7. Dose

Activities on ORR have the potential to release small quantities of radionuclides and hazardous chemicals to the environment. These releases could expose members of the public to low concentrations of radionuclides or hazardous 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 2019, a hypothetical maximally exposed individual (MEI) 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/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 4 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, boating, and irrigation. In addition, if a hypothetical person consumed two harvested 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 an MEI from all these potential exposure pathways combined was estimated to be about 6 mrem. There are no known significant doses from discharges of radioactive constituents from ORR other than those reported. 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 2019 maximum ED was about 6 percent of the limit given in DOE Order 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 aquatic or terrestrial biota.

Due to different permit reporting requirements and instrument capabilities, this report uses various units of measurement. The lists of units of measurement and conversion factors on pages xxvii and xxviii are included to help readers convert numeric values presented herein as needed for specific calculations and comparisons.

7.1 Radiation Dose

Small quantities of radionuclides were released to the environment from operations at ORR facilities in 2019. 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. 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 2019 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 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. The 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 27 emission points on ORR were modeled during 2019. The total includes 3 (2 combined) points at Y-12, 22 points at ORNL, and 2 points at the 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 2019 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 2019, rainfall, as averaged over the six rain gauges located on ORR, was about 183.6 cm (72 in.). The average air temperature was 15.4°C (59.7°F) at the 10 to 15 m levels. The average mixing-layer height was 833.9 m (2,736 ft) for ETTP, 829.7 m (2,722 ft) for ORNL, and 842.5 m (2,764 ft) for Y-12. 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 location used in the dose calculations, 2019

Source	Stack height (m)	Stack diameter (m)	Effective exit gas velocity (m/s)[a]	Distance (m) and direction to the maximally exposed individual			
				From each site		From ORR	
Oak Ridge National Laboratory							
X-Laboratory Hoods							
X-1000	15	0.5	0	4,270	SW	11,260	NE
X-2000	15	0.5	0	4,630	SW	10,910	NE
X-3000	15	0.5	0	5,030	SW	10,510	NE
X-4000	15	0.5	0	5,200	SW	10,360	NE
X-6000	15	0.5	0	5,780	SW	9,800	NE
X-7000	15	0.5	0	5,210	WSW	10,750	NNE
X-2026	22.9	1.05	8.34	4,750	SW	10,790	NE
X-2099	3.66	0.18	16.88	4,740	SW	10,800	NE
X-2531 East Pipe Tunnel	1.07	0.31	0[b]	4,710	SW	10,830	NE
X-Portable Ventilation Units	0.20	0.15	3.23	4,770	SW	10,780	NE
X-3018	61	1.75	0.95	4,960	SW	10,570	NE
X-3020	61	1.22	13.83	4,900	SW	10,640	NE
X-3039	76.2	2.44	6.57	4,970	SW	10,570	NE
X-3544	9.53	0.28	21.66	4,740	SW	10,820	NE
X-3608 Filter Press	8.99	0.36	9.27	4,860	SW	10,720	NE
X-4501	19.81	0.66	10.34	5,150	SW	10,400	NE
X-7503	30.5	0.91	12.88	5,230	SW	10,580	NNE
X-7830 Group	4.6	0.25	8.38	3,840	WSW	12,130	NNE
X-7856-CIP	18.29	0.48	8.83	3,840	WSW	12,190	NNE
X-7877	13.9	0.41	13.56	3,810	WSW	12,180	NNE
X-7880	27.7	1.52	16.97	3,770	WSW	12,200	NNE
X-7911	76.2	1.52	15.14	5,160	WSW	10,810	NNE
X-7935 Building Stack	15.24	0.51	27.18	5,170	SW	10,740	NNE
X-7935 Glove Box	9.14	0.25	0[b]	5,170	SW	10,740	NNE
X-7966	6.10	0.29	6.33	5,240	SW	10,660	NNE
X-8915	104.0	1.22	6.91	8,000	SSW	7,580	NE
X-Decom Areas	15	0.5	0	5,240	SW	10,310	NE
East Tennessee Technology Park							
K-1407-AL CWTS	2.74	0.15	0[b]	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.
[b] The direction of exhaust is horizontal, therefore a zero exit velocity is used.

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

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 percent of the vegetables and produce, 44 percent of the meat, and 40 percent 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, 2019

Tower	Height (m)	Source
	Y-12 National Security Complex	
MT6 (West Y-12)	30	All Y-12 sources
	East Tennessee Technology Park	
MT7 (L1209)	15	K-1407-AL CWTS, K-2500-H-C
	Oak Ridge National Laboratory	
MT4 (Tow A)	15	X-7830, X-7935 Glove Box, X-7935 Building, X 7966, and X-7000 Lab Hoods
	30	X-7503, X-7856-CIP, X-7877, X-7880, and X-7911
MT3 (Tow B)	15	X-6000 Lab Hoods
MT2 (Tow D)	15	X-2099, X-2351 East Pipe Tunnel, X-Portable Ventilation Units, X-3544, X-3608 FP, X-Decom Hoods, X-1000, X-2000, X-3000, and X-4000 Lab Hoods
	35	X-2026, X-4501
	60	X-3018, X-3020, and X-3039
MT12 (Tow F)	10	X-8515 (SNS)

Acronyms:
CWTS = Chromium Water Treatment System
Decom = Decommissioned
FP = Filter Press
ORNL = Oak Ridge National Laboratory
SNS = Spallation Neutron Source

Results

EDs from radionuclides released to the atmosphere from ORR were calculated for ORR as a whole and for each site on ORR for (1) maximally exposed individuals (MEIs) and (2) for the collective population (1,172,530 persons) residing within 80 km (50 miles) of ORR (based on 2010 census data). CAP-88 PC Version 4 was used in 2019 to calculate both individual and collective doses.

