7. Dose

Activities on the 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 2017, a hypothetical maximally exposed individual (MEI)could have received an effective dose (ED) of about 0.3 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/year 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 fish, drinking 730 L/year (193 gal/year) of drinking water, and using the shoreline for 60 h/year as well as swimming and boating.

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 2 mrem. This calculation is conducted to provide an estimated upper-bound ED from consuming wildlife harvested from ORR.

Therefore, the annual dose to a MEI 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. U.S. 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 2017 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 2017. 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

calculated doses, and environmental transport and dosimetry codes that may also tend to overestimate the calculated doses. Therefore, 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 while 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 typically do not irradiate the body uniformly.

Several 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 2017 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 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.

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 24 emission points on ORR were modeled during 2017. The total includes 3 (two combined) points at Y-12 National Security Complex (Y-12), 19 points at Oak Ridge National Laboratory (ORNL), and 2 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.

Table 7.1. Emission point parameters and receptor location used in the dose calculations, 2017

Source	Stack height (m)	Stack diameter (m)	Effective exit gas velocity (m/s)[a]	Maximum distance (m) and direction to the maximally exposed individual			
				At each site		On ORR	
Oak Ridge National Laboratory							
X-Laboratory Hoods							
X-1000 Lab Hoods	15	0.5	0	4,350	SW	11,260	NE
X-2000 Lab Hoods	15	0.5	0	4,770	SW	10,840	NE
X-3000 Lab Hoods	15	0.5	0	5,100	SW	10,510	NE
X-4000 Lab Hoods	15	0.5	0	5,270	SW	10,360	NE
X-5000 Lab Hoods	15	0.5	0	5,560	SW	10,110	NE
X-6000 Lab Hoods	15	0.5	0	5,850	SW	9,800	NE
X-7000 Lab Hoods	15	0.5	0	5,290	WSW	10,750	NNE
X-2026	22.9	1.05	8.62	4,820	SW	10,790	NE
X-2099	3.66	0.18	16.88	4,810	SW	10,800	NE
X-3018	61	1.75	0.95	5,030	SW	10,570	NE
X-3020	61	1.22	14.74	4,970	SW	10,630	NE
X-3039	76.2	2.44	6.56	5,060	SW	10,560	NE
X-3544	9.53	0.279	25.66	4,810	SW	10,820	NE
X-3608 Filter Press	8.99	0.36	9.27	4,930	SW	10,720	NE
X-7503	30.5	0.91	13.13	5,330	SW	10,590	NNE
X-7830 Group	4.6	0.25	7.23	3,920	WSW	12,130	NNE
X-7856-CIP	18.29	0.48	9.27	3,970	WSW	12,110	NNE
X-7877	13.9	0.41	13.56	3,890	WSW	12,180	NNE
X-7880	27.7	1.52	15.53	3,860	WSW	12,200	NNE
X-7911	76.2	1.52	13.84	5,240	WSW	10,820	NNE
X-7935							
X-7935 Building Stack	15.24	0.51	26.85	5,250	SW	10,740	NNE
X-7935 Glove Box	9.14	0.25	4.66	5,250	SW	10,740	NNE
X-7966	6.10	0.29	6.33	5,330	SW	10,620	NNE
X-8915	104.0	1.22	6.86	8,060	SW	7,580	NE
X-Decom Areas	15	0.5	0	5,310	SW	10,310	NE
X-STP	7.6	0.203	7.39	4,590	SW	11,050	NE
East Tennessee Technology Park							
K-1407-AL CWTS	2.74	0.15	0	270	SSW	14,770	ENE
K-2500-H-C	8.23	0.61	12.9	870	ESE	15,400	ENE
Y-12 National Security Complex							
Y-Monitored	20	0.5	0	2,270	NE	2,270	NE
Y-Unmonitored Processes	20	0.5	0	2,270	NE	2,270	NE
Y-Unmonitored Lab Hoods	20	0.5	0	2,270	NE	2,270	NE

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

Acronyms
CIP = Capacity Increase Project
CWTS = Chromium Water Treatment System
Decom= Decommissioned
ORR = Oak Ridge Reservation
STP = Sewage Treatment Plant

Meteorological data used in the calculations for 2017 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 2017, rainfall, as averaged over the five rain gauges located on ORR, was about 150 cm (59 in.). The average air temperature was 15.2°C (59.2°F) at the 10 to 15 m levels, and the average mixing-layer height for ETTP and ORNL was 905.1 m (2,969 ft) and for Y-12 was 839.6 m (2,755 ft). The mixing height is the depth of the atmosphere adjacent to the surface within which air is mixed.

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, 2017

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-C
	Oak Ridge National Laboratory	
MT4 (Tow A)	15	X-7830, X-7877, X-7935 Glove Box, X-7935 Building, X 7966, and X-7000 Lab Hoods
	30	X-7503, X-7856-CIP, X-7880, and X-7911
MT3 (Tow B)	15	X-5000 and X-6000 Lab Hoods
MT2 (Tow D)	15	X-2099, X-3544, X-3608 FP, STP, X-Decom Hoods, X-1000, X-2000, X-3000, and X-4000 Lab Hoods
	35	X-2026
	60	X-3018, X-3020, and X-3039

Acronyms
CIP = Capacity Increase Project
CWTS = Chromium Water Treatment System
Decom= Decommissioned
FP = Filter Press
ORNL = Oak Ridge National Laboratory
STP = Sewage Treatment Plant

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 MEI for ORR was located about 2,270 m northeast of the main Y-12 release point, about 10,820 m north-northeast of the 7911 stack at ORNL, and about 14,770 m east-northeast of the K-1407-AL Chromium Water Treatment System (CWTS) at ETTP (see Figure 7.1). This individual could have received an ED of about 0.3 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 (40 CFR 61 Subpart H).

