Radionuclides discharged to surface waters on ORR can potentially reach members of the public who drink water, eat fish, swim, and boat along the Clinch and Tennessee Rivers. 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.

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 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 2021, a hypothetical maximally exposed individual (MEI) could have received an effective dose (ED) of about 0.5 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 7 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 geese (containing the maximum ^{137}Cs concentration and maximum weight), that person could have received an ED of about 0.2 mrem. This calculation provides an estimated upper-bound ED from consuming wildlife harvested from ORR during 2021. Deer and turkey hunts normally conducted on ORR were canceled in 2021 due to the COVID-19 pandemic.

Therefore, the annual dose for 2021 to an MEI from the combined exposure pathways was estimated to be about 8 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 an individual member of the public may receive from all radionuclide exposure pathways during 1 year to no more than 100 mrem. The 2021 maximum ED from ORR was about 8 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 2021. 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. 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 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 (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

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 2021 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 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 28 emission points on ORR were modeled during 2021. The total includes 3 (2 combined) points at Y-12, 24 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 2021 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 2021, rainfall, as averaged over the six rain gauges located on ORR, was about 150.8 cm (59 in.). The average air temperature was 15.0°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 696.0 m (2,284 ft) for ETTP, 676.4 m (2,219 ft) for ORNL, and 734.2 m (2,409 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 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 7.1. Emission point parameters and receptor locations used in the dose calculations, 2021

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	4,460	SW	9,990	NE
X-2000	15	0.5	0	4,810	SW	9,640	NE
X-3000	15	0.5	0	5,210	SW	9,250	NE
X-4000	15	0.5	0	5,390	SW	9,100	NNE
X-6000	15	0.5	0	5,970	SW	8,550	NNE
X-7000	15	0.5	0	5,450	WSW	9,560	NNE
X-2026	22.9	1.05	7.75	4,920	SW	9,510	NE
X-2099	3.66	0.18	16.42	4,910	SW	9,520	NE
X-3001	6.86	0.44	7.50	5,120	SW	9,320	NE
X-3018	61	1.75	0.95	5,140	SW	9,300	NE
X-3020	61	1.22	13.59	5,080	SW	9,360	NE
X-3026-East	0.81	0.97	0[b]	5,130	SW	9,330	NE
X-3026-West	0.81	0.97	0[b]	5,130	SW	9,330	NE
X-3039	76.2	2.44	5.36	5,150	SW	9,300	NE
X-3544	9.53	0.28	24.80	4,930	SW	9,570	NNE
X-3571	3.35	0.29	0[b]	5,060	SW	9,420	NNE
X-3608 filter press	8.99	0.36	9.27	5,060	SW	9,470	NNE

Table 7.1. Emission point parameters and receptor locations used in the dose calculations, 2020 (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-4501	19.81	0.71	9.89	5,330	SW	9,150	NNE
X-7503	30.5	0.91	13.15	5,460	SW	9,390	NNE
X-7830 group	4.6	0.25	9.70	4,090	WSW	10,910	NNE
X-7856-CIP	18.29	0.48	10.84	4,100	WSW	10,980	NNE
X-7877	13.9	0.41	13.56	4,070	WSW	10,970	NNE
X-7880	27.7	1.52	15.38	4,030	WSW	10,990	NNE
X-7911	76.2	1.52	14.26	5,400	WSW	9,620	NNE
X-7935 building stack	15.24	0.51	27.18	5,400	WSW	9,540	NNE
X-7935 glove box	9.14	0.25	0[b]	5,400	WSW	9,540	NNE
X-7966	6.10	0.29	6.40	5,480	WSW	9,460	NNE
X-8915	104.0	1.22	7.24	8,150	SW	6,280	NE
X-decom areas	15	0.5	0	5,430	SW	9,060	NNE
ETTP							
K-1407-AL CWTS	2.74	0.15	0[b]	210	SSE	13,450	ENE
Y-12 Complex							
Y-monitored	20	0.5	0	2,270	NE	1,090	NNE
Y-unmonitored processes	20	0.5	0	2,270	NE	1,090	NNE
Y-unmonitored lab hoods	20	0.5	0	2,270	NE	1,090	NNE

[a] *Exit gas temperatures are "ambient air."*
[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
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 (1) MEIs and (2) for the collective population (1,172,530 persons) residing within 80 km (50 miles) of ORR, based on 2010 census data (DOC 2012). CAP-88 PC Version 4 was used in 2021 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 1,090 m (0.7 miles) north-northeast of the main Y-12 release point, about 9,620 m (6.0 miles) north-northeast of the 7911 stack at ORNL, and about 13,450 m (8.4 miles) 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 0.5 mrem, which is well below the National Emission Standards for Hazardous Air Pollutants for Radionuclides standard of 10 mrem and is about 0.2 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 22.7 person-rem, which is about 0.006 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 7.2. Meteorological towers and heights used to model atmospheric dispersion from source emissions, 2021

