Radionuclides discharged to surface waters on ORR can potentially reach members of the public who use the Clinch and Tennessee Rivers for fishing, swimming, boating, or drinking water. Water and fish samples are collected at several locations on the Clinch River and are analyzed to ensure that members of the public are not exposed to harmful levels of radioactivity.
ORNL photograph

7

Dose

Activities on ORR have the potential to release small quantities of radionuclides and hazardous chemicals to the environment. The releases could expose members of the public to low concentrations of radionuclides or hazardous chemicals. Monitoring of materials released from ORR 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 2022, a hypothetical maximally exposed individual (MEI) would have received an effective dose (ED) of about 0.2 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 (40 CFR Part 61).

A worst-case analysis of exposures to waterborne radionuclides for all pathways combined gives a maximum possible individual ED of about 0.9 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 person consumed one maximum-weight harvested deer and two maximum-weight harvested geese, all containing the maximum ^{137}Cs concentration, that person could have received an ED of about 2 mrem. This calculation provides an estimated upper-bound ED from consuming wildlife harvested from ORR. Turkey hunts normally conducted on ORR were canceled in 2022 due to the COVID-19 pandemic; however, deer hunts resumed in 2022.

Therefore, the annual dose for 2022 to an MEI from the combined exposure pathways is estimated to have been about 3 mrem. No significant doses from discharges of radioactive constituents from ORR other than those reported are known. DOE Order 458.1, *Radiation Protection of the Public and the Environment* (DOE 2020),

limits the ED that a member of the public may receive from all radionuclide exposure pathways during 1 year to no more than 100 mrem. The 2022 maximum ED from ORR was about 3 percent of the DOE Order 458.1 limit.

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.

7.1. Radiation Dose

Small quantities of radionuclides were released to the environment from operations at ORR facilities in 2022. 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, dose calculations 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, whereas internal exposures usually result in nonuniform irradiation of the body and organs because most radionuclides deposit preferentially in specific organs or tissues. Several specialized terms and units used to characterize exposures to ionizing radiation are defined in Appendix E.

ED is a risk-based dose equivalent 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 (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

The following sections summarize the methods and pathways used to determine potential doses to members of the public and to aquatic and terrestrial biota from radionuclides originating from ORR. Dose calculations are made for a variety of media using both computer models and measured radionuclide concentrations in samples collected on or near ORR.

7.1.2.1. Airborne Radionuclides

The radiological consequences of radionuclides released to the atmosphere from ORR operations during 2022 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 mi) from the center of ORR. 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 EPA sponsorship to demonstrate compliance with 40 CFR 61, Subpart H, which governs the emissions of radionuclides other than radon from DOE facilities. CAP-88 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 (e.g., 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 2022. The total includes 3 (2 combined) points at Y-12, 23 points at ORNL, and 1 point at ETTP. Table 7.1 lists the emission point parameter values and receptor locations used in the dose calculations.

Meteorological data used in the calculations for 2022 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 2022, rainfall, as averaged over the six rain gauges located on ORR, was about 150.2 cm (59 in.). The average air temperature was 14.9°C (59°F) at the 10 to 15 m levels. The average mixing layer height (i.e., the depth of the atmosphere adjacent to the surface within which air is mixed) was 679.2 m (2,228 ft) for ETTP, 691.0 m (2,267 ft) for ORNL, and 679.2 m (2,228 ft) for Y-12. 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 mi) 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 mi) of ORR was calculated using the production rates provided with CAP-88 PC Version 4.

Table 7.1. Emission point parameters and receptor locations used in the dose calculations, 2022

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	
			ORNL				
X-laboratory hoods							
X-1000	15	0.5	0	5,710	ENE	9,990	NE
X-2000	15	0.5	0	5,410	E	9,640	NE
X-3000	15	0.5	0	5,090	E	9,250	NE
X-4000	15	0.5	0	4,870	E	9,100	NNE
X-7000	15	0.5	0	4,280	ENE	9,560	NNE
X-2026	22.9	1.05	6.88	5,430	E	9,510	NE
X-2099	3.66	0.18	16.42	5,420	E	9,520	NE
X-3001	6.86	0.44	7.50	5,250	E	9,320	NE
X-3020	61	1.22	13.53	5,290	E	9,360	NE
X-3026-East	0.81	0.97	0[b]	5,150	E	9,320	NE
X-3026-West	0.81	0.97	0[b]	5,150	E	9,320	NE
X-3039	76.2	2.44	5.36	5,150	E	9,300	NE
X-3544	9.53	0.28	24.80	5,170	ENE	9,570	NNE
X-3571	3.35	0.29	0[b]	5,160	E	9,440	NNE
X-3608 filter press	8.99	0.36	9.27	5,010	ENE	9,470	NNE
X-4501	19.81	0.71	9.71	4,930	E	9,150	NNE

Table 7.1. Emission point parameters and receptor locations used in the dose calculations, 2022 (continued)

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	
ORNL (continued)							
X-7503	30.5	0.91	13.12	4,320	ENE	9,390	NNE
X-7830 group	4.6	0.25	9.66	5,610	ENE	10,910	NNE
X-7856-CIP	18.29	0.48	11.70	5,610	ENE	10,980	NNE
X-7877	13.9	0.41	13.56	5,640	ENE	10,970	NNE
X-7880	27.7	1.52	15.00	5,670	ENE	10,990	NNE
X-7911	76.2	1.52	13.79	4,310	ENE	9,620	NNE
X-7935 building stack	15.24	0.51	24.27	4,330	ENE	9,540	NNE
X-7935 glove box	9.14	0.25	0[b]	4,330	ENE	9,540	NNE
X-7966	6.10	0.29	6.40	4,270	ENE	9,460	NNE
X-8915	104.0	1.22	7.25	4,420	ESE	6,280	NE
X-decom areas	15	0.5	0	4,840	E	9,060	NNE
ETTP							
K-1407-AL CWTS	2.74	0.15	0[b]	400	SW	13,450	ENE
Y-12 Complex							
Y-monitored	20	0.5	0	1,090	NNE	1,090	NNE
Y-unmonitored processes	20	0.5	0	1,090	NNE	1,090	NNE
Y-unmonitored lab hoods	20	0.5	0	1,090	NNE	1,090	NNE

[a] *Exit gas temperatures are ambient air temperatures.*
[b] *The direction of exhaust is horizontal. Therefore, an exit velocity of 0 m/s is used.*
Acronyms:
CIP = Capacity Increase Project
CWTS = Chromium Water Treatment System
Decom = Decommissioned
ETTP = East Tennessee Technology Park
ORNL = Oak Ridge National Laboratory
ORR = Oak Ridge Reservation
Y-12 Complex = Y-12 National Security Complex

Results

EDs from radionuclides released to the atmosphere from ORR were calculated for ORR as a whole and for each site on ORR for MEIs and for the collective population (1,272,478 persons) residing within 80 km (50 mi) of ORR based on 2020 census data (Census 2020). CAP-88 PC Version 4 was used in 2022 to calculate individual and collective doses.

