7. Dose

Activities on ORR have the potential to release small quantities of radionuclides and hazardous chemicals to the environment. These releases could result in exposures of members of the public to low concentrations of radionuclides or chemicals. Monitoring of materials released from the reservation and environmental monitoring and surveillance on and around the reservation provide data used to show that doses from released radionuclides and chemicals are in compliance with the law.

A hypothetical maximally exposed individual could have received in 2011 a ED of about 0.3 mrem from radionuclides emitted to the atmosphere from all ORR sources; this is well below the NESHAP standard of 10 mrem for protection of the public.

A worst-case analysis of exposures to waterborne radionuclides for all pathways combined gives a maximum possible individual ED of about 0.6 mrem. This dose is based on a person eating 21 kg/year of the most contaminated accessible fish, drinking 730 L/year of the most contaminated drinking water, and using the shoreline near the most contaminated stretch of water for 60 h/year.

In addition, if a hypothetical person consumed one deer, one turkey, and two geese (containing the maximum ^{137}Cs concentration and maximum weights), that person could have received an ED of about 2 mrem. This calculation is conducted to provide an estimated upper-bound ED from consuming wildlife harvested from ORR.

Therefore, the annual dose to a maximally exposed individual from all these potential exposure pathways was estimated to be about 3 mrem. DOE O 458.1 limits the ED that an individual may receive from all exposure pathways from all radionuclides released from ORR during 1 year to no more than 100 mrem. The 2011 maximum ED was about 3% of the limit given in DOE O 458.1.

7.1 Radiation Dose

Small quantities of radionuclides were released to the environment from operations at ORR facilities during 2011. 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. The dose estimates are performed using monitored and estimated release data, environmental monitoring and surveillance data, estimated exposure conditions that tend to maximize the calculated EDs, and environmental transport and dosimetry codes that also tend to overestimate the calculated EDs. Thus, the presented doses are conservative estimates of the potential doses received by 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 as long as the radionuclides remain inside a person. Also, external exposures may result in uniform irradiation of the entire body, including all organs, while internal exposures usually result in nonuniform irradiation of the body and organs. When taken into the body, most radionuclides deposit preferentially in specific organs or tissues and thus do not irradiate the body uniformly.

A number of the specialized terms and units used to characterize exposures to ionizing radiation are defined in Appendix E. An important term to understand is “effective dose” (ED). ED is a risk-based equivalent dose that can be 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 rems 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 being considered here are very small, EDs are expressed in millirem (mrem), which is one one-thousandth of a rem. (See Appendix E, Sects. E.5.6 through E.5.12 for a comparison and description of various dose levels.)

7.1.2 Methods of Evaluation

7.1.2.1 Airborne Radionuclides

The radiological consequences of radionuclides released to the atmosphere from ORR operations during 2011 were characterized by calculating, for each major facility and for the entire ORR, EDs to maximally exposed off-site individuals, to on-site members of the public, and to the entire population residing within 50 miles of the ORR center. The dose calculations were made with the CAP-88PC Version 3 software program (CAP-88) 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 implements a steady-state Gaussian plume atmospheric dispersion model to calculate concentrations of radionuclides in the air and on the ground and uses food-chain models to calculate radionuclide concentrations in foodstuffs (vegetables, meat, and milk) and subsequent intakes by humans.

CAP-88 PC Version 3 calculates EDs using radionuclide-specific dose coefficients (ED per unit intake) from Federal Guidance Report Number 13 (EPA 1999). The dose coefficients were calculated by use of the methods of Publication 72 of the International Commission on Radiological Protection (ICRP 1996). These coefficients are weighted sums of equivalent doses to 12 specified tissues or organs plus a remainder term that accounts for the rest of the tissues and organs in the body.

A total of 33 emission points on ORR, each of which includes one or more individual sources, were modeled during 2011. The total includes 3 (two combined) points at the Y-12 Complex, 26 points at ORNL, and 6 points 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 2011 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 2011, rainfall, as averaged over the five rain gauges located on ORR, was 167.2 cm. The average air temperature was 15.1°C, and the average mixing-layer height was 597.6 m. The mixing height is the depth of the atmosphere adjacent to the surface within which air is mixed.

For occupants of residences, the dose calculations assume that the occupant remained at home (actually, unprotected outside the house) during the entire year and obtained food according to the rural pattern defined in the NESHAP background documents (EPA 1989). This pattern specifies that 70% of the vegetables and produce, 44.2% of the meat, and 39.9% of the milk consumed are produced in the local area (e.g., a home garden). The remaining portion of each food is assumed to be produced within 80 km 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 that 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 of ORR was calculated using the production rates provided with CAP-88.

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

Source ID	Stack height (m)	Stack diameter (m)	Effective exit gas velocity (m/s)	Exit gas temperature (°C)	Distance (m) and direction to the maximally exposed individual[a]			
					Plant maximum		Oak Ridge Reservation maximum	
X-Lab Hoods								
X-1000 Lab Hoods	15	0.5	0	Ambient	4350	SW	4350	SW
X-2000 Lab Hoods	15	0.5	0	Ambient	NA[a]		NA	
X-3000 Lab Hoods	15	0.5	0	Ambient	5100	SW	5100	SW
X-4000 Lab Hoods	15	0.5	0	Ambient	5270	SW	5270	SW
X-6000 Lab Hoods	15	0.5	0	Ambient	5970	SW	5970	SW
X-7000 Lab Hoods	15	0.5	0	Ambient	5290	WSW	5290	WSW
X-2026	22.9	1.05	10.91	Ambient	4820	SW	4820	SW
X-2099	3.66	0.178	21.9	Ambient	4810	SW	4810	SW
X-3018	61	4.11	0.17	Ambient	NA[a]		NA	
X-3020	61	1.22	16.34	Ambient	5000	SW	5000	SW
X-3026								
3026 C Pad	2.438	0.203	29.11	Ambient	NA[a]		NA	
3026 D Pad	2.438	0.203	29.11	Ambient	NA[a]		NA	
X-3039	76.2	2.44	11.77	Ambient	5070	SW	5070	SW
X-3085	15	0.2032	87.32	Ambient	5150	SW	5150	SW
X-3544	9.53	0.279	22.01	Ambient	4810	SW	4810	SW
X-3608 Air Stripper	10.97	2.44	0.57	Ambient	4930	SW	4930	SW
X-3608 Filter Press	8.99	0.36	9.27	Ambient	NA[a]		NA	
X-5505								
X-5505M	11	0.305	1.84	Ambient	NA[a]		NA	
X-5505NS	11	0.96	0	Ambient	5550	SW	5550	SW
X-7503	30.5	0.91	11.66	Ambient	5330	SW	5330	SW
X-7830 Group	4.6	0.248	7.93	Ambient	3920	WSW	3920	WSW
X-7856-CIP	18.29	0.483	11.92	Ambient	3970	WSW	3970	WSW
X-7877	13.9	0.406	13.56	Ambient	3890	WSW	3890	WSW
X-7880	27.7	1.52	14.74	Ambient	3970	WSW	3970	WSW
X-7911	76.2	1.52	14.08	Ambient	5240	WSW	5240	WSW
X-7935								
7935 Building Stack	18.29	0.6096	0	Ambient	NA[a]		NA	
7935 Glove Box	9.14	0.254	0	Ambient	NA[a]		NA	
X-7966	6.096	0.292	10.9	Ambient	5330	SW	5330	SW
X-8915	24.38	1.219	6.84	Ambient	8070	SW	8070	SW
X-Decon Areas	15	0.5	0	Ambient	5310	SW	5310	SW
X-STP	7.6	0.203	10.21	Ambient	4590	SW	4590	SW
X-413 Tank W-1A	1.68	0.867	14.38	Ambient	4870	SW	4870	SW
K-1407-U CNF	7.16	1.22	0.625	Ambient	1770	W	5700	SSE
K-2500								
K-2500-H-A	8.23	0.61	12.9	Ambient	960	WSW	6330	SE
K-2500-H-C	8.23	0.61	12.9	Ambient	960	WSW	6330	SE