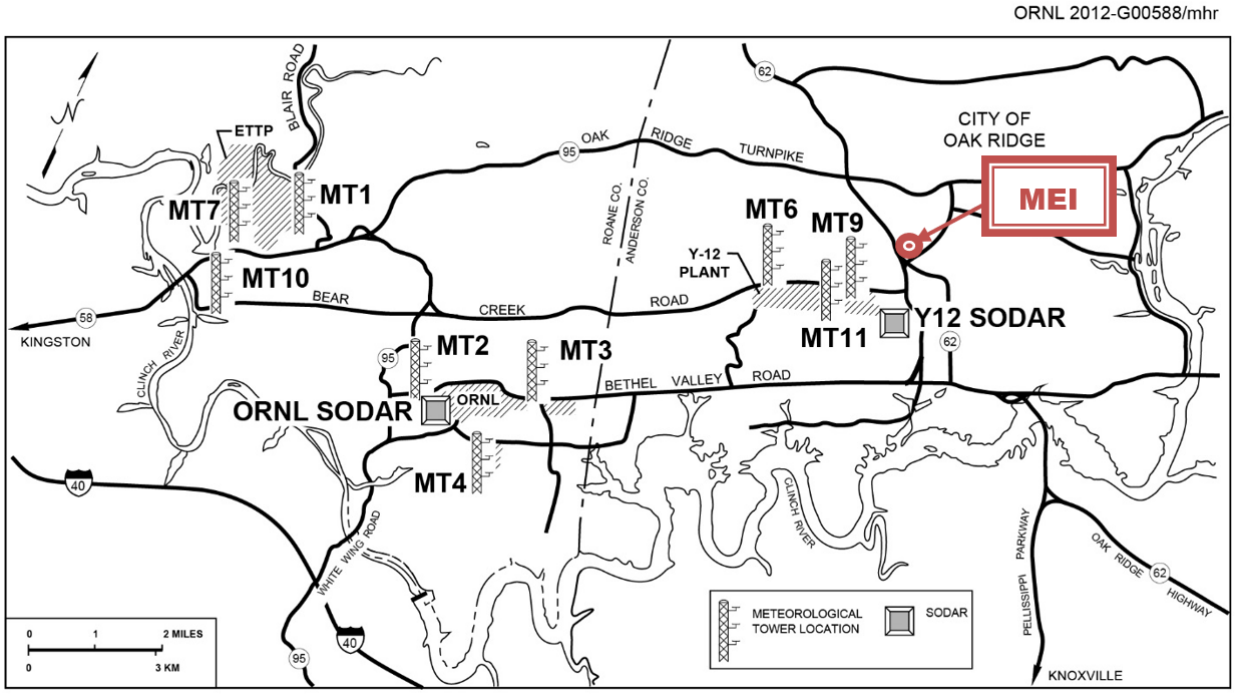

Figure 7.1. Location of the maximally exposed individual (MEI) for ORR

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 10.1 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). CAP-88 PC Version 4 was used in 2017 to calculate both individual and collective doses.

Table 7.3. Calculated radiation doses to maximally exposed off-site individuals from airborne releases from ORR, 2017

Plant	Maximum effective dose, mrem (mSv)			
	At each site		On ORR	
	mrem	mSv	mrem	mSv
Oak Ridge National Laboratory	0.2[a]	0.002	0.07	0.0007
East Tennessee Technology Park	0.0005[b]	5×10^{-6}	7×10^{-6}	7×10^{-8}
Y-12 National Security Complex	0.2[c]	0.002	0.2	0.002
Entire Oak Ridge Reservation	*d*		0.3[e]	0.003

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

Acronyms
MEI = maximally exposed individual
ORR = Oak Ridge Reservation

Table 7.4. Calculated collective effective doses from airborne releases, 2017

Plant	Collective effective dose[a]	
	Person-rem	Person-Sv
Oak Ridge National Laboratory	7.3	0.073
East Tennessee Technology Park	0.0004	4×10^{-6}
Y-12 National Security Complex	2.9	0.029
Entire Oak Ridge Reservation	10.1	0.101

[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 MEI for 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 0.2 mrem from Y-12 airborne 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 ^{99}Tc accounted for about 0.3% of the dose (Figure 7.2). 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 2.9 person-rem, which is about 28% of the collective ED for ORR.

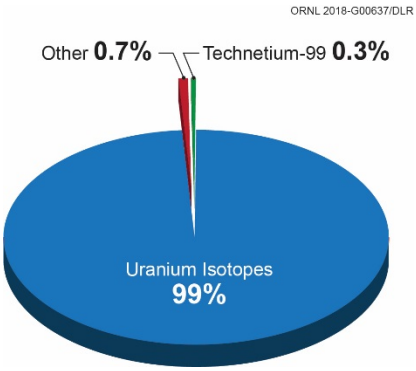

Figure 7.2. Nuclides contributing to the effective dose at Y-12 National Security Complex, 2017

The MEI for ORNL was located at a residence about 5,060 m (3.4 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 0.2 mrem from ORNL airborne emissions. Radionuclides that contributed 10% or more to the dose were ^{212}Pb and ^{11}C, contributing about 30% and 17%, respectively (Figure 7.3). The total contribution from uranium radioisotopes (i.e., ^{232}U, ^{233}U, ^{234}U, ^{235}U, ^{236}U, and ^{238}U) accounted for about 4% of the dose, and ^{238}U contributed about 3% 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 7.3 person-rem or about 72% of the collective ED for ORR.

