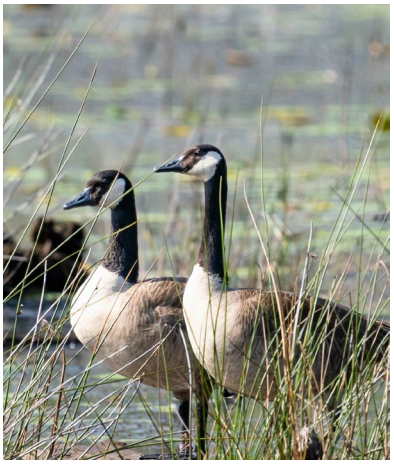


Radionuclides discharged to surface waters on ORR can potentially reach members of the public who use the Clinch and Tennessee Rivers for fishing, swimming, boating, or drinking water. Water and fish samples are collected at several locations on the Clinch River and are analyzed to ensure that members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

Photo by Carlos Jones

7

Dose

Activities on ORR can result in the release of small quantities of radionuclides and hazardous chemicals into the environment that have the potential to expose members of the public. 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 applicable laws and regulations.

In 2024, a hypothetical maximally exposed individual (MEI) would have received an effective dose (ED) of about 0.6 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, Subpart H).

A worst-case analysis of exposures to waterborne radionuclides for all pathways combined gives a maximum possible individual ED of about 0.3 mrem. This dose is based on a person eating 42 kg/year (93 lb/year) of fish, drinking 953 L/year (252 gal/year) of drinking water, using the shoreline for 60 h/year, swimming 30 h/year, boating 63 h/year, and irrigating food or feed crops.

In addition, if a person consumed one maximum-weight harvested deer, one maximum-weight harvested turkey, and three maximum-weight harvested geese, all containing the maximum ^{137}Cs concentration, that person could have received an ED of about 3 mrem. This calculation provides an estimated upper-bound ED from consuming wildlife harvested from ORR.

Therefore, the annual dose for 2024 to an MEI from the combined exposure pathways is estimated to have been about 4 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 2024 maximum ED from ORR is about 4 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 a significant 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 2024. Those releases are 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 measured 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 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). Regardless of radiation type or method of delivery, 1 rem of ED has the same total radiological (and 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 pathways evaluated and methods used to determine potential EDs to members of the public and to aquatic and terrestrial biota from radionuclides originating from ORR. Dose estimates were calculated using radionuclide concentrations measured in samples collected on or near ORR, estimated release data, and computer models.

7.1.2.1. Airborne Radionuclides

The radiological consequences of radionuclides released into the atmosphere from ORR operations during 2024 were characterized by calculating EDs to maximally exposed on- and off-site members of the public and to the entire population residing within 80 km (50 miles) of the center of ORR. The calculations were performed for each major facility and for the entire ORR. The dose calculations were performed 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 *Code of Federal Regulations* (CFR) Part 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 in CAP-88 PC. 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 2024: 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 2024 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 2024, rainfall, as averaged over the six rain gauges located on ORR, was about 119 cm (47 in.). The average air temperature was 15.7°C (60.2°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 591.6 m (1,941 ft) for ETTP, 569.6 m (1,869 ft) for ORNL, and 591.6 m (1,941 ft) for Y-12. For occupants of residences, the dose calculations assumed 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 was assumed to have been produced within 80 km (50 miles) of ORR. The same assumptions were used for occupants of businesses, but the resulting doses were 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, 2024

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	4,490	SW	11,260	NE
X-2000	15	0.5	0	4,840	SW	10,910	NE
X-3000	15	0.5	0	5,240	SW	10,510	NE
X-4000	15	0.5	0	5,430	SW	10,360	NE
X-6000	15	0.5	0	6,010	SW	9,800	NE
X-7000	15	0.5	0	5,560	WSW	10,750	NNE
X-2026	22.9	1.05	6.38	4,940	SW	10,790	NE
X-2099	3.66	0.18	7.05	4,940	SW	10,800	NE
X-3001	6.86	0.44	13.06	5,140	SW	10,590	NE
X-3020	61	1.22	15.07	5,100	SW	10,630	NE
X-3026-East	0.81	0.97	0[b]	5,170	SW	10,580	NE
X-3026-West	0.81	0.97	0[b]	5,170	SW	10,580	NE
X-3039	74.68	2.53	4.99	5,180	SW	10,570	NE
X-3525	17.25	0.35	9.39	5,120	SW	10,650	NE
X-3571	3.35	0.29	0b	5,080	SW	10,700	NE
X-3608 filter press	8.99	0.36	9.27	5,110	SW	10,720	NE

Table 7.1. Emission point parameters and receptor locations used in the dose calculations, 2024 (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	23.47	0.69	15.34	5,370	SW	10,410	NE
X-7503	30.5	0.91	13.24	5,560	WSW	10,600	NNE
X-7830 group	4.6	0.25	9.78	4,230	WSW	12,130	NNE
X-7856-CIP	18.29	0.48	9.37	4,250	WSW	12,190	NNE
X-7877	13.9	0.41	13.56	4,210	WSW	12,180	NNE
X-7880	27.7	1.52	15.50	4,170	WSW	12,200	NNE
X-7911	76.2	1.52	13.05	5,520	WSW	10,810	NNE
X-7935 building stack	15.24	0.51	24.27	5,510	WSW	10,740	NNE
X-7935 glove box	9.14	0.25	0[b]	5,510	WSW	10,740	NNE
X-7966	6.10	0.29	10.82	5,580	WSW	10,660	NNE
X-7977B	5.03	0.02	1.04	5,610	WSW	10,770	NNE
X-8915	104.0	1.22	6.37	8,140	SW	7,580	NE
X-decom areas	15	0.5	0	5,470	SW	10,310	NE
ETTP							
K-1407-AL CWTS	2.74	0.15	0[b]	270	SSW	14,770	ENE
Y-12 Complex							
Y-monitored	20	0.5	0	2,270	NE	2,270	NE
Y-unmonitored processes	20	0.5	0	2,270	NE	2,270	NE
Y-unmonitored lab hoods	20	0.5	0	2,270	NE	2,270	NE

[a] *Exit gas temperatures are ambient air 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

Table 7.2. Meteorological towers and heights used to model atmospheric dispersion from source emissions, 2024

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, 7977B, and X-7000 lab hoods
	30	X-7503, X-7856-CIP, X-7877, X-7880, X-7911, and X-7935 building stack
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-3525, and X-4501
	60	X-3020 and X-3039
MT12 (Tower F)	10	X-8915