Table 7.1. (continued)

Source ID	Stack height (m)	Stack diameter (m)	Effective exit gas velocity (m/s)	Exit gas temperature (°C)	Distance (m) and direction to the maximally exposed individual[a]			
					Plant maximum		Oak Ridge Reservation maximum	
K-2500-H-D	8.23	0.91	12.9	Ambient	940	WSW	6340	SE
K-2527-BR	2.0	0.3	0	Ambient	850	W	6280	SE
K-1407-AL CWTS	2.74	0.15	0	Ambient	1770	W	5710	SSE
Y-Monitored	20	0.5	0	Ambient	2270	NE	13340	SW
Y-Unmonitored Processes	20	0.5	0	Ambient	2270	NE	13340	SW
Y-Unmonitored Lab Hoods	20	0.5	0	Ambient	2270	NE	13340	SW

[a]NA: effective doses (EDs) were calculated to be zero; therefore, distance and direction to maximally exposed individuals could not be determined.
"X" prefix designates Oak Ridge National Laboratory.
"K" prefix designates East Tennessee Technology Park.
"Y" prefix designates Y-12 National Security Complex.

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

Tower	Height (m)	Source
		Y-12 National Security Complex
MT6	30[a]	All Y-12 sources
MT6	60	Spallation Neutron Source (ORNL)
		East Tennessee Technology Park
MT7	10	K-1407-U, K-1407-ALCWTS, K-2500-HA, K-2500-HC, K-2500-HD, and K-2527-BR
		Oak Ridge National Laboratory
MT4	10	X-7830, X-7966, X-7935
MT4	30	X-7503, X-7856-CIP, X-7877, X-7880, X-7911, and X-7000 Lab Hoods
MT3	30	X-6000 Lab Hoods
MT2	10	X-2099, X-3074, X3026 C & D, X3038,X3085, X-3544, X-3608FP, X-3508AS, STP, Tank W-1A
MT2	30	X-2026, X-5505(NS & M), X-Decon Areas, and X-1000, 2000, 3000, & 4000 Lab Hoods
MT2	100	X-3018, X-3020, and X-3039

[a]Wind speeds adjusted to match conditions at a height of 30 m.

7.1.2.1.1 Results

Calculated EDs from radionuclides emitted to the atmosphere from ORR are listed in Table 7.3 (maximum individual) and Table 7.4 (collective). The hypothetical maximally exposed individual for ORR was located about 13,340 m southwest of the main Y-12 Complex release point, about 5,240 m west-southwest of the 7911 stack at ORNL, and about 5,700 m south-southeast of the K-1407-U CNF at ETTP. This individual could have received an ED of about 0.3 mrem, which is well below the NESHAP standard of 10 mrem, and is about 0.1% of the roughly 300 mrem that the average individual receives from natural sources of radiation. Based on the 2010 population census data, the calculated collective ED to the entire population within 80 km of ORR (about 1,172,530 persons) was about 13 person-rem, which is about 0.004% of the 363,484 person-rem that this population received from natural sources of radiation (based on an individual dose of about 300 mrem/year).

Table 7.3. Calculated radiation doses to maximally exposed off-site individuals from airborne releases, 2011

Plant	Effective dose, mrem (mSv)	
	At plant max	At Oak Ridge Reservation max
Oak Ridge National Laboratory	0.24(0.0024)[a]	0.24 (0.0024)
East Tennessee Technology Park	0.007(0.00007)[b]	0.0002 (0.000002)
Y-12 National Security Complex	0.1(0.001)[c]	0.01(0.0001)
Entire Oak Ridge Reservation	*d*	0.3(0.003)[e]

[a]The maximally exposed individual was located 5070 m SW of X-3039 and 5240 m WSW of X-7911.

[b]The maximally exposed individual was located 1770 m W of K-1407-U CNF.

[c]The maximally exposed individual is located 2270 m NE of the Y-12 National Security Complex release point.

[d]Not applicable.

[e]The maximally exposed individual for the entire ORR is the ORNL maximally exposed individual.

Table 7.4. Calculated collective effective doses from airborne releases, 2011

Plant	Collective effective dose[a]	
	Person-rem	Person-Sv
Oak Ridge National Laboratory	11.7	0.117
East Tennessee Technology Park	0.02	0.0002
Y-12 National Security Complex	1.3	0.013
Entire Oak Ridge Reservation	13	0.13

[a]Collective effective dose to the 1,172,530 persons residing within 80 km of ORR (based on 2010 census data).

The maximally exposed individual for the Y-12 Complex was located at a residence about 2270 m northeast of the main Y-12 Complex release point. This individual could have received an ED of about 0.1 mrem from Y-12 emissions. Inhalation and ingestion of uranium radioisotopes (i.e., ^{232}U, ^{233}U, ^{234}U, ^{235}U, ^{236}U, and ^{238}U) accounted for essentially all (about 99%) of the dose. The contribution of Y-12 Complex emissions to the 50-year committed collective ED to the population residing within 80 km of ORR was calculated to be about 1.3 person-rem, which is about 10% of the collective ED for ORR.

The maximally exposed individual for ORNL was located at a residence about 5,070 m southwest of the 3039 stack and 5,240 m west-southwest of the 7911 stack. This individual could have received an ED of about 0.24 mrem from ORNL emissions. Radionuclides contributing 5% or more to the dose include ^{212}Pb (36%), ^{125}I (21%), ^{238}U (11%), ^{11}C (8%), ^{138}Cs (8%), and ^{41}Ar (6%). The contribution of ORNL emissions to the collective ED to the population residing within 80 km of ORR was calculated to be about 11.7 person-rem, about 90% of the collective ED for ORR.

The maximally exposed individual for the ETTP was located at a business about 1770 m west of the K-1407-U CNF (the TSCA incinerator is no longer in operation). The ED received by this individual was calculated to be about 0.007 mrem. About 91% of the dose is from uranium radioisotopes (^{234}U, ^{235}U, ^{238}U), and about 8% of the dose is from ^{99}Tc. The contribution of ETTP emissions to the collective ED to the population residing within 80 km of ORR was calculated to be about 0.02 person-rem, or about 0.2% of the collective ED for the reservation.

The reasonableness of the estimated radiation doses can be inferred by comparing EDs estimated from measured radionuclide air concentrations with EDs estimated from calculated (using CAP-88 and emission data) radionuclide air concentrations at the ORR PAMs (Table 7.5). Based on measured radionuclide air concentrations that could have been released from operations on ORR for hypothetical individuals assumed to reside at the PAMs could have received EDs between 0.003 and 0.04 mrem/year. These doses do not include contributions from naturally occurring ^{40}K and ^{7}Be. Based on calculated radionuclide air concentrations released from operations on ORR, hypothetical individuals assumed to reside at the PAMs could have received EDs between 0.07 and 0.2 mrem/year. As shown in Table 7.5, EDs calculated using CAP-88 tend to be higher than or equivalent to EDs calculated using measured air concentrations.

