7. Dose

Activities on the 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 a total effective dose (ED) of about 0.3 mrem from radionuclides emitted to the atmosphere from all of the sources on the ORR in 2009; this is well below the National Emission Standards for Hazardous Air Pollutants 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 2 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. The estimated dose to an individual from the direct radiation pathway is estimated to be approximately 0.4 mrem.

In addition, if a hypothetical person consumed 1 deer, 1 turkey, and 2 geese (containing the maximum ^{137}Cs concentration and maximum weights), that person could have received an ED of approximately 3 mrem. This calculation is conducted to provide an estimated upper-bound ED from consuming wildlife harvested from the ORR.

Therefore, the annual dose to a maximally exposed individual from all these potential exposure pathways was estimated to be approximately 5 mrem. DOE Order 5400.5 limits the ED that an individual may receive from all exposure pathways from all radionuclides released from the ORR during 1 year to no more than 100 mrem. The 2009 maximum ED was approximately 5% of the limit given in DOE Order 5400.5.

7.1 Radiation Dose

Small quantities of radionuclides were released to the environment from operations at ORR facilities during 2009. 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 effective doses, and environmental transport and dosimetry codes that also tend to overestimate the calculated effective doses. Thus, the presented doses are conservative estimates of the potential doses received by people in the vicinity of the ORR.

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 F. 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 F, Sects. F.5.6 through F.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 2009 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 center of the ORR. The dose calculations were made using 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* (FGR) Number 13 (EPA 1999). The dose coefficients were calculated using 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 41 emission points on the ORR, each of which includes 1 or more individual sources, were modeled during 2009. The total includes 3 (2 combined) points at the Y-12 Complex, 31 points at ORNL, and 7 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 2009 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 2009, rainfall, as averaged over the four rain gauges located on the ORR, was 163.4 cm. The average air temperature was 14.2°C, and the average mixing-layer height was 568.8 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 National Emission Standards for Hazardous Air Pollutants (NESHAPs) 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 the 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 one-half a year and that less than one-half of a worker's food intake occurs at work. For collective ED estimates, production of beef, milk, and crops within 80 km of the ORR was calculated using production rates provided with CAP-88.

7.1.2.1.1 Results

Calculated EDs from radionuclides emitted to the atmosphere from the ORR are listed in Table 7.3 (maximum individual) and Table 7.4 (collective). The hypothetical maximally exposed individual for the ORR was located about 13,340 m southwest of the main Y-12 National Security Complex release point, about 5,240 m west-southwest of the 7911 stack at ORNL, and about 5,270 m south-southeast of the Toxic Substances Control Act (TSCA) Incinerator (stack K-1435) at the ETTP. This individual could have received an ED of about 0.3 mrem, which is well below the NESHAPs standard of 10 mrem and is 0.1 % of the 310 mrem that the average individual receives from natural sources of radiation. The calculated collective ED to the entire population within 80 km of the ORR (about 1,040,041 persons) was

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	4770	SW	4770	SW
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	9.27	Ambient	4820	SW	4820	SW
X-2099	3.66	0.178	16.67	Ambient	4810	SW	4810	SW
X-2523	7	0.3	6.25	Ambient	4670	SW	4670	SW
X-3018	61	4.11	0.23	Ambient	NA[a]		NA	
X-3020	61	1.22	15.65	Ambient	5000	SW	5000	SW
X-3039	76.2	2.44	12.6	Ambient	5070	SW	5070	SW
X-3074 Group	4	0.25	0	Ambient	NA		NA	
X-3544	9.53	0.279	18.52	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		NA	
X-5505								
X-5505M	11	0.305	2.8	Ambient	NA		NA	
X-5505NS	11	0.96	0	Ambient	5550	SW	5550	SW
X-7503	30.5	0.91	9.5	Ambient	5330	SW	5330	SW
X-7830 Group	4.6	0.248	8.5	Ambient	3920	WSW	3920	WSW
X-7855 TRU Bunker	1.0	0.32	0.44	Ambient	4350	SW	4350	SW
X-7856-CIP	18.29	0.483	12.38	Ambient	3970	WSW	3970	WSW
X-7877	13.9	0.406	13.56	Ambient	3890	WSW	3890	WSW
X-7880	27.7	1.52	0	Ambient	3970	WSW	3970	WSW
X-7911	76.2	1.52	12.91	Ambient	5240	WSW	5240	WSW
X-7935								
7935 Bldg Stack	12.57	0.51	11.6	Ambient	NA		NA	
7935 Glove Box	5.5	0.2	0	Ambient	NA		NA	
X-7966	6.096	0.292	11.58	Ambient	5330	SW	5330	SW
X-8915	24.38	1.219	5.83	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
K-1407-U CNF	7.16	1.22	0.625	Ambient	450	WSW	5700	SSE
K-1423 SWR	7.62	0.71	12.8	Ambient	110	SE	5920	SE
K-1435 Incinerator	30.5	1.37	6.18	80.01	1000	W	5270	SSE
K-1435-C Tanks	18.29	0.2	0	Ambient	970	W	5270	SSE
K-2500								
K-2500-H-A	8.23	0.61	12.9	Ambient	540	SE	6330	SE
K-2500-H-D	8.23	0.91	12.9	Ambient	550	SE	6340	SE
K-1093	0.305	0.305	0	Ambient	2860	NE	5930	ESE