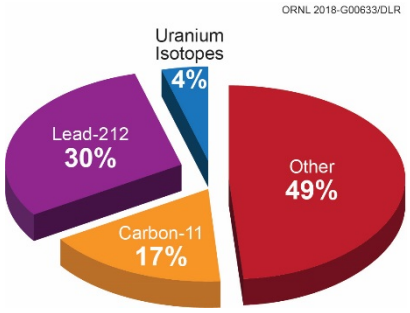

Figure 7.3. Nuclides contributing to effective dose at Oak Ridge National Laboratory, 2017

The MEI for ETTP was located at a business about 270 m (0.2 miles) south- southwest of the K-1407-AL CWTS. The ED received by this individual from airborne emissions was calculated to be about 0.0005 mrem. About 91% of the dose is from uranium radioisotopes (^{234}U, ^{235}U, ^{236}U, and ^{238}U), and 6% of the dose is from ^{99}Tc (Figure 7.4). 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 0.0004 person-rem, or about 0.004% of the collective ED for the reservation.

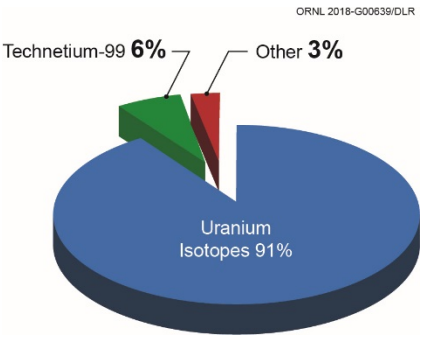

Figure 7.4. Nuclides contributing to effective dose at East Tennessee Technology Park, 2017

To evaluate the validity of the estimated doses calculated using CAP-88 PC Version 4 and emissions data (Table 7.5), the doses are compared to the EDs calculated using measured air concentrations of radionuclides (excluding naturally occurring ^{7}Be and ^{40}K) at ORR perimeter area monitoring (PAM) stations and at ORNL ambient air monitors 1 and 11 (AAM1 and AAM11). Based on measured air concentrations, hypothetical individuals assumed to reside at AAM1, AAM11, and PAM stations 35–49 could have received EDs between 0.007 and 0.08 mrem/year. Based on emissions data using CAP-88 PC Version 4, the above individuals could have received EDs between 0.05 and 0.4 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 ORR, ORNL, and ETTP ambient air monitoring stations, 2017

Station	Calculated effective doses			
	Using air monitor data		Using CAP-88[a] and emission data	
	mrem/year	mSv/year	mrem/year	mSv/year
		ORR and ORNL		
1	0.02	0.0002	0.2	0.002
11	0.03	0.0003	0.2	0.002
35	0.009	0.00009	0.05	0.0005
37	0.08	0.0008	0.1	0.001
39	0.007	0.00007	0.2	0.002
40	0.02	0.0002	0.4	0.004
46	0.01	0.0001	0.1	0.001
49	0.01	0.0001	0.1	0.001
52	0.02	0.0002	0.02	0.0002
		ETTP		
K2	0.0006	0.000006	0.06	0.0006
K6	0.002	0.00002	0.05	0.0005
K11	0.001	0.00001	0.03	0.0003
K12	0.003	0.00003	0.03	0.0003

[a] CAP-88 PC Version 4 software, developed under US Environmental Protection Agency sponsorship to demonstrate compliance with 40 CFR 61, Subpart H.

Acronyms
ETTP = East Tennessee Technology Park
ORNL = Oak Ridge National Laboratory
ORR = Oak Ridge Reservation

Station 52, located remotely from ORR, gives an indication of potential EDs from background sources. Based on measured air concentrations, the ED was estimated to be 0.02 mrem/year (the isotopes ^{7}Be and ^{40}K were not included in the background air monitoring station calculation); the estimated ED based on calculated air concentrations using CAP-88 PC Version 4 was also estimated to be 0.02 mrem/year. The measured air concentrations of ^{7}Be were similar at the PAM stations and at the background air monitoring station.

Of interest is a comparison of EDs calculated using measured air concentrations of radionuclides at PAM stations located near the MEIs for each plant and EDs calculated for those individuals using source emissions data. Station K11 is located near the on-site MEI for ETTP. The ED calculated with measured air concentrations was 0.001 mrem/year, which is lower than the ED of 0.03 mrem/year estimated using source emissions data. Ambient air station 11 is located near the off-site MEI for ORNL. The ED calculated with measured air concentrations was 0.03 mrem/year, which is lower than the ED of 0.2 mrem/year estimated using source emissions data. PAM station 40 is located near the off-site MEI for Y-12 Complex and ORR and the ED calculated with measured air concentrations was 0.02 mrem/year, which is also less than the ED of 0.4 mrem/year estimated 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. Discharges from Y-12 enter the Clinch River via Bear Creek and East Fork Poplar Creek (EFPC), each of which enters Poplar Creek before it enters the Clinch River, and 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:

- Melton Hill Lake above all possible ORR inputs
- Melton Hill Lake
- Upper Clinch River (from Melton Hill Dam to confluence with Poplar Creek)
- Lower Clinch River (from confluence with Poplar Creek to confluence with the Tennessee River)
- Upper Watts Bar Lake (from near the confluence of the Clinch and Tennessee Rivers to below Kingston)
- the lower system (the remainder of Watts Bar Lake and Chickamauga Lake to Chattanooga)
- 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 and 6.6). 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 and/or detected. 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 can 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, utilizing the two methods to estimate potential doses takes into account both field measurements and discharge measurements.