The location of the MEI with reference to ORR (i.e., the location where a hypothetical individual would receive the maximum ED from radionuclides emitted to the atmosphere on ORR) is about 2,270 m northeast of the main Y-12 release point, about 10,810 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 0.4 mrem, which is well

below the National Emission Standards for Hazardous Air Pollutants for Radionuclides standard of 10 mrem and is about 0.1 percent of the roughly 300 mrem that the average individual receives from natural sources of radiation (40 CFR 61 Subpart H). The maximum individual EDs calculated for each site and for ORR are listed in Table 7.3.

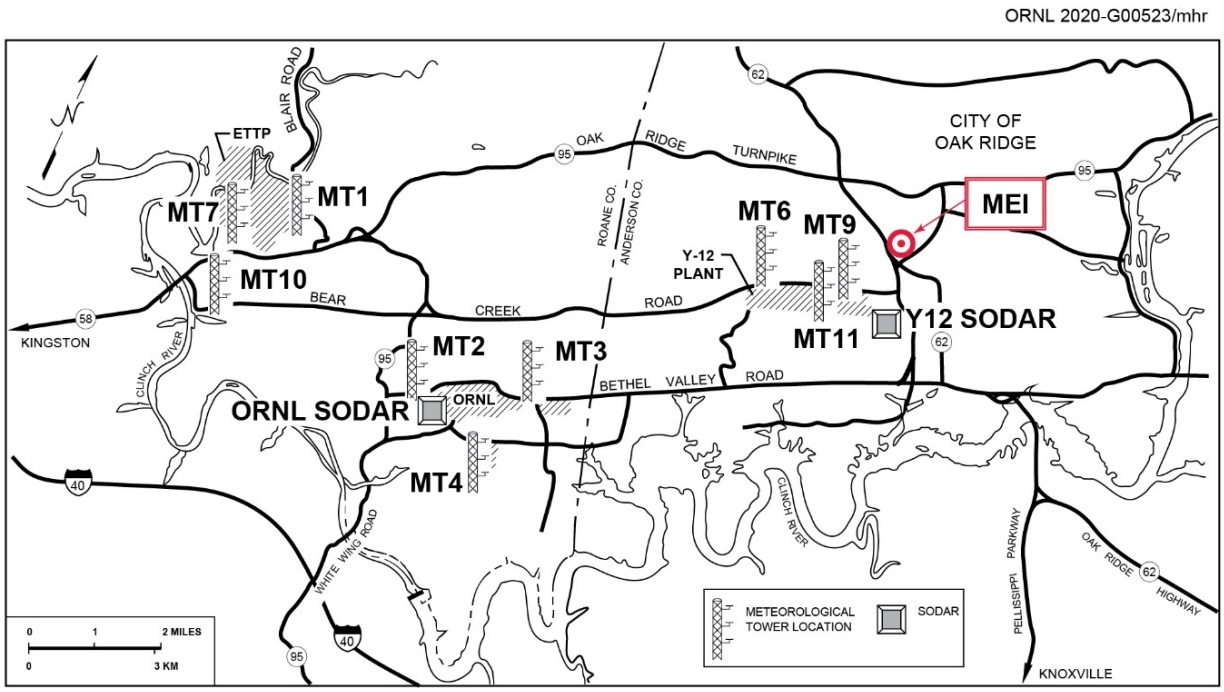

Figure 7.1. Location of the maximally exposed individual (MEI) for ORR (2019 Data)

Table 7.4 lists the collective EDs. The calculated collective ED was about 12.4 person-rem, which is about 0.004 percent 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).

Table 7.3. Calculated radiation doses to maximally exposed individuals from airborne releases from the Oak Ridge Reservation, 2019

Plant	Maximum effective dose, mrem (mSv)			
	From each site		From ORR	
	mrem	mSv	mrem	mSv
Oak Ridge National Laboratory	0.2[a]	0.002	0.07	0.0007
East Tennessee Technology Park	0.0003[b]	3×10^{-6}	3×10^{-6}	3×10^{-8}
Y-12 National Security Complex	0.36[c]	0.0036	0.36	0.0036
Entire Oak Ridge Reservation	*d*	*d*	0.4[e]	0.004

[a] The MEI was located 4,970 m SW of X-3039 and 5,160 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 MEI.

Acronym:
MEI = maximally exposed individual

Table 7.4. Calculated collective effective doses from airborne releases, 2019

Plant	Collective effective dose[a]	
	Person-rem	Person-Sv
Oak Ridge National Laboratory	7.3	0.073
East Tennessee Technology Park	0.0002	2×10^{-6}
Y-12 National Security Complex	5.1	0.051
Entire Oak Ridge Reservation	12.4	0.124

[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 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 0.36 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 96 percent, and other radionuclides accounted for about 4 percent 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 5.1 person-rem, which is about 41 percent of the collective ED for ORR.