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	
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 Complex
MT6	20[a]	All Y-12 sources
MT6	60	Spallation Neutron Source (ORNL)
		East Tennessee Technology Park
MT1	60	K-1435 Incinerator
MT7	10	K-1407-U, K-1423-SWR, K-1435-C WFT,K-2500-HA, K-2500-HD, and K-1093
		Oak Ridge National Laboratory
MT4	10	X-7830, X-7966, X-7935, X-7855
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-2523, X-3074, X-3544, X-3608FP, and X-STP
MT2	30	X-2026, X-3608AS, 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 20 m.

about 17 person-rem, which is approximately 0.005 % of the 312,012 person-rem that this population received from natural sources of radiation (based on an individual dose of 310 mrem/year).

The maximally exposed individual for the Y-12 National Security Complex was located at about 2,270 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 the ORR was calculated to be about 1 person-rem, which is approximately 6% of the collective ED for the 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

Table 7.3. Calculated radiation doses to maximally exposed off-site individuals from airborne releases, 2009

Plant	Effective dose, mrem (mSv)	
	At plant max	At Oak Ridge Reservation max
Oak Ridge National Laboratory	0.3 (0.003)[a]	0.3 (0.003)
East Tennessee Technology Park	0.06 (0.0006)[b]	0.007 (0.00007)
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 1000 m W of K-1435.

[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, 2009

Plant	Collective effective dose[a]	
	Person-rem	Person-Sv
Oak Ridge National Laboratory	15	0.15
East Tennessee Technology Park	0.9	0.009
Y-12 National Security Complex	1	0.01
Entire Oak Ridge Reservation (ORR)	17	0.17

[a]Collective effective dose to the 1,040,041 persons residing within 80 km of the ORR (based on 2000 census data).

of about 0.28 mrem from ORNL emissions. Radionuclides contributing 1% or more to the dose include ^{41}Ar (9%), ^{212}Pb (27%),^{138}Cs (30%),^{125}I (15%), ^{11}C (6%), ^{129}I (4%), ^{138}Xe (1.5%), and ^{88}Kr (1%). The contribution of ORNL emissions to the collective ED to the population residing within 80 km of the ORR was calculated to be about 14.8 person-rem, approximately 88% of the collective ED for the ORR.

The maximally exposed individual for the ETTP was located at a business about 1000 m west of the TSCA Incinerator stack. The ED received by this individual was calculated to be about 0.06 mrem. About 66% of the dose is from ingestion and inhalation of plutonium isotopes (^{238}Pu, ^{239}Pu, ^{240}Pu), 17% of the dose is from uranium radioisotopes (^{234}U, ^{235}U, ^{238}U), about 3% is from ^{3}H, and 9% is from ^{241}Am. The contribution of ETTP emissions to the collective ED to the population residing within 80 km of the ORR was calculated to be about 0.9 person-rem, or approximately 5% 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 perimeter air monitoring stations (PAMs) (Table 7.5). Based on measured radionuclide air concentrations that could have been released from operations on the ORR (i.e., excluding naturally occurring ^{7}Be and ^{40}K), hypothetical individuals assumed to reside at the PAMs could have received EDs between 0.001 and 0.7 mrem/year. Based on calculated radionuclide air concentrations released from operations on the ORR, hypothetical individuals assumed to reside at the PAMs could have received EDs between 0.05 and 0.3 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, with the exception of the estimated doses at PAM 37.

Table 7.5. Hypothetical effective doses from living at the Oak Ridge Reservation and the East Tennessee Technology Park ambient-air monitoring stations, 2009

Station	Calculated effective doses			
	Using air monitor data		Using CAP-88[a] and emission data	
	mrem/year	mSv/year	mrem/year	mSv/year
35	0.04	0.0004	0.1	0.001
37	0.7	0.007	0.1	0.001
38	0.07	0.0007	0.08	0.0008
39	0.001	0.00001	0.3	0.003
40	0.1	0.001	0.3	0.003
42	0.04	0.0004	0.09	0.0009
46	0.09	0.0009	0.1	0.001
48	0.02	0.0002	0.2	0.002
52	0.08	0.0008	*b*	*b*
K2	0.04	0.0004	0.09	0.0009
K6	0.02	0.0002	0.05	0.0005
K9	0.02	0.0002	0.05	0.05
K11	0.09	0.0009	0.1	0.001

[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.