Table 7.5. Hypothetical effective doses from living at the Oak Ridge Reservation and the East Tennessee Technology Park ambient-air monitoring stations, 2011

Station	Calculated effective doses			
	Using air monitor data		Using CAP-88[a] and emission data	
	mrem/year	mSv/year	mrem/year	mSv/year
35	0.02	0.0002	0.09	0.0009
37	0.01	0.0001	0.1	0.001
38	0.02	0.0002	0.07	0.0007
39	0.003	0.00003	0.2	0.002
40	0.02	0.0002	0.2	0.002
42	0.04	0.0004	0.07	0.0007
46	0.04	0.0004	0.1	0.001
48	0.02	0.0002	0.2	0.002
52	0.02	0.0002	*b*	*B*
K2	0.02	0.0002	0.05	0.0005
K6	0.007	0.00007	0.04	0.0004
K9	0.009	0.00009	0.04	0.0004
K11	0.07	0.0007	0.05	0.0005

[a]CAP-88PC Version 3 software, developed under EPA sponsorship to demonstrate compliance with 40 CFR 61, Subpart H.

[b]Effective dose was not calculated using CAP-88 and emission data at the given ambient air monitoring location.

As an indication of doses from the background air monitoring station (Station 52), the ED was calculated from measured air concentrations, which was 0.02 mrem/year. (The isotopes ^{7}Be and ^{40}K also were not included in the background air monitoring station calculation.) It should be noted that measured air concentrations of ^{7}Be were similar at the PAMs and at the background air monitoring station.

Of particular interest is a comparison of doses calculated using measured air concentrations of radionuclides at PAMs located near the maximally exposed individuals for each plant and doses calculated for those individuals using CAP-88 and measured emissions. PAM 46 is located near the maximally exposed individual for the Y-12 Complex. The ED calculated with measured air concentrations was 0.03 mrem/year, which is less than the ED of 0.1 mrem/year calculated at the PAM 46 air monitor station using CAP-88. This year the maximally exposed individual location for ORR/ORNL was located off-site near the PAM 39 air monitoring location; the ED calculated with measured air concentrations was 0.003 mrem/year, which was considerably less than the 0.2 mrem/year calculated using CAP-88. The K-6 Air Monitoring Station is located relatively near the ETTP maximally exposed individual (at a business); the ED calculated using measured air concentrations was about

0.007 mrem/year, which is considerably lower than the ETTP maximally exposed individual annual dose of 0.04 mrem estimated using CAP-88.

7.1.2.2 Waterborne Radionuclides

Radionuclides discharged to surface waters from ORR enter the Tennessee River system by way of the Clinch River (see Section 1.3.4 for the surface water setting of ORR). Discharges from the Y-12 Complex enter the Clinch River via Bear Creek and East Fork Poplar Creek, both of which enter Poplar Creek before it enters the Clinch River, and by discharges from Rogers Quarry into McCoy Branch and then into Melton Hill Lake. Discharges from ORNL enter the Clinch River via White Oak Creek and enter Melton Hill Lake via some small drainage creeks. Discharges from the ETTP enter the Clinch River either directly or via Poplar Creek. This section discusses the potential radiological impacts of these discharges to persons who drink water; eat fish; and swim, boat, and use the shoreline at various locations along the Clinch and Tennessee Rivers.

For assessment purposes, surface waters potentially affected by ORR are divided into seven segments: (1) Melton Hill Lake above all possible ORR inputs, (2) Melton Hill Lake, (3) Upper Clinch River (from Melton Hill Dam to confluence with Poplar Creek), (4) Lower Clinch River (from confluence with Poplar Creek to confluence with the Tennessee River), (5) Upper Watts Bar Lake (from near the confluence of the Clinch and Tennessee rivers to below Kingston), (6) the lower system (the remainder of Watts Bar Lake and Chickamauga Lake to Chattanooga), and (7) Poplar Creek (including the confluence of East Fork Poplar Creek).

Two methods are used to estimate potential radiation doses to the public. The first method uses radionuclide concentrations in the medium of interest (i.e., in water and fish) determined by laboratory analyses of water and fish samples (see Sections 6.4 and 6.6). The second method calculates possible radionuclide concentrations in water and fish from measured radionuclide discharges and known or estimated stream flows. In both methods, reported concentrations of radionuclides were used if the reported value was both statistically significant and greater than half its detection limit. 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. Estimated doses from measured radionuclide concentrations are presented with and without contributions of naturally occurring radionuclides. The advantages of the second method are that most radionuclides discharged from ORR will be quantified and that naturally occurring radionuclides will not be considered or will be accounted for separately; the disadvantage is the use of models to estimate the concentrations of the radionuclides in water and fish. Both methods use the same models (Hamby 1991) to estimate radionuclide concentrations in media and at locations other than those that are sampled (e.g., downstream). However, combining the two methods allows the potential radiation doses to be bounded. The EDs estimated by both methods, in each of the surface water segments, are provided in Appendix E.

7.1.2.2.1 Drinking Water

Several water treatment plants that draw water from the Clinch and Tennessee river systems could be affected by discharges from ORR. No in-plant radionuclide concentration data are available for any of these plants; all of the dose estimates given below likely are high because they are based on radionuclide concentrations in water before it enters a processing plant. For purposes of assessment, it was assumed that the drinking water consumption rate for the maximally exposed individual is 730 L/year and the drinking water consumption rate for the average person is 370 L/year. The average drinking water consumption rate is used to estimate the collective ED. At all locations in 2011, estimated maximum EDs to a person drinking water were calculated using both measured radionuclide concentrations in and measured radionuclide discharges to off-site surface water, excluding naturally occurring radionuclides such as ^{40}K.

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], there would be no estimated dose to a hypothetical maximally exposed person drinking such water. The collective ED to the 31,495 persons who drink water from the city of Oak Ridge water plant would also be 0 person-rem.

Melton Hill Lake. The only water treatment plant located on Melton Hill Lake that could be affected by discharges from ORR is a Knox County plant. This plant is located near surface water sampling location CRK 58. A maximally exposed individual could have received an ED of about 2×10^{-8} mrem; the collective dose to the 60,688 persons who drink water from this plant could have been 7×10^{-7} person-rem.

Upper Clinch River. The ETTP (Gallaher) water plant draws water from the Clinch River near CRK 23. For assessment purposes, it is assumed that workers obtain half their annual water (370 L) intake at work. Such a worker could have received an ED of about 0.006 mrem; the collective dose to the 843 workers who drink water from this plant could have been about 0.003 person-rem.

Lower Clinch River. There are no known drinking water intake sections in this river segment (from the confluence of Poplar Creek to the confluence of the Tennessee River).

Upper Watts Bar Lake. The Kingston and Rockwood municipal water plants draw water from the Tennessee River not very far from its confluence with the Clinch River. A maximally exposed individual could have received an ED of about 0.02 mrem; the collective dose to the 22,556 persons who drink water from these plants could have been about 0.2 person-rem.

Lower system. Several water treatment plants are located on tributaries of Watts Bar Lake and Chickamauga Lake. Persons drinking water from these plants could not have received EDs greater than the 0.01 mrem calculated for drinking Kingston and Rockwood water. The dilution from Upper Watts Bar Lake to the Lower system is considered to be negligible. The collective dose to the 279,274 persons who drink water within the lower system could have been about 2 person-rem.

Poplar Creek/Lower East Fork Poplar Creek. No drinking water intakes are located on Poplar Creek or Lower East Fork Poplar Creek.