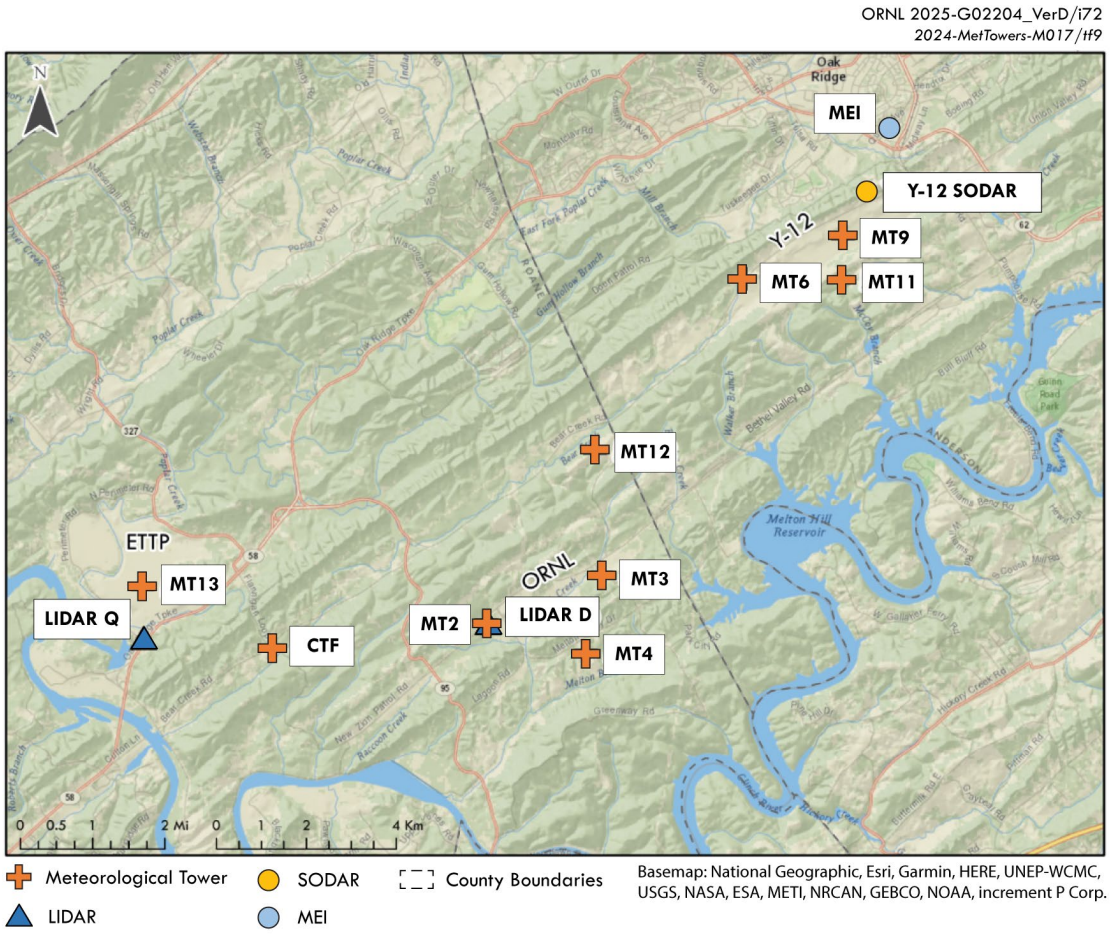
Acronyms:
CIP = Capacity Increase Project
CWTS = Chromium Water Treatment System
decom = decommissioned
ETTP = East Tennessee Technology Park
FP = filter press
ORNL = Oak Ridge National Laboratory
Y-12 Complex = Y-12 National Security Complex

Results

EDs from radionuclides released into the atmosphere from ORR were calculated for ORR as a whole and for each site on ORR for MEIs and for the collective population (1,276,842 persons) residing within 80 km (50 miles) of ORR based on 2020 Census data (Census 2020). CAP-88 PC Version 4 was used in 2024 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 into the atmosphere from ORR) was about 2,270 m (1.4 miles) northeast of the main Y-12 release point, about 10,810 m (6.7 miles) north-northeast of the 7911 stack at ORNL, and about 14,770 m (9.2 miles) east-northeast of the K-1407-AL Chromium Water Treatment System at ETTP (Figure 7.1). This individual could have received an ED of about 0.6 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 Part 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 23.9 person-rem, which is about 0.006 percent of the 383,053 person-rem that this population received from natural sources of radiation (based on an individual dose of about 300 mrem/year).



Acronyms:

CTF = Central Training Facility
ETTP = East Tennessee Technology Park
LIDAR = light detection and ranging
MEI = maximally exposed individual
ORNL = Oak Ridge National Laboratory
ORR = Oak Ridge Reservation
SODAR = sonic detection and ranging
Y-12 = Y-12 National Security Complex

Figure 7.1. Location of the maximally exposed individual for ORR, 2024

Table 7.3. Calculated radiation doses to maximally exposed individuals from airborne releases from ORR, 2024

Site	Maximum effective dose, mrem and mSv			
	From each site		From ORR	
	mrem	mSv	mrem	mSv
ORNL[a]	0.3	0.003	0.08	0.0008
ETTP[b]	0.0002	2×10^{-6}	1×10^{-6}	1×10^{-8}
Y-12 Complex[c]	0.5	0.005	0.5	0.005
Entire ORR[d]	e	e	0.6	0.006

[a] *The ORNL MEI was located 5,180 m SW of X-3039 and 5,520 m WSW of X-7911.*

[b] *The ETTP MEI was located 270 m SSW of the K-1407-AL Chromium Water Treatment System.*

[c] *The Y-12 MEI was located 2,270 m NE of the main Y-12 Complex release point.*

[d] *The MEI for the entire ORR was 2,270 m NE of the Y-12 Complex release point, 10,810 m NNE of X-7911, and 14,770 m ENE of the 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, 2024

Site	Collective effective dose[a]	
	Person-rem	Person-Sv
ORNL	13.8	0.138
ETTP	6×10^{-5}	6×10^{-7}
Y-12 Complex	10.1	0.101
Entire ORR	23.9	0.239

[a] *Collective effective dose to the 1,276,842 persons residing within 80 km (50 miles) of 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 2,270 m (1.4 miles) northeast of the main Y-12 release point. This individual could have received an ED of about 0.5 mrem from Y-12 airborne emissions. Uranium radioisotopes (i.e., ^{233}U, ^{234}U, ^{235}U, ^{236}U, and ^{238}U) accounted for about 98 percent, and other radionuclides accounted for about 2 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 10.1 person-rem, which is about 42 percent of the collective ED for ORR.