An indication of doses from sources other than those on the ORR can be obtained from the ED calculated from measured air concentrations at the background air monitoring station (Station 52), which was 0.08 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 40 is located near the maximally exposed individual for the Y-12 Complex. The ED calculated using measured air concentrations was 0.001 mrem/year, which is less than the ED of 0.3 mrem/year calculated at the PAM 40 air monitor station using CAP-88. PAM 39 is located near the maximally exposed individual location for ORR/ORNL; the ED calculated using measured air concentrations was 0.001 mrem/year, which was considerably less than the 0.3 mrem/year calculated using CAP-88. The K-11 Air Monitoring Station is located near the ETTP maximally exposed individual (at a business); the ED calculated using measured air concentrations was about 0.045 mrem/year (half of 0.09 mrem/year to account for the business receptor), which is similar to the ETTP maximally exposed individual annual dose of 0.06 mrem estimated using CAP-88.

7.1.2.2 Waterborne Radionuclides

Radionuclides discharged to surface waters from the ORR enter the Tennessee River system by way of the Clinch River (see Sect. 1.3.4 for the surface water setting of the 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 the 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 confluence of the Clinch and Tennessee rivers to below Kingston), (6) the lower system (the remainder of Watts Bar Lake and Chicamauga 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 Sects. 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. 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 the 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 the 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 F.

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 the 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 2009, 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), EDs to a hypothetical maximally exposed person drinking such water was estimated to be 3×10^{-9} mrem. The collective ED to the 30,514 persons who drink water from the city of Oak Ridge water plant could have been 5×10^{-8} person-rem. If naturally occurring radionuclides are included, individual and collective EDs could have been 0.9 mrem and 14 person-rem, respectively.

Melton Hill Lake. The only water treatment plant located on Melton Hill Lake that could be affected by discharges from the 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 0.0005 mrem; the collective dose to the 52,706 persons who drink water from this plant could have been 0.01 person-rem. If naturally occurring radionuclides are included, the EDs could have been 0.9 mrem and 24 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 0.2 mrem; the collective dose to the

843 workers who drink water from this plant could have been about 0.08 person-rem. If naturally occurring radionuclides are included, the EDs could have been about 2 mrem and 1 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 0.03 mrem; the collective dose to the 24,804 persons who drink water from these plants could have been about 0.4 person-rem. If naturally occurring radionuclides are included, the EDs could have been 0.6 mrem and 7 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 0.03 mrem calculated for drinking Kingston and Rockwood water. The collective dose to the 275,183 persons who drink water within the lower system could have been about 4 person-rem. If naturally occurring radionuclides are included, the EDs could have been about 0.6 mrem and 63 person-rem.

Poplar Creek/Lower East Fork Poplar Creek. There are no drinking water intake locations on Poplar Creek or on 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 2009 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 F. The number of individuals that could have eaten fish is based on lake creel surveys conducted annually by TWRA. The Melton Hill, Watts Bar, and Chickamauga creel surveys are used to estimate the number of individuals that 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 0.5 mrem. The collective ED to the 242 persons who could have eaten such fish could have been 0.04 person-rem. If naturally occurring radionuclides are included, the EDs could have been 4 mrem and 0.3 person-rem.

Melton Hill Lake. An avid fish consumer who ate fish from Melton Hill Lake could have received an ED of about 0.0007 mrem. The collective ED to the 2,179 persons who could have eaten such fish could be about 0.0005 person-rem. If naturally occurring radionuclides are included, the EDs could have been 1 mrem and 0.9 person-rem.

Upper Clinch River. An avid fish consumer who ate fish from the Upper Clinch River could have received an ED of about 1 mrem. The collective ED to the 470 persons who could have eaten such fish could have been about 0.2 person-rem. If naturally occurring radionuclides are included, the EDs could have been 7 mrem and 1 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 0.8 mrem. The collective ED to the 1,097 persons who could have eaten such fish could have been about 0.3 person-rem. If naturally occurring radionuclides are included, the EDs could have been 9 mrem and 3 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 0.2 mrem. The collective ED to the 3,136 persons who could have eaten such fish could be about 0.2 person-rem. If naturally occurring radionuclides are included, the EDs could have been 3 mrem and 3 person-rem.

Lower system. An avid fish consumer who ate fish from the lower system could have received an ED of about 0.2 mrem. The collective ED to the 28,600 persons who could have eaten such fish could have been about 2 person-rem. If naturally occurring radionuclides are included, the EDs could have been 3 mrem and 21 person-rem.

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 1 mrem. Assuming 100 people could have eaten fish from Lower East Fork Poplar Creek and 100 from Poplar Creek, the collective ED could have been about 0.04 person-rem. If naturally occurring radionuclides are included, the EDs could have been 2 mrem and 0.07 person-rem.

7.1.2.2.3 Other Uses

Other uses of the 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 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 2009, 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. When compared with EDs from eating fish from the same waters, the EDs from these other uses would be considerably less.

The number of individuals that 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 maximally exposed other user of upper Melton Hill Lake above possible ORR inputs (CRK 66) could have received an ED of about 0.0004 mrem. The collective ED to the 10,412 other users could have been 0.0007 person-rem. If naturally occurring radionuclides are included, individual and collective EDs could have been 0.003 mrem and 0.007 person-rem, respectively.