The location of the ORR MEI (i.e., the location where a hypothetical individual would receive the maximum ED from radionuclides emitted to the atmosphere from ORR) is about 1,090 m (0.7 m) north-northeast of the main Y-12 release point, about 9,620 m (6.0 mi) north-northeast of the 7911 stack at ORNL, and about 13,450 m (8.4 mi) 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 0.2 mrem, which is well below the National Emission Standards for Hazardous Air Pollutants for Radionuclides standard of 10 mrem and is about 0.07 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.

Table 7.4 lists the collective EDs. The calculated collective ED was about 11.5 person-rem, which is about 0.003 percent of the 381,743 person-rem that this population received from natural sources of radiation (based on an individual dose of about 300 mrem/year).

Table 7.2. Meteorological towers and heights used to model atmospheric dispersion from source emissions, 2022

Tower	Height (m)	Source
		Y-12 Complex
MT6 (West Y-12)	30	All Y-12 sources
		ETTP
MT13 (Tower J)	20	K-1407-AL CWTS
		ORNL
MT4 (Tower A)	15	X-7830 group, X-7935 glove box, X-7966, and X-7000 lab hoods
	30	X-7503, X-7856-CIP, X-7877, X-7880, X-7911, and X-7935 building stack
MT2 (Tower D)	15	X-2099, X-3001, X-3026-East, X-3026-West, X-3571, X-3608 FP, X-decom hoods, X-1000, X-2000, X-3000, and X-4000 lab hoods
	35	X-2026, X-3544, and X-4501
	60	X-3020 and X-3039
MT12 (Tower F)	10	X-8915

Acronyms:
CIP = Capacity Increase Project
CWTS = Chromium Water Treatment System
Decom = Decommissioned
ETTP = East Tennessee Technology Park
FP = Filter Press
ORNL = Oak Ridge National Laboratory
Y-12 Complex = Y-12 National Security Complex

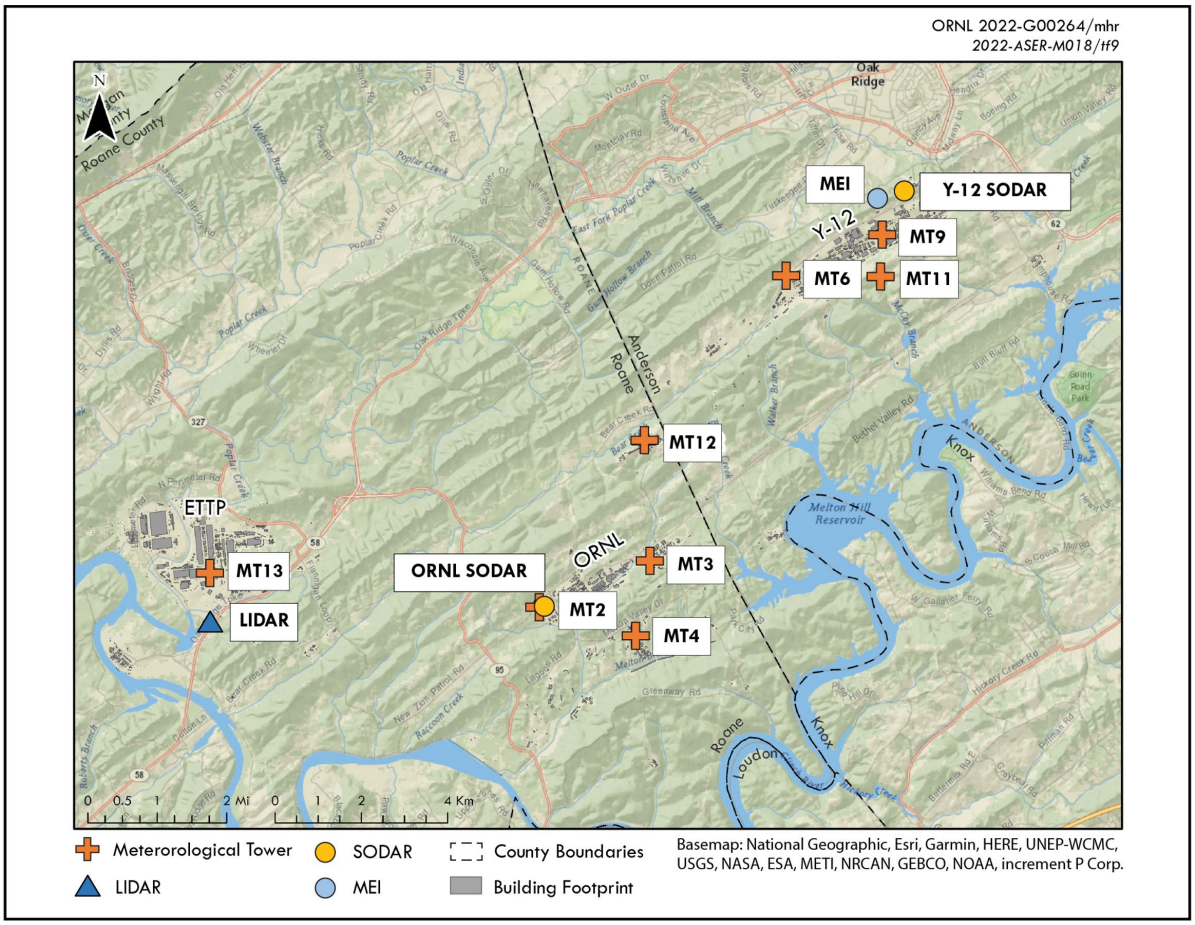

Figure 7.1. Location of the maximally exposed individual for ORR, 2022

Table 7.3. Calculated radiation doses to maximally exposed individuals from airborne releases from ORR, 2022

Site	Maximum effective dose, mrem and mSv			
	From each site		From ORR	
	mrem	mSv	mrem	mSv
ORNL[a]	0.2	0.002	0.08	0.0008
ETTP[b]	0.0002	2×10^{-6}	2×10^{-6}	2×10^{-8}
Y-12 Complex[c]	0.1	0.001	0.1	0.001
Entire ORR[d]	e	e	0.2	0.002

[a] *The ORNL MEI was located 5,150 m E of X-3039 and 4,310 m ENE of X-7911.*
[b] *The ETTP MEI was located 400 m SW of K-1407-AL Chromium Water Treatment System.*
[c] *The Y-12 MEI was located 1,090 m NNE of the main Y-12 Complex release point.*
[d] *The MEI for the entire ORR is 1,090 m NNE of Y-12 Complex release point, 9,300 m NE of X-3039, and 13,450 m ENE of K-1407-AL Chromium Water Treatment System.*
[e] *Not applicable.*

Acronyms:
ETTP = East Tennessee Technology Park
MEI = maximally exposed individual
ORNL = Oak Ridge National Laboratory
ORR = Oak Ridge Reservation
Y-12 Complex = Y-12 National Security Complex

Table 7.4. Calculated collective effective doses from airborne releases, 2022

Plant	Collective effective dose[a]	
	Person-rem	Person-Sv
ORNL	9.9	0.099
ETTP	0.0001	1×10^{-6}
Y-12 Complex	1.6	0.016
Entire ORR	11.5	0.115

[a] *Collective effective dose to the 1,272,478 persons residing within 80 km (50 mi) of the ORR (based on 2020 census data).*

Acronyms:
ETTP = East Tennessee Technology Park
ORNL = Oak Ridge National Laboratory
ORR = Oak Ridge Reservation
Y-12 Complex = Y-12 National Security Complex

The MEI for Y-12 was located at a residence about 1,090 m (0.7 mi) north-northeast of the main Y-12 release point. This individual could have received an ED of about 0.1 mrem from Y-12 airborne emissions. Uranium radioisotopes (i.e., ^{233}U, ^{234}U, ^{235}U, ^{236}U, and ^{238}U) accounted for about 92 percent, and other radionuclides accounted for about 8 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 mi) of ORR was calculated to be about 1.6 person-rem, which is about 14 percent of the collective ED for ORR.