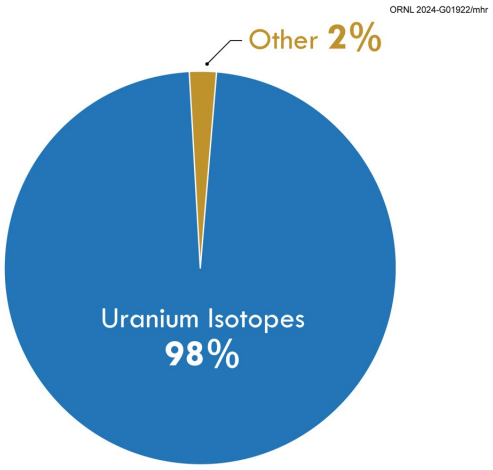


Figure 7.2. Nuclides contributing to effective dose at the Y-12 Complex, 2024

The MEI for ORNL was located at a residence about 5,180 m (3.2 miles) southwest of the 3039 stack and 5,520 m (3.4 miles) west-southwest of the 7911 stack. This individual could have received an ED of about 0.3 mrem from ORNL airborne emissions. Lead-212 contributed about 69 percent, ^{237}Np contributed about 11 percent, and ^{41}Ar, ^{11}C, and ^{138}Cs each contributed about 4 percent to the ORNL ED (Figure 7.3). The total contribution from ^{232}U, ^{233}U, ^{234}U, ^{235}U, ^{236}U, ^{238}U, ^{239}U, and ^{240}U accounted for about 0.09 percent of the dose. Of the uranium isotopes, ^{234}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 13.8 person-rem, or about 58 percent of the collective ED for ORR.

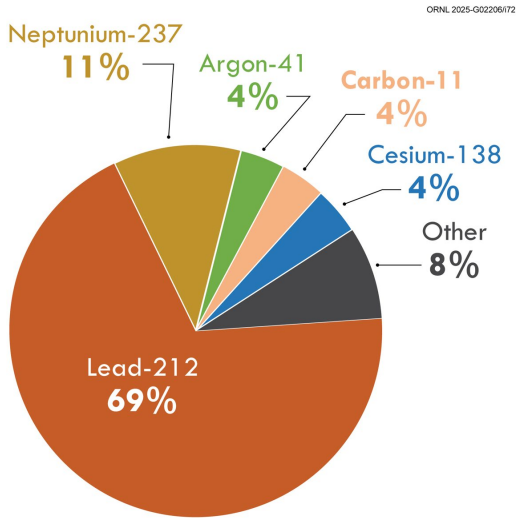


Figure 7.3. Nuclides contributing to effective dose at ORNL, 2024

The MEI for ETTP was located at a business about 270 m (0.17 miles) south-southwest of the K-1407-AL Chromium Water Treatment System. The ED received by this individual from airborne emissions was calculated to have been about 0.0002 mrem. About 82 percent of the dose was from uranium radioisotopes (^{233}U, ^{234}U, ^{235}U, ^{236}U, and ^{238}U), nearly 8 percent of the dose was from progeny of uranium isotopes, and almost 11 percent of the dose was from ^{99}Tc (Figure 7.4). The 2024 contribution of ETTP emissions to the collective ED to the population residing within 80 km (50 miles) of ORR was calculated to have been about 0.00006 person-rem, or about 0.0003 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, ^{3}H, and ^{99}Tc at selected locations.

In 2024, in addition to ^{3}H and uranium isotopes, ^{60}Co, ^{214}Bi, ^{210}Pb, ^{212}Pb, ^{214}Pb, ^{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 listed in Table 7.5 and at the background location, Station 52. On average, the dose contribution from ^{210}Pb at ambient air sampling locations was nearly 4.6 mrem. Measured air concentrations of ^{210}Pb were excluded from calculated EDs because ^{210}Pb is naturally occurring and was emitted from only two sources on ORR at concentration levels significantly below those measured in ambient air samples.

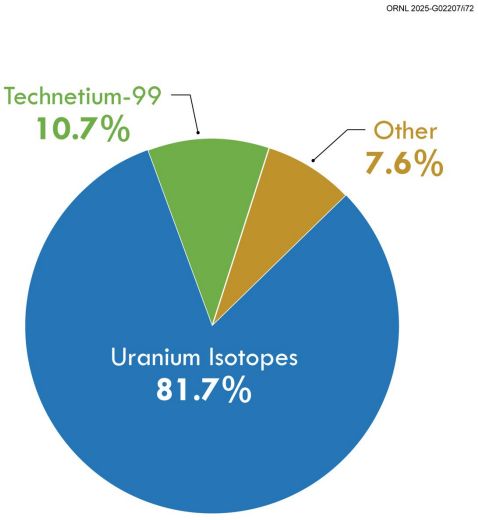


Figure 7.4. Nuclides contributing to effective dose at ETTP, 2024

Based on measured air concentrations, hypothetical individuals assumed to reside at the ambient air stations could have received EDs between 0.02 and 0.07 mrem/year, while EDs calculated using CAP-88 PC Version 4 and emissions data were between 0.1 and 3.2 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.

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 2024. Technetium-99 was detected in one sample at Station 35 but was not

detected at the background location. Based on measured air concentrations (excluding the naturally occurring isotopes ^{7}Be and ^{40}K), the ED at Station 52 was estimated to be 0.02 mrem/year. Based on air concentrations calculated using CAP-88 PC Version 4, the ED was estimated to be 0.06 mrem/year. The measured air concentrations of ^{7}Be at ORR stations were similar to those 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 11 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 0.4 mrem/year. Station 40 is located near the offsite MEI for the Y-12 Complex and ORR. The ED calculated with measured air concentrations was 0.02 mrem/year, and the ED estimated using source emissions data was 0.7 mrem/year. Station K11 is located near the on-site MEI for ETTP. The ED calculated with measured air concentrations was 2×10^{-4} mrem/year, and the ED calculated using source emissions data was 0.08 mrem/year.