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
MT3 (Tower B)	15	X-6000 lab hoods
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, X-4501
	60	X-3018, X-3020, and X-3039
MT12 (Tower F)	10	X-8515 (SNS)

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
SNS = Spallation Neutron Source
Y-12 Complex = Y-12 National Security Complex

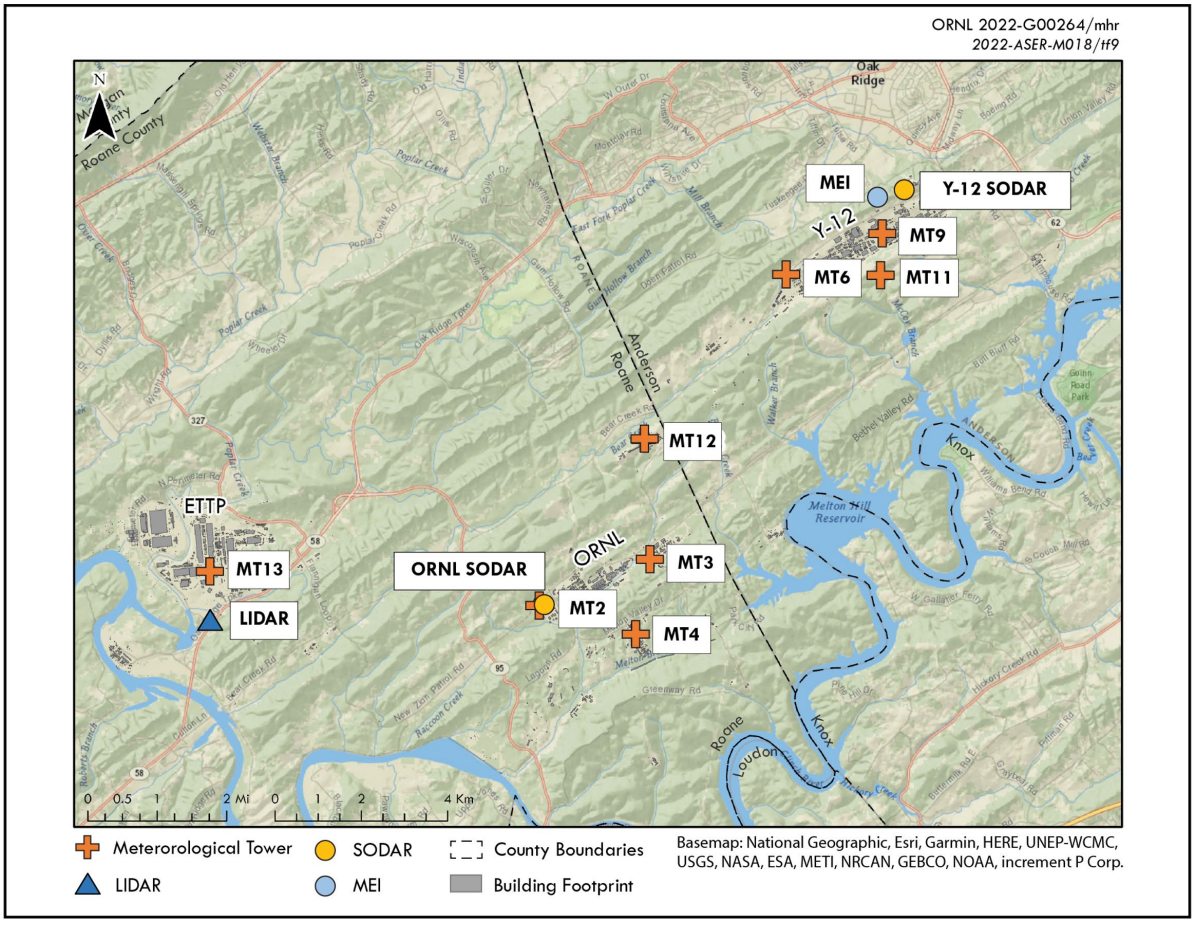

Figure 7.1. Location of the maximally exposed individual for ORR, 2021

Table 7.3. Calculated radiation doses to maximally exposed individuals from airborne releases from ORR, 2021

Plant	Maximum effective dose, mrem (mSv)			
	From each site		From ORR	
	mrem	mSv	mrem	mSv
ORNL	0.45[a]	0.0045	0.2	0.002
ETTP	0.0002[b]	2×10^{-6}	2×10^{-6}	2×10^{-8}
Y-12 Complex	0.3[c]	0.003	0.3	0.003
Entire ORR	*d*	*d*	0.5[e]	0.005

[a] *The MEI was located 5,150 m SW of X-3039 and 5,400 m WSW of X-7911.*
[b] *The MEI was located 210 m SSE of K-1407-AL Chromium Water Treatment System.*
[c] *The MEI was located 2,270 m NE of Y-12 Complex release point.*
[d] *Not applicable.*
[e] *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 6,280 m NE of X-8915.*

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, 2021

Plant	Collective effective dose[a]	
	Person-rem	Person-Sv
ORNL	18.4	0.184
ETTP	0.0002	2×10^{-6}
Y-12 Complex	4.3	0.043
Entire ORR	22.7	0.227

[a] *Collective effective dose to the 1,172,530 persons residing within 80 km (50 miles) of the ORR (based on 2010 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 2,270 m (1.4 miles) northeast of the main Y-12 release point. This individual could have received an ED of about 0.3 mrem from Y-12 airborne emissions. Uranium radioisotopes (i.e., ^{233}U, ^{234}U, ^{235}U, ^{236}U, and ^{238}U) accounted for about 95 percent, and other radionuclides accounted for about 5 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 4.3 person-rem, which is about 19 percent of the collective ED for ORR.