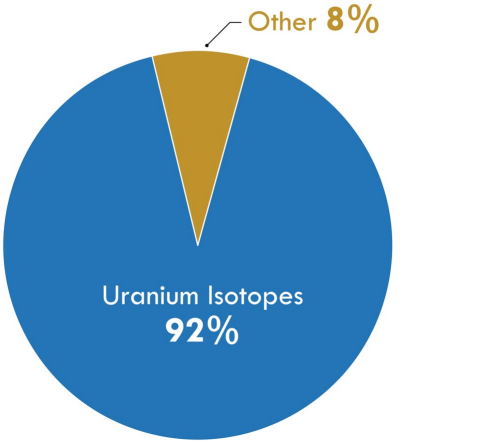

Figure 7.2. Nuclides contributing to effective dose at the Y-12 Complex, 2022

The MEI for ORNL was located at a residence about 5,150 m (3.2 m) east of the 3039 stack and 4,310 m (2.7 mi) east-northeast of the 7911 stack. This individual could have received an ED of about 0.2 mrem from ORNL airborne emissions. Lead-212 contributed about 42 percent, ^{138}Cs contributed about 21 percent, ^{11}C contributed about 21 percent, and ^{41}Ar contributed about 4 percent to the ORNL ED (Figure 7.3). The total contribution from uranium radioisotopes (i.e., ^{232}U, ^{233}U, ^{234}U, ^{235}U, ^{236}U, ^{238}U, ^{239}U, and ^{240}U) accounted for about 0.4 percent of the dose. Of those, ^{238}U made the largest contribution. The contribution of ORNL emissions to the collective ED to the population residing within 80 km (50 mi) of ORR was calculated to be about 9.9 person-rem or about 86 percent of the collective ED for ORR.

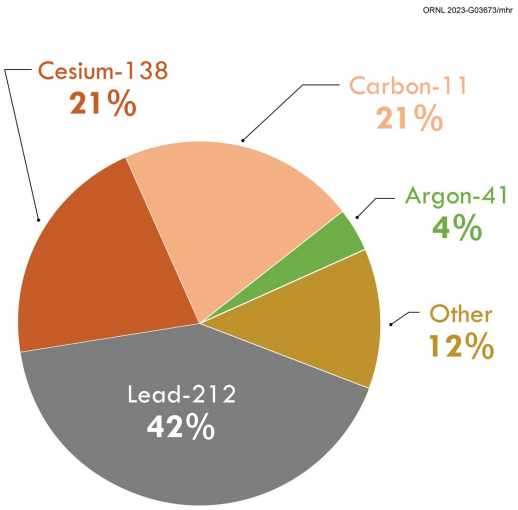

Figure 7.3. Nuclides contributing to effective dose at ORNL, 2022

The MEI for ETTP was located at a business about 400 m (0.24 mi) southwest of the K-1407-AL CWTS. The ED received by this individual from airborne emissions was calculated to be about 0.0002 mrem. About 91 percent of the dose was from uranium radioisotopes (^{233}U, ^{234}U, ^{235}U, ^{236}U, and ^{238}U), about 3 percent of the dose was from progeny of uranium isotopes, and about 6 percent of the dose was from ^{99}Tc (Figure 7.4).
The contribution of ETTP emissions to the collective ED to the population residing within 80 km (50 mi) of ORR was calculated to be about 0.0001 person-rem, or about 0.001 percent of the collective ED for ORR.

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 radionuclide air concentrations (excluding naturally occurring ^{7}Be and ^{40}K) measured in samples collected at the ORR ambient air locations (Figure 6.3). In 2022, analysis of ambient air samples transitioned to a different laboratory, resulting in possible variations in analytical procedures and reporting methodologies. Analyses included gross alpha, gross beta, gamma emitters, isotopic uranium, and ^{3}H.

In 2022, in addition to ^{3}H and uranium isotopes, ^{214}Bi, ^{210}Pb, ^{212}Pb, ^{124}Sb, ^{208}Tl, and ^{99}Tc were detected at ORR ambient air stations. Lead-210, a naturally occurring radioisotope, was detected at all ORR ambient air sampling locations and at the background location, Station 52 (Table 7.5). On average, the dose contribution from ^{210}Pb at ambient air sampling locations was nearly 2.3 mrem. Measured air concentrations of ^{210}Pb were excluded in calculated EDs because it is naturally occurring and was only emitted from one source on ORR at levels significantly below those measured in ambient air samples.

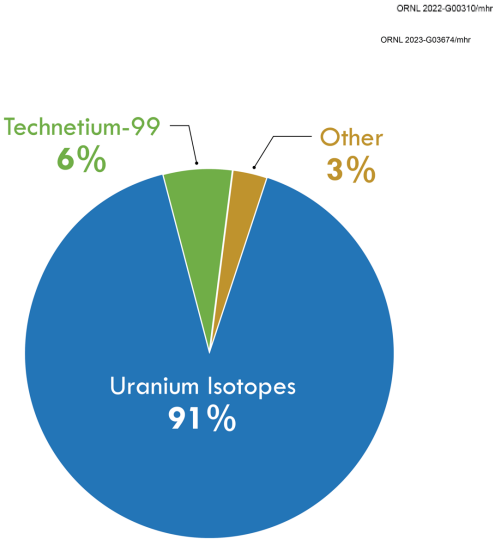

Figure 7.4. Nuclides contributing to effective dose at ETTP, 2022

Based on measured air concentrations, hypothetical individuals assumed to reside at the ambient air stations could have received EDs between 0.02 and 0.06 mrem/year, while EDs calculated using CAP-88 PC Version 4 and emissions data were 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 tended to be greater than or similar to EDs calculated using measured air concentrations.

Station 52, located remotely from ORR, gives an indication of potential EDs from background sources. Samples from Stations 35 and 52 were analyzed for ^{99}Tc in 2022. Technetium-99 was detected at the background location and in the sample at Station 35. Based on measured air concentrations (excluding the naturally occurring isotopes ^{7}Be and ^{40}K), the ED at Station 52 was estimated to be 0.06 mrem/year. Based on air concentrations calculated using CAP-88 PC Version 4, the ED was estimated to be 0.01 mrem/year.