Table 7.5. Hypothetical effective doses from living near ORR and ETTP ambient air monitoring stations, 2024

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	0.4	0.004
2	0.03	0.0003	0.4	0.004
3	0.05	0.0005	3.2	0.032
11	0.03	0.0003	0.4	0.004
35[b]	0.07	0.0007	0.1	0.001
37	0.02	0.0002	0.3	0.003
40	0.02	0.0002	0.7	0.007
46	0.02	0.0002	0.3	0.003
49	0.02	0.0002	0.3	0.003
52[b,c]	0.02	0.0002	0.06	0.0006
		ETTP		
K11	1×10^{-4}	1×10^{-6}	0.08	0.0008
K12	3×10^{-5}	3×10^{-7}	0.07	0.0007

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

[b] *In 2024, analysis for ^{99}Tc in samples from Stations 35 and 52 was performed.*

[c] *Background ambient air monitoring station.*

Acronyms:

CAP-88 PC = Clean Air Act Assessment Package—1988

ETTP = East Tennessee Technology Park

ORR = Oak Ridge Reservation

7.1.2.2. Waterborne Radionuclides

Radionuclides discharged to surface waters from ORR enter the Tennessee River system via 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 these rivers 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 the confluence with Poplar Creek)
- Lower Clinch River (from the confluence with Poplar Creek to the 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 (from the remainder of Watts Bar Lake and Chickamauga Lake to Chattanooga)
- Poplar Creek (including the confluence with 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 with known or estimated streamflows. Both methods use reported concentrations of radionuclides to estimate radiation doses if the reported value is statistically significant 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 2022). 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 fiscal year 2024, the Oak Ridge Office of Environmental Management 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 are likely high. (No in-plant radionuclide concentration data are available for the treatment plants.)

Based on a nationwide health and nutrition survey (EPA 2023) and weighted based on the combined population of Anderson, Knox, Loudon, and Roane Counties, which reflects 2020 decennial US Census data (Census 2020; Fryar et al. 2021), the drinking water consumption rate for the MEI is assumed to be 953 L/year (252 gal/year), and the drinking water consumption rate for the average person is 284 L/year (75 gal/year). The average drinking water consumption rate was used to estimate the collective EDs. The EDs for the seven surface water segments were 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 0.04 mrem. The collective ED to the 46,765 persons who drink water from the City of Oak Ridge water plant would have been 0.6 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 0.04 mrem; the collective dose to the 70,666 persons who drink water from this plant could have been 0.9 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 0.007 mrem. The collective dose to the 34,485 persons who drink water from these plants could have been about 0.07 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 0.006 mrem. The collective dose to the 359,577 persons who drink water from the lower system could have been about 0.5 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 health and nutrition survey (EPA 2023) and weighted based on the combined population of Anderson, Knox, Loudon, and Roane Counties, which reflects 2020 decennial US Census data (Census 2020; Fryar et al. 2021), avid fish consumers were assumed to have eaten 42 kg (93 lb) of fish during 2024. The average person used for collective dose calculations was assumed to have consumed 11 kg (24 lb) of fish in 2024. The average fish consumption value is based on a nationwide food consumption survey (EPA 2023) and is weighted based on the 2020 decennial US Census populations of Anderson, Knox, Loudon, and Roane Counties (Census 2020; Fryar et al. 2021). The maximum ED at each location was estimated using one of the two previously mentioned methods: by using measured radionuclide concentrations in fish or by calculating 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 2024; TWRA 2025). Routine fish tissue analyses include gross alpha, gross

beta, gamma spectroscopy for gamma emitters, and ^{3}H. Detected or statistically significant radionuclides in 2024 included ^{7}Be, ^{40}K, ^{90}Sr, ^{99}Tc, ^{230}Th, and ^{232}Th.

In 2024, the maximum EDs from fish consumption at upper Melton Hill Lake and both upper and lower Clinch River were determined using measured radionuclide concentrations in samples collected at CRK 70 and CRK 32 (catfish) and CRK 16 (sunfish). However, the maximum fish consumption EDs at the remaining locations were based on 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 0.2 mrem. The collective ED to the 13 persons who could have eaten fish harvested at that location could have been about 0.0007 person-rem.
- **Melton Hill Lake.** An avid fish consumer who ate fish from Melton Hill Lake could have received an ED of about 0.1 mrem. The collective ED to the 119 persons who could have eaten fish harvested at that location could have been about 0.003 person-rem.
- **Upper Clinch River.** An avid fish consumer who ate fish from the upper Clinch River could have received an ED of about 0.2 mrem. The collective ED to the 104 persons who could have eaten fish harvested at that location could have been about 0.004 person-rem.
- **Lower Clinch River.** An avid fish consumer who ate fish from the lower Clinch River could have received an ED of about 0.2 mrem. The collective ED to the 243 persons who could have eaten fish harvested at that location could have been about 0.01 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 0.02 mrem. The collective ED to the 693 persons who could have eaten fish harvested at that location could have been about 0.003 person-rem.
- **Lower system.** An avid fish consumer who ate fish from the lower system could have received an ED of about 0.02 mrem. The collective ED to the approximately 8,235 persons who could have eaten fish harvested at that location could have been about 0.03 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, but it is considered unlikely that a person would consume fish from those locations. Assuming 200 persons could have eaten fish from lower EFPC and from Poplar Creek, the collective ED could have been about 0.006 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 radioactivity data and shoreline use. The number of individuals who could have been other users is 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 0.002 mrem. The collective ED to the 14,483 other users could have been 0.003 person-rem.
- **Melton Hill Lake.** An individual other user of Melton Hill Lake could have received an ED of about 0.003 mrem. The collective ED to the 40,044 other users could have been about 0.01 person-rem.
- **Upper Clinch River.** An individual other user of the upper Clinch River could have received an ED of about 4×10^{-6} mrem. The collective ED to the 13,114 other users could have been about 4×10^{-6} 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 0.006 person-rem.
- **Upper Watts Bar Lake.** An individual other user of upper Watts Bar Lake could have received an ED of about 7×10^{-7} mrem. The collective ED to the 87,424 other users could have been about 4×10^{-6} person-rem.
- **Lower system (Watts Bar and Chickamauga Lakes).** An individual other user of the lower system could have received an ED of about 7×10^{-7} mrem. The collective ED to the 3,173,423 other users could have been about 0.0001 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 6×10^{-5} mrem. The collective ED to the 200 other users of Poplar Creek and lower EFPC could have been about 2×10^{-6} person-rem.

Irrigation

Although no known locations 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 US 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 4×10^{-70} to 0.05 mrem in 2024. The average instream dose at CRK 16 was estimated to have been about 0.008 mrem. Based on all water discharges at CRK 16, the sum of doses was estimated to have been 2×10^{-6} mrem. The individual was assumed to have consumed 16 kg (35 lb) of leafy vegetables, 92 kg (203 lb) of produce, 262 L (69 gal) of milk, and 63 kg (139 lb) of meat (beef) during the year. The doses were calculated using per capita committed ED coefficients for water and milk ingestion (DOE 2022).

