River could have received an ED of about 0.002 mrem. The collective ED to the 7,559 other users could have been about 0.004 person-rem.

- **Upper Watts Bar Lake.** An individual other user of upper Watts Bar Lake could have received an ED of about 6×10^{-4} mrem. The collective ED to the 21,609 other users could have been about 0.004 person-rem.

- **Lower system.** An individual other user of the lower system could have received an ED of about 5×10^{-4} mrem. The collective ED to the 325,259 other users could have been about .03 person-rem.

- **Poplar Creek/Lower EFPC.** An individual other user of Lower EFPC, above its confluence with Poplar Creek, could have received an ED of about 0.005 mrem. The collective ED to the 200 other users of Poplar Creek and Lower EFPC could have been about 2×10^{-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 0.8 mrem to a person obtaining his or her full annual complement of fish from and participating in other water uses on Lower EFPC. The maximum collective ED to the 80 km (50 mile) population could be as high as 2 person-rem. These are small percentages of individual and collective doses attributable to natural background radiation, about 0.3% of the average individual background dose of roughly 300 mrem/year and 6×10^{-4} % of the 351,759 person-rem that this population received from natural sources of radiation.

Table 7.6. Summary of annual maximum individual (mrem) and collective (person-rem) effective doses (EDs) from waterborne radionuclides, 2015[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	1×10^{-3}	5×10^{-5}	2×10^{-6}	0.001
Collective ED	0.03	6×10^{-7}	7×10^{-7}	0.03
Melton Hill Lake (CRK 58, Knox County Water Plant)				
Individual ED	0.001	5×10^{-5}	2×10^{-6}	0.001
Collective ED	0.04	5×10^{-6}	6×10^{-6}	0.04
Upper Clinch River (CRK 23,32)				
Individual ED	NA[d]	0.03	0.002	0.03
Collective ED	NA[d]	0.001	0.002	0.003
Lower Clinch River (CRK 16)				
Individual ED	NA[d]	0.03	0.002	0.03
Collective ED	NA[d]	0.003	0.004	0.007
Upper Watts Bar Lake, Kingston Municipal Water Plant				
Individual ED	0.02	0.006	6×10^{-4}	0.02
Collective ED	0.2	0.002	0.004	0.2
Lower system (Lower Watts Bar Lake and Chickamauga Lake)				
Individual ED	0.01	0.005	5×10^{-4}	0.02
Collective ED	1.5	0.02	0.03	2

Table 7.6. Summary of annual maximum individual (mrem) and collective (person-rem) effective doses (EDs) from waterborne radionuclides, 2015[a,b](Continued)

	Drinking water	Eating fish	Other uses	Total[c]
Lower East Fork Poplar Creek and Poplar Creek				
Individual ED	NA[d]	0.8	0.005	0.8
Collective ED	NA[d]	0.04	0.0002	0.04

[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.

7.1.2.2.5 Irrigation

Although there are no known locations that use 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. Based on measured and calculated concentrations of radionuclides at CRK 16, which is a location on the lower Clinch River and downstream of the ORR, the maximum potential dose (excluding ^{7}Be and ^{40}K, naturally occurring radionuclides) to an individual due to irrigation ranged from 0 to 0.03 mrem in 2015. 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.

7.1.2.3 Radionuclides in Other Environmental Media

The CAP-88 PC 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 2015, milk samples were collected from a nearby dairy (in Claxton, Tennessee), 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, ^{3}H, and ^{90}Sr were detected in all samples from both the nearby dairy and the composite of several reference locations. Annual EDs attributable to ^{40}K at both "locations" were estimated to be about 11 mrem and 15 mrem, respectively. Excluding ^{40}K, a naturally occurring radionuclide, the doses associated with tritium and strontium were estimated to be 0.05 mrem for the Claxton dairy and 0.04 mrem for the composite of several reference locations.

7.1.2.3.2 Food Crops

The food-crop sampling program is described in Chapter 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 0.08 and 0.2 mrem, depending on garden location. Of this total, between 0 and 0.08 mrem could have come from eating tomatoes, between 0.007 and 0.08 mrem from eating lettuce, and between 0 and 0.1 mrem 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 could have received a committed ED of 0.3 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 2015, the gardeners were asked about water sources and fertilizers used, and it was 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 radionuclides, not radionuclides discharged from ORR.