Melton Hill Lake. An individual other user of Melton Hill Lake could have received an ED of about 0.0004 mrem. The collective ED to the 24,294 other users could have been about 0.002 person-rem. If naturally occurring radionuclides are included, the EDs could have been 0.002 mrem and 0.02 person-rem.

Upper Clinch River. An individual other user of the upper Clinch River could have received an ED of about 0.2 mrem. The collective ED to the 3,424 other users could have been about 0.03 person-rem. If naturally occurring radionuclides are included, the EDs could have been 0.3 mrem and 0.05 person-rem.

Lower Clinch River. An individual other user of the lower Clinch River could have received an ED of about 0.1 mrem. The collective ED to the 7,990 other users could have been about 0.3 person-rem. If naturally occurring radionuclides are included, the EDs could have been 0.2 mrem and 0.6 person-rem.

Upper Watts Bar Lake. An individual other user of upper Watts Bar Lake could have received an ED of about 0.05 mrem. The collective ED to the 22,830 other users could have been about 0.4 person-rem. If naturally occurring radionuclides are included, the EDs could have been 0.09 mrem and 0.7 person-rem.

Lower system. An individual other user of the lower system could have received an ED of about 0.05 mrem. The collective ED to the 405,164 other users could have been about 4 person-rem. If naturally occurring radionuclides are included, the EDs could have been 0.09 mrem and 6 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 0.03 mrem. The collective ED to the 200 other users of Poplar Creek and Lower East Fork Poplar Creek could have been about 0.001 person-rem. If naturally occurring radionuclides are included, the EDs could have been 0.04 mrem and 0.001 person-rem.

7.1.2.2.4 Summary

Table 7.6 is a summary of potential EDs from identified waterborne radionuclides around the ORR. Adding worst-case EDs for all pathways in a water-body segment gives a maximum individual ED of about 2 mrem to a person obtaining his or her full annual complement of drinking water and fish from and participating in other water uses on Upper Clinch River. The maximum collective ED to the 50-mile population could be as high as 9 person-rem. These are small percentages of individual and collective doses attributable to natural background radiation, about 0.7 % of the average individual background dose of 310 mrem/year and 0.003% of the 312,012 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[a,b]

	Drinking water	Eating fish	Other uses	Total[c]
Upstream of all Oak Ridge Reservation discharge locations (Clinch River kilometer [CRK] 66, City of Oak Ridge Water Plant)				
Individual ED	0.000000003	0.5	0.0004	0.5
Collective ED	0.00000005	0.04	0.0007	0.04
Melton Hill Lake (CRK 58, Knox County Water Plant)				
Individual ED	0.0005	0.0007	0.0004	0.002
Collective ED	0.01	0.0005	0.002	0.02
Upper Clinch River (CRK 23, Gallaher Water Plant, CRK 32)				
Individual ED	0.2	1.2	0.2	2
Collective ED	0.08	0.2	0.03	0.3
Lower Clinch River (CRK 16)				
Individual ED	NA[d]	0.8	0.1	0.9
Collective ED	NA[d]	0.3	0.3	0.6
Upper Watts Bar Lake, Kingston Municipal Water Plant				
Individual ED	0.03	0.2	0.05	0.3
Collective ED	0.4	0.2	0.4	1
Lower system (Lower Watts Bar Lake and Chickamauga Lake)				
Individual ED	0.03	0.2	0.05	0.3
Collective ED	4	2	4	9
Lower East Fork Poplar Creek and Poplar Creek				
Individual ED	NA[d]	1.0	0.03	1
Collective ED	NA[d]	0.05	0.001	0.04

[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.

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 the ORR, or both.

7.1.2.3.1 Milk

During 2009, milk sample were collected from two “locations”: a nearby dairy and a composite of several reference locations. Significant concentrations of ^{40}K were detected in all samples and radioactive strontium was detected in one of six samples from the nearby dairy. It is assumed that the annual milk consumption rate is 310 liters. Potential EDs attributable to ^{40}K at both “locations” were about 9 mrem/year. The dose due to strontium at the nearby dairy was about 0.04 mrem.

7.1.2.3.2 Food Crops

The food-crop sampling program is described in Sect. 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 the ORR. Dose estimates are based on hypothetical consumption rates of vegetables that contain statistically significant amounts of detected radionuclides that could have come from the 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 0.02 and 0.4 mrem, depending on garden location. Of this total, between 0 and 0.1 mrem could have come from eating tomatoes, between 0.006 and 0.4 mrem from eating lettuce, and between 0 and 0.06 mrem from eating turnips. The highest dose to a gardener could have been about 0.4 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 about 0.03 mrem, 0.02 mrem from tomatoes and 0.01 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 3 and 4 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 was from ^{90}Sr and ^{210}Po, a hypothetical home gardener could have received an additional ED of between 4 and 55 mrem. Of this total, between 0 and 54 mrem could have come from eating tomatoes, between 0.9 and 3 mrem from eating lettuce, and between 0.2 and 10 mrem from eating turnips. It is believed that most of the excess unidentified beta and alpha activities are due to naturally occurring or fertilizer-introduced radionuclides (e.g., ^{210}Po), not radionuclides discharged from the ORR. Excess beta activity was detected at only two locations, one of which was the distant garden.