Summary

Table 7.6 summarizes potential EDs from identified waterborne radionuclides around ORR. The estimated maximum individual ED was about 0.3 mrem to a person who obtained his or her drinking water and annual complement of fish from the water systems in Table 7.6 and who participated in other water uses throughout those systems. The total collective ED from waterborne radionuclides to the population engaging in these activities was estimated to have been about 2.1 person-rem. These doses are small relative to the overall doses from natural sources of radiation; the estimated maximum individual ED from identified waterborne radionuclides is about 0.1 percent of the average individual background dose of roughly 300 mrem/year, and the total collective ED from waterborne radionuclides is about 0.0006 percent of the 383,053 person-rem that the population within 80 km (50 miles) received from natural sources of radiation.

Table 7.6. Summary of annual maximum individual (mrem) and collective (person-rem) effective doses from waterborne radionuclides, 2024[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	0.04	0.2[d]	0.002	0.3
Collective	0.6	0.0007[d]	0.003	0.6
Melton Hill Lake (CRK 58, Knox County water plant)				
Individual	0.04	0.1	0.003	0.02
Collective	0.9	0.003	0.01	0.9
Upper Clinch River (CRK 23, CRK 32)				
Individual	e	0.2	4×10^{-6}	0.2
Collective	e	0.004	4×10^{-6}	0.004
Lower Clinch River (CRK 16)				
Individual	e	0.2[d]	0.001	0.2
Collective	e	0.01	0.006	0.02
Upper Watts Bar Lake (Kingston municipal water plant)				
Individual	0.007	0.02	7×10^{-7}	0.03
Collective	0.07	0.003	4×10^{-6}	0.07
Lower system (lower Watts Bar Lake and Chickamauga Lake)				
Individual	0.006	0.02	7×10^{-7}	0.02
Collective	0.5	0.03	0.0001	0.6
Lower East Fork Poplar Creek and Poplar Creek				
Individual	e	0.1	6×10^{-5}	0.1
Collective	e	0.006	2×10^{-6}	0.006

[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 of 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 contain radionuclides released from ORR.

Milk, vegetables, hay, wildlife, and fish are sampled and analyzed annually, as available, 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 obtained. No additional suitable locations were identified in 2024. Milk sampling will resume when dairy operations in appropriate areas are located.

Vegetables

The food crop sampling program is described in Chapter 6. Tomatoes and leafy greens were obtained from four local gardens, and both were obtained from the same distant background location in Putnam County. Samples of root vegetables were not available in 2024. Sample analyses included gross alpha, gross beta, gamma emitters, and isotopic uranium. In samples of leafy greens, statistically significant concentrations of ^{7}Be, ^{40}K, $^{233/234}$U, and ^{238}U were detected. In tomato samples, statistically significant concentrations of ^{40}K and ^{208}Tl were detected. Dose estimates are based on hypothetical consumption rates of vegetables that contain statistically significant or detected concentrations of radionuclides that could have come from ORR. Based on a nationwide food consumption survey (EPA 2011) and weighted based on the combined 2020 decennial US Census population of Anderson, Knox, Loudon, and Roane Counties (Census 2020; Fryar et al. 2021), a hypothetical home gardener was assumed to have eaten a maximum of about 16 kg (35 lb) of homegrown leafy greens and 74 kg (163 lb) of homegrown tomatoes. The hypothetical local gardener could have received an ED of between 0 and 0.03 mrem from leafy greens depending on the garden location. Because ^{40}K and ^{208}Tl do not contribute to dose from ingestion, the hypothetical gardener would have received no additional dose from eating tomatoes. A person eating vegetables from the distant background garden could have received a committed ED of 0.06 mrem from eating leafy greens.

Potassium-40 was detected in tomato and leafy green samples and accounted for most of the beta activity but was excluded from calculated EDs because it is a naturally occurring, fertilizer-introduced radionuclide. Potassium-40 concentrations in tomatoes were similar at all garden locations, including the background location, and were comparable in samples of leafy greens from all of the garden locations except for the background location where it was significantly higher. If the ^{40}K detected in the samples had been included in ED calculations, it would have added about 3 mrem to the hypothetical home gardener's ED. In 2024, gardeners who provided vegetable samples were asked about water sources and fertilizers used. Only natural fertilizers, such as leaf litter, manure, and compost, were used at three of the four garden locations and at the background location. Water sources for the gardens typically include rain or city water. Most of the activity found in vegetables is thought to be due to ^{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 2024, statistically significant concentrations of ^{40}K and $^{233/234}$U were detected in hay samples. Potassium-40 is naturally occurring and is not included in reported EDs from drinking milk and eating beef; however, it contributed about 17 mrem, primarily from beef, to the total dose. Excluding the dose contributions from ^{40}K, the ED from drinking milk and eating beef was 0.004 mrem.

White-tailed deer

TWRA conducted three 2-day deer hunts on ORR in 2024: November 2 and 3, November 9 and 10, and November 14 and 15. (See Section 6.6.5.) During the hunts, 192 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 and were retained in 2024.

The average ^{137}Cs concentration in muscle tissue of the 192 released deer was 0.6 pCi/g; the maximum ^{137}Cs concentration in the released deer was 1.2 pCi/g. The ^{137}Cs activity in most samples was less than minimum detectable levels. The average weight of released deer was approximately 44 kg (97 lb); the maximum weight was 84 kg (185 lb). The EDs attributed to field-measured ^{137}Cs concentrations and actual field weights of the released deer ranged from about 0.04 to 2 mrem, with an average of about 0.7 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 (44 kg [97 lb], assuming that 55 percent of the field weight was edible meat) with the 2024 average field-measured concentration of ^{137}Cs (0.6 pCi/g), that individual could have received an ED of about 0.7 mrem. If an individual consumed a deer of maximum weight and ^{137}Cs content, that individual could have received an ED of about 3 mrem.

In 2024, muscle tissue samples from four released deer were collected and analyzed 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] Analytical results for ^{90}Sr concentrations in the muscle tissue of the four released deer ranged from 0 to 0.1 pCi/g. Using the analytical results for ^{137}Cs and ^{90}Sr (excluding ^{40}K, a naturally occurring radionuclide) and actual deer weights, the estimated doses ranged from about 0.2 to 0.3 mrem for the four released deer.

The maximum ED to an individual consuming venison from two or three deer was also evaluated. In 2024, 23 hunters each harvested 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 have been between about 0.5 and 2 mrem.