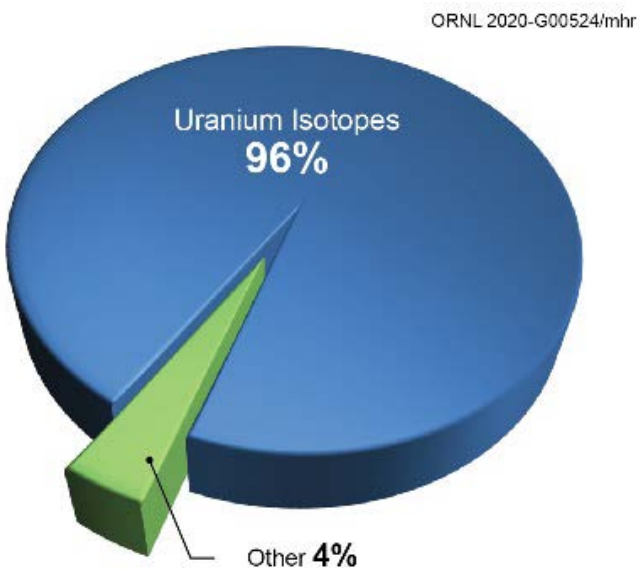

Figure 7.2. Nuclides contributing to the effective dose at Y-12 National Security Complex, 2019

The MEI for ORNL was located at a residence about 4,970 m (3.1 miles) southwest of the 3039 stack and 5,160 m (3.2 miles) west-southwest of the 7911 stack. This individual could have received an ED of about 0.2 mrem from ORNL airborne emissions. Lead-212 contributed 40 percent, ^{232}Th contributed 22 percent, and ^{138}Cs contributed 15 percent of the ORNL dose (Figure 7.3). The total contribution from uranium radioisotopes (i.e., ^{230}U, ^{232}U, ^{233}U, ^{234}U, ^{235}U, ^{236}U, ^{238}U, ^{239}U, and ^{240}U) accounted for about 0.02 percent of the dose, and ^{238}U contributed about 0.01 percent 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 59 percent of the collective ED for ORR.

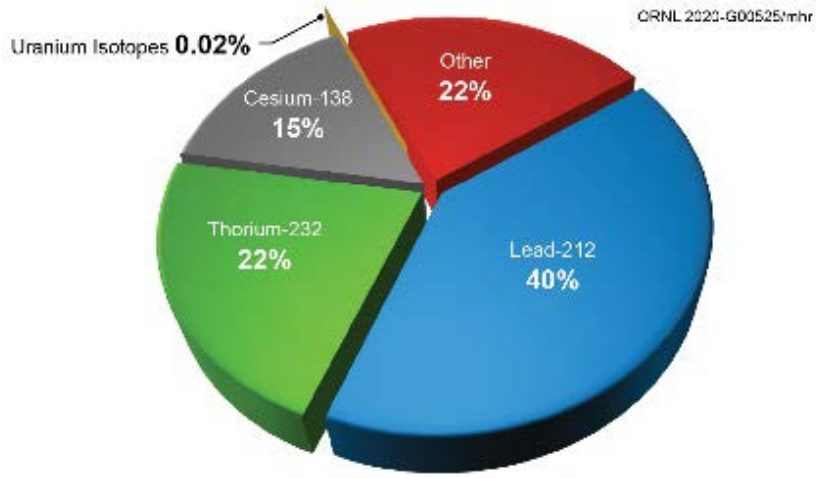

Figure 7.3. Nuclides contributing to effective dose at Oak Ridge National Laboratory, 2019

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 0.0003 mrem. About 95 percent of the dose is from uranium radioisotopes (^{233}U, ^{234}U, ^{235}U, ^{236}U, and ^{238}U), and about 4 percent 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 0.0002 person-rem, or about 0.002 percent of the collective ED for ORR.

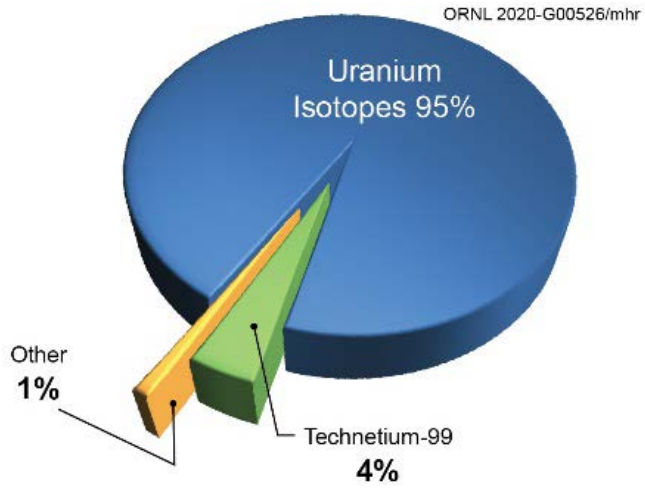

Figure 7.4. Nuclides contributing to effective dose at East Tennessee Technology Park, 2019

To evaluate the validity of the estimated doses calculated using CAP-88 PC Version 4 and emissions data (Table 7.5), the doses were compared to the EDs calculated using measured air concentrations of radionuclides (excluding naturally occurring ^{7}Be and ^{40}K) at ORR perimeter air monitoring (PAM) stations and at ORNL ambient air monitors 1, 2, 3, and 11 (AAM1, AAM2, AAM3, and AAM11). Based on measured air concentrations, hypothetical individuals assumed to reside at AAM1, AAM2, AAM3, AAM11, and PAM stations 35–49 could have received EDs between 0.0005 and 0.02 mrem/year. Based on emissions data using CAP-88 PC Version 4, the above individuals could have received EDs between

0.06 and 0.7 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 East Tennessee Technology Park ambient air monitoring stations, 2019

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	0.0007	7×10^{-6}	0.4	0.004
2	0.0008	8×10^{-6}	0.2	0.002
3	0.007	7×10^{-5}	0.7	0.007
11	0.0005	6×10^{-6}	0.3	0.003
35[b]	0.02	0.0002	0.06	0.0006
37	0.0007	7×10^{-6}	0.2	0.002
40	0.002	2×10^{-5}	0.5	0.005
46	0.0009	9×10^{-6}	0.2	0.002
49	0.0008	8×10^{-6}	0.2	0.002
52[b,c]	0.004	4×10^{-5}	0.02	0.0002
		ETTP		
K2	0.006	6×10^{-5}	0.07	0.0007
K11	0.04	0.0004	0.03	0.0003
K12	0.03	0.0003	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.
[b] At Stations 35 and 52, ^{99}Tc was requested for analyses as well as other radionuclides.
[c] Background ambient air monitoring station.