7.1.2.3.3 White-Tailed Deer

TWRA conducted three 2-day deer hunts during 2015 on the Oak Ridge Wildlife Management Area, which is part of ORR (see Chapter 6). During the hunts, 244 deer were harvested and were brought to the TWRA checking station. At the station, a bone sample and a muscle tissue sample were taken from each deer. The samples were field-counted for radioactivity to ensure that the deer met wildlife release criteria (less than net counts not greater than 1 ½ times background (~20 pCi/g) of beta activity in bone or 5 pCi/g of 137Cs in edible tissue). One deer exceeded the limit for beta-particle activity in bone and was retained. The remaining 243 deer were released to the hunters.

The average 137Cs concentration in muscle tissue of the 243 released deer, as determined by field counting, was 0.47 pCi/g; the maximum 137Cs concentration in released deer was 0.89 pCi/g. Most of the 137Cs concentrations were less than minimum detectable levels. The average weight of released deer was approximately 41 kg (90 lb); the maximum weight was 78 kg (172 lb). The EDs attributed to field-measured 137Cs concentrations and actual field weights of the released deer ranged from about 0 to 1 mrem, with an average of about 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 41 kg (90 lb) deer (assuming 55% field weight is edible meat) containing the 2015 average field-measured concentration of 137Cs (0.47 pCi/g) could have received an ED of about 0.5 mrem. The maximum field-measured 137Cs concentration was 0.89 pCi/g, and the maximum deer weight was 78 kg (172 lb). A hunter who consumed a hypothetical deer of maximum weight and 137Cs content could have received an ED of about 1 mrem.

Muscle tissue samples collected in 2015 from 13 deer (12 released and 1 retained) were subjected to laboratory analyses. 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 either equal to or greater than the analytical results and that all were less than the administrative limit of 5 pCi/g. Using analytically measured ^{137}Cs and ^{90}Sr (excluding ^{40}K, a naturally occurring radionuclide) and actual deer weights, the estimated doses for the 12 released deer ranged from 0 to 0.7 mrem**.** The estimated dose for a human consuming the retained deer would have been 0.8 mrem.

The maximum ED to an individual consuming venison from two or three deer was also evaluated. Twenty-four hunters each harvested two deer 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 0.5 and 1.4 mrem**.**

The collective ED from eating all the harvested venison from ORR with a 2015 average field-derived ^{137}Cs concentration of 0.47 pCi/g and an average weight of 41 kg (90 lb) is estimated to be about 0.1 person-rem.

7.1.2.3.4 Canada Geese

During the 2015 goose roundup, 27 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 0.18 pCi/g, with a maximum ^{137}Cs concentration in the released geese of 0.29 pCi/g. All of the ^{137}Cs concentrations were below minimum detectable activity levels. The average weight of the geese screened during the roundup was about 4 kg (8.8 lb), and the maximum weight was about 5.1 kg (11.2 lb).

The EDs attributed to field-measured ^{137}Cs concentrations and actual field weights of the geese ranged from 0.007 to 0.02 mrem. However, for bounding purposes, if a person consumed a released goose with an average weight of 4 kg (8.8 lb) and an average ^{137}Cs concentration of 0.18 pCi/g, the estimated ED would be approximately 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 0.29 pCi/g and maximum weight of 5.1 kg (11.2 lb) is about 0.04 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 0.08 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 transuranic elements (^{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 2015: April 11–12 and April 18–19. In addition, a hunter requested screening of a turkey legally harvested by an archery deer hunter during the 2015 fall deer hunt

season on December. Forty-six birds were harvested (including the turkey harvested in December), and none were retained. The average 137Cs concentration measured in the released turkeys was 0.1 pCi/g, and the maximum 137Cs concentration was 0.16 pCi/g. All of the 137Cs concentrations were below minimum detectable activity levels. The average weight of the turkeys released was about 8.9 kg (19.5 lb). The maximum turkey weight was about 11.3 kg (25 lb).

The EDs attributed to the field-measured 137Cs concentrations and the actual field weights of the released turkeys ranged from about 0.02 to 0.03 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 8.9 kg (19.5 lb) and an average 137Cs concentration of 0.1 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 137Cs concentration of 0.16 pCi/g and the maximum weight of 11.3 kg (25 lb) was about 0.05 mrem. It is assumed that approximately half the weight of a wild turkey is edible. No tissue samples were analyzed in 2015.

The collective ED from consuming all the harvested wild turkey meat (46 birds) with an average field-derived 137Cs concentration of 0.1 pCi/g and average weight of 8.9 kg (19.5 lb) is estimated to be about 0.001 person-rem.