The collective ED from eating venison from all the deer harvested on ORR in 2024 was estimated to have been about 0.1 person-rem based on the 2024 average field-derived ^{137}Cs concentration of 0.6 pCi/g and an average weight of 44 kg (97 lb). The collective dose is based on the number of harvested deer. Additional individuals may also have consumed the harvested venison, but the collective dose would be essentially the same.

Canada geese

Twenty-nine geese were captured during the 2024 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 0.4 pCi/g. The maximum ^{137}Cs concentration in the released geese was 2 pCi/g. All ^{137}Cs concentrations were below minimum detectable activity levels. The average weight of the geese screened during the roundup was about 2.8 kg (6.2 lb), and the maximum weight was about 4.9 kg (11 lb).

The EDs attributed to field-measured ^{137}Cs concentrations of the geese ranged from 0.02 to 0.2 mrem. However, for bounding purposes, if a person consumed a released goose with an average weight of 2.8 kg (6.2 lb) and an average ^{137}Cs concentration of 0.4 pCi/g, the estimated ED would have been approximately 0.03 mrem. About half the weight of a Canada goose was assumed to be edible. The estimated ED was about 0.2 mrem for an individual who consumed a goose with the maximum ^{137}Cs concentration of 2 pCi/g and maximum weight of 4.9 kg (11 lb).

It is possible that a person could have eaten more than one goose that spent time on ORR. The average seasonal goose bag per active hunter from Tennessee in the Mississippi Flyway was 3.4 (±47 percent) geese per hunting season between

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

2022 and 2023 (US Fish and Wildlife Service 2024). A person who consumed three geese of maximum weight with the highest measured concentration of ^{137}Cs would have received an ED of about 0.7 mrem.

Between 2000 and 2009, 22 samples of goose tissue were analyzed. Potential doses were evaluated based on laboratory-determined concentrations of the following radionuclides: ^{40}K, ^{137}Cs, ^{90}Sr, thorium (^{228}Th, ^{230}Th, and ^{232}Th), uranium ($^{233/234}$U, ^{235}U, and ^{238}U), and transuranic elements (^{241}Am, $^{243/244}$Cm, ^{238}Pu, and $^{239/240}$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

Two wild turkey hunts took place on the reservation in 2024: April 13 and 14 and April 20 and 21. Participating hunters are permitted to harvest one turkey per season from the reservation. If a turkey is retained, the hunter is permitted to harvest another turkey. Thirty-seven turkeys were harvested during the turkey hunts, and no additional turkeys were harvested during the deer hunts. No harvested turkeys were retained. The average weight of the released turkeys was about 8.9 kg (19.6 lb). The maximum weight was about 10.8 kg (23.9 lb). Turkeys were field counted for radioactivity to ensure that they met wildlife release criteria (<5 pCi/g of ^{137}Cs in tissue). The average ^{137}Cs concentration in the released turkeys was 0.1 pCi/g, with a maximum concentration of 0.15 pCi/g. All ^{137}Cs concentrations were below minimum detectable activity levels.

The EDs attributed to ^{137}Cs concentrations field measured in the turkeys ranged from 0.02 to 0.04 mrem. However, for bounding purposes, if a person consumed a released turkey with an average weight of 8.9 kg (19.6 lb) and an average ^{137}Cs concentration of 0.1 pCi/g, the estimated ED would have been approximately 0.02 mrem. About half the weight of a turkey was assumed to be edible. The estimated ED to an individual who consumed a hypothetical turkey with the maximum ^{137}Cs concentration of 0.15 pCi/g and maximum weight of 10.8 kg (23.9 lb) was about 0.04 mrem.

The collective ED from eating all the harvested turkeys from ORR with a 2024 average field-derived ^{137}Cs concentration of 0.1 pCi/g and an average weight of 8.9 kg (19.6 lb) is estimated to be about 0.0008 person-rem. The collective dose is based on the number of harvested turkeys. It is possible that additional individuals may have consumed the harvested turkeys; however, the collective dose would be essentially the same.

A tissue sample from one turkey that was collected opportunistically on ORR was analyzed in 2024. Detected or statistically significant radionuclides included ^{241}Am, ^{40}K, ^{90}Sr, and ^{230}Th. The turkey weighed 7.7 kg (17 lb). The estimated ED to a hypothetical individual who consumed this turkey was 0.03 mrem. 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, and ^{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 were 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 2024, exposure rates averaged about 9.4 µR/h and ranged from 7.6 to 11.5 µR/h. These exposure rates correspond to an annual average dose of about 58 mrem with a range of 47 to 71 mrem. At the background ambient air station, the exposure rate averaged about 8 µR/h and ranged from 7.6 to 9.8 µR/h. The resulting average annual dose was about 52 mrem with a

range of 47 to 60 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 a person was exposed to all the sources and pathways for the duration of 2024, that person could have received a total ED of about 4 mrem. Of that total, 0.6 mrem would have come from airborne emissions, approximately 0.3 mrem from waterborne emissions (0.04 mrem from drinking water, 0.2 mrem from consuming fish, 0.003 mrem from other water uses along the Clinch River, and 0.05 mrem from irrigation at CRK 16), and about 3 mrem from consuming wildlife. Direct radiation measurements at six ORR ambient air monitoring stations were at or near background levels in 2024. There were 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 2020 through 2024 are given in Table 7.8. In 2024, the air pathway dose was consistent with the dose in 2023, which increased relative to recent years largely due to an increase in calculated emissions from Y-12. Increases in the fish consumption dose and drinking water dose in 2021 were due to the contribution of ^{241}Am detected in the second-quarter water sample taken at CRK 58. Fish consumption and drinking water doses decreased in 2022 and have remained relatively low. Recent direct radiation measurements indicated doses near background levels. Doses from consumption of wildlife have been similar for the past 5 years, although the dose from consumption of deer and geese increased slightly in 2024.

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, an aquatic organism assessment was conducted using the RESRAD-Biota code (Version 1.8), a companion tool for implementing DOE technical standard DOE-STD-1153-2019, *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. A BCG is the limiting concentration of a radionuclide in sediment or water that would not cause dose limits for protection of aquatic biota populations to be exceeded.

The intent of the graded approach is to protect populations of aquatic organisms from the effects of exposure to anthropogenic ionizing radiation. Certain organisms are more sensitive to ionizing radiation than others. Therefore, 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.