7.1.2.2.2 Eating Fish

Fishing is quite common on the Clinch and Tennessee river systems. For assessment purposes, it was assumed that avid fish consumers would have eaten 21 kg of fish during 2011 and that the average person, who is used for collective dose calculations, would have consumed 6.9 kg of fish. The estimated maximum ED will be based on either the first method, measured radionuclide concentrations in fish, or by the second method, which calculates possible radionuclide concentrations in fish from measured radionuclide discharges and known or estimated stream flows. The EDs estimated by both methods, in each of the surface water segments, are provided in Appendix E. The number of individuals who could have eaten fish is based on lake creel surveys conducted annually by TWRA. The 2009 Melton Hill, Watts Bar, and Chickamauga creel surveys are used to estimate the numbers of individuals who harvested fish from these water bodies.

Upper Melton Hill Lake above all possible ORR inputs. For reference purposes, a hypothetical avid fish consumer who ate fish caught at CRK 66, which is above all possible ORR inputs, could have received an ED of about 0.2 mrem. The collective ED to the 28 persons who could have eaten such fish was about 0.002 mrem.

Melton Hill Lake. An avid fish consumer who ate fish from Melton Hill Lake could have received an ED of about 7×10^{-8} mrem. The collective ED to the 282 persons who could have eaten such fish could be about 7×10^{-9} person-rem.

Upper Clinch River. An avid fish consumer who ate fish from the Upper Clinch River could have received an ED of about 0.3 mrem. The collective ED to the 392 persons who could have eaten such fish could have been about 0.04 person-rem.

Lower Clinch River. An avid fish consumer who ate fish from the Lower Clinch River (CRK 16) could have received an ED of about 0.02 mrem. The collective ED to the 914 persons who could have eaten such fish could have been about 0.005 person-rem.

Upper Watts Bar Lake. An avid fish consumer who ate fish from Upper Watts Bar Lake could have received an ED of about 0.004 mrem. The collective ED to the 2612 persons who could have eaten such fish could be about 0.004 person-rem.

Lower system. An avid fish consumer who ate fish from the lower system could have received an ED of about 0.004 mrem. The collective ED to the 30,422 persons who could have eaten such fish could have been about 0.03 person-rem. The dilution from Upper Watts Bar Lake to the Lower system is considered to be negligible.

Poplar Creek/Lower East Fork Poplar Creek. An avid fish consumer who ate fish from Lower East Fork Poplar Creek above its confluence with Poplar Creek could have received an ED of about 0.4 mrem. Assuming that 100 people could have eaten fish from Lower East Fork Poplar Creek and 100 from Poplar Creek, the collective ED could have been about 0.02 person-rem.

7.1.2.2.3 Other Uses

Other uses of ORR area waterways include swimming or wading, boating, and use of the shoreline. A highly exposed "other user" was assumed to swim or wade for 30 h/year, boat for 63 h/year, and use the shoreline for 60 h/year. The average individual, who is used for collective dose estimates, was assumed to swim or wade for 10 h/year, boat for 21 h/year, and use the shoreline for 20 h/year. Measured and calculated concentrations of radionuclides in water and the LADTAP XL code (Hamby 1991) were used to estimate potential EDs from these activities. At all locations in 2011, the estimated maximally exposed individual EDs were based on measured off-site surface water radionuclide concentrations and exclude naturally occurring radionuclides such as ^{40}K.

The number of individuals who could have been other users is different for each section of water because the data sources differ. For Watts Bar parts (Upper Clinch River through Lower Watts Bar), the assumption for other users is five times the number of people who harvest fish. For Chickamauga and Melton Hill, the number for other users is based on surveys conducted by TVA.

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) would have no estimated dose. The collective ED to the 10,412 other users would also not have an estimated dose.

Melton Hill Lake. An individual other user of Melton Hill Lake could have received an ED of about 5×10^{-4} mrem. The collective ED to the 24,294 other users could have been about 3×10^{-3} person-rem.

Upper Clinch River. An individual other user of the upper Clinch River could have received an ED of about 2×10^{-5} mrem. The collective ED to the 468 other users could have been about 3×10^{-6} person-rem.

Lower Clinch River. An individual other user of the lower Clinch River could have received an ED of about 5×10^{-5} mrem. The collective ED to the 9,527 other users could have been about 2×10^{-4} person-rem.

Upper Watts Bar Lake. An individual other user of upper Watts Bar Lake could have received an ED of about 2×10^{-5} mrem. The collective ED to the 27,221 other users could have been about 2×10^{-4} person-rem.

Lower system. An individual other user of the lower system could have received an ED of about 2×10^{-5} mrem. The dilution from Upper Watts Bar Lake to the Lower system is considered to be negligible. The collective ED to the 585,167 other users could have been about 7×10^{-4} person-rem.

Poplar Creek/Lower East Fork Poplar Creek. An individual other user of Lower East Fork Poplar Creek, above its confluence with Poplar Creek, could have received an ED of about 0.02 mrem. The collective ED to the 200 other users of Poplar Creek and Lower East Fork Poplar Creek could have been about 6×10^{-4} person-rem.

7.1.2.2.4 Summary

Table 7.6 is a summary of potential EDs from identified waterborne radionuclides around ORR. Adding worst-case EDs for all pathways in a water-body segment gives a maximum individual ED of about 0.4 mrem to a person obtaining his or her full annual complement of fish from, and participating in, other water uses on Lower East Fork Poplar Creek. The maximum collective ED to the 50-mile population could be as high as 2 person-rem. These are small percentages of individual and collective doses attributable to natural background radiation, about 0.1% of the average individual background dose of roughly 300 mrem/year and 0.006% of the 363,484 person-rem that this population received from natural sources of radiation.

Table 7.6. Summary of annual maximum individual (mrem) and collective (person-rem) effective doses (EDs) from waterborne radionuclides, 2011[a,b]

	Drinking water	Eating fish	Other uses	Total[c]
Upstream of all Oak Ridge Reservation discharge locations (CRK 66, City of Oak Ridge Water Plant)				
Individual ED	0	0.2	0	0.2
Collective ED	0	0.002	0	0.002
Melton Hill Lake (CRK 58, Knox County Water Plant)				
Individual ED	0.00000002	0.00000007	0.0005	0.0005
Collective ED	0.0000007	0.000000007	0.003	0.003
Upper Clinch River (CRK 23, Gallaher Water Plant, CRK 32)				
Individual ED	0.006	0.3	0.00002	0.3
Collective ED	0.003	0.04	0.000003	0.04
Lower Clinch River (CRK 16)				
Individual ED	NA[d]	0.02	0.00005	0.02
Collective ED	NA[d]	0.005	0.0002	0.005
Upper Watts Bar Lake, Kingston Municipal Water Plant				
Individual ED	0.02	0.004	0.00002	0.02
Collective ED	0.2	0.004	0.0002	0.2
Lower system (Lower Watts Bar Lake and Chickamauga Lake)				
Individual ED	0.02	0.004	0.00002	0.02
Collective ED	2	0.03	0.0007	2
Lower East Fork Poplar Creek and Poplar Creek				
Individual ED	NA[d]	0.4	0.02	0.4
Collective ED	NA[d]	0.02	0.0006	0.02

[a]1 mrem = 0.01 mSv.

[b]Doses based on measured radionuclide concentrations in water or estimated from measured discharges and known or estimated stream flows.

[c]Total doses and apparent sums over individual pathway doses may differ due to rounding.

[d]Not at or near drinking water supply locations.