Table 7.5. Hypothetical effective doses from living near ORR and ETTP ambient air monitoring stations, 2022

Station	Calculated effective doses			
	Using air monitor data		Using CAP-88[a] and emission data	
	mrem/year	mSv/year	mrem/year	mSv/year
		ORR		
1	0.03	0.0003	0.2	0.002
2	0.03	0.0003	0.2	0.002
3	0.04	0.0004	0.4	0.004
11	0.03	0.0003	0.2	0.002
35[b]	0.06	0.0006	0.05	0.0005
37	0.02	0.0002	0.1	0.001
40	0.03	0.0003	0.2	0.002
46	0.03	0.0003	0.1	0.001
49	0.03	0.0003	0.08	0.0008
52[b,c]	0.06	0.0006	0.01	0.0001
		ETTP		
K11	3×10^{-5}	3×10^{-7}	0.03	0.0003
K12	*d*	*d*	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] *In 2022, analysis to detect ^{99}Tc was requested for Stations 35 and 52.*
[c] *Background ambient air monitoring station.*
[d] *No radionuclides were detected during 2022 at this location.*
Acronyms:
ETTP = East Tennessee Technology Park
ORR = Oak Ridge Reservation

The measured air concentrations of ^{7}Be were similar at ORR stations and at the background air monitoring station.

EDs calculated using measured air concentrations of radionuclides at ambient air stations located near the MEIs for each site are significantly less than EDs calculated using source emissions data. Station 1 is located near the off-site MEI for ORNL. The ED calculated with measured air concentrations was 0.03 mrem/year, and the ED estimated using source emissions data was 0.2 mrem/year. Station 46 is located near the off-site MEI for the Y-12 Complex and ORR. The ED calculated with measured air concentrations was 0.03 mrem/year, and the ED estimated using source emissions data was 0.1 mrem/year. Station K11 is located near the on-site MEI for ETTP. The ED calculated with measured air concentrations was 3×10^{-5}, and the ED calculated using source emissions data was 0.03 mrem/year.

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), which both enter Poplar Creek before it enters the Clinch River. Discharges from Rogers Quarry enter McCoy Branch, which flows into Melton Hill Lake. Discharges from ORNL enter the Clinch River via White Oak Creek (WOC) and enter Melton Hill Lake via 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 get drinking water from the Clinch and Tennessee Rivers and use them for fishing, swimming, boating, and other shoreline activities.

For assessment purposes, surface waters potentially affected by ORR are divided into the following seven segments:

- Melton Hill Lake above all possible ORR inputs
- Melton Hill Lake
- Upper Clinch River (from the 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 water and fish determined by laboratory analyses of water and fish samples (see Sections 6.4 and 6.6.4). The second method calculates possible radionuclide concentrations in water and fish from measured radionuclide discharges and known or estimated streamflows. Both methods use reported concentrations of radionuclides to estimate radiation doses if the reported value is 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), and the doses are calculated using per capita committed ED coefficients for water ingestion (DOE 2021). Utilizing the two methods to estimate potential doses accounts for field measurements and discharge measurements.

Drinking Water Consumption

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. During FY 2022, 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.

Water drawn into treatment plants from the Clinch and Tennessee River systems could be affected by discharges from ORR. Because they are based on radionuclide concentrations in water before it enters a processing plant, the dose estimates given in this section likely are high. (No in-plant radionuclide concentration data are available for the treatment plants.)

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 EDs. The EDs for the seven surface water segments are as follows:

- **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 0.1 mrem. The collective ED to the 46,765 persons who drink water from the City of Oak Ridge water plant would be 3 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 0.1 mrem; the collective dose to the 70,666 persons who drink water from this plant could have been 4 person-rem.
- **Upper Clinch River.** There are no known drinking water intakes in this river segment.
- **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 0.03 mrem. The collective dose to the 31,325 persons who drink water from these plants could have been about 0.4 person-rem.
- **Lower system.** Several water treatment plants are located on tributaries of Watts Bar Lake and Chickamauga Lake. An MEI drinking water from those plants could have received an ED of about 0.02 mrem. The collective dose to the 307,526 persons who drink water from the lower system could have been about 3 person-rem.
- **Poplar Creek/lower EFPC.** No drinking water intakes are located on Poplar Creek or on lower EFPC.

Fish Consumption

Fishing is 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, avid fish consumers were assumed to have eaten 27 kg (60 lb) of fish during 2022. The average person used for collective dose calculations was assumed to have consumed 11 kg (24 lb) of fish in 2022. The maximum ED at each location is estimated using one of two methods: the first method uses measured radionuclide concentrations in fish; the second method calculates possible radionuclide concentrations in fish from measured radionuclide discharges and known or estimated streamflows. The number of individuals who could have eaten fish is based on lake creel surveys and commercial fishing reporting conducted annually by the Tennessee Wildlife Resources Agency (TWRA) (TWRA 2019, TWRA 2021, TWRA 2022). Routine fish tissue analyses include gross alpha, gross beta, gamma spectroscopy for gamma emitters, and ^{3}H. Detected and/or statistically significant radionuclides in 2022 included ^{40}K, ^{3}H, ^{90}Sr, ^{230}Th, and ^{232}Th.

In 2022, the maximum EDs from fish consumption at upper Melton Hill Lake and upper Clinch River were determined using measured radionuclide concentrations in fish samples collected at CRK 70 and CRK 32. However, the maximum fish consumption EDs at the remaining locations were estimated using the measured radionuclide concentrations in water to estimate radionuclide concentrations in fish.

- **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 0.7 mrem. The collective ED to the 13 persons who could have eaten fish harvested at that location was about 0.004 person-rem.

- **Melton Hill Lake.** An avid fish consumer who ate fish from Melton Hill Lake could have received an ED of about 0.4 mrem. The collective ED to the 119 persons who could have eaten fish harvested at that location could be about 0.02 person-rem.
- **Upper Clinch River.** An avid fish consumer who ate fish from the upper Clinch River could have received an ED of about 0.5 mrem. The collective ED to the 42 persons who could have eaten fish harvested at that location could have been about 0.008 person-rem.
- **Lower Clinch River.** An avid fish consumer who ate fish from the lower Clinch River could have received an ED of about 0.4 mrem. The collective ED to the 99 persons who could have eaten fish harvested at that location could have been about 0.02 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 0.08 mrem. The collective ED to the 283 persons who could have eaten fish harvested at that location could be about 0.009 person-rem.
- **Lower system.** An avid fish consumer who ate fish from the lower system could have received an ED of about 0.07 mrem. The collective ED to the about 8,650 persons who could have eaten fish harvested at that location could have been about 0.2 person-rem.
- **Poplar Creek/lower EFPC.** An avid fish consumer who ate fish from Poplar Creek/lower EFPC could have received an ED of about 0.1 mrem; it is considered unlikely that a person would consume fish from those locations. Assuming 200 people could have eaten fish from lower EFPC and from Poplar Creek, the collective ED could have been about 0.007 person-rem.