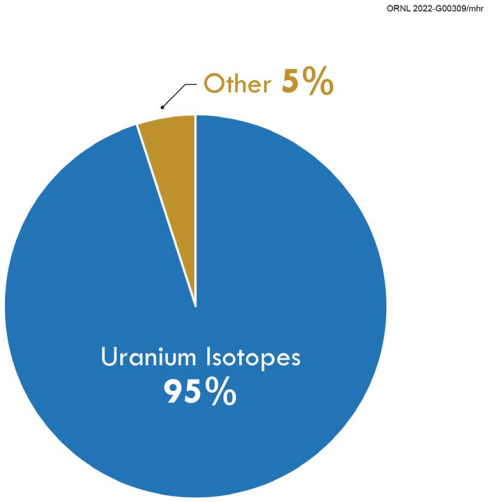

Figure 7.2. Nuclides contributing to effective dose at Y-12 Complex, 2021

The MEI for ORNL was located at a residence about 5,150 m (3.2 miles) southwest of the 3039 stack and 5,400 m (3.4 miles) west-southwest of the 7911 stack. This individual could have received an ED of about 0.45 mrem from ORNL airborne emissions. Lead-212 contributed about 55 percent, ^{138}Cs contributed about 14 percent, ^{11}C contributed about 6 percent, and ^{41}Ar contributed about 5 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 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 miles) of ORR was calculated to be about 18.4 person-rem or about 81 percent of the collective ED for ORR.

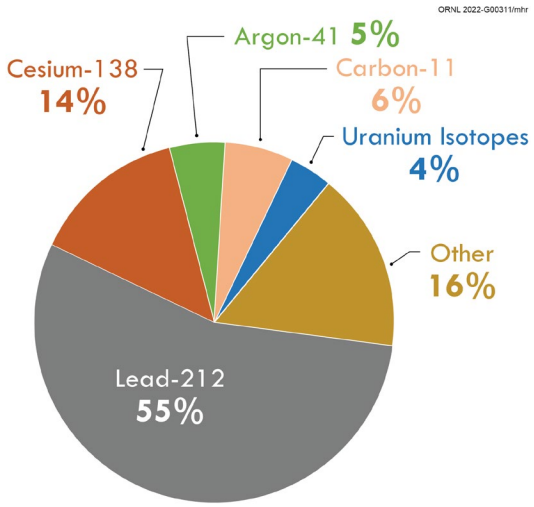

Figure 7.3. Nuclides contributing to effective dose at ORNL, 2021

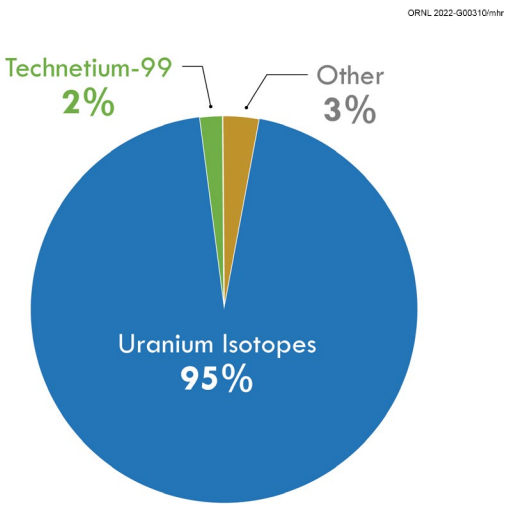

Figure 7.4. Nuclides contributing to effective dose at ETTP, 2021

The MEI for ETTP was located at a business about 210 m (0.1 miles) south-southeast of the K-1407-AL CWTS. The ED received by this individual from airborne emissions was calculated to be about 0.0002 mrem. About 95 percent of the dose is from uranium radioisotopes (^{233}U, ^{234}U, ^{235}U, ^{236}U, and ^{238}U), about 3 percent of the dose is from progeny of uranium isotopes, and about 2 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 0.0008 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 addition to analyses for gross alpha, gross beta, gamma emitters, isotopic uranium, and tritium, an expanded list of radionuclides are included in the analytical suite every 5 years.

In 2021, in addition to tritium and isotopes of uranium, detected radionuclides at ORR ambient air stations included ^{241}Am, ^{214}Bi, $^{243/244}$Cm, ^{214}Pb, ^{237}Np, $^{238/239/240}$Pu, ^{89}Sr, and $^{228/230/232}$Th.