Abbreviations

CRK = Clinch River kilometer

7.1.2.3 Radionuclides in Other Environmental Media

The CAP-88 computer codes are used to calculate radiation doses from ingestion of meat, milk, and vegetables that contain radionuclides released to the atmosphere. These doses are included in the dose calculations for airborne radionuclides. However, some environmental media, including milk and vegetables, are sampled as part of the surveillance program. The following dose estimates are based on environmental sampling results and may include contributions from radionuclides occurring in the natural environment, released from ORR, or both.

7.1.2.3.1 Milk

During 2011, milk samples were collected from (1) a nearby dairy and (2) a composite of several reference locations. Significant concentrations of ^{40}K were detected in all samples, and radioactive strontium was detected in all but one sample from the nearby dairy and the composite of several reference locations. Potential EDs attributable to ^{40}K at both "locations" were about 12 mrem/year. The doses due to strontium at the nearby dairy and the composite reference locations were estimated to be about 0.08 and 0.07 mrem, respectively.

7.1.2.3.2 Food Crops

The food-crop sampling program is described in Section 6.5. Samples of tomatoes, lettuce, and turnips were obtained from seven gardens, six local and one distant. These vegetables represent fruit-bearing, leafy, and root vegetables. All radionuclides found in the food crops are found in the natural environment and in commercial fertilizers, and all but ^{7}Be and ^{40}K also are emitted from ORR. Dose estimates are based on hypothetical consumption rates of vegetables that contain statistically significant amounts of detected radionuclides that could have come from ORR. Based on a nationwide food consumption survey (EPA 1997), a hypothetical home gardener was assumed to have eaten 30 kg of homegrown tomatoes, 10 kg of homegrown lettuce, and 20 kg of homegrown turnips. The hypothetical gardener could have received a 50-year committed ED of between 0 and 0.05 mrem, depending on garden location. Of this total, 0 mrem could have come from eating tomatoes, between 0 and 0.03 mrem from eating lettuce, and between 0 and 0.02 mrem from eating turnips. The highest dose to a gardener could have been about 0.05 mrem from consuming all three types of homegrown vegetables. A person eating food from the distant (background) garden could have received a committed ED of essentially 0 mrem from consumption of all three vegetables (less than 1×10^{-6} mrem turnips, 0 mrem from tomatoes, and less than 1×10^{-6} mrem from lettuce).

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, between 4 and 5 mrem to the hypothetical home gardener's ED.

Many of the samples contained detected activities of unidentified beta- and alpha-emitting radionuclides. By subtracting identified activities of beta- and alpha-emitting radionuclides from the unidentified beta and alpha activities, excess beta and alpha activities were estimated. If the excess unidentified beta and alpha activities were from ^{90}Sr and ^{210}Po, a hypothetical home gardener could have received an additional ED of between 3 and 26 mrem. Of this total, between 0 and 24 mrem could have come from eating tomatoes, between 2 and 8 mrem from eating lettuce, and between 1 and 2 mrem from eating turnips. It is believed that most of the excess unidentified alpha activities are due to naturally occurring or fertilizer-introduced radionuclides (e.g., ^{210}Po), not radionuclides discharged from ORR.

7.1.2.3.3 White-Tailed Deer

TWRA conducted three 2-day deer hunts during 2011 on the Oak Ridge Wildlife Management Area, which is part of ORR (see Section 6.7). During the hunts, 321 deer were harvested and were brought to the TWRA checking station. At the station, a bone sample and a tissue sample were taken from each deer; these samples were field counted for radioactivity to ensure that the deer met wildlife release criteria (less than 20 pCi/g of beta-particle activity in bone or 5 pCi/g of ^{137}Cs in edible tissue). Three deer exceeded the limit for beta-particle activity in bone and were retained. The remaining 318 deer were released to the hunters.

The average ^{137}Cs concentration in tissue of the 318 released deer, as determined by field counting, was 0.54 pCi/g; the maximum ^{137}Cs concentration in a released deer was 1 pCi/g. Many of the ^{137}Cs concentrations were less than minimum detectable levels. Of the released deer, the average weight was about 87 lb and the maximum weight was 183 lb. The EDs attributed to field-measured ^{137}Cs concentrations and actual field weights of the released deer ranged from about 0 to 1.4 mrem, with an average of 0.6 mrem.

Also evaluated were potential doses attributed to deer that might have moved off ORR and been harvested elsewhere. In this scenario, an individual who consumed one hypothetical average-weight (87 lb) deer (assuming 55% field weight is edible meat) containing the 2011 average field-measured concentration of ^{137}Cs (0.54 pCi/g) could have received an ED of about 0.6 mrem. The maximum field-measured ^{137}Cs concentration was 1 pCi/g, and the maximum deer weight was 183 lb. A hunter who consumed a hypothetical deer of maximum weight and ^{137}Cs content could have received an ED of about 2.2 mrem.

Tissue samples collected in 2011 from 15 deer (12 released and 3 retained) were subjected to laboratory analysis. Requested radioisotopic analyses included ^{137}Cs, ^{90}Sr, and ^{40}K radionuclides. Comparison of the field results to analytical ^{137}Cs concentrations found that the field concentrations were all but in one case greater than the analytical results and all were less than the administrative limit of 5 pCi/g. Using analytically measured ^{137}Cs and ^{90}Sr and excluding ^{40}K (a naturally occurring radionuclide) and actual deer weights, the estimated doses for the 15 deer (both retained and released) ranged between 0.04 and 9 mrem**.** When present, the primary contributor to dose was ^{90}Sr.

The maximum ED to an individual consuming venison from two or three deer was also evaluated. There were about 26 hunters/households who harvested two deer or more from ORR. Based on ^{137}Cs concentrations determined by field counting and actual field weight, the ED range to a hunter who consumed two or more harvested deer was estimated to be between 0.2 to 1.7 mrem**.**

The collective ED from eating all the harvested venison from ORR with a 2011 average field-derived ^{137}Cs concentration of 0.5 pCi/g and an average weight of 87 lb is estimated to be about 0.2 person-rem.

7.1.2.3.4 Canada Geese

During the 2011 goose roundup, 49 geese were weighed and subjected to whole-body gamma scans. The geese were field counted for radioactivity to ensure that they met wildlife release criteria (less than 5 pCi/g of ^{137}Cs in tissue). The average ^{137}Cs concentration was 0.18 pCi/g, with a maximum ^{137}Cs concentration in the released geese of 0.45 pCi/g. Most of the ^{137}Cs concentrations were below MDA levels. The average weight of the geese screened during the roundup was about 8.7 lb, and the maximum weight was about 11.2 lb.

The EDs attributed to field-measured ^{137}Cs concentrations and actual field weights of the geese ranged from 0 to 0.02 mrem. However, for bounding purposes, if a person consumed a released goose with an average weight of 10.4 lb and an average ^{137}Cs concentration of 0.18 pCi/g, the estimated ED would be about 0.02 mrem. It is assumed that about half the weight of a Canada goose is edible. The maximum estimated ED to an individual who consumed a hypothetical released goose with the maximum ^{137}Cs concentration of 0.45 pCi/g and the maximum weight of 11.2 lb was about 0.06 mrem, although the actual maximum dose to an individual who could have consumed one of the roundup geese was estimated to be 0.02 mrem.

It is possible that a person could eat more than one goose that spent time on ORR. Most hunters harvest on average one to two geese per hunting season (USFWS 1995). If one person consumed two hypothetical geese of maximum weight with the highest measured concentration of ^{137}Cs, that person could have received an ED of about 0.1 mrem.