Other Uses

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). Another survey was conducted regarding visitor and property owner activities for Chickamauga and Watts Bar Reservoirs (Poudyal et al. 2017). The data from these surveys 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.

Upper Melton Hill Lake above all possible ORR inputs. A hypothetical maximally exposed other user of upper Melton Hill Lake above possible ORR inputs (CRK 66) could have received an ED of about 2×10^{-5} mrem. The collective ED to the 14,483 other users could have been 2×10^{-5} person-rem.

- **Melton Hill Lake.** An individual other user of Melton Hill Lake could have received an ED of about 0.002 mrem. The collective ED to the 40,044 other users could have been about 0.005 person-rem.
- **Upper Clinch River.** An individual other user of the upper Clinch River could have received an ED of about 0.001 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 0.001 mrem. The collective ED to the 30,599 other users could have been about 0.004 person-rem.
- **Upper Watts Bar Lake.** An individual other user of upper Watts Bar Lake could have received an ED of about 0.0004 mrem. The collective ED to the 87,424 other users could have been about 0.003 person-rem.
- **Lower system (Watts Bar and Chickamauga Lakes).** An individual other user of the lower system could have received an ED of about 0.0003 mrem. The collective ED to the 3,173,423 other users could have been about 0.06 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 0.0002 mrem. The collective ED to the 200 other users of Poplar Creek and lower EFPC could have been about 3×10^{-6} 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 instream 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 1×10^{-7} to 0.1 mrem in 2022. The average instream dose at CRK 16 was estimated to be about 0.04 mrem. Based on all water discharges at CRK 16, the sum of doses was estimated to be 2×10^{-6} mrem. 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. Additionally, the doses are calculated using per capita committed ED coefficients for water and milk ingestion (DOE 2021).

Summary

Table 7.6 summarizes potential EDs from identified waterborne radionuclides around ORR. The estimated maximum individual ED would be about 0.8 mrem to a person obtaining his or her drinking water and annual complement of fish (60 lb) from those water systems and participating in other water uses throughout those systems. The total collective ED from waterborne radionuclides to the population engaging in these activities was estimated to be about 10 person-rem. The relative percentages of individual and collective doses are small; they constitute about 0.3 percent of the average individual background dose of roughly 300 mrem/year and 0.003 percent of the 381,743 person-rem that the 80 km (50 mile) 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, 2022[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	0.1	0.7[d]	0.00002	0.8
Collective	3	0.004[d]	0.00002	3
Melton Hill Lake (CRK 58, Knox County water plant)				
Individual	0.1	0.4	0.002	0.5
Collective	4	0.02	0.005	4
Upper Clinch River (CRK 23, 32)				
Individual	NA[e]	0.5[d]	0.001	0.5
Collective	NA[e]	0.008[d]	0.001	0.01
Lower Clinch River (CRK 16)				
Individual	NA[e]	0.4	0.001	0.4
Collective	NA[e]	0.02	0.004	0.02
Upper Watts Bar Lake (Kingston municipal water plant)				
Individual	0.03	0.08	0.0004	0.1
Collective	0.4	0.009	0.003	0.4
Lower system (lower Watts Bar Lake and Chickamauga Lake)				
Individual	0.02	0.07	0.0003	0.1
Collective	3	0.2	0.06	3
Lower East Fork Poplar Creek and Poplar Creek				
Individual	NA[e]	0.1	0.0002	0.1
Collective	NA[e]	0.007	0.000003	0.007

[a] *1 mrem = 0.01 mSv.*
[b] *Doses based on measured radionuclide concentrations in water or estimated from measured discharges and known or estimated streamflows.*
[c] *Total doses and apparent sums over individual pathway doses may differ because of rounding.*
[d] *Doses based on measured radionuclide concentrations in fish samples.*
[e] *Not at or near drinking water supply locations.*
Acronym: *CRK = Clinch River kilometer*

7.1.2.3. Radionuclides in Food

The CAP-88 PC computer codes are used to calculate radiation doses from ingestion of meat, milk, and vegetables that could potentially contain radionuclides released from ORR.

Milk, vegetables, hay, wildlife, and fish are sampled annually, as available, for analysis to characterize doses from radionuclides that could be consumed in food products that originated at local farms and gardens and in game harvested by hunting and fishing on or near ORR.

Milk

Since 2016, no dairies in potential ORR deposition areas have been located, and no milk samples have been collected. Surveys to identify dairies in potential deposition areas are conducted each year. A small dairy operation located in the vicinity of ORR was identified in 2020, but milk samples could not be to be obtained. No additional suitable locations were identified in 2021 or 2022. Milk sampling will resume when dairy operations in appropriate areas are located.

Vegetables

The food crop sampling program is described in Chapter 6. Samples of leafy greens and root vegetables were not available in 2022, but tomatoes were obtained from three local gardens and one distant background location. The background location was in Claiborne County. Only ^{40}K was detected in tomatoes at all locations. No additional radionuclides were detected in the tomatoes. Potassium-40 is found in the natural environment and may also be emitted from ORR. Potassium-40 concentrations in tomatoes were similar at all garden locations, including the background location. In 2022, a hypothetical person consuming tomatoes at any of these garden locations, including the distant (background) garden location, would not receive a committed ED in excess of that from naturally occurring ^{40}K.

An example of a naturally occurring and fertilizer-introduced radionuclide is ^{40}K, which was identified in the samples and accounted for most of the beta activity. The presence of ^{40}K in the samples added, on average, about 2 mrem to the hypothetical home gardener's ED. In 2022, gardeners who provided vegetable samples were asked about water sources and fertilizers used. Fertilizers were used at two of the three garden locations and at the background location.

Water sources for the gardens typically include city water. Most of the activity found in vegetables is thought to be due to the ^{40}K and to unidentified, naturally occurring beta-emitting radionuclides, not emissions from ORR.

Hay

Another environmental pathway that is typically evaluated is eating beef and drinking milk obtained from hypothetical cattle that eat hay harvested from one location on ORR. Hay samples collected on ORR are normally analyzed for gross alpha, gross beta, gamma emitters, and uranium isotopes. In 2022, statistically significant concentrations of ^{7}Be and ^{40}K were detected in hay samples. Both ^{7}Be and ^{40}K are naturally occurring and are not included in reported EDs from drinking milk and eating beef. Hay samples were not available in 2021, however from 2016 to 2020, the ED from drinking milk and eating beef ranged from 0.0009 mrem to 0.09 mrem.

White-Tailed Deer

The annual deer hunts were cancelled in 2020 and 2021 because of the COVID-19 pandemic but resumed in 2022. In 2022, TWRA conducted three 2-day deer hunts on ORR. (See Sect.6.6.5.) During the hunts, 280 deer were harvested and taken to the TWRA checking station, where a bone sample and a muscle tissue sample were collected from each deer. The samples were field-counted for radioactivity to ensure that the deer met the wildlife release criteria of net counts less than 1.5 times background (~20 pCi/g $^{89/90}$Sr) of beta activity in bone and 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 in 2022.