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. Technetium-99 was analyzed at Station 35 and Station 52, and the ^{99}Tc air concentration at Station 52 was nearly twice the concentration at Station 35. Based on measured air concentrations, the ED was estimated to be 0.004 mrem/year (the isotopes ^{7}Be and ^{40}K were not included in the background air monitoring station calculation); based on air concentrations calculated using CAP-88 PC Version 4, the ED was 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 0.04 mrem/year, which is slightly higher than the ED of 0.03 mrem/year estimated using source emissions data. AAM11 is located near the off-site MEI for ORNL. The ED calculated with measured air concentrations was 0.0005 mrem/year, which is lower than the ED of 0.3 mrem/year estimated using source emissions data. PAM station 40 is located near the off-site MEI for the Y-12

Complex and ORR, and the ED calculated with measured air concentrations was 0.002 mrem/year, which is also less than the ED of 0.5 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 enter 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 370 L/year (98 gal/year). The average drinking water consumption rate is used to estimate the collective ED. At all locations in 2019, estimated maximum EDs to a person drinking water were calculated using both measured radionuclide concentrations in off-site surface water and measured radionuclide discharges to the 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 Clinch River kilometer [CRK] 66 near the City of Oak Ridge Water Intake Plant), an MEI drinking water at this location could have received an ED of about 3×10^{-10} mrem. The collective ED to the 49,253 persons who drink water from the City of Oak Ridge Water Plant would be 6×10^{-9} 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. An MEI could have received an ED of about 2×10^{-8} mrem; the collective dose to the 65,346 persons who drink water from this plant could have been 5×10^{-7} person-rem.
- **Upper Clinch River.** The 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. An MEI could have received an ED of about 0.01 mrem. The collective dose to the 31,190 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 those plants could not have received EDs greater than about 0.01 mrem. The collective dose to the 311,562 persons who drink water within the lower system could have been about 1 person-rem.
- **Poplar Creek/Lower EFPC.** No drinking water intakes are located on Poplar Creek or on Lower EFPC.

Groundwater

During FY 2019 the Oak Ridge Office of Environmental Management (OREM) continued to collect and analyze samples from the off-site groundwater monitoring well array west of the Clinch River adjacent to Melton Valley. 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 2019. For the average person used for collective dose calculations, it was assumed that 11 kg (24 lb) of fish was consumed in 2019. The estimated maximum ED is 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 2019a). In 2019, the maximum ED from fish consumption was determined using measured radionuclide concentrations in fish samples, which were collected at three different locations. An expanded analysis was conducted on fish samples as compared to previous years. Plutonium-239/240 was the primary contributor to dose due to fish consumption at CRK 70 (92%), which is above all ORR discharge locations. However, a reanalysis of the sample from this location resulted in a lower concentration of $^{239/240}$Pu than was reported for the original analysis, and the result was below the minimum detectable concentration for the analytical method. Although the results from the second analysis were more consistent with expectations for this background location, a conservative approach was taken, and the original (higher) concentrations were used for dose calculations. The primary contributors to dose at CRK 32 were ^{228}Th, ^{230}Th, and ^{237}Np (39%, 47%, and 14%, respectively). Plutonium-239/240 contributed 71% of the dose at CRK 16, and ^{241}Am was responsible for 24% of the dose at that location.

- **Upper Melton Hill Lake above All Possible ORR Inputs.** For reference purposes, a hypothetical avid fish consumer who ate fish caught at CRK 70, which is above all possible ORR inputs, could have received an ED of about 1 mrem. The collective ED to the nine persons who could have eaten such fish was about 0.005 person-rem.
- **Upper Clinch River.** An avid fish consumer who ate fish from the upper Clinch River (CRK 32) could have received an ED of about 2 mrem. The collective ED to the 67 persons who could have eaten such fish could have been about 0.04 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 4 mrem. The collective ED to the 157 persons who could have eaten such fish could have been about 0.2 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). A recent survey was conducted regarding visitor and property owner activities for Chickamauga and Watts Bar Reservoirs (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 0.002 mrem. The collective ED to the 14,483 other users could have been 0.003 person-rem.
- **Melton Hill Lake.** An individual other user of Melton Hill Lake could have received an ED of about 0.003 mrem. The collective ED to the 40,044 other users could have been about 0.02 person-rem.