Based on measured air concentrations, hypothetical individuals assumed to reside at the ambient air stations could have received EDs between 0.01 and 0.03 mrem/year, while EDs calculated using CAP-88 PC Version 4 and emissions data were between 0.1 and 1.1 mrem/year. As shown in Table 7.5, EDs calculated using CAP-88 PC Version 4 and emissions data were greater than EDs calculated using measured air concentrations at all monitoring stations.

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 2021. No ^{99}Tc was detected at the background location but was detected in the sample at Station 35. Based on measured air concentrations, the ED at Station 52 was estimated to be 0.01 mrem/year (the naturally occurring 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 0.03 mrem/year.

Table 7.5. Hypothetical effective doses from living near ORR and ETTP ambient air monitoring stations, 2021

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	0.01	0.0001	0.7	0.007
2	0.01	0.0001	0.5	0.005
3	0.01	0.0001	1.1	0.011
11	0.02	0.0002	0.5	0.005
35[b]	0.03	0.0003	0.1	0.001
37	0.01	0.0001	0.3	0.003
40	0.02	0.0002	0.6	0.006
46	0.01	0.0001	0.3	0.003
49	0.01	0.0001	0.3	0.003
52[b,c]	0.01	0.0001	0.03	0.0003
		ETTP		
K11	*d*	*d*	0.06	0.0006
K12	9×10^{-7}	9×10^{-9}	0.06	0.0006

[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 2021, analysis to detect ^{99}Tc was requested for Stations 35 and 52.*
[c] *Background ambient air monitoring station.*
[d] *No radionuclides were detected during 2021 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 are significantly less than EDs calculated using source emissions data.

- Station 11 is located near the off-site MEI for ORNL. The ED calculated with measured air concentrations was 0.02 mrem/year, and the ED estimated using source emissions data was 0.5 mrem/year.
- Station 40 is located near the off-site MEI for the Y-12 Complex. The ED calculated with measured air concentrations was 0.02 mrem/year, and the ED estimated using source emissions data was 0.6 mrem/year.
- Station K11 is located near the on-site MEI for ETTP. There were no detected radionuclide air concentrations at the ETTP station K11 in 2021; however, the ED calculated using source emissions data was 0.06 mrem/year.
- Station 46 is located near the off-site MEI for the ORR. The ED calculated with measured air concentrations was 0.01 mrem/year, and the ED estimated using source emissions data was 0.3 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 use the Clinch and Tennessee Rivers for drinking the water, fishing, swimming, boating, and other shoreline uses.

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 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 6.6.4).

The second method calculates possible radionuclide concentrations in water and fish from measured radionuclide discharges and known or estimated streamflows. 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), and the doses are calculated using per capita committed ED coefficients for water ingestion (DOE 2021). Utilizing the two methods to estimate potential doses takes into account both 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 2021 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. 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. Additionally, as discussed in Section 6.4.2, ^{241}Am was detected in 2021 in the second quarter water sample collected from Clinch River kilometer (CRK) 58, which is located upstream of all DOE inputs.

Am-241 was not detected in samples from other surface water sampling locations and had not previously been detected at CRK 58. There were no further ^{241}Am detections in samples collected in the third or fourth quarters of 2021. Available data indicates that laboratory contamination was the likely source of the detected ^{241}Am; however, a conservative approach was taken, and the reported concentration was used in dose calculations. Because CRK 58 is upstream of ORR inputs into the Clinch River, all water-related doses for locations downstream of CRK 58 calculated using measured radionuclide concentrations increased significantly in 2021. 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.

- **Upper Melton Hill Lake above all possible ORR inputs.** Based on samples from Melton Hill Lake above possible ORR inputs (at CRK 66 near the City of Oak Ridge Water Intake Plant), an MEI drinking water at this location could have received an ED of about 0.03 mrem. The collective ED to the 48,535 persons who drink water from the City of Oak Ridge Water Plant would be 0.8 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 3 mrem; the collective dose to the 65,346 persons who drink water from this plant could have been 91 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 0.5 mrem. The collective dose to the 31,958 persons who drink water from these plants could have been about 8 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 0.4 mrem. The collective dose to the 315,054 persons who drink water within the lower system could have been about 53 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, it was assumed that avid fish consumers would have eaten 27 kg (60 lb) of fish during 2021. For the average person used for collective dose calculations, it was assumed that 11 kg (24 lb) of fish was consumed in 2021. The estimated maximum ED at each location 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 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 2019, TWRA 2021a, TWRA 2021b). Routine fish tissue analyses include gross alpha, gross beta, gamma

spectroscopy for gamma emitters, and tritium. Additional radionuclide analyses are performed every 5 years, and because several of these analytes were detected in 2019, they were also included in the 2020 analytical suite. Additional detected radionuclides in 2019 and 2020 included ^{241}Am, ^{237}Np, ^{238}Pu, $^{239/240}$Pu, ^{90}Sr, ^{228}Th, ^{230}Th, ^{232}Th, ^{234}U, and ^{238}U. Based on the 2019 and 2020 detections and the resulting fish ingestion dose, additional radionuclide analyses were performed again in 2021.