Earlier evaluations of doses based on laboratory-determined concentrations of radionuclides included 40K, 137Cs, 90Sr, 230Th, 3H, 234U, 235U, 238U, and transuranic elements (241Am, 244Cm, 237Np, 239Pu). The total dose, less the contribution of 40K, 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. In 2014, high-pressure ion chamber detectors, which had been used since the early 1990s to measure external radiation exposure rates, were replaced with Geiger-Müller (GM)–based detectors. In 2015, exposure rates measured by the new GM-type detectors averaged about 10.5 μR/h and ranged from 9.6 to 11.7 μR/h. These exposure rates correspond to an annual average ED of about 65 mrem and a range of 59 to 72 mrem. At the remote PAM station, the exposure rate measured with the new GM instrument averaged about 9.5 μR/h (annual ED of 58 mrem). The annual dose based on measured exposure rates at or near the ORR boundaries were somewhat greater than the exposure rate measured at the remote location but were within the state external exposure rates range due to natural external background sources.

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 2015, that person could have received a total ED of about 3 mrem. Of that total, 0.4 mrem would have come from airborne emissions and approximately 1 mrem from waterborne emissions (0.02 mrem from drinking water, 0.8 mrem from consuming fish and 0.005 mrem from other water uses along Lower East Fork Popular Creek, and 0.03 mrem from irrigation at CRK16), no appreciable dose above background

from external radiation, and about 1 mrem from consumption of wildlife. There are no known significant doses from discharges of radioactive constituents from ORR other than those reported.

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	0.4	0.004	0.4	10.8	0.108	1,172,530[b]	
Liquid effluents							
Drinking water	0.02	0.0002	0.02	1.8	0.018	446,981[c]	
Eating fish	0.8	0.008	0.8	0.06	0.0006	11,717[d]	
Other activities	0.005	0.00005	0.005	0.04	0.0004	468,234[d]	
Irrigation	0.03	0.003	0.03				
Other Pathways							
Eating deer	1[e]	0.01	1	0.1	0.001	244	
Eating geese	0.08[f]	0.0008	0.08	*g*	*g*		
Eating turkey	0.05[h]	0.0005	0.05	0.001	0.00001	46	
Direct radiation	NA[i]	NA					
All pathways	**3**	**0.003**	**3**	**13**	**0.13**	**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. Current exposure rates at PAM stations are at or near background levels.

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 2015

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 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 12.8 person-rem. This dose is about 0.004% of the 363,484 person-rem that this population received from natural sources during 2015.

7.1.4 Five-Year Trends

EDs associated with selected exposure pathways for the years 2011 to 2015 are given in Table 7.8. In 2015, the air pathway dose decreased slightly due in part to using CAP-88 PC Version 4, which updated the time-in-flight calculation that can influence doses from short-lived radionuclides. The dose from fish consumption is comparable to the dose estimated in 2011. The increase in the 2014 fish consumption was due to a composite fish sample collected at CRK16, in which ^{90}Sr was a primary dose contributor. In 2013, an increase in the dose from fish consumption was observed; this increase in dose was primarily due to 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, but the doses in 2015 are comparable to earlier estimated doses. Doses from consumption of wildlife have been similar for the last 5 years with a slight decrease in dose from consumption of venison in 2015.

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

Pathway	2011	2012	2013	2014	2015
Air pathway (all routes)	0.3	0.3	0.4	0.6	0.4
Surface water pathway					
Fish consumption (Clinch River)	0.3	0.08	1.5	1.2	0.03
Drinking water (Kingston)	0.02	0.02	0.01	0.003	0.02
Clinch River	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]
Deer	2	2	2	2	1
Geese	0.1	0.1	0.1	0.1	0.08
Turkey	0.1	0.06	0.08	0.04	0.05

[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 2015, the DOE-related source doses were considerably below the 25 mrem criterion. 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. Ten facilities responded to the DOE request. Two facilities used the COMPLY, a computerized screening tool for evaluating radiation exposure from atmospheric releases of radionuclides (EPA 2016). One facility reported annual doses from airborne emissions of 0.27 mrem; the other facility reported < 10 mrem (COMPLY, level 1). Another facility, using CAP-88 PC Version 4 for evaluating radiation exposure from atmospheric releases of radionuclides, reported an annual dose from

airborne emissions of 0.2 mrem. Most of the non-DOE facilities reported no water emissions and only one facility reported that sewer discharges were less than the sum of ratios. Doses from direct radiation ranged from none to an annual dose of 28 mrem, based on area monitors located within one of the facilities and fence-line TLDs used by another facility. The estimated an annual dose to members of the public associated with the fence-line TLDs was 28 mrem. 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 annual public dose limit 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 (1.8), 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 and sediment concentrations [Melton Branch, WOC, and White Oak Dam (WOD)] at the following seven different instream sampling locations.