Drinking Water Consumption

Surface Water

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; however, the dose estimates given in this section 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 MEI is 730 L/year (193 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 2017, 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 and ^{7}Be.

- **Upper Melton Hill Lake above all possible ORR inputs.** Based on samples from Melton Hill Lake above possible ORR inputs (at CRK 66 near the City of Oak Ridge Water Intake Plant), a MEI drinking water at this location could have received an ED of about 0.02 mrem. The collective ED to the 47,933 persons who drink water from the City of Oak Ridge water plant would be 0.4 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 MEI could have received an ED of about 0.02 mrem; the collective dose to the 63,779 persons who drink water from this plant could have been 0.5 person-rem.
- **Upper Clinch River.** ETTP (Gallaher) water plant, which drew water from the Clinch River near CRK 23, was deactivated in 2014; 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 far from its confluence with the Clinch River. A MEI could have received an ED of about 0.01 mrem. The collective dose to the 30,895 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 those plants could not have received EDs greater than the 0.009 mrem. The collective dose to the 301,075 persons who drink water within the lower system could have been about 1.0 person-rem.
- **Poplar Creek/Lower EFPC.** No drinking water intakes are located on Poplar Creek or on lower EFPC.

Groundwater

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, and results were compared to EPA MCLs. The analyses show that beta trends have remained stable over the past 5 years. For detailed information on results see 2017 Remediation Effectiveness Report for the U.S. Department of Energy (DOE 2017). Currently, no water is consumed from these off-site groundwater wells.

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 2017. For the average person used for collective dose calculations, it was assumed that 11 kg (24 lb) of fish was consumed in 2017. 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 number of individuals who could have eaten fish is based on lake creel surveys conducted annually by the Tennessee Wildlife Resources Agency (TWRA 2017).

- **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 0.006 mrem. The collective ED to the nine persons who could have eaten such fish was about 2×10^{-5} person-rem.
- **Melton Hill Lake.** An avid fish consumer who ate fish from Melton Hill Lake could have received an ED of about 0.006 mrem. The collective ED to the 79 persons who could have eaten such fish could be about 2×10^{-4} person-rem.
- **Upper Clinch River.** An avid fish consumer who ate fish from the upper Clinch River could have received an ED of about 0.04 mrem. The collective ED to the 100 persons who could have eaten such fish could have been about 0.002 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 0.05 mrem. The collective ED to the 233 persons who could have eaten such fish could have been about 0.006 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 0.004 mrem. The collective ED to the 666 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 about 9,825 persons who could have eaten such fish could have been about 0.01 person-rem.
- **Poplar Creek/Lower East Fork Poplar Creek.** An avid fish consumer who ate fish from Poplar Creek could have received an ED of about 1.0 mrem. Assuming 100 people could have eaten fish from lower EFPC and from Poplar Creek, the collective ED could have been about 0.05 person-rem.

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. The potential EDs from these activities were estimated from measured and calculated concentrations of radionuclides in water; the equations that were used were derived from the LADTAP XL code (Hamby 1991) and were modified to account for radioactive data and shoreline use. The number of individuals who could have been other users are different for each section of water. Recreational activities for Melton Hill Reservoir are based on surveys conducted by the University of Tennessee (Stephens et al. 2006) and a recent survey was conducted regarding visitor and property owner activities for Chickamauga and Watts Bar Reservoir (Poudyal et al. 2017). The survey data from these reports were used to identify the variety of recreational activities on these water bodies. It was found that respondents often participated in more than one recreational activity. This information has replaced earlier assumptions regarding number of people involved in water recreational activities.

- **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 1×10^{-6} mrem. The collective ED to the 14,483 other users could have been 5×10^{-7} person- rem.
- **Melton Hill Lake.** An individual other user of Melton Hill Lake could have received an ED of about 6×10^{-4} mrem. The collective ED to the 40,044 other users could have been about 0.003 person-rem.
- **Upper Clinch River.** An individual other user of the upper Clinch River could have received an ED of about 7×10^{-6} mrem. The collective ED to the 14,568 other users could have been about 6×10^{-6} person-rem.
- **Lower Clinch River.** An individual other user of the lower Clinch River could have received an ED of about 0.0004 mrem. The collective ED to the 33,992 other users could have been about 0.001 person-rem.
- **Upper Watts Bar Lake.** An individual other user of upper Watts Bar Lake could have received an ED of about 0.0001 mrem. The collective ED to the 97,119 other users could have been about 0.0009 person-rem.
- **Lower system (Watt Bar and Chickamauga Lakes).** An individual other user of the lower system could have received an ED of about 0.0001 mrem. The collective ED to the 3,401,402 other users could have been about 0.02 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 5×10^{-4} mrem. The collective ED to the 200 other users of Poplar Creek and Lower EFPC could have been about 2×10^{-5} person-rem.