In 2021, the maximum ED from fish consumption at Upper Melton Hill Lake was determined using measured radionuclide concentrations in fish samples collected at CRK 70. However, the maximum fish consumption EDs at the remaining locations downstream of CRK 58 were estimated using the measured radionuclide concentrations in water to estimate radionuclide concentrations in fish. The CRK 58 radionuclide water concentrations included contributions from ^{241}Am detected in the water sample in the second quarter of 2021.

- **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 0.9 mrem. The collective ED to the 13 persons who could have eaten fish harvested at that location was about 0.005 person-rem.
- **Melton Hill Lake.** An avid fish consumer who ate fish from Melton Hill Lake could have received an ED of about 3 mrem. The collective ED to the 119 persons who could have eaten fish harvested at that location could be about 0.2 person-rem.
- **Upper Clinch River.** An avid fish consumer who ate fish from the upper Clinch River could have received an ED of about 3 mrem. The collective ED to the 42 persons who could have eaten fish harvested at that location could have been about 0.05 person-rem.
- **Lower Clinch River.** An avid fish consumer who ate fish from the lower Clinch River could have received an ED of about 3 mrem. The collective ED to the 99 persons who could have eaten fish harvested at that location could have been about 0.1 person-rem.
- **Upper Watts Bar Lake.** An avid fish consumer who ate fish from upper Watts Bar Lake could have received an ED of about 0.5 mrem. The collective ED to the 283 persons who could have eaten fish harvested at that location could be about 0.06 person-rem.
- **Lower System.** An avid fish consumer who ate fish from the lower system could have received an ED of about 0.5 mrem. The collective ED to the about 9,578 persons who could have eaten fish harvested at that location could have been about 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 0.2 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 0.01 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). 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. Doses listed for locations downstream of CRK 58 include contributions from ^{241}Am detected in the water sample collected from CRK 58 in the second quarter of 2021.

- **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 0.004 mrem. The collective ED to the 14,483 other users could have been 0.005 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 0.008 person-rem.
- **Upper Clinch River.** An individual other user of the upper Clinch River could have received an ED of about 0.004 mrem. The collective ED to the 13,114 other users could have been about 0.005 person-rem.
- **Lower Clinch River.** An individual other user of the lower Clinch River could have received an ED of about 0.004 mrem. The collective ED to the 30,599 other users could have been about 0.01 person-rem.
- **Upper Watts Bar Lake.** An individual other user of upper Watts Bar Lake could have received an ED of about 0.001 mrem. The collective ED to the 87,424 other users could have been about 0.008 person-rem.
- **Lower system (Watts Bar and Chickamauga Lakes).** An individual other user of the lower system could have received an ED of about 0.001 mrem. The collective ED to the 3,173,423 other users could have been about 0.2 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 5×10^{-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 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 1.4 mrem in 2021. The average instream dose at CRK 16 based on instream sample locations was estimated to be about 0.2 mrem. The sum of doses from all water discharges at CRK16 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 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 6 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 total collective ED from waterborne radionuclides to the population engaging in these activities was

estimated to be about 154 person-rem. The collective dose would have been significantly lower without the contribution from the ^{241}Am in the sample collected at CRK 58 (~ 5 person-rem), which is suspected to have originated from laboratory contamination and not from sources contributing to the Clinch River. However, the relative percentages of individual and collective doses are small; they constitute about 2 percent of the average individual background dose of roughly 300 mrem/year and 0.04 percent of the 351,759 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, 2021[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	0.03	0.9[d]	0.004	0.9
Collective	0.8	0.005[d]	0.005	0.8
Melton Hill Lake (CRK 58, Knox County Water Plant)				
Individual	3	3	0.003	6
Collective	91	0.2	0.008	91
Upper Clinch River (CRK 23, 32)				
Individual	NA[e]	3	0.004	3
Collective	NA[e]	0.05	0.005	0.06
Lower Clinch River (CRK 16)				
Individual	NA[e]	3	0.004	3
Collective	NA[e]	0.1	0.01	0.1
Upper Watts Bar Lake, Kingston Municipal Water Plant				
Individual	0.5	0.5	0.001	1
Collective	8	0.06	0.008	8
Lower system (Lower Watts Bar Lake and Chickamauga Lake)				
Individual	0.4	0.5	0.001	0.9
Collective	53	2	0.2	55
Lower East Fork Poplar Creek and Poplar Creek				
Individual	NA[e]	0.2	0.0002	0.2
Collective	NA[e]	0.01	5×10^{-6}	0.01

[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 collected at CRK 70.*

[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. Lack of availability and social distancing procedures established in response to the COVID-19 pandemic restricted some sampling in 2021, as described in the following sections. (Fish consumption is discussed in Section 7.1.2.2 in conjunction with potential doses from waterborne radionuclides originating on 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. 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, root vegetables, and tomatoes were obtained from a total of five local gardens and one distant background location. Leafy greens and turnips were collected at one location, and tomatoes were collected at all five local garden locations. The background location used was in Claiborne County. Only ^{40}K was detected in tomatoes at all locations and ^{208}Tl (progeny of ^{228}Th) was detected in a tomato sample at one location. Thallium-208 has a very short half-life (3.05 min) and did not contribute to ingestion dose. No other radionuclides were detected in the food crops.