The average ^{137}Cs concentration in muscle tissue of the 280 released deer was 0.5 pCi/g; the maximum ^{137}Cs concentration in released deer was 0.8 pCi/g. The ^{137}Cs activity in each sample was less than minimum detectable levels. The average weight of released deer was approximately 47 kg (103 lb); the maximum weight was 87 kg (192 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 0.6 mrem.

Potential doses from the consumption of deer that might have moved off ORR and been harvested elsewhere were also evaluated. In this scenario, if an individual consumed one average-weight deer (47 kg [103 lb], assuming that 55 percent of the field weight is edible meat) with the 2022 average field-measured concentration of ^{137}Cs (0.5 pCi/g), that invidiual could have received an ED of about 0.6 mrem. The maximum field-measured ^{137}Cs concentration was 0.8 pCi/g, and the maximum deer weight was 87 kg (192 lb). If an individual consumed a deer of maximum weight and ^{137}Cs

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

content, that individual could have received an ED of about 2 mrem.

In 2022, muscle tissue samples from seven released deer were collected and analayzed for radionuclides. Analyses included ^{137}Cs, ^{90}Sr, and ^{40}K. Comparison of the released-deer field results with analytical ^{137}Cs concentrations showed that the field concentrations were greater than the analytical results and that all concentrations were less than the administrative limit of 5 pCi/g (ORNL 2011; ORNL 2020).[1] Using the analytical results for ^{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 1 mrem.

The maximum ED to an individual consuming venison from two or three deer was also evaluated. Thirty-three hunters harvested either two or three deer from ORR. Based on ^{137}Cs concentrations determined by field counting and actual field weights, the ED to a hunter who consumed two or more deer was estimated to be between about 0.4 and 2 mrem.

The collective ED from eating venison from all the deer harvested on ORR in 2022 is estimated to be about 0.2 person-rem based on the 2022 average field-derived ^{137}Cs concentration of 0.5 pCi/g and an average weight of 47 kg (103 lb). The collective dose is based on number of harvested deer. Additional individuals may also have consumed the harvested venison, but the collective dose would be essentially the same.

Canada Geese

Sixteen geese were captured during the 2022 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 0.3 pCi/g. The maximum ^{137}Cs concentration in the released geese was 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 2.7 kg (6 lb), and the maximum weight was about 4.3 kg (9.5 lb).

The EDs attributed to field-measured ^{137}Cs concentrations of the geese ranged from 0.017 to 0.019 mrem. However, for bounding purposes, if a person consumed a released goose with an average weight of 2.7 kg (6 lb) and an average ^{137}Cs concentration of 0.3 pCi/g, the estimated ED would be approximately 0.02 mrem. About half the weight of a Canada goose is assumed to be edible. The estimated ED would be about 0.04 mrem for an individual who consumed a goose with the maximum ^{137}Cs concentration of 0.4 pCi/g and maximum weight of 4.3 kg (9.5 lb).

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 ranged from 1.9 to 3.0 geese per hunting season between 1999 and 2010 (TWRA 2010). Hypothetically, a person who consumed two geese of maximum weight with the highest measured concentration of ^{137}Cs, would 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 potential dose, omitting the contribution of naturally occurring ^{40}K, ranged from 0.01 to 0.5 mrem. The average potential dose was 0.2 mrem (EP&WSD 2010).

Eastern Wild Turkey

Wild turkey hunts scheduled on ORR for 2020 through 2022 were canceled because of the COVID-19 pandemic. Typically, hunters are permitted to harvest one turkey from the reservation in each hunting season. Harvested turkeys are field-counted for radioactivity to ensure that they meet wildlife release criteria (< 5 pCi/g of ^{137}Cs in tissue). If the release criteria are not met, the turkey is retained, and the hunter is permitted to harvest another turkey.

No turkeys were retained from 2015 through 2019. The average weights of the released turkeys for those years ranged from 8.1 kg (17.8 lb) to 8.9

kg (19.5 lb) and the maximum weights ranged from 10 kg (22 lb) to 11.3 kg (25 lb). The average ^{137}Cs concentration in turkeys harvested on ORR from 2015 through 2019 was 0.1 pCi/g; maximum concentrations ranged from 0.16 to 0.3 pCi/g. Almost all ^{137}Cs concentrations were below minimum detectable activity levels.

The EDs attributed to ^{137}Cs concentrations from field-measurementson on turkeys harvested from 2015 through 2019 ranged from 0.004 to 0.04 mrem. For bounding purposes, if a person consumed an average weight released turkey with an average ^{137}Cs concentration during years 2015 through 2019, the estimated ED would have been approximately 0.02 mrem. About half the weight of a turkey is assumed to be edible. The estimated ED to an individual who consumed a turkey assumed to have the maximum ^{137}Cs concentration and maximum weight ranged from about 0.04 to 0.08 mrem.

No tissue samples were analyzed from 2015 through 2019, and hunts scheduled on ORR for 2020 through 2022 were canceled. 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, omitting the contribution of naturally occurring ^{40}K, ranged from 0.06 to 0.2 mrem (EP&WSD 2010).

7.1.2.4. 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). Because of radiological activities on ORR, external radiation exposure rates are measured at six of the ORR ambient air monitoring stations and at Station 52, the reference ambient air station (Figure 6.2). External gamma exposure rates were continuously recorded by dual-range Geiger-Müller tube detectors colocated with ORR ambient air stations. In 2022, exposure rates averaged about 9.4 μR/h and ranged from 8.0 to 12.8 μR/h. The exposure rates correspond to an annual average dose of about 58 mrem with a range of 49 to 79 mrem. At the background ambient air station, the exposure rate averaged about 9 μR/h and ranged from 8.0 to 11.4 μR/h. The resulting average annual dose was about 54 mrem with a range of 49 to 70 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 ambient air monitoring Stations 11 and 46.

7.1.3. Current-Year Summary

A summary of the maximum EDs to individuals by exposure pathway is given in Table 7.7. In the unlikely event that any person was exposed to all those sources and pathways for the duration of 2022, that person could have received a total ED of about 3 mrem. Of that total, 0.2 mrem would have come from airborne emissions, approximately 0.9 mrem from waterborne emissions (0.1 mrem from drinking water, 0.7 mrem from consuming fish, 2×10^{-5} mrem from other water uses along the Clinch River, and 0.1 mrem from irrigation at CRK 16), and about 2 mrem from consumption of wildlife. Direct radiation measurements at six ORR ambient air monitoring stations were at or near background levels in 2022. There are no known significant doses from discharges of radioactive constituents from ORR other than those reported.

7.1.4. Five-Year Trends

EDs associated with selected exposure pathways for 2018 through 2022 are given in Table 7.8. In 2022, the air pathway dose decreased but is similar to air pathway doses that have been estimated over the past 5 years. 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 although results were generally lower, there was not a statistically significant difference, and the original results were used in dose calculations. The increase in fish consumption and drinking

water doses in 2021 was due to the contribution of ^{241}Am detected in the second-quarter water sample taken at CRK 58. Recent direct radiation measurements indicate doses near background levels. Doses from consumption of wildlife have been similar for the last 5 years, although the dose from consumption of geese increased slightly in 2021.