Between 2000 and 2009, 22 geese tissue samples 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 transuranics (^{241}Am, $^{243/244}Cm$, ^{238}Pu, $^{239/240}Pu$). The total dose, less the contribution of ^{40}K, ranged from 0.01 to 0.5 mrem, with an average of 0.2 mrem (EPWSD 2010).

7.1.2.3.5 Eastern Wild Turkey

Participating hunters are allowed to harvest one turkey from the reservation in a given season unless a harvested turkey is retained, in which case, the hunter is allowed to hunt for another turkey. Three wild turkey hunts were held on the reservation in 2011: April 9–10, April 16–17, and October 22–23. Two additional turkeys were surveyed, one November 12 and the other December 10. Sixty-two birds were harvested, and none were retained. The average ^{137}Cs concentration measured in the released turkeys was 0.1 pCi/g, and the maximum ^{137}Cs concentration was 0.2 pCi/g. The average weight of the turkeys released was about 18.3 lb. The maximum turkey weight was about 23.1 lb.

The EDs attributed to the field-measured ^{137}Cs concentrations, and the actual field weights of the released turkeys ranged from about 0.001 to 0.03 mrem. Potential doses were also evaluated for turkeys that might have moved off ORR and been harvested elsewhere. In this scenario, if a person consumed a wild turkey with an average weight of 18.3 lb and an average ^{137}Cs concentration of 0.1 pCi/g, the estimated ED would be about 0.02 mrem. The maximum estimated ED to an individual who consumed a hypothetical released turkey with the maximum ^{137}Cs concentration of 0.2 pCi/g and the maximum weight of 23.1 lb was about 0.05 mrem. It is assumed that approximately half the weight of a wild turkey is edible. No tissue samples were analyzed in 2011.

The collective ED from consuming all the harvested wild turkey meat (62 birds) with an average field-derived ^{137}Cs concentration of 0.1 pCi/g and average weight of 18.3 lb is estimated to be about 0.001 person-rem.

Two turkey tissue samples were analyzed for radionuclides in 2001 and 2005. Between 2000 and 2009, 22 geese tissue samples were analyzed. An evaluation 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 transuranics (^{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 (EPWSD 2010).

7.1.2.3.6 Direct Radiation

External exposure rates due to background sources in the state of Tennessee average about 6.4 μR/h and range from 2.9 to 11 μR/h (Myrick 1981). These exposure rates correspond to ED rates between 18 and 69 mrem/year, with an average of 40 mrem/year.

External radiation exposure rates are measured at numerous locations on and off ORR. Exposure rates measured at five PAMs around ORR during 2011 averaged about 8.2 μR/h and ranged from 0 to 10 μR/h. These exposure rates correspond to an average ED rate of about 51 mrem/year and a range of 40 to 55 mrem/year. At the remote PAM, the exposure rate averaged 7 μR/h (approximately 43 mrem/year) and ranged from 6.6 to 7.5 μR/h (41 to 47 mrem/year). All measured exposure rates at or near the ORR boundaries fall within the range of statewide background levels.

7.1.3 Current-Year Summary

A summary of the maximum EDs to individuals by pathway of exposure is given in Table 7.7. In the unlikely event that any person was irradiated by all of those sources and pathways for the duration of 2011, that person could have received a total ED of about 3 mrem. Of that total, 0.3 mrem would have come from airborne emissions and 0.3 mrem from waterborne emissions (0.02 mrem from drinking water, 0.3 mrem from consuming fish, and 0.02 mrem from other water uses along the upper Clinch River), and no appreciable dose above background from external radiation.

Table 7.7. Summary of maximum potential effective doses to an adult by exposure pathway

Pathway	Dose to maximally exposed individual		Percentage of DOE mrem/year limit (%)	Estimated population dose		Population within 80 km	Estimated background radiation population dose (person-rem)[a]
	mrem	mSv		person-rem	person-Sv		
Airborne effluents:							
All pathways	0.3	0.003	0.3	13	0.13	1,172,530[b]	
Liquid effluents:							
Drinking water	0.02	0.0002	0.02	1.7	0.017	394,856[c]	
Eating fish	0.3	0.003	0.3	0.1	0.001	51,805[d]	
Other activities	0.02	0.0002	0.02	0.005	0.00005	492,653[d]	
Eating deer	2[e]	0.02	2	0.2	0.002	318	
Eating geese	0.1[f]	0.001	0.1	*g*	*g*		
Eating turkey	0.1[h]	0.001	0.1	0.001	0.00001	62	
Direct radiation	NA[i]	NA					
All pathways	3	0.03	3	15	0.15	1,172,530	363,484

[a]Estimated background population dose is based on the roughly 300 mrem/year individual dose and the population within 80 km of the Oak Ridge Reservation.

[b]Population based on 2010 census data.

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

[d]Population estimates based on population within 80 km and fraction of fish harvested from Melton Hill, Watts Bar, and Chickamauga reservoirs. Melton Hill and Chickamauga recreational use information was obtained from the Tennessee Valley Authority (Stephens, B., et al. 2006 and Stephens, B., et al. 2007).

[e]From consuming one hypothetical worst-case deer, a combination of the heaviest deer harvested and the highest measured concentrations of ^{137}Cs in released deer on ORR in 2011; population dose based on number of hunters that harvested deer.

[f]From consuming two hypothetical worst-case geese, each a combination of the heaviest goose harvested and the highest measured concentrations of ^{137}Cs in released geese.

[g]Population doses were not estimated for the consumption of geese since no geese were brought to checking station during the goose hunt.

[h]From consuming one hypothetical worst-case turkey, a combination of the heaviest turkey harvested and the highest measured concentrations of ^{137}Cs in released turkey. The population dose is based on the number of hunters that harvested turkey.

[i]Direct radiation dose estimates were conducted, although exposure rates near the Clinch River were near background levels. In addition, direct radiation monitoring is no longer conducted for locations that were formerly the UF_6 cylinder storage yards and the K-770 Scrap Yard. Direct dose measurements have been taken and have confirmed that there is no longer a source of potential dose to the public above the background levels.

The dose of 3 mrem is about 3% of the annual dose (roughly 300 mrem) from background radiation. The ED of 3 mrem includes the person who received the highest EDs from eating wildlife harvested on ORR. If the maximally exposed individual did not consume wildlife harvested from ORR, the estimated dose would be about 1 mrem.

DOE Order 458.1 limits the ED that an individual may receive from all exposure pathways from all radionuclides released from ORR during 1 year to no more than 100 mrem. The 2011 maximum ED should not have exceeded about 3 mrem, or about 3% of the limit given in DOE Order 458.1. (For further information, see Sections E.5.6 through E.5.12 in Appendix E, which summarize dose levels associated with a wide range of activities.)

The total collective ED to the population living within an 80 km radius of ORR was estimated to be about 15 person-rem. This dose is about 0.004% of the 363,484 person-rem that this population received from natural sources during 2011.

7.1.4 Five-Year Trends

Dose equivalents associated with selected exposure pathways for the years 2006 to 2011 are given in Table 7.8. In 2011 a decrease in the dose from fish consumption was observed as compared to earlier years. Also doses from external radiation have dropped due to the cleanup of the UF_6 cylinder storage yards and K-770 Scrap Yard. Recent measurements along the Clinch River indicate doses near background levels.