Tomato samples at two locations, lettuce samples at one location, and turnip samples at three locations were analyzed for an additional suite of alpha-emitting radionuclides. For tomatoes, results of the additional radionuclide analyses had no effect on dose estimates for one location, but at the second location, the estimated dose increased by a factor of about 5 over the dose attributed to typically analyzed radionuclides. For lettuce, the additional analyses caused the estimated dose to increase by a factor of 12 over the dose attributed to typically analyzed radionuclides at the one sampled location. For turnips, the results of the additional analyses were similar at both locations and increased the estimated dose by a factor of about 7 over the dose attributed to typically analyzed radionuclides.

7.1.2.3.3 White-Tailed Deer

The Tennessee Wildlife Resources Agency (TWRA) conducted three 2-day deer hunts during 2009 on the Oak Ridge Wildlife Management Area, which is part of the ORR (see Sect. 6.7). During the hunts, 354 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). Two deer exceeded the limit for beta-particle activity in bone and were retained. The remaining 352 deer were released to the hunters.

The average ^{137}Cs concentration in tissue of the 352 released deer, as determined by field counting, was 0.6 pCi/g; the maximum ^{137}Cs concentration in a released deer was 1.2 pCi/g. Many of the ^{137}Cs concentrations were less than minimum detectable levels. Of the released deer, the average weight was 86.8 lb and the maximum weight was 189 lb. The EDs attributed to field-measured ^{137}Cs concentrations and actual field weights of the released deer ranged from about 0.01 to 1.7 mrem.

Also evaluated were potential doses attributed to deer that might have moved off the ORR and been harvested elsewhere. In this scenario, an individual who consumed one hypothetical average-weight (86.8 lb) deer (assuming 55% field weight is edible meat) containing the 2009 average field-measured concentration of ^{137}Cs (0.6 pCi/g) could have received an ED of about 0.7 mrem. The maximum field-measured ^{137}Cs concentration was 1.2 pCi/g, and the maximum deer weight was 189 lb. A hunter who consumed a hypothetical deer of maximum weight and ^{137}Cs content could have received an ED of about 3 mrem.

The maximum estimated ED from consuming venison from an actual released deer (based on field ^{137}Cs concentrations and weights) and including the maximum 2009 detected analytical ^{90}Sr result (0.07 pCi/g, which was at the minimum detectable level) is estimated to be about 2 mrem.

Tissue samples collected in 2009 from 14 deer (12 released and 2 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 greater than or essentially equal to the analytical results and all were less than the administrative limit of 5 pCi/g. The ^{90}Sr concentrations analyzed in these tissue samples were in most cases less than the minimum detectable levels. Using ^{137}Cs and ^{90}Sr (at maximum measured concentrations and excluding ^{40}K, a naturally occurring radionuclide) analytical tissue data and actual deer weights, the estimated doses for the 14 deer (both retained and released) ranged between 0.09 to 2 mrem.

The maximum ED to an individual consuming venison from two or four deer was also evaluated. There were about 35 hunters/households who harvested 2 deer or more from the 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 range between 0.4 to 2.8 mrem.

The collective ED from eating all the harvested venison from ORR with a 2009 average field-derived ^{137}Cs concentration of 0.6 pCi/g and average weight of 86.8 lb is estimated to be about 0.2 person-rem.

7.1.2.3.4 Canada Geese

During the 2009 goose roundup, 63 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 0.25 pCi/g, with maximum ^{137}Cs concentration in the released geese of 0.93 pCi/g. Most of the ^{137}Cs concentrations were below minimum detectable activity levels. The average weight of the geese screened during the roundup was about 7.9 lb and the maximum weight was about 11.5 lb.

The EDs attributed to field-measured ^{137}Cs concentrations and actual field weights of the geese ranged from 0 to 0.03 mrem. However, for bounding purposes, if a person consumed a released goose with an average weight of 7.9 lb and an average ^{137}Cs concentration of 0.25 pCi/g, the estimated ED would be about 0.02 mrem. It is assumed that approximately 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 0.93 pCi/g and the maximum weight of 11.5 lb was about 0.1 mrem.

Though the actual maximum dose to an individual who could consumed one of the roundup geese was estimated to be 0.03 mrem.

It is possible that a person could eat more than one goose that spent time on the 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 0.3 mrem.

No geese tissue samples were analyzed in 2008 and 2009. In 2007, a muscle sample from a seriously injured goose that had to be euthanized was analyzed for ^{3}H, ^{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, $^{239/240}Pu$). Many of the analytical results were below minimum detectable activity (MDA) levels. Assuming MDA levels, excluding ^{40}K concentrations (naturally occurring radionuclide), and average weight from the goose roundup, the estimated dose from consuming this goose would have been about 0.3 mrem.