7.1.5. Doses to Aquatic and Terrestrial Biota

The following sections summarize the results of assessments conducted to determine the potential effect of radionuclides originating from ORR on aquatic and terrestrial biota.

7.1.5.1. Aquatic Biota

DOE Order 458.1 (DOE 2020) 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 (Version 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.

Table 7.7. Summary of maximum estimated effective doses from ORR activities to an adult by exposure pathway, 2022

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	0.2	0.002	0.2	11.5	0.115		1,272,478[b]
Liquid effluents							
Drinking water	0.1	0.001	0.1	10	0.1		456,282[c]
Eating fish	0.7	0.007	0.7	0.3	0.003		9,406[d]
Other activities	2×10^{-5}	2×10^{-7}	2×10^{-5}	0.07	0.007		3,359,287[d]
Irrigation	0.1	0.001	0.1				
Other pathways							
Eating deer	2[e]	0.02[e]	2	0.2[e]	0.002[e]		
Eating geese	0.1[f]	0.001[f]	0.1	g	g		
Eating turkeys	h	h	h	h	h		
Direct radiation	NA[i]	NA					
All pathways							
Total	3[i]	0.03	3	22	0.22	381,743	

[a] *Estimated background collective dose is based on the roughly 300 mrem/year individual dose and the population within 80 km (50 mi) of ORR.*

[b] *Population is based on 2020 census data.*

[c] *Population estimates are based on community and noncommunity drinking water supply data from the Tennessee Department of Environment and Conservation Division of Water.*

[d] *Population estimates for fish are based on creel and commercial fishing data. Fractions of fish harvested from Melton Hill, Watts Bar, and Chickamauga Reservoirs are based on creel survey data. 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 visitors that may live outside the 80 km radius.*

[e] *Estimates for eating deer are based on consuming one hypothetical deer of the heaviest weight measured among the captured deer and with the highest ^{137}Cs concentration measured in the released deer on ORR; collective dose is based on number of harvested deer.*

[f] *Estimates for eating geese are based on consuming two hypothetical geese, each with the heaviest weight measured among the captured geese and with the highest measured concentration of ^{137}Cs in the 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] *No turkeys were harvested on ORR during 2022 because of the COVID-19 pandemic.*

[i] *Current exposure rate measurements at perimeter air monitoring stations are at or near background levels.*

[i] *Dose estimates have been rounded.*

Acronyms:

DOE = US Department of Energy

ORR = Oak Ridge Reservation

Table 7.8. Trends in effective dose from ORR activities, 2018–2022 (mrem)[a]

Pathway	2018	2019	2020	2021	2022
Airborne Effluents—all pathways	0.2	0.4	0.4	0.5	0.2
Fish consumption (Clinch River)	0.09	4	2	3	0.4
Drinking water (Kingston)	0.03	0.01	0.02	3	.03
Deer	2	2	*b*	*b*	*2*
Geese	0.1	0.1	0.07	0.2	0.1
Turkeys	0.05	0.04	*b*	*b*	*b*

[a] *1 mrem = 0.01 mSv*

[b] *Wild turkey hunts scheduled on ORR for 2020 through 2022, and deer hunts for 2020 and 2021, were canceled because of the COVID-19 pandemic.*

Acronym: *ORR = Oak Ridge Reservation*

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, protecting the more sensitive organisms is generally assumed to adequately protect other, less sensitive organisms. Depending on the radionuclide, either aquatic organisms (e.g., crustaceans) or riparian organisms (e.g., raccoons) may be more sensitive and are typically the limiting organisms for the general screening phase of the graded approach for aquatic system evaluations.

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

- Melton Branch (X13) and Melton Branch Weir
- WOC headwaters (WOC 6.8), WOC (X14), and White Oak Dam (WOD) (X15)
- WOC 7500 Bridge
- First Creek
- Fifth Creek
- Northwest Tributary
- Raccoon Creek

- Solid Waste Storage Area 4 SW1(tributary to WOC)
- Waste Area Grouping 6 Monitoring Station 3 (tributary to WOC at WOD)
- CRK 16, 32, 58, and 66

Based on the results of the general screening phase, in which the maximum concentrations of radionuclides in water are compared with default BCGs, the absorbed dose rates to aquatic organisms at all ORNL locations were below the DOE aquatic dose limit of 1 rad/day.

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
- Discharge Point S24
- Discharge Point S17 (unnamed tributary to the Clinch River)
- Discharge Point S19 (Rogers Quarry)
- Outfall 200 on EFPC

Absorbed dose rates to aquatic organisms at the Y-12 locations were below the DOE aquatic dose limit of 1 rad/day based on general screenings or second-level screenings at the Surface Water Hydrological Information Support System Station 9422-1 and Outfall 200.

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)
- CRK 16 and 23

Absorbed dose rates to aquatic organisms were below the DOE aquatic dose limit of 1 rad/day at the ETTP sampling locations based on general screening results.

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 2020). An absorbed dose rate of 0.1 rad/day is recommended as the limit for terrestrial animal exposure to radioactive material in soils. RESRAD-Biota code (Version 1.8), a companion tool for implementing DOE technical standard *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota* (DOE 2019), was used for the terrestrial organism assessment to demonstrate compliance with this limit. As is the case with aquatic and riparian biota, certain terrestrial organisms are more sensitive to ionizing radiation than others, and it is generally assumed that protecting the more-sensitive organisms will adequately protect other, less-sensitive organisms.

Initial soil sampling for terrestrial dose assessment was initiated in 2007 and was reassessed in 2014 and 2021. Additionally, 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. ORR site-specific bioaccumulation factors were calculated using 2007 and 2014 maximum soil concentrations and radionuclide concentrations in tissue for biota inhabiting the WOC floodplain.

In 2007, 2014, and 2021, 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. This biota sampling strategy was developed using 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 2021, soil samples were collected from the same general locations as those collected in 2007 and 2014. Soil sampling locations are identified as follows:

- **WOC floodplain.** Analytes detected in soil samples at this location in 2021 include ^{241}Am, ^{137}Cs, ^{60}Co, $^{243/244}$Cm, ^{238}Pu, $^{239/240}$Pu, ^{40}K, $^{89/90}$Sr, $^{233/234}$U, ^{235}U, and ^{238}U.
- **Mitchell Branch floodplain.** Analytes detected in soil samples at this location in 2021 include ^{241}Am, $^{239/240}$Pu, ^{99}Tc, $^{233/234}$U, and ^{238}U.
- **Bear Creek Valley floodplain.** Analytes detected in soil samples at this location in 2021 include ^{241}Am, $^{243/244}$Cm, $^{233/234}$U, ^{235}U, and ^{238}U.
- **EFPC floodplain.** Analytes detected in soil samples at this location in 2021 include $^{233/234}$U, ^{235}U, and ^{238}U.
- **Background locations.** Soils were also sampled in 2021 near Gum Hollow Branch, which represents Conasauga group geologic formations, and near Bearden Creek, which represents Chickamauga group geologic formations. Analytes detected in soil samples at the background locations in 2021 include ^{241}Am, ^{137}Cs, $^{239/240}$Pu, ^{40}K, $^{89/90}$Sr, $^{233/234}$U, ^{235}U, and ^{238}U.