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 a member 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 ORR, the maximum potential dose (excluding the naturally occurring radionuclides ^{7}Be and ^{40}K) to an individual due to irrigation ranged from 2×10^{-7} to 0.03 mrem in 2017. 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.

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 1 mrem to a person obtaining his or her full annual complement of fish from and participating in other water uses throughout these water systems. Excluding Lower EFPC and Poplar Creek from the other water systems evaluated (Melton Hill, Clinch River, Watts Bar Lake, and Chickamauga Lake), the estimated maximum individual ED would be about 0.05 mrem. The maximum collective ED to the 80 km (50 mile) population was estimated to be 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 0.0006% 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 from waterborne radionuclides, 2017[a,b]

Effective dose	Source			Total[c]
	Drinking water	Eating fish	Other uses	
Upstream of all Oak Ridge Reservation discharge locations (CRK 66, City of Oak Ridge Water Plant)				
Individual	0.02	0.006	1×10^{-6}	0.02
Collective	0.4	2×10^{-5}	5×10^{-7}	0.4
Melton Hill Lake (CRK 58, Knox County Water Plant)				
Individual	0.02	0.006	0.0006	0.02
Collective	0.5	0.0002	0.003	0.5
Upper Clinch River (CRK 23, 32)				
Individual	NA[d]	0.04	7×10^{-6}	0.04
Collective	NA[d]	0.002	6×10^{-6}	0.002
Lower Clinch River (CRK 16)				
Individual	NA[d]	0.05	0.0004	0.05
Collective	NA[d]	0.006	0.001	0.007
Upper Watts Bar Lake, Kingston Municipal Water Plant				
Individual	0.01	0.004	0.0001	0.01
Collective	0.1	0.001	0.0009	0.2
Lower system (Lower Watts Bar Lake and Chickamauga Lake)				
Individual	0.009	0.003	0.0001	0.01
Collective	1	0.01	0.02	1
Lower East Fork Poplar Creek and Poplar Creek				
Individual	NA[d]	1.0	0.0005	1.0
Collective	NA[d]	0.05	2×10^{-5}	0.05

[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 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. Some environmental media, including milk and vegetables, have been sampled in previous years as part of ORR surveillance program. However, milk and vegetable samples were not available to be collected in 2017.

7.1.2.4 Food

Milk

During 2017, no milk samples were collected from a nearby dairy (in Claxton, Tennessee) because the dairy farm went out of business. Milk samples had been collected from that dairy for several years. Surveys to locate other dairies in areas that could receive deposition from ORR activities are conducted annually; however, the survey did not identify any dairies to replace the one that went out of business in 2016. The milk-sampling program will resume when a replacement for that dairy is identified.

Vegetables

Farms selling tomatoes, lettuce, and turnips near ORR and from reference locations outside the potential DOE impact area were not identified in 2017. No vegetable samples were collected for analysis. The vegetable-sampling program will resume when producers are identified.

Hay

Another environmental pathway that was evaluated was eating beef and drinking milk obtained from hypothetical cattle that ate hay harvested from one location on ORR. Hay samples collected on ORR during June 2017 were analyzed for gross alpha, gross beta, gamma emitters, and uranium isotopes. Radionuclides detected in hay are shown in Table 7.7. Statistically significant concentrations of ^{7}Be, ^{40}K, ^{214}Pb, ^{234}U, and ^{238}U were detected at that sampling location. Excluding the doses from ^{7}Be and ^{40}K (both naturally occurring), the average ED from drinking milk and eating beef was estimated to be 0.004 mrem.

Table 7.7. Concentrations of radionuclides detected in hay, 2017 (pCi/kg)[a]

Gross alpha	Gross beta	^{7}Be	^{40}K	^{234}U	^{235}U	^{238}U	^{214}Pb
b	10.1	7.91	0.0125	0.00327	*b*	0.00282	0.525

[a]Detected radionuclides are those detected above the minimum detectable activity. 1 pCi = 3.7×10^{-2} Bq.
[b]Value was not detected above the minimum detectable activity.

White-Tailed Deer

TWRA conducted three 2-day deer hunts during 2017 on the Oak Ridge Wildlife Management Area, which is part of ORR (see Chapter 6). During the hunts, 137 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 the wildlife release criteria of less than net counts not greater than 1½ times background (~20 pCi/g $^{89/90}$Sr) of beta activity in bone or the administrative limit of 5 pCi/g of ^{137}Cs in edible tissue (ORNL 2011). No deer exceeded the wildlife release criteria.

The average ^{137}Cs concentration in muscle tissue of the 137 released deer, as determined by field counting, was 0.5 pCi/g; the maximum ^{137}Cs concentration in released deer was 0.8 pCi/g. Most of the ^{137}Cs concentrations were less than minimum detectable levels. The average weight of released deer was

approximately 35 kg (77 lb); the maximum weight was 76 kg (167 lb). The EDs attributed to field-measured ^{137}Cs concentrations and actual field weights of the released deer ranged from about 0.02 to 1.1 mrem, with an average of about 0.4 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 deer (35 kg [77 lb], assuming that 55% of the field weight is edible meat) containing the 2017 average field-measured concentration of ^{137}Cs (0.5 pCi/g) could have received an ED of about 0.4 mrem. The maximum field-measured ^{137}Cs concentration was 0.8 pCi/g, and the maximum deer weight was 76 kg (167 lb). A hunter who consumed a hypothetical deer of maximum weight and ^{137}Cs content could have received an ED of about 2 mrem.