These radionuclides can be found in the natural environment and 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 72 kg (159 lb) of homegrown tomatoes (Scofield 2015). In 2021, no committed ED from consuming tomatoes, leafy greens, or root vegetables would be received by a hypothetical local gardener at any of the six of the garden locations in excess of that from naturally occurring ^{7}Be and ^{40}K, including a person eating vegetables from the distant (background) garden location.

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 3 mrem to the hypothetical home gardener's ED. In 2021, gardeners who provided vegetable samples were asked about water sources and fertilizers used. Fertilizers were used at all garden locations.

Water sources for the gardens were either city water or well water. It is thought that most of the activity found in vegetables is due to the ^{40}K and to unidentified naturally occurring alpha 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; however, hay samples were not available in 2021. Hay samples collected on ORR are normally analyzed for gross alpha, gross beta, gamma emitters, and uranium isotopes. Once every 5 years, additional radionuclides are included in the analyses of hay samples. Statistically significant concentrations of ^{7}Be, ^{40}K, ^{90}Sr, ^{3}H, ^{234}U, ^{235}U, and ^{238}U were detected

in 2020. Excluding the doses from ^{7}Be and ^{40}K (both naturally occurring radionuclides), the average ED from drinking milk and eating beef was estimated to be 0.09 mrem. From 2016 to 2019, the ED from drinking milk and eating beef ranged from 0.002 0.0009 mrem to 0.007 mrem.

White-Tailed Deer

Due to the COVID-19 pandemic, deer hunts typically conducted by the Tennessee Wildlife Resources Agency on the Oak Ridge Wildlife Management Area were canceled for 2020 and 2021. In previous years, harvested deer were taken to the TWRA checking station, and a bone and muscle tissue sample were obtained from each deer. The samples are field-counted for radioactivity to ensure that the deer meet the wildlife release criteria of 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]. For perspective, in 2015, one deer exceeded the release criteria, and in 2016 two deer exceeded the release criteria. No deer harvested in 2017, 2018, or 2019 exceeded the wildlife release criteria.

The average ^{137}Cs concentration in muscle tissue of the released deer in the years 2015 through 2019, as determined by field counting, ranged from 0.4 to 0.5 pCi/g. The maximum ^{137}Cs concentration in released deer ranged from 0.6 to 0.9 pCi/g. Most of the ^{137}Cs concentrations were less than minimum detectable levels. The average weight of released deer in 2015 to 2019 ranged from approximately 35 to 42 kg (77 to 92 lb); the maximum weight ranged from 76 to 82 kg (167 to 181 lb). The EDs attributed to field-measured ^{137}Cs concentrations and actual field weights of the released deer from 2015 to 2019 ranged from about 0 to 1 mrem. The average ED ranged from 0.4 to 0.6 mrem.

Potential doses attributed to the consumption of deer that might have moved off ORR and been harvested elsewhere were also evaluated in 2015 through 2019. EDs were calculated using average weights and ^{137}Cs concentrations of deer harvested at the ORR hunts. In that scenario, an individual who consumed one average-weight deer (assuming that 55 percent of the field weight is edible meat) containing the average field-measured concentration of ^{137}Cs could have received an ED ranging from 0.4 to 0.6 mrem. A hunter who consumed a deer of maximum weight and ^{137}Cs content could have received an ED of between 1 to 2 mrem.

Muscle tissue samples collected from released deer are subjected to laboratory analyses. Requested radioisotopic analyses include ^{137}Cs, ^{90}Sr, and ^{40}K radionuclides. Comparison of released-deer field results to analytical ^{137}Cs concentrations typically find that field concentrations are equal to or greater than analytical results. Using analytically measured ^{137}Cs and ^{90}Sr (excluding ^{40}K, a naturally occurring radionuclide) and actual deer weights, the estimated doses for the released deer in the years 2015 through 2019 ranged from about 0 to 0.7 mrem.

The maximum ED to an individual consuming venison from two or three deer was also evaluated. Based on ^{137}Cs concentrations determined by field counting and actual field weight, the ED to a hunter who consumed two or more harvested deer in the years 2015 through 2019 was between about 0.2 and 2 mrem.

The collective ED from eating all the harvested venison from ORR between the years 2015 and 2019 using average field-derived ^{137}Cs concentrations and average deer weight ranged from about 0.06 to 0.2 person-rem.