- **Upper Clinch River.** An individual other user of the upper Clinch River could have received an ED of about 0.0008 mrem. The collective ED to the 13,114 other users could have been about 0.001 person-rem.
- **Lower Clinch River.** An individual other user of the lower Clinch River could have received an ED of about 5×10^{-8} mrem. The collective ED to the 30,599 other users could have been about 1×10^{-7} person-rem.
- **Upper Watts Bar Lake.** An individual other user of upper Watts Bar Lake could have received an ED of about 2×10^{-8} mrem. The collective ED to the 87,424 other users could have been about 1×10^{-7} person-rem.
- **Lower system (Watts Bar and Chickamauga Lakes).** An individual other user of the lower system could have received an ED of about 1×10^{-8} mrem. The collective ED to the 3,173,423 other users could have been about 3×10^{-6} 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 0.0007 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 0 to 0.06 mrem in 2019. The individual was assumed to consume 24 kg of leafy vegetables, 90 kg of produce, 321 L of milk, and 63 kg of meat (beef) during the year.

Summary

Table 7.6 is a summary of potential EDs from identified waterborne radionuclides around ORR. 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 4 mrem to a person obtaining his or her drinking water and annual complement of fish from those water systems, and participating in other water uses throughout those systems. The maximum collective ED to the 80 km (50 mile) population was estimated to be 2 person-rem. The percentages of individual and collective doses are small and are attributable to natural background radiation. They constitute about 1 percent of the average individual background dose of roughly 300 mrem/year and 0.0006 percent 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, 2019[a,b]

Effective dose	Source			Total[d]
	Drinking water	Eating fish[c]	Other uses	
Upstream of all Oak Ridge Reservation discharge locations (CRK 66, City of Oak Ridge Water Plant)				
Individual	3×10^{-10}	1	0.002	1
Collective	6×10^{-9}	0.005	0.003	0.008

Table 7.6. Summary of annual maximum individual (mrem) and collective (person-rem) effective doses from waterborne radionuclides, 2019[a,b] (continued)

Effective dose	Source			Total[d]
	Drinking water	Eating fish[c]	Other uses	
Melton Hill Lake (CRK 58, Knox County Water Plant)				
Individual	2×10^{-8}	NA[e]	0.003	0.003
Collective	5×10^{-7}	NA[e]	0.02	0.02
Upper Clinch River (CRK 23, 32)				
Individual	NA[f]	2	0.0008	2
Collective	NA[f]	0.04	0.001	0.04
Lower Clinch River (CRK 16)				
Individual	NA[f]	4	5×10^{-8}	4
Collective	NA[f]	0.2	1×10^{-7}	0.2
Upper Watts Bar Lake, Kingston Municipal Water Plant				
Individual	0.01	NA[e]	2×10^{-8}	0.01
Collective	0.2	NA[e]	1×10^{-7}	0.2
Lower system (Lower Watts Bar Lake and Chickamauga Lake)				
Individual	0.01	NA[e]	1×10^{-8}	0.01
Collective	1.3	NA[e]	3×10^{-6}	1.3
Lower East Fork Poplar Creek and Poplar Creek				
Individual	NA[f]	NA[e]	0.0007	0.0007
Collective	NA[f]	NA[e]	2×10^{-5}	2×10^{-5}

[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] Doses based on measured radionuclide concentrations in fish samples collected at CRK 16, CRK 32, and CRK 70.
[d] Total doses and apparent sums over individual pathway doses may differ because of rounding.
[e] Not a fish sample collection location.
[f] Not at or near drinking water supply locations.

Acronym:
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 the ORR surveillance program. However, milk samples were not available in 2019.

7.1.2.4 Food

Milk

During 2019, no milk samples were collected. Milk samples had been collected from a nearby dairy in Claxton, Tennessee, for several years; however it went out of business in 2016. Surveys to locate nearby dairies in areas that may be impacted by ORR activities are conducted periodically. The recent survey did not identify any dairies to replace the one that went out of business. The milk-sampling program will resume when a replacement for that dairy is identified.

Vegetables

The food-crop sampling program is described in Chapter 6. Samples of leafy greens, root vegetables, and tomatoes were obtained from a total of five local gardens and two distant background locations. Leafy greens were collected at four locations, root vegetables were collected at three locations, and tomatoes were collected at all five local garden locations. The background location was the same for leafy greens and root vegetables, and a separate background location was used for tomatoes. All radionuclides detected in the food crops can be found in the natural environment, and all but ^{7}Be and ^{40}K may also be emitted from ORR. Dose estimates are based on hypothetical consumption rates of vegetables that contain statistically significant amounts and/or 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 24 kg (53 lb) of homegrown leafy greens, 90 kg (198 lb) of homegrown root vegetables, and 72 kg (159 lb) of homegrown tomatoes. The hypothetical local gardener could have received an ED of between 0.1 and 0.4 mrem, depending on garden location and vegetable consumed, as shown in Table 7.7. Of this total, between 0.02 and 0.2 mrem could have come from eating leafy greens, between 0.06 and 0.3 mrem from eating root vegetables, and between 0.03 and 0.1 mrem from eating tomatoes. The highest dose to a hypothetical local gardener could have been about 0.6 mrem from consuming all three types of homegrown vegetables using the maximum doses for each, regardless of collection location. A person eating vegetables from the two distant (background) gardens could have received a committed ED of 0.3 mrem from eating leafy greens, 0 mrem from eating root vegetables, and 0.1 mrem from eating tomatoes.

Table 7.7. Summary of estimated effective doses from consumption of homegrown vegetables, 2019

Vegetable	Local doses (mrem)	Background doses (mrem)
Leafy greens	0.02–0.2	0.3
Root vegetables	0.06–0.3	0
Tomatoes	0.03–0.1	0.1
Max dose all garden locations	0.6	0.4

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 13 mrem to the hypothetical home gardener's ED. In 2019, the gardeners were asked about water sources and fertilizers used. It was reported that fertilizers were used at four garden locations. Water was used at two of the garden locations, and the water sources included a well and a creek. It is believed ^{40}K and most of the excess unidentified alpha activities are due to naturally occurring radionuclides, not radionuclides discharged from ORR.