Muscle tissue samples collected in 2017 from six released deer 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 (ORNL 2011). Using analytically measured ^{137}Cs and ^{90}Sr (excluding ^{40}K, a naturally occurring radionuclide) and actual deer weights, the estimated doses for the six released deer ranged from 0 to 0.2 mrem.

The maximum ED to an individual consuming venison from two or three deer was also evaluated. Seventeen hunters harvested either two or three 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 0.4 and 1.2 mrem.

The collective ED from eating all the harvested venison from ORR with a 2017 average field-derived ^{137}Cs concentration of 0.5 pCi/g and an average weight of 35 kg (77 lb) is estimated to be about 0.06 person-rem. The collective dose is based on number of hunters that harvested deer. It is possible that additional individuals may also consume the harvested venison; however, the collective dose would remain the same.

Canada Geese

Sixteen geese were captured during the 2017 goose roundup and were subjected to live 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 (ORNL 2005). The average ^{137}Cs concentration was 0.2 pCi/g, with a maximum ^{137}Cs concentration in the released geese of 0.3 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 3.8 kg (8.3 lb), and the maximum weight was about 4.9 kg (10.7 lb).

The EDs attributed to field-measured ^{137}Cs concentrations of the geese ranged from 0.018 to 0.02 mrem. However, for bounding purposes, if a person consumed a released goose with an average weight of 3.8 kg (8.3 lb) and an average ^{137}Cs concentration of 0.2 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 estimated ED to an individual who consumed a hypothetical goose with the maximum ^{137}Cs concentration of 0.3 pCi/g and maximum weight of 4.9 kg (10.7 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). Hypothetically, if one person consumed two

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 samples of goose tissue 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).

Eastern Wild Turkey

Participating hunters are permitted to harvest one turkey from the reservation in a given season unless a harvested turkey is retained, in which case, the hunter is permitted to hunt for another turkey. Two wild turkey hunts took place on the reservation in 2017: April 8–9 and April 22–23. Thirty-one turkeys were harvested during that time frame; no harvested turkeys were retained. The average ^{137}Cs concentration measured in the released turkeys was 0.1 pCi/g, and the maximum ^{137}Cs concentration was 0.3 pCi/g. All of the ^{137}Cs concentrations were below minimum detectable activity levels. The average weight of the released turkeys was about 8.4 kg (18.5 lb). The maximum turkey weight was about 10.8 kg (23.7 lb).

The EDs attributed to the field-measured ^{137}Cs concentrations of the released turkeys ranged from about 0.02 to 0.04 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 that scenario, if a person consumed a wild turkey with an average weight of 8.4 kg (18.5 lb) and an average ^{137}Cs 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 ^{137}Cs concentration of 0.3 pCi/g and the maximum weight of 10.8 kg (23.7 lb) was about 0.08 mrem. It is assumed that approximately half the weight of a wild turkey is edible. No tissue samples were analyzed in 2017.

The collective ED from consuming all the harvested wild turkey meat (31 birds) with an average field-derived ^{137}Cs concentration of 0.1 pCi/g and an average weight of 8.4 kg (18.5 lb) is estimated to be about 0.0007 person-rem. The collective dose is based on number of hunters who harvested turkeys. It is possible that additional individuals may also consume the harvested turkey meat; however, the collective dose would remain the same.

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 transuranic elements (^{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).

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). Due to radiological activities on ORR, external radiation exposure rates are measured at perimeter and on-site ambient air monitoring stations. External gamma exposure rates were continuously recorded by dual-range Geiger-Müller tube detectors co-located with ORR ambient air stations. In 2017, exposure rates averaged about 10.2 µR/h and ranged from 8.7 to 14.4 µR/h. These exposure rates correspond to an annual average dose of about 63 mrem with a range of 54 to 89 mrem. At the remote PAM station, the exposure rate averaged about 9.6 µR/h and ranged from 8.7 to 11.4 µR/h. The resulting average annual dose was about 59 mrem with a range of 54 to 71 mrem. The annual dose based on measured exposure rates at or near ORR boundaries were typically within the range of the doses measured at the remote location; slightly higher exposure rates were observed at PAM station 39.

7.1.3 Current-Year Summary

A summary of the maximum EDs to individuals by pathway of exposure is given in Table 7.8. In the unlikely event that any person was exposed to all those sources and pathways for the duration of 2017, that person could have received a total ED of about 3 mrem. Of that total, 0.3 mrem would have come from airborne emissions, approximately 1 mrem from waterborne emissions (0.02 mrem from drinking water, 1 mrem from consuming fish, 0.0005 mrem from other water uses along the Clinch River, and 0.03 mrem from irrigation at CRK 16), and about 2 mrem from consumption of wildlife. Current direct radiation measurements at PAM stations are at or near background levels. There are no known significant doses from discharges of radioactive constituents from ORR other than those reported.