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. Two wild turkey hunts were held on the reservation in 2009, one April 5–6 and the other April 12–13. Thirty-six 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 0.14 pCi/g. The average weight of the turkeys released was about 19.3 lb. The maximum turkey weight was about 25.7 lb.

The EDs attributed to field-measured ^{137}Cs concentrations and actual field weights of the released turkeys ranged from about 0.0005 to 0.03 mrem. Potential doses were also evaluated for turkeys that might have moved off the ORR and been harvested elsewhere. In this scenario, if a person consumed a wild turkey with an average weight of 19.3 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 0.14 pCi/g and the maximum weight of 25.7 lb was about 0.04 mrem. It is assumed that approximately half the weight of a wild turkey is edible. No tissue samples were analyzed in 2009.

The collective ED from consuming all the harvested wild turkey meat (36 birds) with an average field-derived ^{137}Cs concentration of 0.1 pCi/g and average weight of 19.3 lb is estimated to be about 0.0008 person-rem.

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 the ORR. Exposure rates measured at five PAMs around the ORR during 2009 averaged about 7.7 μR/h and ranged from 5.5 to 9.1 μR/h. These exposure rates correspond to an average ED rate of about 48 mrem/year and a range of 34 to 57 mrem/year. At the remote PAM, the exposure rate averaged 6.7 μR/h (approximately 41 mrem/year). All measured exposure rates at or near the ORR boundaries fall within the range of state-wide background levels.

Prior to 1994, a cesium experimental plot was considered a potential source of direct radiation to fishermen on the Clinch River. This plot was remediated in 1994. Prior to remediation, external exposure rate measurements indicated that a hypothetical fisherman who spent 5 h/week (250 h/year) on the river could have received a dose of about 1 mrem above background.

External exposure rate measurements taken over a 3-month period in 2008 on the Clinch River shoreline near the old cesium experimental plot averaged 8.6 μR/h and ranged between 8.2 and 9.2 μR/h. This corresponds to an average annual ED of about 54 mrem with a range between 51 and 57 mrem. These exposure and dose rates fall within the range of measured state-wide background rates and rates measured around the ORR. Based on these measurements and average background values, the hypothetical fisherman should not receive an ED greater than 0.4 mrem above the state-wide average ED from external exposures. This ED falls within the state-wide range of external dose rates and is within and adequately represented by the range of local external doses rates.

Direct radiation monitoring is no longer conducted for the UF_6 cylinder storage yards and the K-770 Scrap Yard at ETTP. These former sources of direct radiation have been remediated, and direct dose measurements confirm that they are no longer sources of potential dose to the public above 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 2009, that person could have received a total ED of about 5 mrem. Of that total, 0.3 mrem would have come from airborne emissions and 2 mrem from waterborne emissions, (0.2 mrem from drinking water, 1.2 mrem from consuming fish, and 0.2 mrem from other water uses along the upper Clinch River), and 0.4 mrem from external radiation.

This dose is about 2% of the annual dose (310 mrem) from background radiation. The ED of 5 mrem includes the person who received the highest EDs from eating wildlife harvested on the ORR. If the maximally exposed individual did not consume wildlife harvested from the ORR, the estimated dose would be about 2 mrem.

DOE Order 5400.5 limits the ED that an individual may receive from all exposure pathways from all radionuclides released from the ORR during 1 year to no more than 100 mrem. The 2009 maximum ED should not have exceeded about 5 mrem, or about 5% of the limit given in DOE Order 5400.5. (For further information, see Sects. F.5.6 through F.5.12 in Appendix F, 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 the ORR was estimated to be about 28 person-rem. This dose is about 0.009% of the 312,012 person-rem that this population received from natural sources during 2009.

7.1.4 Five-Year Trends

Dose equivalents associated with selected exposure pathways for the years from 2006 to 2009 are given in Table 7.8. The variations in values over the 5-year period likely are not statistically significant. The dose estimates for direct radiation along the Clinch River have been corrected for background.

7.1.5 Potential Contributions from Non-DOE Sources

There are several non-DOE facilities on or near the ORR that could contribute radiation doses to the public. These facilities submit annual reports to demonstrate compliance with NESHAPs 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. Nine facilities responded to the DOE request. Based on these responses, no member of the public should have received an annual ED greater than 10 mrem due to airborne releases from these facilities. One facility, which used the COMPLY screening tool for evaluating radiation exposure from atmospheric releases of radionuclides, stated only that the facility is in compliance and the annual dose is less than 10 mrem; three other facilities stated estimated annual doses from airborne emissions at about 3E-4 mrem, 1.2 mrem, and 9.13E-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 20 mrem/year due to direct radiation was estimated at the boundary of one of the facilities. One facility provided a dose estimate of external radiation; however, the area monitoring station was located in this facility’s laboratory.