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 May and July 2019 were analyzed for gross alpha, gross beta, gamma emitters, and uranium isotopes. Radionuclides detected in hay are shown in Chapter 6, Table 6.5. Statistically significant concentrations of ^{40}K, ^{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.

White-Tailed Deer

The Tennessee Wildlife Resources Agency (TWRA) conducted three 2-day deer hunts during 2019 on the Oak Ridge Wildlife Management Area, which is part of ORR (see Chapter 6). During the hunts, 221 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; ORNL 2020).[1] No deer exceeded the wildlife release criteria.

The average ^{137}Cs concentration in muscle tissue of the 221 released deer, as determined by field counting, was 0.5 pCi/g; the maximum ^{137}Cs concentration in released deer was 0.6 pCi/g. Most of the ^{137}Cs concentrations were less than minimum detectable levels. The average weight of released deer was approximately 40 kg (87 lb); the maximum weight was 82 kg (181 lb). The EDs attributed to field-measured ^{137}Cs concentrations and actual field weights of the released deer ranged from about 0.1 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 deer (40 kg [87 lb], assuming that 55 percent of the field weight is edible meat) containing the 2019 average field-measured concentration of ^{137}Cs (0.5 pCi/g) could have received an ED of about 0.5 mrem. The maximum field-measured ^{137}Cs concentration was 0.6 pCi/g, and the maximum deer weight was 82 kg (181 lb). A hunter who consumed a hypothetical deer of maximum weight and ^{137}Cs content could have received an ED of about 1 mrem.

Muscle tissue samples collected in 2019 from seven 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 greater than the analytical results and that all were less than the administrative limit of 5 pCi/g (ORNL 2011; ORNL 2020).[1] Using analytically measured ^{137}Cs and ^{90}Sr (excluding ^{40}K, a naturally occurring radionuclide) and actual deer weights, the estimated doses for the seven released deer ranged from about 0.1 to 0.5 mrem.

The maximum ED to an individual consuming venison from two or three deer was also evaluated. Twenty-eight 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 about 0.4 and 2 mrem.

The collective ED from eating all the harvested venison from ORR with a 2019 average field-derived ^{137}Cs concentration of 0.5 pCi/g and an average weight of 40 kg (87 lb) is estimated to be about 0.1 person-rem. The collective dose is based on number of harvested deer. It is possible that additional

[1] The 2020 version of CSD-AM-RML-RA01 supersedes the 2011 version.

individuals may also consume the harvested venison; however, the collective dose would be essentially the same.

Canada Geese

Thirty geese were captured during the 2019 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). The average ^{137}Cs concentration was 0.2 pCi/g, with a maximum ^{137}Cs concentration in the released geese of 0.4 pCi/g. All ^{137}Cs concentrations were below minimum detectable activity levels. The average weight of the geese screened during the roundup was about 3.4 kg (8 lb), and the maximum weight was about 4.9 kg (11 lb).

The EDs attributed to field-measured ^{137}Cs concentrations of the geese ranged from 0.017 to 0.02 mrem. However, for bounding purposes, if a person consumed a released goose with an average weight of 3.4 kg (8 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 0.4 pCi/g and maximum weight of 4.9 kg (11 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 0.1 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

Two wild turkey hunts took place on the reservation in 2019: April 13 and 14 and April 27 and 28. 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. Thirty-two turkeys were harvested during that time frame, and 1 additional turkey was harvested during the deer hunt, for a total of 33 turkeys. No harvested turkeys were retained. The average weight of the released turkeys was about 8.6 kg (19 lb). The maximum turkey weight was about 11 kg (24 lb). Turkeys 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 0.1 pCi/g, with a maximum ^{137}Cs concentration in the released turkeys of 0.2 pCi/g. Almost all ^{137}Cs concentrations were below minimum detectable activity levels.

The EDs attributed to ^{137}Cs concentrations field-measured in the turkeys ranged from 0.004 to 0.03 mrem. However, for bounding purposes, if a person consumed a released turkey with an average weight of 8.6 kg (19 lb) and an average ^{137}Cs concentration of 0.1 pCi/g, the estimated ED would be approximately 0.02 mrem. It is assumed that about half the weight of a turkey is edible. The estimated ED to an individual who consumed a hypothetical turkey with the maximum ^{137}Cs concentration of 0.2 pCi/g and maximum weight of 11 kg (24 lb) is about 0.04 mrem.

The collective ED from eating all the harvested turkeys from ORR with a 2019 average field-derived ^{137}Cs concentration of 0.1 pCi/g and an average weight of 8.6 kg (19 lb) is estimated to be about 0.0007 person-rem. The collective dose is based on number of harvested turkeys. It is possible that additional individuals may also consume the harvested turkeys; however, the collective dose would be essentially the same.

No tissue samples were analyzed in 2019. 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 PAM stations. External gamma exposure rates were continuously recorded by dual-range Geiger-Müller tube detectors co-located with ORR ambient air stations. In 2019, exposure rates averaged about 10 µR/h and ranged from 8.6 to 12.1 µR/h. These exposure rates correspond to an annual average dose of about 61 mrem with a range of 52 to 74 mrem. At the background ambient air station, the exposure rate averaged about 9.1 µR/h and ranged from 8.5 to 10.6 µR/h. The resulting average annual dose was about 56 mrem with a range of 52 to 65 mrem. The annual doses based on measured exposure rates at or near ORR boundaries were typically within the range of the doses measured at the background location; slightly higher exposure rates were observed at AAM11 and AAM46.