- Melton Branch [Melton Branch (X13)]
- WOC [WOC headwaters, WOC (X14), and WOD (X15)]
- First Creek
- Fifth Creek
- Northwest Tributary

All locations, except Melton Branch (X13), WOC (X14) and WOD (X15), passed the general screening phase (comparison of maximum radionuclide water concentrations to default BCGs). Melton Branch (X13), WOC (X14), and WOD (X15) passed when average radionuclide water concentrations were compared to default BCGs. This resulted in absorbed dose rates to aquatic organisms below the DOE aquatic dose limit of 1 rad/day at all seven sampling locations.

At Y-12, doses to aquatic organisms were estimated from surface water concentrations and sediment concentrations (at Station 9422-1 and S24) at the following five different instream sampling locations.

- Surface Water Hydrological Information Support System Station 9422-1 (also known as station 17)
- Bear Creek at kilometer 9.2 (BCK 9.2)

- Discharge Point S24, Bear Creek at BCK 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 12 different instream sampling locations.

- Mitchell Branch at K1700; Mitchell Branch kilometers 0.45, 0.59, 0.71, 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 that were below the DOE aquatic dose limit of 1 rad/day at all 12 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 was 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 effects 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. 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. The water intake for ETTP used to be located near CRK 23 which was deactivated in 2014 and 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 MCLs.

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 vinyl chloride in water collected at both locations.

Table 7.9. Chemical hazard quotients and estimated risks for drinking water, 2015

Chemical	Hazard quotient	
	CRK 23[a]	CRK 16[b]
Metals		
Antimony	0.01	0.01
Arsenic	0.06	0.07
Cadmium	0.009	0.01
Chromium	0.005	0.005
Copper	0.002	0.002
Lead	0.02	

Table 7.9 (continued)

Chemical	Hazard quotient	
	CRK 23[a]	CRK 16[b]
Mercury	0.0002	0.0003
Nickel	0.003	0.003
Selenium	0.01	0.006
Silver	0.0002	0.0002
Thallium	0.02	0.02
Uranium	0.003	0.002
Zinc	0.0006	0.0007
Organics		
cis 1,2,Dichlorethene	0.01	0.01
1,1,1 Tricholoroethane	1×10^{-5}	1×10^{-5}
Trichloroethene	0.05	0.05
Vinyl Chloride	0.009	0.009
Risk for carcinogens		
Arsenic	1×10^{-5}	1×10^{-5}
Trichloroethene	6×10^{-7}	6×10^{-7}
Vinyl Chloride	2×10^{-5}	2×10^{-5}

[a]Clinch River near the water deactivated 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 were 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 MCLs (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). Volatile organic compounds 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 2015. 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.

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 polychlorinated biphenyls (PCBs), also referred to as PCB-1260. An HQ at or less than 1 was estimated for sunfish at all three locations (CRK 16, CRK 32, and CRK 70). An HQ greater than 1 for Aroclor-1260 was estimated in 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 and arsenic 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 estimated in 2015 for Aroclor-1260 for sunfish and catfish at CRK 70 and 32 were similar to risk values estimated in 2014. The Aroclor-1260 risk values for sunfish and catfish at CRK 16 estimated in 2015 were slightly elevated compared to the estimated risks in 2014.

Table 7.10. Chemical hazard quotients and estimated risks for carcinogens in fish, 2015[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						
Arsenic	0.7	0.9	0.6	0.4	0.5	0.8
Barium	0.001	0.002	0.003	0.0003	0.0002	0.0002
Chromium	0.02	0.04	0.04	0.02	0.03	0.02
Copper	0.009	0.009	0.01	0.009	0.01	0.009
Manganese	0.008	0.02	0.04	0.002	0.003	0.002
Mercury	0.1	0.1	0.3	0.3	0.2	0.3
Nickel	0.002		0.004	0.003	0.02	0.004
Selenium	0.2	0.2	0.2	0.1	0.1	0.2
Strontium	0.003	0.006	0.008	0.0003	0.0003	0.0002
Thallium	0.06	0.2	0.1	0.06	0.1	0.05
Uranium			0.0005			0.0004
Vanadium						
Zinc	0.04	0.05	0.05	0.03	0.03	0.03
Hazard quotients for pesticides and Aroclors						
Aroclor-1260	0.9	1	5	7	5	9.6
Risks for carcinogens						
Arsenic	1E-4	2E-4	1E-4	9E-5	1E-4	2E-4
Aroclor-1260	2E-5	2E-5	8E-5	1E-4	9E-5	2E-4
PCBs (mixed)[e]	2E-5	2E-5	8E-5	1E-4	9E-5	2E-4

[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

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