Canada Geese

Thirty-four geese were captured during the 2021 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 0.29 pCi/g. The maximum ^{137}Cs concentration in the released geese was 0.59 pCi/g. All ^{137}Cs concentrations

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

were below minimum detectable activity levels. The average weight of the geese screened during the roundup was about 3.4 kg (7.5 lb), and the maximum weight was about 5.4 kg (11.9 lb).

The EDs attributed to field-measured ^{137}Cs concentrations of the geese ranged from 0.008 to 0.03 mrem. However, for bounding purposes, if a person consumed a released goose with an average weight of 3.4 kg (7.5 lb) and an average ^{137}Cs concentration of 0.29 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 would be about 0.08 mrem for an individual who consumed a goose with the maximum ^{137}Cs concentration of 0.59 pCi/g and maximum weight of 5.4 kg (11.9 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 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 0.2 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, less the contribution of ^{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 the ORR for 2020 and 2021 were canceled because of the COVID-19 pandemic. Typically, hunters are permitted to harvest one turkey from the reservation in a given 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 during years 2015 through 2019. The average weights of the released turkeys for the years 2015 through 2019 ranged from 8.1 kg (17.8 lb) to 8.9 kg (19.5 lb). The maximum turkey weight for those same years ranged from 10 kg (22 lb) to 11.3 kg (25 lb). The average ^{137}Cs concentration from 2015 through 2019 was 0.1 pCi/g, and maximum ^{137}Cs concentrations ranged from 0.16 to 0.3 pCi/g in the released turkeys. Almost all ^{137}Cs concentrations were below minimum detectable activity levels.

The EDs attributed to ^{137}Cs concentrations field-measured in the turkeys from 2015 through 2019 ranged from 0.004 to 0.04 mrem. For bounding purposes, if a person consumed a released turkey with an average weight and an average ^{137}Cs concentration during years 2015 through 2019, the estimated ED would have been 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 turkey with 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 2020. 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).

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). Due to 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 6.4). External gamma exposure rates were continuously recorded by dual-range Geiger-

Müller tube detectors co-located with ORR ambient air stations. In 2021, exposure rates averaged about 10 μR/h and ranged from 8.2 to 12.6 μR/h. The exposure rates correspond to an annual average dose of about 58 mrem with a range of 50 to 77 mrem. At the background ambient air station, the exposure rate averaged about 9 μR/h and ranged from 8.1 to 9.4 μR/h. The resulting average annual dose was about 52 mrem with a range of 50 to 58 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 2021, that person could have received a total ED of about 8 mrem. Of that total, 0.5 mrem would have come from airborne emission, approximately 7 mrem from waterborne emissions (3 mrem from drinking water, 3 mrem from consuming fish, 0.003 mrem from other water uses along the Clinch River, and 1.4 mrem from irrigation at CRK 16), and about 0.2 mrem from consumption of wildlife. Direct radiation measurements at six ORR ambient air monitoring stations were at or near background levels in 2021. 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 years 2017 through 2021 are given in Table 7.8. In 2021, the air pathway dose increased but is similar to air pathway doses that have been estimated over the last 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 while 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 is 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 consumption of geese increased slightly in 2021. (No deer or turkey were harvested on ORR during 2021 due to the COVID-19 pandemic.)

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 (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, 2021

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	0.5	0.005	0.5	22.7	0.227		1,172,530[b]
Liquid effluents[c]							
Drinking water	3	0.03	3	152	1.52		460,893[d]
Eating fish	3	0.03	3	2	0.02		10,334[e]
Other activities	0.003	3×10^{-5}	0.003	0.2	0.002		3,359,287[e]
Irrigation	1.4	0.014	1.4				
Other pathways							
Eating deer	*f*	*f*		*f*	*f*		
Eating geese	0.2[g]	0.002	0.2	*h*	*h*		
Eating turkey	*i*	*i*		*i*	*i*		
Direct radiation	NA[i]	NA					
All pathways							
Total	8[k]	0.08	8	177	1.77	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] *Increases in individual and collective doses for the waterborne pathway are primarily due to the impact from ^{241}Am detected in the water sample collected from CRK 58 in the second quarter of 2021.*

[d] *Population estimates based on community and non-community drinking water supply data from the Tennessee Department of Environment and Conservation Division of Water.*

[e] *Population estimates for fish based on creel and commercial fishing data. Fraction of fish harvested from Melton Hill, Watts Bar, and Chickamauga Reservoirs were 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.*

[f] *No deer were harvested on the ORR during 2021 due to the COVID-19 pandemic.*

[g] *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.*

[h] *Collective doses were not estimated for the consumption of geese because no geese were harvested for consumption during the goose roundup.*

[I] *No turkeys were harvested on the ORR during 2021 due to the COVID-19 pandemic.*

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

[k] *Dose estimates have been rounded.*

Table 7.8. Trends in effective dose from ORR activities, 2017–2021 (mrem)[a]