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 2019, that person could have received a total ED of about 6 mrem. Of that total, 0.4 mrem would have come from airborne emissions, approximately 4 mrem from waterborne emissions (0.01 mrem from drinking water, 4 mrem from consuming fish, 0.003 mrem from other water uses along the Clinch River, and 0.06 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.

The dose of 6 mrem is about 2 percent of the annual dose (roughly 300 mrem) from background radiation. The ED of 6 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 4 mrem. DOE Order 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 2019 maximum ED should not have exceeded about 6 mrem, or about 6 percent of the limit given in DOE Order 458.1.

The total collective ED to the population living within an 80 km (50 mile) radius of ORR was estimated to be about 14.3 person-rem. This dose is about 0.004 percent of the 351,759 person-rem that this population received from natural sources during 2019.

Table 7.8. Summary of maximum estimated effective doses from Oak Ridge Reservation activities to an adult by exposure pathway, 2019

Pathway	Dose to maximally exposed individual		Percentage of DOE mrem/year limit (%)	Estimated collective radiation dose[a]			
				Pathway		Background (person-rem)	Total Population
	mrem	mSv		person-rem	person-Sv		
Airborne effluents							
All pathways	0.4	0.004	0.4	12.4	0.124		1,172,530[b]
Liquid effluents							
Drinking water	0.01	0.0001	0.01	1.5	0.015		457,351[c]
Eating fish	4	0.04	4	0.3	0.003		233[d]
Other activities	0.003	3×10^{-5}	0.003	0.02	0.0002		3,359,287[d]
Irrigation	0.06	0.0006	0.06				
Other pathways							
Eating deer	2[e]	0.02	2	0.1	0.001		221
Eating geese	0.1[f]	0.001	0.1	*g*	*g*		
Eating turkey	0.04[h]	0.0004	0.04	0.0007	7×10^{-6}		33
Direct radiation	NA[i]	NA					
All pathways							
Total	**6[j]**	**0.06**	**6**	**14.3**	**0.143**	**351,759**	

[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 (ORR).
[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 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 the Tennessee Valley Authority (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 hunters that harvested two or three deer on ORR in 2019. It is assumed that one individual may have consumed these deer. The collective dose is based on the number of 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 on ORR. The collective dose is based on the number of harvested turkey.
[i] Current exposure rate measurements at perimeter air monitoring stations are at or near background levels.
[j] Dose estimates have been rounded.

7.1.4 Five-Year Trends

EDs associated with selected exposure pathways for years 2015 to 2019 are given in Table 7.9. In 2019, the air pathway dose is within the range of air pathway doses that have been estimated over the last 5 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. 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 2019 fish consumption dose was due to a catfish sample collected at CRK 16, in which $^{239/240}$Pu was a primary dose contributor; however, the catfish sample collected at CRK 70, which is above ORR discharge locations, also contained $^{239/240}$Pu. Catfish and sunfish samples from both CRK 16 and CRK 70 were reanalyzed, and while results were generally lower, there was not a statistically significant difference, and the original results were used in dose calculations. There was a decrease in drinking water dose in 2019, but the doses 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.

Table 7.9. Trends in effective dose from Oak Ridge Reservation activities, 2015–2019 (mrem)[a]

Pathway	2015	2016	2017	2018	2019
All routes—inhalation	0.4	0.2	0.3	0.2	0.4
Fish consumption (Clinch River)	0.03	1.3	0.05	0.09	4
Drinking water (Kingston)	0.02	0.03	0.01	0.03	0.01
Deer	1	1	2	2	2
Geese	0.08	0.2	0.08	0.1	0.1
Turkey	0.05	0.05	0.08	0.05	0.04

[a] 1 mrem = 0.01 mSv

7.1.5 Doses to Aquatic and Terrestrial Biota

7.1.5.1 Aquatic Biota

DOE Order 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 2019). 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 (X13)
- WOC headwaters (WOC 6.8), WOC (X14), and White Oak Dam (WOD) (X15)

- WOC 7500 Bridge
- First Creek
- Fifth Creek
- Northwest Tributary
- Raccoon Creek
- Clinch River CRKs 16, 32, 58, and 66

All locations, except WOD (X15) passed the general screening phase (comparison of maximum radionuclide water concentrations to default BCGs). WOD (X15) passed when average water concentrations and adjusted bioaccumulation factors for ^{137}Cs and ^{90}Sr were used to reflect site-specific bioaccumulation of these radionuclides in fish. Riparian organisms are the limiting receptor for ^{137}Cs and ^{90}Sr in surface water; however, the best available bioaccumulation data for this area are for fish. Because fish are consumed by riparian organisms (e.g., raccoons), adjustment of the fish bioaccumulation factor modified the bioaccumulation of ^{137}Cs and ^{90}Sr 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 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 the ETTP sampling locations.

7.1.5.2 Terrestrial Biota

A terrestrial organism assessment was conducted to evaluate impacts on biota in accordance with requirements in DOE Order 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 2019) 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. The next evaluation of exposure to terrestrial organisms will be conducted within the next couple years or if an abnormal event occurs that could have adverse effects on terrestrial organisms.

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.