Table 7.8. Summary of maximum estimated effective doses from ORR activities to an adult by exposure pathway, 2017

Pathway	Dose to maximally exposed individual		Percentage of DOE mrem/year limit (%)	Estimated collective radiation dose[a]		
				Pathway		Background (person-rem)
	mrem	mSv		person-rem	person-Sv	
Airborne effluents						
All pathways	0.3	0.003	0.3	10.1	0.101	1,172,530[b]
Liquid effluents						
Drinking water	0.02	0.0002	0.02	2.0	0.02	443,682[c]
Eating fish	1	0.001	0.1	0.07	0.0007	11,112[d]
Other activities	0.0005	5×10^{-6}	0.0005	0.02	0.0002	2,172,173[d]
Irrigation	0.03	0.003	0.03			
Other pathways						
Eating deer	2[e]	0.02	2	0.06	0.0006	137
Eating geese	0.08[f]	0.0008	0.08	*g*	*g*	
Eating turkey	0.08[h]	0.0008	0.08	0.0007	7×10^{-6}	31
Direct radiation	NA[i]	NA				
All pathways						
Total	**3[j]**	**0.003**	**3**	**13**	**0.13**	**363,484**

[a] Estimated background collective 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 TDEC Division of Water.
[d] Population estimates for fish based on creel data and fraction of fish harvested from Melton Hill, Watts Bar, and Chickamauga reservoirs. Melton Hill, Watts Bar and Chickamauga recreational use information was obtained from TVA (Stephens et al. 2006 and Poudyal et al. 2017). Other activities include swimming, boating, and shoreline use; the population estimates include individuals involved in more than one activity and also include visitors that may live outside the 80 km radius.
[e] Estimates for eating deer are based on 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 the Oak Ridge Reservation; collective dose based on number of hunters that harvested deer.
[f] Estimates for eating geese are based on 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] Collective doses were not estimated for the consumption of geese because no geese were harvested for consumption during the goose roundup.
[h] Estimates for eating turkey are based on 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 collective dose is based on the number of hunters who harvested turkey.
[I] Current exposure rate measurements at PAM stations are at or near background levels.
[j] Dose estimates have been rounded.

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 MEI did not consume wildlife harvested from ORR, the estimated dose would be about 1 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 2017 maximum ED should not have exceeded about 3 mrem, or about 3% of the limit given in DOE O 458.1.

The total collective ED to the population living within an 80 km (50 mile) radius of ORR was estimated to be about 13 person-rem. This dose is about 0.004% of the 363,484 person-rem that this population received from natural sources during 2017.

7.1.4 Five-Year Trends

EDs associated with selected exposure pathways for years 2013 to 2017 are given in Table 7.9. In 2017, the air pathway dose is within the range of air pathway doses that have been estimated over the last 5 years; though 2014 air pathway dose was somewhat higher than the other 4 years. Starting in 2016, dose estimates take into account terrain height for the Spallation Neutron Source because it is located on a ridge above most of ORR. The 2017 dose from fish consumption is comparable to the doses estimated in 2015. In 2016, some issues associated with cross-contamination in analytical equipment used to quantify radionuclides in ORR-wide surface water samples from CRK 66, 58, 32, 23, and 16 led to biased results for several 2016 sampling events. The increase in the 2014 fish consumption 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; 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. There was a decrease in drinking water dose in 2014, but the doses in 2017 are comparable to other earlier estimated doses. Recent direct radiation measurements indicate doses near background levels. Doses from consumption of wildlife have been similar for the last 5 years with a slight increase in dose due to consumption of geese in 2016 and slight increase in dose from consumption of venison and turkey in 2017.

Table 7.9. Trends in effective dose from ORR activities, 2013–2017 (mrem)[a]

Pathway	2013	2014	2015	2016	2017
Air					
All routes	0.4	0.6	0.4	0.2	0.3
Surface water					
Fish consumption (Clinch River)	1.5	1.2	0.03	1.3	0.05
Drinking water (Kingston)	0.01	0.003	0.02	0.03	0.01
Wildlife consumption					
Deer	2	2	1	1	2
Geese	0.1	0.1	0.08	0.2	0.08
Turkey	0.08	0.04	0.05	0.05	0.08

[a] 1 mrem = 0.01 mSv.

7.1.5 Potential Contributions from Non-DOE Sources

DOE O 458.1 (DOE 2011) requires that if 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 2017, 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. Fifteen facilities responded to DOE's request. Ten facilities had no radiological emissions. Three facilities reported doses from air emissions either using COMPLY, a computerized screening tool for evaluating radiation exposure from atmospheric releases of radionuclides (EPA 2016) or CAP-88 PC. One facility reported annual doses from airborne emissions of about 0.4 mrem 1 mile southwest of the facility, one facility reported an annual dose of 0.21 mrem at fence line, and the third facility reported an annual dose < 10 mrem (COMPLY, level 1). Doses from direct radiation ranged from none to an annual dose of 2 mrem, based on measurements at the facility and immediate surroundings. Therefore, annual doses from air and water emissions and external radiation from both non-DOE and DOE sources should be less than 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 (DOE 2011) 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 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 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 instream sampling locations.

- Melton Branch (Melton Branch [X13])
- WOC headwaters, WOC (X14), and White Oak Dam (WOD) (X15)
- First Creek
- Fifth Creek
- Northwest Tributary
- Clinch River CRKs 16, 23, 32, 58, and 66

All locations, except WOC (X14) and WOD (X15) passed the general screening phase (comparison of maximum radionuclide water concentrations to default BCGs). White Oak Creek (X14) passed when average radionuclides were compared to default BCGs. WOD (X15) passed when average water concentrations and adjusted bioaccumulation factors for both ^{137}Cs and ^{90}Sr were used to reflect site-specific bioaccumulation of these radionuclides in fish. Riparian organisms are the limiting receptor for both ^{137}Cs and ^{90}Sr in surface water; however, the best available bioaccumulation data for WOC are for fish. Because fish are consumed by riparian organisms (e.g., raccoons), adjustment of the fish bioaccumulation factor modified the bioaccumulation of both ^{90}Sr and ^{137}Cs in riparian organisms. This resulted in absorbed dose rates to aquatic organisms below DOE aquatic dose limit of 1 rad/day at the ORNL 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 instream sampling locations.