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	17	0.17	1,040,041[b]	
Liquid effluents:							
Drinking water	0.2	0.002	0.2	4	0.04	353,536[c]	
Eating fish	1.2	0.012	1.2	2	0.02	35,683[d]	
Other activities	0.2	0.002	0.2	4	0.04	463,903[d]	
Eating deer	3[e]	0.03	3	0.2	0.002	352	
Eating geese	0.1[f]	0.001	0.1	*g*	*g*		
Eating turkey	0.04[h]	0.0004	0.04	0.0008	0.000008	36	
Direct radiation	0.4[i]	0.004	0.4				
All pathways	5	0.05		28	0.28	1,040,041	312,012

[a]Estimated background population dose is based on 310 mrem/year individual dose and the population within 80 km of the Oak Ridge Reservation.

[b]Population based on 2000 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 the ORR in 2009; 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.

7.1.6 Doses to Aquatic and Terrestrial Biota

7.1.6.1 Aquatic Biota

DOE Order 5400.5, Chap. II, sets an absorbed dose rate limit of 1 rad/d to native aquatic organisms from exposure to radioactive material in liquid wastes discharged to natural waterways (see Appendix F for definitions of absorbed dose and rad). To demonstrate compliance with this limit, the aquatic organism assessment was conducted using the RESRAD-Biota code (Versions 1.21 and 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.

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

Pathway	2005	2006	2007	2008	2009
All air	0.9	0.8	0.3	0.4	0.3
Fish consumption (Clinch River)	0.3	0.7	0.9	0.6	1.2
Drinking water (Kingston)	0.03	0.02	0.04	0.05	0.03
Direct radiation (Clinch River)	0.4	0.5[b,c]	0.4[d]	0.4[d]	0.4[d]
Direct radiation (Poplar Creek)	1[b]	0.8[b]	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.

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 11 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, and
- Clinch River (CRKs 23, 32, and 66).

All locations, except First Creek, WCK 1.0, and WCK 2.6 passed the initial screening phase (comparison of maximum radionuclide water concentrations to default BCGs). For Fifth Creek, WCK 1.0 (White Oak Creek at the dam) and WCK 2.6, average concentrations were used, and the default bioaccumulation factors for both ^{137}Cs and ^{90}Sr were adjusted to reflect on-site bioaccumulation of these radionuclides in fish. Riparian organisms are the limiting receptor for both ^{137}Cs and ^{90}Sr in surface water; however, the best available bioaccumulation data for White Oak Creek (which was also used for First Creek) are for fish. Because fish are consumed by riparian organisms (e.g., raccoons), adjustment of the fish bioaccumulation factor modified the bioaccumulation of both ^{90}Sr and ^{137}Cs in riparian organisms. This resulted in absorbed dose rates to aquatic organisms below the DOE aquatic dose limit of 1 rad/d at all 11 sampling locations.

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

- Surface Water Hydrological Information Support System Station 9422-1 (also known as Station 17)
- 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)

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

At ETTP, doses to aquatic organisms were estimated from surface water concentrations at 11 different instream sampling locations:

- Mitchell Branch at K1700, MIKs 0.45, 0.59, 0.74, and MIK 1.4 (upstream location),
- Poplar Creek at K-716 (downstream),
- K1007-B and K-1710 (upstream location),
- K901-A (downstream of ETTP operations), and
- 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/d at all nine sampling locations.

7.1.6.2 Terrestrial Biota

To evaluate impacts on biota, in accordance with requirements in DOE Order 450.1, the terrestrial organism assessment was conducted using the RESRAD-Biota code (Versions 1.21 and 1.5). An absorbed dose rate of 0.1 rad/d 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. The screening conceptual model for terrestrial animals has the animal (e.g., deer mouse) surrounded by soil with soil presenting both an internal and external dose pathway. The screening conceptual model for terrestrial animals also includes the potential for exposure to contaminated water from soil pore water or by drinking from contaminated ponds or rivers. In this terrestrial biota assessment only site soil data were used.

Soil sampling for terrestrial dose assessment was initiated in 2007. This biota sampling strategy was developed 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 the 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 and radionuclide analytes are identified below:

- *White Oak Creek floodplain and upland location*. The sampling locations were located at the confluence of Melton Branch and White Oak Creek, White Oak Creek floodplain upstream of White Oak Lake, and off Burial Ground Road and Seepage Pit Loop. Soil radionuclide analytes included ^{241}Am, ^{244}Cm, ^{60}Co, ^{137}Cs, ^{40}K, ^{239}Pu/^{240}Pu, and ^{90}Sr, ^{234}U, and ^{238}U.
- *Bear Creek Valley floodplain.* The sampling locations were on Bear Creek floodplain below the Bone Yard and near the Environmental Monitoring Waste Management Facility (EMWMF). Soil radionuclide analytes include ^{241}Am, ^{238}Pu, ^{234}U, and ^{238}U.
- *Mitchell Branch Floodplain*. The sampling locations were Mitchell Branch floodplain near 1407C and the Laydown Yard and where Mitchell Branch enters Poplar Creek. Soil radionuclide analytes included ^{239}Pu/^{240}Pu, ^{234}U, and ^{238}U.
- *Background locations.* One sampling location was on Gum Hollow, which represents Conasauaga soils, and the other sampling location was near Bearden Creek, which represents Chickamauga soils. Soil radionuclide analytes include ^{241}Am, ^{243}Cm/^{244}Cm, ^{60}Co, ^{137}Cs, ^{40}K, ^{238}Pu, ^{239}Pu/^{240}Pu , ^{90}Sr, ^{234}U, and ^{238}U.