Table 7.8. Trends in effective dose (mrem)[a] for selected pathways

Pathway	2007	2008	2009	2010	2011
All air	0.3	0.4	0.3	0.4	0.3
Fish consumption (Clinch River)	0.9	0.6	1.2	0.3	0.3
Drinking water (Kingston)	0.04	0.05	0.03	0.03	0.02
Direct radiation (Clinch River)	0.4[d]	0.4[d]	0.4[d]	NA[d]	NA[d]
Direct radiation (Poplar Creek)	NA[d]	NA[d]	NA[d]	NA[d]	NA[d]

[a]1 mrem = 0.01 mSv.

[b]Included gamma and neutron radiation measurement data. In 2006, the Poplar Creek location was near the K-1066E Cylinder Yard.

[c]This location is along the bank of the Clinch River near the K-770 Scrap Yard.

[d]Direct radiation dose estimates were conducted, although exposure rates near the Clinch River were near background levels. In addition, direct radiation monitoring is no longer conducted for locations that were formerly the UF_6 cylinder storage yards and the K-770 Scrap Yard. Direct dose measurements have been taken and confirmed that there is no longer a source of potential dose to the public above the background levels.

7.1.5 Potential Contributions from Non-DOE Sources

There are several non-DOE facilities on or near ORR that could contribute radiation doses to the public. These facilities submit annual reports to demonstrate compliance with NESHAP regulations and the terms of their operating licenses. DOE requested information pertaining to potential radiation doses to members of the public who also could have been affected by releases from these facilities. Four facilities responded to the DOE request. Three facilities, which used the COMPLY screening tool for evaluating radiation exposure from atmospheric releases of radionuclides, stated estimated annual doses from airborne emissions at about 1.9, 0.5, and 2.2×10^{-4} mrem, respectively. Therefore, doses from airborne emissions from both non-DOE and DOE sources should be less than 10 mrem. A maximally exposed individual dose of about 22.7 mR/year due to direct radiation was estimated along a protected boundary of one of the facilities. Therefore, doses from air and water emissions and external radiation from both non-DOE and DOE sources should be less than the DOE Order 458.1 requirement of 100 mrem.

7.1.6 Doses to Aquatic and Terrestrial Biota

7.1.6.1 Aquatic Biota

DOE Order 458.1 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 (1.5), a companion tool for implementing the DOE technical standard, *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial*

Biota (DOE 2002). The code serves as DOE's biota dose evaluation tool and uses the screening [i.e., biota concentration guides (BCGs)] and analysis methods in the technical standard. The BCG is the limiting concentration of a radionuclide in sediment or water that would not cause dose limits for protection of aquatic biota populations to be exceeded.

The intent of the graded approach is to protect populations of aquatic organisms from the effects of exposure to anthropogenic ionizing radiation. Certain organisms are more sensitive to ionizing radiation than others. Therefore, it is generally assumed that protecting the more-sensitive organisms will adequately protect other less-sensitive organisms. Depending on the radionuclide, either aquatic organisms (e.g., crustaceans) or riparian organisms (e.g., raccoons) may be considered to be the more sensitive and are typically the limiting organisms for the general screening phase of the graded approach for aquatic organisms. The screening conceptual model for generating the media-specific BCGs places both the aquatic and riparian animal at the sediment-water interface. In the screening conceptual model, sediment presents an external dose hazard to the aquatic animal, whereas water presents both an internal and external dose hazard. For riparian animals, sediment and water present both internal and external dose hazards. The riparian pathways of exposure combine aspects of both terrestrial and aquatic systems.

The graded approach for evaluating radiation doses to aquatic biota consists of a three-step process that involves (1) data assembly, (2) general screening of media-specific radionuclide concentrations to media-specific BCGs, and (3) site-specific screening and analysis. In the general screening phase, surface water radionuclide concentrations and sediment radionuclide concentrations can be compared to the media-specific BCGs using default parameters. This aquatic dose assessment was based primarily on surface water sampling data.

At ORNL, doses to aquatic organisms are based on surface water concentrations at the following 10 different instream sampling locations.

- Melton Branch [Melton Branch kilometer (MEK) 0.2]
- White Oak Creek [White Oak Creek kilometers (WCK) 1.0, 2.6, and 6.8]
- First Creek
- Fifth Creek
- Raccoon Creek
- Northwest Tributary
- Clinch River (CRKs 23 and 66)

All locations except MEK 0.2, WCK 1.0, and WCK 2.6 passed the initial screening phase (comparison of maximum radionuclide water concentrations to default BCGs). MEK 0.2, WCK 1.0 (White Oak Creek at the dam), and WCK 2.6 passed, when comparing average radionuclide water concentrations to default BCGs. This resulted in absorbed dose rates to aquatic organisms below the DOE aquatic dose limit of 1 rad/day at all 10 sampling locations.

At the Y-12 Complex, doses to aquatic organisms were estimated from surface water concentrations at the following six different instream sampling locations.

- Surface Water Hydrological Information Support System Station 9422-1 (also known as Station 17)
- Outfall 200
- C-11 (upstream of 94221 and downstream from Outfall 200)
- Discharge Point S24, Bear Creek at Bear Creek kilometer (BCK) 9.4
- Discharge Point S17 (unnamed tributary to the Clinch River)
- Discharge Point S19 (Rogers Quarry)

Surface Water Hydrological Information Support System 9422-2, C-11, and Discharge Points S17 and S19 passed the general screening phase (maximum water concentrations and default parameters for BCGs). Discharge Point S24 and Outfall 200 passed using average water concentrations. This resulted in absorbed dose rates to aquatic organisms below the DOE aquatic dose limit of 1 rad/day at all five Y-12 Complex locations.

At ETTP, doses to aquatic organisms were estimated from surface water concentrations at the following 13 different instream sampling locations.

- Mitchell Branch at K1700, MIKs 0.45, 0.59, 0.71, 0.82, and MIK 1.4 (upstream location)
- Poplar Creek at K-716 (downstream)
- K1007-B and K-1710 (upstream location)
- K-700 Slough and K901-A (downstream of ETTP operations)
- Clinch River (CRK 16 and CRK 23)

All of these locations passed the initial general screening (using maximum concentrations and default parameters for BCGs). This resulted in absorbed dose rates to aquatic organisms below the DOE aquatic dose limit of 1 rad/day at all 13 sampling locations.

7.1.6.2 Terrestrial Biota

To evaluate impacts on biota, in accordance with requirements in DOE Order 450.1, a terrestrial organism assessment was conducted. An absorbed dose rate of 0.1 rad/day is recommended as the limit for terrestrial animal exposure to radioactive material in soils. As for aquatic and riparian biota, certain terrestrial organisms are more sensitive to ionizing radiation than others, and it is generally assumed that protecting the more sensitive organisms will adequately protect other less-sensitive organisms. Soil sampling for terrestrial dose assessment was initiated in 2007. This biota sampling strategy was developed by taking into account guidance provided in *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota* (DOE 2002) and existing radiological information on the concentrations and distribution of radiological contaminants on ORR. The soil sampling focused on unremediated areas, such as floodplains and some upland areas. Floodplains are often downstream of contaminant source areas and are dynamic systems where soils are eroding in some places and being deposited in others. Soil sampling locations are identified as follows.

- White Oak Creek floodplain and upland location
- Bear Creek Valley floodplain
- Mitchell Branch floodplain
- Two background locations: Gum Hollow and near Bearden Creek

With the exception of samples collected on the White Oak Creek floodplain (collected on the confluence of Melton Branch and White Oak Creek and collected on the White Oak Creek floodplain upstream from White Oak Dam), samples taken at all other soil sampling locations passed either the initial-level screening (comparison of maximum radionuclide soil concentrations to default BCGs) or second-level screening, for which BCG default parameters and average soil concentrations were used. Cesium-137 is the primary dose contributor in the soil samples collected on the White Oak Creek floodplain. Radiological risk to wildlife associated with ^{137}Cs on the White Oak Creek floodplain is known and will be addressed in future CERCLA records of decisions.