- Surface Water Hydrological Information Support System Station 9422-1 (also known as station 17)
- Bear Creek at Bear Creek 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 DOE aquatic dose limit of 1 rad/day at the Y-12 locations.

At ETTP, doses to aquatic organisms were estimated from surface water concentrations at the following 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 DOE aquatic dose limit of 1 rad/day at the ETTP sampling locations.

7.1.6.2 Terrestrial Biota

A terrestrial organism assessment was conducted to evaluate impacts on biota in accordance with requirements in DOE O 458.1 (DOE 2011). 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. In 2014, as well 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 collected in 2014 were in similar locations as in 2007; except one location where a soil sample was not collected due to site inaccessibility. Except for samples collected on the WOC floodplain (collected on the WOC floodplain upstream from WOD), samples collected 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

7.2.1.1 Surface Water

To evaluate the drinking water pathway, hazard quotients (HQs) were estimated downstream of ORNL and downstream of ORR discharge points (Table 7.10). 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 MEI is 730 L/year (2 L/day). 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 but was deactivated in 2014. Therefore, it is not considered in this evaluation.

CRK 16 is located downstream of all DOE discharge points. Although CRK 16 is not a source of drinking water, data from this location were used as an indicator of the potential effect of drinking water from the Clinch River. As shown in Table 7.10, HQs were less than 1 for detected chemical analytes for which there are reference doses or a maximum contaminant level.

Acceptable risk levels for carcinogens typically range in magnitude from 10^{-4} to 10^{-6}. A risk value of 7×10^{-6} was calculated for the intake of arsenic in water collected at CRK 16.

Table 7.10. Chemical hazard quotients and estimated risks for drinking water from the Clinch River at CRK 16, 2017[a]

Chemical	Hazard quotient
Metals	
Antimony	0.004
Arsenic	0.04
Cadmium	0.02
Mercury	0.005
Nickel	0.002
Selenium	0.001
Uranium	0.03
Zinc	0.004
Risk for carcinogens	
Arsenic	7×10^{-6}

[a] Clinch River kilometer (CRK) 16, downstream of all US Department of Energy inputs.

7.2.1.2 Groundwater

Groundwater monitoring is conducted west of the Clinch River across from the Melton Valley waste management areas. These wells have been sampled semiannually from 2010 through 2017. Data are summarized in *2017 Remediation Effectiveness Report for the U.S. Department of Energy* (DOE 2017).

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 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 2017. 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 7.11, for consumption of sunfish and catfish, HQ values of less than 1 were calculated for all detected analytes except for Aroclor-1260, a polychlorinated biphenyl (PCB), also referred to as PCB-1260. An HQ greater than 1 for Aroclor-1260 was estimated in both 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 chromium (as Cr^{+6}) for sunfish at all three locations and for Aroclor-1260 in sunfish and catfish collected at all three locations. The concentration for chromium was estimated at or below the analytical detection limit. The Tennessee Department of Environment and Conservation (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 (TDEC 2017). TDEC has issued a precautionary fish consumption advisory for catfish in the Clinch River arm of Watts Bar Reservoir (TWRA 2018).

Table 7.11. Chemical hazard quotients and estimated risks for carcinogens in fish caught and consumed from locations on ORR, 2017[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						
Aluminum		<0.001	<0.001		J0.001	J0.002
Antimony	J0.3		J0.3	<0.3		J0.4
Chromium	0.03	J0.04	J0.05	J0.02	J0.02	J0.02
Copper	0.008	0.009	0.008	0.008	0.009	0.009
Iron	0.006	0.004	0.009	0.01	0.009	0.01
Lead	J0.1	< 0.1	0.9	J 0.2	J 0.1	J0.2
Lithium	J0.03	J0.03	J0.03	J0.04	0.04	J0.04
Manganese	0.008	0.006	0.01	0.002	0.002	0.002
Mercury	0.05	0.2	0.1	0.2	0.06	0.08
Selenium	0.3	0.2	0.3	0.2	0.2	0.2
Strontium	0.003	0.004	0.005	< 0.00009	<0.00009	< 0.00008
Thallium	0.2	0.3	0.4	< 0.1	<0.1	J0.2
Uranium			J0.003			< 0.003
Zinc	0.05	0.04	0.05	0.03	0.02	0.02
Hazard quotients for pesticides and Aroclors						
Aroclor-1260	0.8	J0.8	0.8	3	12	6
Risks for carcinogens						
Chromium	J2E-5	J2E-5	J3E-5	J1E-5	J1E-5	J1E-5
Lead	J6E-8	<5E-8	5E-7	8E-8	J6E-8	J1E-7
Aroclor-1260	1E-5	J1E-5	1E-5	4E-5	2E-4	9E-5
PCBs (mixed)[e]	1E-5	J1E-5	1E-5	4E-5	2E-4	9E-5

[a] A blank space for a location indicates that the parameter was undetected. A prefix "J" indicates that the concentration was estimated at or below the analytical detection limit by the laboratory and "< "indicates that the concentration was not quantifiable at the analytical detection limit.
[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
ORR = Oak Ridge Reservation

7.3 References

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