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 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) records of decisions.

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. Biota sampling in the White Oak Creek floodplain was conducted in 2009. The biota sampling locations were at 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). A gridded area was established in each sampling area. The biota sampling areas were in similar locations and areas as the soil sampling areas. There were three composite samples associated with each sampling area and approximately 25 mice were collected per site.

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 and as secondary contributors (7.0E-4 and 5.97E-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 (8.2E-4 and 7.8E-4 rad/day, respectively). For the background location, Gum Hollow, ^{40}K was the major contributor to dose (7.4E-4 rad/day) with ^{238}U as the secondary dose contributor (3.5E-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.

7.2 Chemical Dose

7.2.1 Drinking Water Consumption

To evaluate the drinking water pathway, hazard quotients (HQs) were estimated upstream and downstream of the ORR discharge points (Table 7.9). The hazard quotient is a ratio that compares the estimated exposure dose or intake to the reference dose (see Appendix G 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.

Table 7.9. Chemical hazard quotients and estimated risks for drinking water, 2009

Chemical	Hazard quotient[a]	
	CRK 23[b]	CRK 16[c]
Arsenic		B 0.008
Barium	B 0.005	B 0.005
Beryllium		
Boron	B 0.002	B 0.002
Cadmium	B 0.008	B 0.007
Chromium	B 0.02	B 0.004
Copper	B 0.0007	B 0.0005
Lead	B 0.1	B 0.1
Manganese	0.008	0.009
Nickel	B 0.002	B 0.001
Selenium	B 0.003	
Vanadium	B 0.002	B 0.002
Zinc	0.0006	B 0.0001
Risk for carcinogens		
Arsenic		B 2E-5
1,2 Dichloroethane	J1E-06[a]	

Abbreviations:
CRK = Clinch River kilometer
[a]Melton Hill Reservoir near the water intake for ETTP.
[b]Clinch River downstream of all U.S. Department of Energy inputs.
[c]A prefix "B" (specific to metals or anions) or "J" indicates that the value is estimated at or below the analytical detection limit.

Acceptable risk levels for carcinogens typically range from $10E^{-4}$ to $10E^{-6}$. A risk value greater than 10^{-5} was calculated for the intake of arsenic in water collected at CRK 23.

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/d (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 G 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 are PCBs, also referred to as PCB-1254 and -1260). An HQ greater than 1 for Aroclor-1254 was estimated in catfish at two locations (CRKs 16 and 32). An HQ greater than 1 for Aroclor-1260 was estimated in catfish at three locations (CRKs 16, 32, and 70) and at two locations (CRK 16 and 70) in sunfish. Overall, the HQs were approximately within the same order of magnitude to those estimated in 2008.

Table 7.10. Chemical hazard quotients and estimated risks for carcinogens in fish, 2009[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	0.1	0.1	0.2	0.2	0.2	0.2
Barium	0.0006	0.0003	0.0002	0.00006	0.00007	0.00006
Boron	< 0.0002	0.0003	0.0003	0.0002	0.0004	0.0002
Cadmium	0.01	0.02	0.01	0.02	0.02	<0.01
Chromium	0.02	0.03	0.02	0.02	0.02	0.02
Copper	0.006	0.005	0.005	0.005	0.003	0.006
Lead		<0.2			0.3	
Manganese	0.003	0.003	0.002	0.0009	0.0009	0.001
Mercury	0.06	0.06	0.3	0.1	0.2	0.2
Nickel	< 0.0009	0.001	0.002	0.001	<0.0009	
Selenium	0.2	0.2	0.2	0.1	0.1	0.1
Strontium	0.002	0.0009	0.0004	0.0001	0.00007	0.00008
Thallium	0.1		0.1	0.09	0.08	0.07
Uranium	0.00007	0.00007	0.0002	0.00005	0.00007	0.07
Vanadium			0.001	<0.001		0.00005
Zinc	0.04	0.03	0.03	0.02	0.02	0.02
Hazard quotient for pesticides and Aroclors						
Aroclor-1254				0.6	5	2.8
Aroclor-1260	1.6	0.7	1.2	2.7	11	4
Risks for carcinogens						
Aroclor-1254				1E–5	9E–5	5E–5
Aroclor-1260	3E–5	1E–5	2E–5	4E–4	2E–4	7E–4
PCBs (mixed)[e]	3E–5	1E–5	2E–5	5E–4	3E–4	1E–4

CRK=Clinch River kilometer

[a]A prefix "<" 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 U.S. Department of Energy inputs.

[e]Mixed polychlorinated biphenyls (PCBs) consist of the summation of Aroclors detected or estimated.

For carcinogens, risk values at or greater than 10^{-5} were calculated for the intake of Aroclor-1254 found in catfish collected at all three locations. 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 to those estimated in 2008.

7.3 References

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