Biota sampling in the White Oak Creek floodplain was conducted in 2009. White-footed mice (*Peromyscus leucopus*), deer mice (*Peromyscus maniculatus*), and hispid cotton rats (*Sigmodon hispidus)* were selected for sampling since 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 White Oak Creek and in the floodplain upstream of White Oak Lake. In addition, biota samples were collected at a background location (Gum Hollow). The maximum radionuclide tissue concentrations and maximum soil radionuclide concentrations for each sample location were used to estimate the terrestrial dose. The tissue concentrations were used to estimate the internal dose. To evaluate the external dose, the soil concentrations previously collected were also included in the dose assessment. The external dose was the primary contributor to the total dose. For White Oak Creek, ^{137}Cs was the major contributor to the total dose (0.023 rad/day) with ^{90}Sr and ^{40}K as secondary contributors (7.0×10^{-4} and 5.97×10^{-4} rad/day, respectively). For Melton Branch, ^{137}Cs was the major contributor to dose (0.009 rad/day) with ^{90}Sr and ^{40}K as secondary contributors (8.2×10^{-4} and 7.8×10^{-4} rad/day, respectively). For the background location, Gum Hollow, ^{40}K was the major contributor to dose (7.4×10^{-4} rad/day) with ^{238}U as the secondary dose contributor (3.5×10^{-4} rad/day). Based on measured concentrations in soil and tissue, the absorbed doses to the mice and voles analyzed along the confluence of Melton Branch and White Oak Creek and in the floodplain upstream of White Oak Lake were less than 0.1 rad/day.

Based on the low level exposure rates found in the terrestrial organisms during the 2009 sampling, the sampling period has been changed from annual to periodic. The next evaluation of exposure to terrestrial organisms would be within the next 5 years or if an abnormal event occurs that could have adverse impacts on terrestrial organisms.

7.2 Chemical Dose

7.2.1 Drinking Water Consumption

To evaluate the drinking water pathway, hazard quotients (HQs) were estimated downstream of ORNL and downstream of ORR discharge points (Table 7.9). The HQ is a ratio that compares the estimated exposure dose or intake to the reference dose. (See Appendix F for a detailed description of the chemical dose methodology.) Chemical analytes were measured in surface water samples collected at CRK 23 and CRK 16. CRK 23 is located near the water intake for ETTP; CRK 16 is located downstream of all DOE discharge points. As shown in Table 7.9, HQs were less than 1 for detected chemical analytes for which there are reference doses or maximum contaminant levels.

Acceptable risk levels for carcinogens typically range in magnitude from 10^{-4} to 10^{-6}. A risk value slightly greater than 10^{-5} was calculated for the intake of arsenic in water collected at both locations.

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 the ORR discharge points. In the current assessment, a fish consumption rate of 60 g/day (21 kg/year) is assumed for both the noncarcinogenic and carcinogenic pollutants. This is the same fish consumption rate used in the estimation of the maximum exposed radiological dose from consumption of fish. (See Appendix F for a detailed description of the chemical dose methodology.)

As shown in Table 7.10, for consumption of sunfish and catfish, HQ values of less than 1 were calculated for the all detected analytes except for Aroclor-1254 and Aroclor-1260 (which is a PCB, also referred to as PCB-1254 or PCB-1260). An HQ greater than 1 for Aroclor-1254 was estimated in sunfish and catfish at one location (CRK 32). An HQ greater than 1 for Aroclor-1260 was estimated in sunfish and catfish at all three locations (CRKs 16, 32, and 70). Overall, the HQs were approximately within the same order of magnitude as those estimated in 2011.

For carcinogens, risk values at or greater than 10^{-5} were calculated for the intake of Aroclor-1254 found in sunfish and catfish collected at one location (CRK 32). For sunfish and catfish, risk values at or greater than 10^{-5} were also calculated for the intake of Aroclor-1260 collected at all three locations. 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 and has issued a precautionary fish consumption advisory for catfish in the Clinch River arm of Watts Bar Reservoir (TWRA 2009). Overall, the risk values were approximately within the same order of magnitude as those estimated in 2011.

Table 7.9. Chemical hazard quotients and estimated risks for drinking water, 2011

Chemical	Hazard quotient	
	CRK 23[a]	CRK 16[b]
Arsenic	0.03	0.06
Barium	0.005	0.005
Boron	0.002	0.002
Chromium		0.005
Lead	0.02	0.02
Manganese	0.005	0.007
Mercury	0.0002	0.0007
Nickel	0.004	0.003
Selenium	0.002	0.003
Thallium		0.01
Uranium	0.002	0.002
Vanadium	0.003	0.004
Risk for carcinogens		
Arsenic	2×10^{-5}	1×10^{-5}

[a]Melton Hill Reservoir near the water intake for ETTP.
[b]Clinch River downstream of all US Department of Energy inputs.

Abbreviations

CRK = Clinch River kilometer

Table 7.10. Chemical hazard quotients and estimated risks for carcinogens in fish, 2011[a]

Carcinogen	Sunfish			Catfish		
	CRK 70[b]	CRK 32[c]	CRK 16[d]	CRK 70[b]	CRK 32[c]	CRK 16[d]
Hazard quotient for metals						
Antimony	0.3	0.3	0.2		0.2	0.2
Barium	0.0007	0.01	0.2	0.1	0.00008	0.0001
Boron	< 0.0003	0.007	0.05	0.04	<0.0003	<0.0003
Chromium	0.03	0.03	0.04	0.03	0.02	0.02
Lead	<0.2		0.2	0.2		<0.2
Manganese	0.006	0.009	0.01	0.006	0.002	0.002
Mercury	0.1	0.1	0.4	0.1	0.1	0.1
Nickel	<0.0008			0.04		
Selenium	0.3	0.3	0.3	0.2	0.2	0.2
Strontium	0.002	0.003	0.004	0.0008	0.0002	0.0002
Thallium	0.2	0.1	0.1	0.05	0.06	0.06
Uranium			0.0003			<0.0002
Zinc	0.03	0.05	0.1	0.07	0.02	0.02

Table 7.10. (continued)

Carcinogen	Sunfish			Catfish		
	CRK 70[b]	CRK 32[c]	CRK 16[d]	CRK 70[b]	CRK 32[c]	CRK 16[d]
			Hazard quotient for pesticides and Aroclors			
Aroclor-1254		0.8			4	
Aroclor-1260	2	2	2	8	5	10
			Risks for carcinogens			
Aroclor-1254		1E-5			6E-5	
Aroclor-1260	4E–5	4E–5	4E–5	1E–4	9E–5	2E–4
PCBs (mixed)[e]	4E–5	5E–5	4E–5	1E–4	2E–4	2E–4

[a]The symbol "<" indicates the value for a parameter was not quantifiable at the analytical detection limit, and a blank space indicates that the parameter was undetected.
[b]Melton Hill Reservoir, above the city of Oak Ridge Water Plant.
[c]Clinch River, downstream of Oak Ridge National Laboratory.
[d]Clinch River, downstream of all US Department of Energy inputs.
[e]Mixed polychlorinated biphenyls (PCBs) consist of the summation of Aroclors detected or estimated.

Abbreviations

CRK=Clinch River kilometer

7.3 References

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