Pathway	2017	2018	2019	2020	2021
All routes—inhalation	0.3	0.2	0.4	0.4	0.5
Fish consumption (Clinch River)	0.05	0.09	4	2	3
Drinking water (Kingston)	0.01	0.03	0.01	0.02	3
Deer	2	2	2	*b*	*b*
Geese	0.08	0.1	0.1	0.07	0.2
Turkey	0.08	0.05	0.04	*b*	*b*

[a] *1 mrem = 0.01 mSv*
[b] *No deer or turkey were harvested on ORR in 2021.*
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, 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 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

All locations passed the general screening phase (comparison of maximum radionuclide water concentrations to default BCGs), except for WOC 7500 Bridge and WOD (X15). These locations passed second-level screening, for which BCG default parameters and average water concentrations were used. Second-level screening 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
- Discharge Point S24
- Discharge Point S17 (unnamed tributary to the Clinch River)
- Discharge Point S19 (Rogers Quarry)
- Outfall 200 on EFPC

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

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

All 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 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 (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. 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 (B_{iv}) were calculated using 2007 and 2014 maximum soil concentrations and radionuclide concentrations in tissue for biota inhabiting the WOC floodplain.

In 2021, as well as in 2014 and 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. 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 2021, soil samples were collected from the same general locations as those collected in 2014 and 2007. 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.

All soil samples, except for those collected on the WOC floodplain upstream of WOD, passed the initial-level screening (i.e., 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. Based on current measured concentrations in soil on the WOC floodplain and results of second-level screening (i.e., comparison of average radionuclide soil concentrations to default BCGs), further evaluation is required.

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 as a result 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).

Table 7.9. Chemical hazard quotients and estimated risks for drinking water from the Clinch River at CRK 23 and 16, 2021

Analyte	Hazard quotient	
	CRK 23[a]	CRK 16[b]
Metals		
Antimony	2×10^{-2}	2×10^{-2}
Arsenic	9×10^{-2}	9×10^{-2}
Cadmium	2×10^{-2}	2×10^{-2}
Chromium	3×10^{-2}	3×10^{-2}
Copper	1×10^{-3}	1×10^{-3}
Lead	6×10^{-2}	6×10^{-2}
Mercury	2×10^{-4}	3×10^{-4}
Nickel	2×10^{-3}	2×10^{-3}
Selenium	5×10^{-3}	5×10^{-3}
Silver	6×10^{-4}	6×10^{-4}
Thallium	2×10^{-1}	2×10^{-1}
Uranium	2×10^{-2}	3×10^{-2}
Zinc	9×10^{-4}	5×10^{-4}
Volatile organics		
1,1,1-Trichloroethane	4×10^{-6}	4×10^{-6}
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	1×10^{-5}	2×10^{-5}
Chromium	2×10^{-5}	2×10^{-5}
Lead	3×10^{-8}	3×10^{-8}
Trichloroethene	2×10^{-7}	2×10^{-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.*
Acronym:
CRK = Clinch River kilometer

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. Mercury concentrations were measured but not detected above the analytical method detection limit in surface water samples collected at CRK 66 and CRK 32 during 2021.

As shown in Table 7.9, at all locations, HQs were less than 1 for detected chemical analytes in water for which there are reference doses or a maximum contaminant levels. 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.

7.2.1.2. Groundwater

During FY 2021, 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, it was assumed that avid fish consumers would have eaten 27 kg (60 lb) of fish during 2021. 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 7.10, for consumption of sunfish and catfish, HQ values of less than 1 were calculated for all detected analytes except for arsenic in sunfish at CRK 32. For carcinogens, risk values at or greater than 10^{-6} were calculated for the intake of Aroclor-1260 for catfish collected at CRK 32 and CRK 16. A risk value greater than 10^{-6} was also calculated for the intake of arsenic for sunfish at CRK 32. The estimated risk values for consumption of sunfish and catfish are within the EPA's acceptable risk range of 10^{-4} to 10^{-6}. However, 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 2020). TDEC has also issued a precautionary fish consumption advisory for catfish in the Clinch River arm and Tennessee River portion of Watts Bar Reservoir (TDEC 2020).

Table 7.10. Chemical hazard quotients and estimated risks for fish caught and consumed from locations on ORR, 2021[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						
Aluminum						
Antimony						
Arsenic		1.0				
Barium			0.0009			
Boron						
Cadmium						
Chromium						
Cobalt						
Copper	0.004	0.007	0.008	0.005	0.003	0.009
Iron			0.009			0.01
Manganese		0.001	0.008	0.002		0.004
Mercury						
Selenium		0.2	0.09			
Strontium			0.001			
Thallium						
Zinc	0.03	0.05	0.04	0.03	0.02	0.03
Hazard quotients for Aroclors						
Aroclor-1260					0.9	J0.7
Risks for carcinogens						
Arsenic		2E-04				
Chromium						
Aroclor-1260					1E-05	J1E-05
PCBs (mixed)[e]					1E-05	J1E-05

[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, 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 consist of 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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