Table 7.7. Summary of maximum estimated effective doses from ORR activities to an adult by exposure pathway, 2024

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	0.6	0.006	0.6	23.9	0.239		1,276,842[b]
Liquid effluents							
Drinking water	0.04	0.0004	0.04	2.0	0.02		511,493[c]
Eating fish	0.2	0.002	0.2	0.06	0.0006		9,607[d]
Other activities	0.003	3×10^{-5}	0.003	0.02	0.0002		3,359,287[d]
Irrigation	0.05	0.0005	0.05				
Other pathways							
Eating deer	3[e]	0.03[e]	3	0.1[e]	0.001[e]		192[e]
Eating geese	0.7[f]	0.007[f]	0.07	g	g		
Eating turkeys	0.04[h]	0.0004[h]	0.04	8×10^{-4} [h]	8×10^{-6} [h]		37[h]
Direct radiation	N/A[i]	N/A					
All pathways							
Total	4[i]	0.04	4	26	0.26	383,053	

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

[f] *Estimates for eating geese are based on consuming three 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] *Estimates for eating turkey are based on consuming a hypothetical turkey with the heaviest weight measured in the harvested turkeys and with the highest ^{137}Cs concentration measured in the released turkeys on ORR; collective dose is based on the number of harvested turkeys.*

[i] *Current exposure rate measurements at ambient 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, 2020–2024 (mrem)[a]

Pathway	2020	2021	2022	2023	2024
Airborne effluents—all pathways	0.4	0.5	0.2	0.6	0.6
Fish consumption (Clinch River)	2	3	0.4	0.7	0.2
Drinking water (Kingston)	0.02	3	0.03	0.006	0.007
Deer	*b*	*b*	2	1	3
Geese	0.07	0.2	0.1	0.08	0.7[c]
Turkeys	*b*	*b*	*b*	0.04	0.04

[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.*

[c] *In 2024, goose consumption dose was based on consuming three geese, but for previous years, it was based on consuming two geese.*

Acronym: *ORR = Oak Ridge Reservation*

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)
- ORNL Sewage Treatment Plant Wastewater Discharge Point (X01)
- WOC 7500 Bridge
- First Creek
- Fifth Creek
- Northwest Tributary
- Raccoon Weir
- Waste Area Grouping 6 Monitoring Station 3 (tributary to WOC at WOD)
- CRK 16, CRK 32, CRK 58, and CRK 66

Based on the results of the general screening phase, in which the maximum concentrations of radionuclides in water were compared with default BCGs, or second-level screenings at X01, X15, and Northwest Tributary, in which the average concentrations of radionuclides in water were 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 for aquatic biota or 0.1 rad/day for riparian biota. Lead-210, a naturally occurring radioisotope, was detected in one water sampling event at each of the following locations: First Creek, Raccoon Weir, and Northwest Tributary. Because ^{210}Pb is naturally occurring, has not typically been reported at these locations, and was only detected during one water sampling event, aquatic biota screenings performed for these locations omitted ^{210}Pb while analytical results are further investigated. Follow-up evaluations will be performed if necessary once results have been confirmed.

At Y-12, doses to aquatic organisms were estimated from surface water concentrations 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 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 CRK 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 *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 protecting the more sensitive organisms is generally assumed to adequately protect other, less sensitive organisms.

Soil sampling for terrestrial dose assessment was initiated in 2007 and was repeated 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 samples collected in 2007 and 2014. Soil sampling locations were as follows:

- **WOC floodplain.** Analytes detected in soil samples at this location in 2021 included ^{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 included ^{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 included ^{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 included $^{233/234}$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 included ^{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 general-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 the 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 the 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.

Evaluations of exposure to terrestrial organisms are typically conducted every 5 years or sooner if an abnormal event occurs that could have adverse impacts on terrestrial organisms.

7.2. Chemical Dose

Chemicals released during ORR operations could migrate to off-site locations, resulting in potential exposure of the public. The following sections summarize the results of an informational risk assessment 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 sources near ORR and are analyzed to determine the presence and concentrations 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).

An HQ is a ratio that compares the estimated exposure dose or intake to a 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 health and nutrition survey (EPA 2023) and weighted based on the combined population of Anderson, Knox, Loudon, and Roane Counties, which reflects 2020 decennial US Census data (Census 2020; Fryar et al. 2021), the drinking water consumption rate for the MEI is assumed to be 953 L/year (2.6 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.

Table 7.9. Chemical hazard quotients and estimated risks for drinking water from the Clinch River at CRK 23 and CRK 16, 2024

Analyte	Hazard quotient	
	CRK 23[a]	CRK 16[b]
	Metals	
Chromium	c	5×10^{-2}
Copper	5×10^{-4}	4×10^{-4}
Mercury	7×10^{-5}	6×10^{-4}
Uranium	3×10^{-2}	3×10^{-2}
Risks for carcinogens		
Chromium	c	3×10^{-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

Calculated HQs for 2024 for CRK 16 and CRK 23 (Table 7.9) were based on detected water concentration values. At all locations, HQs were less than 1 for chemical analytes in water for which there are reference doses. Maximum contaminant levels were also not exceeded (Table 7.9). Beginning in 2022, mercury concentrations at CRK 66, CRK 32, and CRK 16 were measured using a more sensitive analysis method with a lower reporting limit than was used in previous years. HQs were 4×10^{-5} for CRK 66, 1×10^{-4} for CRK 32, 7×10^{-5} for CRK 23, and 6×10^{-4} for CRK 16 in 2024. 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 contaminants in drinking water from the Clinch River.

7.2.1.2. Groundwater

During fiscal year 2024, the Oak Ridge Office of Environmental Management 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 accumulate in tissues of 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 health and nutrition survey (EPA 2023) and weighted based on the combined population of Anderson, Knox, Loudon, and Roane Counties, which reflects 2020 decennial US Census data (Census 2020; Fryar et al. 2021), avid fish consumers were assumed to have eaten 42 kg (93 lb) of fish during 2024. This fish consumption rate of 115 g/day (42 kg/year) was used for estimating exposure to both 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, HQs of less than 1 were calculated for all detected analytes at all locations. For consumption of catfish, HQs of less than 1 were calculated for all detected analytes except for Aroclor 1248 (CRK 16) and Aroclor 1254 and Aroclor 1260 (CRK 70, CRK 32, and CRK 16) (Table 7.10). For carcinogens, risk values greater than 10^{-6} were calculated for the intake of chromium VI in sunfish at CRK 32 and for Aroclor 1254 and Aroclor 1260 (CRK 16). For catfish, risk values greater than 10^{-6} were calculated for chromium VI (CRK 16), Aroclor 1248 (CRK 16), and Aroclor 1254 and Aroclor 1260 (CRK 70, CRK 32, and CRK 16). The Tennessee Department of Environment and Conservation has issued a fish advisory that states that catfish should not be consumed from the entire Melton Hill Reservoir or from the Tennessee River portion of Watts Bar Reservoir because of polychlorinated biphenyl contamination (TDEC 2023). The Tennessee Department of Environment and Conservation has also issued a precautionary fish consumption advisory for catfish in the Clinch River arm of Watts Bar Reservoir (TDEC 2023).