7.2 Chemical Dose

7.2.1 Drinking Water Consumption

7.2.1.1 Surface Water

To evaluate the drinking water exposure pathway, hazard quotients (HQs) and risks 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 for noncarcinogens. HQ values of less than 1 indicate an unlikely potential for adverse noncarcinogenic health effects. Likewise, risks are evaluated from estimated exposure dose or intake and cancer slope factors. Acceptable risk levels for carcinogens range from 10^{-4} (risk of developing cancer over a human lifetime is 1 in 10,000) to 10^{-6} (risk of developing cancer over a human lifetime is 1 in 1,000,000) (see Appendix F). 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 66, CRK 32, CRK 23, and CRK 16. The water intake for ETTP used to be located near CRK 23 but was deactivated in 2014. Mercury concentrations were measured but not detected above the analytical method detection limit in surface water samples collected at CRK 66 and CRK 32.

As shown in Table 7.10, at all locations, HQs were less than 1 for detected chemical analytes for which there are reference doses or a maximum contaminant level. 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 a surrogate to evaluate potential exposure to drinking water from the Clinch River.

Acceptable risk levels for carcinogens typically range in magnitude from 10^{-4} to 10^{-6}. Risk values of 6×10^{-6} and 5×10^{-6} were calculated for the intake of arsenic in water collected at CRK 16 and CRK 23, respectively. Risk values of 1×10^{-6} and 3×10^{-6} were calculated for the intake of chromium in water collected at CRK 16 and CRK 23, respectively.

Table 7.10. Chemical hazard quotients and estimated risks for drinking water from the Clinch River at CRK 23 and 16, 2019[a]

Analyte	Hazard quotient	
	CRK 23[b]	CRK 16[c]
Metals		
Antimony	0.003	0.002
Arsenic	0.03	0.03
Cadmium	0.001	0.001
Chromium	0.005	0.003
Copper	0.0007	0.0006
Lead	0.02	0.02
Mercury	4×10^{-5}	0.0002
Nickel	0.0008	0.0005
Selenium	0.0007	0.001
Silver	4×10^{-5}	4×10^{-5}
Thallium	0.04	0.04
Uranium	0.02	0.02
Zinc	0.0004	4×10^{-5}
Volatile organics		
1,1,1-Trichloroethane	4×10^{-6}	4×10^{-6}
cis-1,2-Dichloroethene	0.004	0.004
Trichloroethane	0.02	0.02
Vinyl chloride	0.001	0.001
Risks for carcinogens		
Arsenic	5×10^{-6}	6×0^{-6}
Chromium	3×10^{-6}	1×10^{-6}
Lead	6×10^{-9}	6×10^{-9}

[a] CRK = Clinch River kilometer
[b] CRK 23, is located across from East Tennessee Technology Park, no longer a water intake location.
[c] CRK 16 is downstream of all US Department of Energy inputs and not a water intake location.

Acronym:
CRK = Clinch River kilometer.

7.2.1.2 Groundwater

As mentioned in Section 6.5, during FY 2019 OREM continued to collect and analyze samples from the off-site groundwater monitoring well array west of the Clinch River adjacent to Melton Valley. 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 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 2019. This fish consumption rate of 74 g/day (27 kg/year) is assumed for estimating exposure for both the noncarcinogenic and carcinogenic chemicals. 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 catfish at all three locations (CRKs 16, 32, and 70).

For carcinogens, risk values at or greater than 10^{-6} were calculated for the intake of chromium (as Cr^{+6}) and Aroclor-1260 for sunfish and catfish collected at all three locations except for catfish at CRK 32. All concentrations for chromium were 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 2019). TDEC has issued a precautionary fish consumption advisory for catfish in the Clinch River arm of Watts Bar Reservoir (TWRA 2019b).

Table 7.11. Chemical hazard quotients and estimated risks for fish caught and consumed from locations on the Oak Ridge Reservation, 2019[a]

	Sunfish			Catfish		
	CRK 70[b]	CRK 32[c]	CRK 16[d]	CRK 70[b]	CRK 32[c]	CRK 16[d]
Hazard quotients for metals						
Barium	J0.0007	J0.001	J0.0008			J0.002
Chromium	J0.03	J0.02	J0.02	J0.02	J0.001	J0.02
Copper	J0.004	J0.002	J0.002	0.01	J0.0004	0.008
Hazard quotients for metals						
Iron	0.008	0.004	0.003	0.005	0.0006	0.004
Manganese	0.006	0.01	0.005	J0.001	J9E-5	0.002
Mercury	0.1	J0.07	0.1	0.3	0.1	0.1
Selenium	0.1	0.1	0.1	J0.1	J0.01	0.1
Strontium	0.002	0.002	0.002			J0.0001
Thallium	J0.1	J0.2	J0.1		J0.009	
Zinc	0.03	0.03	0.02	0.01	0.001	0.02
Hazard quotients for Aroclors						
Aroclor-1260	J0.5	J0.5	J0.4	4	4	14

Table 7.11. Chemical hazard quotients and estimated risks for fish caught and consumed from locations on the Oak Ridge Reservation, 2019[a] (continued)

	Sunfish			Catfish		
	CRK 70[b]	CRK 32[c]	CRK 16[d]	CRK 70[b]	CRK 32[c]	CRK 16[d]
	Risks for carcinogens					
Chromium	J2E-5	J1E-5	J1E-5	J8E-6	J7E-7	J1E-5
Aroclor-1260	J7E-6	J8E-6	J7E-6	6E-5	6E-5	2E-4
PCBs (mixed)[e]	J7E-6	J8E-6	J7E-6	6E-5	6E-5	2E-4

[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.
[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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