In 2021, all soil samples except for those collected on the WOC floodplain upstream of WOD passed the initial-level screening (a comparison of maximum radionuclide soil concentrations to default BCGs). Cesium-137 was the primary dose contributor to terrestrial biota on the WOC floodplain and was also the primary dose contributor in 2007 and 2014. Strontium-90 also contributed significantly to wildlife dose on the WOC floodplain in 2021 but to a lesser extent than ^{137}Cs. Because of measured concentrations in soil on the WOC floodplain and results of second-level screening (comparison of average radionuclide soil concentrations to default BCGs), further evaluation was completed using ORR site-specific bioaccumulation factors and average radionuclide soil concentrations. The results of additional screening evaluation indicated that absorbed dose rates to terrestrial organisms on the WOC floodplain were less than the DOE limit of 0.1 rad/day.

Future evaluations of exposure to terrestrial organisms will be conducted within the next 5 years or sooner if an abnormal event occurs that could have adverse impacts on terrestrial organisms.

7.2. Chemical Dose

Chemicals released because of ORR operations can move through the environment to off-site locations, resulting in potential exposure of the public. The following sections summarize the results of risk assessments for chemicals found in drinking water and fish on or near ORR.

7.2.1. Drinking Water Consumption

Surface water and groundwater are both potential sources of drinking water for populations in areas adjacent to ORR. Samples of surface water and groundwater are collected from water sources near ORR and are analyzed for their chemical content to determine the presence and concentration of chemicals that could pose a health risk for the local population.

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 to the Clinch River (Table 7.9).

The HQ is a ratio that compares the estimated exposure dose or intake to the reference dose for noncarcinogens. HQs 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, the drinking water consumption rate for the MEI is assumed to be 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.

Nearly all calculated HQs and risk levels for carcinogens (Table 7.9) for CRK 16 and CRK 23 are based on water concentration values reported as the detection limit of the instrumentation and analysis method used except for chromium at CRK 23; nickel at CRK 16; and copper, mercury, and uranium at CRK 16 and CRK 23. At all locations, HQs were less than 1 for chemical analytes in water for which there are reference doses or maximum contaminant levels (Table 7.9). In 2022, mercury concentrations were measured at CRK 66, CRK 32, and CRK 16 using a more sensitive analysis method with a lower reporting limit than was used in previous years. HQs were 2×10^{-4} for CRK 66 and 1×10^{-4} for CRK 32 in 2022. For carcinogens, risk values greater than 10^{-6} were calculated for the hypothetical intake of drinking water containing chromium (as Cr^{+6}), arsenic, and vinyl chloride at locations CRK 23 and 16. The estimated risk values are within the EPA's acceptable risk range of 10^{-4} to 10^{-6}. CRK 16, located downstream of all ORR discharge points, is not a source of drinking water, but data from that location were used as surrogates to evaluate potential exposure to drinking water from the Clinch River.

Table 7.9. Chemical hazard quotients and estimated risks for drinking water from the Clinch River at CRK 23 and 16, 2022

Analyte	Hazard quotient	
	CRK 23[a]	CRK 16[b]
Metals		
Antimony	4×10^{-2}	4×10^{-2}
Arsenic	1×10^{-1}	1×10^{-1}
Cadmium	7×10^{-3}	7×10^{-3}
Chromium	9×10^{-3}	8×10^{-3}
Copper	4×10^{-4}	4×10^{-4}
Lead	9×10^{-2}	9×10^{-2}
Mercury	3×10^{-5}	1×10^{-3}
Nickel	6×10^{-4}	6×10^{-4}
Selenium	7×10^{-3}	7×10^{-3}
Silver	1×10^{-3}	1×10^{-3}
Thallium	3×10^{-1}	3×10^{-1}
Uranium	3×10^{-2}	3×10^{-2}
Zinc	2×10^{-4}	2×10^{-4}
Volatile organics		
1,1,1-Trichloroethane	4×10^{-6}	4×10^{-6}
Acetone	c	3×10^{-4}
cis-1,2-Dichloroethene	4×10^{-3}	4×10^{-3}
Trichloroethene	2×10^{-2}	2×10^{-2}
Vinyl chloride	3×10^{-3}	3×10^{-3}
Risks for carcinogens		
Arsenic	2×10^{-5}	2×10^{-5}
Chromium	5×10^{-6}	4×10^{-6}
Lead	4×10^{-8}	4×10^{-8}
Trichloroethene	1×10^{-7}	1×10^{-7}
Vinyl chloride	4×10^{-6}	4×10^{-6}

[a] *CRK 23 is no longer a water intake location.*
[b] *CRK 16 is downstream of all DOE inputs to the Clinch River and not a water intake location.*
[c] *The parameter was undetected.*
Acronym:
CRK = Clinch River kilometer

7.2.1.2. Groundwater

During FY 2022, OREM continued to collect and analyze samples from the off-site groundwater monitoring well array west of the Clinch River adjacent to Melton Valley (see Section 6.5). 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, avid fish consumers were assumed to have eaten 27 kg (60 lb) of fish during 2022. This fish consumption rate of 74 g/day (27 kg/year) is assumed for estimating exposure to 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.

For consumption of sunfish and catfish, HQs of less than 1 were calculated for all detected analytes except for Aroclor-1254 (CRK 16) and Aroclor-1260 (CRK 32 and CRK 16) in catfish (Table 7.10). For carcinogens, risk values at or greater than 10^{-6} were calculated for the intake of Aroclor-1254 (CRK 16) and Aroclor-1260 (CRK 32 and CRK 16) in catfish. 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) or the Tennessee River portion of Watts Bar Reservoir because of PCB contamination (TDEC 2022). TDEC has also issued a precautionary fish consumption advisory for catfish in the Clinch River arm of Watts Bar Reservoir (TDEC 2022).

Table 7.10. Chemical hazard quotients and estimated risks for fish caught and consumed from locations on ORR, 2022[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			0.002			
Copper	0.003	0.002	0.002	0.003	0.007	
Iron					0.008	
Manganese	0.001	0.002	0.02	0.002	0.002	0.001
Mercury					0.6	
Selenium	0.1	0.08	0.06			
Strontium			0.007			
Zinc	0.03	0.01	0.03	0.009	0.03	0.01
Hazard quotients for Aroclors						
Aroclor-1254						9
Aroclor-1260					3	11
Risks for carcinogens						
Aroclor-1254						1×10^{-4}
Aroclor-1260					4×10^{-5}	2×10^{-4}
PCBs (mixed)[e]					4×10^{-5}	3×10^{-4}

[a] *Blank space for a location indicates that the parameter was undetected.*
[b] *Melton Hill Reservoir, reference location 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 PCBs comprise the summation of Aroclors detected or estimated.*
Acronyms:
CRK = Clinch River kilometer
ORR = Oak Ridge Reservation
PCB = polychlorinated biphenyl

7.3. References

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