Table 7.10. Chemical hazard quotients and estimated risks for fish caught and consumed from locations on ORR, 2024[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			2×10^{-3}			
Chromium		0.5				0.4
Copper	5×10^{-3}	6×10^{-3}	5×10^{-3}	5×10^{-3}	5×10^{-3}	4×10^{-3}
Iron		0.02				
Manganese	3×10^{-3}	1×10^{-2}	8×10^{-3}	3×10^{-3}	4×10^{-3}	2×10^{-3}
Mercury				0.9		
Selenium	0.2		0.1			
Strontium			4×10^{-3}			
Zinc	0.02	0.03	0.04	0.02	0.02	0.02
Hazard quotients for Aroclors						
Aroclor 1248						2
Aroclor 1254			0.6	2	1	6
Aroclor 1260			0.7	3	2	5
Risks for carcinogens						
Chromium		3×10^{-5}				2×10^{-5}
Aroclor 1248						3×10^{-5}
Aroclor 1254			9×10^{-6}	3×10^{-5}	2×10^{-5}	9×10^{-5}
Aroclor 1260			1×10^{-5}	5×10^{-5}	2×10^{-5}	7×10^{-5}
PCBs (mixed)[e]			2×10^{-5}	8×10^{-5}	4×10^{-5}	2×10^{-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

40 CFR Part 61, Subpart H. "Subpart H—National Emission Standards for Emissions of Radionuclides Other than Radon from Department of Energy Facilities." *US Code of Federal Regulations*, Washington, DC. Retrieved February 25, 2021, from https://www.ecfr.gov/cgi-bin/text-idx?SID=eff89c419f5d1ed63e14b4d1765f4bf9&mc=true&node=pt40.10.61&rgn=div5#sp40.10.61.h.

Census 2020. 2020 Census Results. US Census Bureau, Washington, DC. https://www.census.gov/programs-census-results.html.

DOE 2019. *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota*. DOE-STD-1153-2019. US Department of Energy, Washington, DC.

DOE 2020. *Radiation Protection of the Public and the Environment*. DOE Order 458.1, Ltd. Chg. 4. Approved February 11, 2011 (Ltd. Chg. 4 dated September 15, 2020). US Department of Energy, Washington, DC.

DOE 2022. *Derived Concentration Technical Standard*. DOE-STD-1196-2022. US Department of Energy, Washington, DC.

EP&WSD 2010. *Radiological Monitoring and Dose Report for Selected Wildlife Populations Oak Ridge Reservation*. EPWSD-EPS-TP-01, Oak Ridge National Laboratory, Environmental Protection and Waste Services Division, Oak Ridge, Tennessee.

EPA 2011. *Exposure Factors Handbook.* EPA/600/R-090/052F, US Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment, Washington, DC.

EPA 2015. *CAP-88 & CAP-88 PC*. US Environmental Protection Agency, November 2015, Washington, DC. Retrieved February 25, 2021, from https://www.epa.gov/radiation/cap-88-cap-88-pc.

EPA 2023. *What We Eat in America—Food Commodity Intake Database 2005-10*. US Environmental Protection Agency, Office of Pesticide Programs, and University of Maryland. Retrieved April 7, 2024, from https://fcid.foodrisk.org.

Fryar et al. 2021. Fryar, C.D., M.D. Carroll, Q. Gu, J. Afful, and C.L Ogden. *Anthropometric Reference Data for Children and Adults: United States, 2015-2018*. Vital and Health Statistics, Series 3, Number 46. National Center for Health Statistics, Hyattsville, Maryland.

Hamby 1991. Hamby, D.M., "LADTAP XL: An Improved Electronic Spreadsheet Version of LADTAP II." DE93003179, Westinghouse Savannah River Company, Aiken, South Carolina.

NCRP 2009. *Ionizing Radiation Exposure of the Population of the United States.* NCRP Report No. 160, National Council on Radiation Protection and Measurements, Bethesda, Maryland.

NRC 1977. *Regulatory Guide 1.109, Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I*. US Nuclear Regulatory Commission, Washington, DC.

ORNL 2011. *Deer Hunt Radiation Monitoring Guidelines.* CSD-AM-RML-RA01, Oak Ridge National Laboratory, Chemical Sciences Division, Oak Ridge, Tennessee.

ORNL 2020. *Wildlife Monitoring at the TWRA Monitoring Station.* CSD-AM-RML-RA01, Oak Ridge National Laboratory, Chemical Sciences Division, Oak Ridge, Tennessee.

Poudyal et al. 2017. Poudyal, N.C., H. Gotwald, B. English, K. Jensen, J. Menard, C. Caplenor, C. Maldonado, and D. Watkins, "Results from Visitor and Property Owner Surveys on Chickamauga, Norris, and Watts Bar Reservoir in Summer 2016." University of Tennessee Institute of Agriculture, March 24.

Stephens et al. 2006. Stephens, B. et al. *Recreation Use on Melton Hill Reservoir*. Human Dimensions Research Lab, University of Tennessee Agriculture Institute.

TDEC 2023. *Posted Streams, Rivers, and Reservoirs in Tennessee*. Tennessee Department of Environment and Conservation, Division of Water Resources, Nashville, Tennessee. Retrieved April 26, 2024, from https://www.tn.gov/content/dam/tn/environment/water/watershed-planning/wr_wq_fish-advisories.pdf.

TWRA 2019. *Final Report, Report No. 19-06, Tennessee Statewide Creel Survey, 2018 Results*, Fisheries Management Division, Tennessee Wildlife Resources Agency.

TWRA 2021. *Final Report, Report No. 21-06, Tennessee Statewide Creel Survey, 2020 Results*, Fisheries Management Division, Tennessee Wildlife Resources Agency.

TWRA 2024. *Final Report, Report No. 24-04, Tennessee Statewide Creel Survey, 2023 Results*, Fisheries Management Division, Tennessee Wildlife Resources Agency.

TWRA 2025*. Tennessee's Commercial Fish and Mussel Report, Report No. 25-03,* Fisheries Management Division, Tennessee Wildlife Resources Agency.

US Fish and Wildlife Service 2024. *Migratory Bird Hunting Activity and Harvest during the 2022-23 and 2023-24 Hunting Seasons*. US Fish and Wildlife Service.