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; the calculated doses are compared with existing state and federal criteria.

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 2007; 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 1 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.

Calculations to determine possible doses from consumption of deer, geese, and turkey harvested on or near the ORR resulted in the following: an individual who consumed an average-weight deer containing the average ^{137}Cs concentration could have received an ED of about 0.7 mrem, an individual who consumed an average-weight goose containing the average ^{137}Cs concentration could have received 0.02 mrem, and an individual who consumed an average-weight turkey containing the average ^{137}Cs concentration could have received 0.02 mrem. If a hypothetical person consumed one deer and two 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.

7.1 Radiation Dose

Small quantities of radionuclides were released to the environment from operations at the ORR facilities during 2007. 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 dose estimates do not necessarily reflect doses received by typical people in the vicinity of the ORR; these estimates likely are overestimates.

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 the 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 effective dose, 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, Table F.2, 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 2007 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 the CAP-88PC Version 3, which was 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. This package 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.

This is the first year CAP-88PC Version 3 has been used. A major difference between the earlier CAP-88 and the CAP-88 PC Version 3 is the use of dose coefficients from Federal Guidance Report (FGR) Number 13 (EPA 1999). The FGR 13 dose coefficients are based on the methods in Publication 72 of the International Commission on Radiological Protection (ICRP 1996). The dose coefficients are used to calculate effective doses (EDs), instead of effective dose equivalents (EDEs), which were calculated in earlier CAP-88 versions. The ED, as was the EDE, is the weighted sum of equivalent dose over specified tissues or organs. For the ED there are tissue-weighting factors for 12 tissues or organs (as well as 1 for remainder organs and tissues), as compared to the EDE for which there were 6 tissue-weighting factors (and 1 for remainder organs and tissues). In addition to tissue-weighting factor modifications; there have been updates to the lung model, gastrointestinal absorption fractions, and biokinetic models used for selected elements.

A total of 33 emission points on the ORR, each of which includes 1 or more individual sources, were modeled during 2007. The total includes 5 (2 combined) points at the Y-12 Complex, 22 points at ORNL, and 6 points at ETTP. Table 7.1 is a list of the emission-point parameter values and receptor locations used in the dose calculations.

Meteorological data used in the calculations for 2007 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 2007, rainfall, as averaged over the four rain gauges located on the ORR, was 911.4 mm. The average air temperature was 16.1°C, and the average mixing-layer height was 590 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 (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 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.

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

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			
					Plant maximum		Oak Ridge Reservation maximum	
X-Lab Hoods								
X-1000 Lab Hoods	15	0.5	0	Ambient	NA		NA	
X-3000 Lab Hoods	15	0.5	0	Ambient	5130	E	5130	E
X-4000 Lab Hoods	15	0.5	0	Ambient	4630	E	4630	E
X-6000 Lab Hoods	15	0.5	0	Ambient	4160	E	4160	E
X-7000 Lab Hoods	15	0.5	0	Ambient	3210	NE	3210	NE
X-2026	22.9	1.05	9.96	Ambient	5296	E	5296	E
X-2099	3.66	0.178	22.1	Ambient	5296	E	5296	E
X-2523	7	0.3	8.16	Ambient	5339	E	5339	E
X-3018	61	4.11	0.23	Ambient	5125	E	5125	E
X-3020	61	1.22	15.21	Ambient	5125	E	5125	E
X-3039	76.2	2.44	13.28	Ambient	5060	E	5060	E
X-3074 Group	4	0.25	10.69	Ambient	NA		NA	
X-3544	9.53	0.279	6.616	Ambient	5080	ENE	5080	ENE
X-3608 Air Stripper	10.97	2.44	0.57	Ambient	4965	ENE	4965	ENE
X-3608 Filter Press	8.99	0.36	9.27	Ambient	NA		NA	
X-5505								
X-5505M	11	0.305	2.4	Ambient	NA		NA	
X-5505NS	11	0.96	0	Ambient	4360	E	4360	E
X-7503	30.5	0.91	11.34	Ambient	4289	ENE	4289	ENE
X-7830 Group	4.6	0.248	8.35	Ambient	5342	ENE	5342	ENE
X-7856-CIP	18.29	0.483	12.49	Ambient	5342	ENE	5342	ENE
X-7877	13.9	0.406	13.56	Ambient	5342	ENE	5342	ENE
X-7880	27.7~~43~~	1.52	14.2	Ambient	5342	ENE	5342	ENE
X-7911	76.2	1.52	12.81	Ambient	4259	ENE	4259	ENE
X-7966	6.096	0.292	10.11	Ambient	4259	ENE	4259	ENE
X-8915	24.38	1.219	5.67	Ambient	4273	ESE	4273	ESE
X-Decon Areas	15	0.5	0	Ambient	5060	E	5060	E
X-STP	7.6	0.203	10.21	Ambient	5219	ENE	5219	ENE
K-1407-U CNF	7.16	1.22	0.625	Ambient	357	WSW	11298	E
K-1423 SWR	7.62	0.71	12.8	Ambient	204	ESE	11827	E
K-1435 Incinerator	30.5	1.37	6.2	78.74	685	W	10961	E
K-1435-C Tanks	18.29	0.2	0	Ambient	685	W	10961	E
K-25 Seg Shop 18A	18.3	1.37	2.56	Ambient	532	E	12174	E
K-WWTF	4.06	0.34	0	Ambient	687	W	10959	E

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			
					Plant maximum		Oak Ridge Reservation maximum	
Y-Monitored	20	0.5	0	Ambient	2307	NE	5797	S
Y-Room Exhaust	20	0.5	0	Ambient	2307	NE	5797	S
Y-Unmonitored Processes	20	0.5	0	Ambient	2307	NE	5797	S
Y-Unmonitored Lab Hoods	20	0.5	0	Ambient	2307	NE	5797	S

[a]NA: effective doses (EDs) were calculated to be zero.
"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. Summary of Oak Ridge Reservation meteorological towers, sampling heights, and sources

Tower	Height (m)	Source
		Y-12 Complex
MT6	20[a]	All Y-12 sources and Spallation Neutron Source (ORNL)
		East Tennessee Technology Park
MT1	10	K-1435 Tanks
MT1	60	K-1435 Incinerator
MT7	10	K-1407-U, K-1423-SWR, K-WWTF
MT7	30	K-25 Segmentation Shop 18A
		Oak Ridge National Laboratory
MT4	10	X-7830, X-7966,
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, 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.

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 5,800 m south of the main Y-12 National Security Complex release point, about 4,260 m east northeast of the 7911 stack at ORNL, and about 10,961 m east 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 NESHAP standard of 10 mrem and is 0.1% of the 300 mrem that the average individual receives from natural sources of radiation. The calculated collective ED to the

Table 7.3. Calculated radiation doses to maximally exposed off-site individuals from airborne releases, 2007

Plant	Effective dose, mrem (mSv)	
	At plant max	At Oak Ridge Reservation max
Oak Ridge National Laboratory	0.26 (0.0026)[a]	0.26 (0.0026)
East Tennessee Technology Park	0.02 (0.0002)[b]	0.009 (0.00009)
Y-12	0.15 (0.0015)[c]	0.009 (0.00009)
Entire Oak Ridge Reservation	*d*	0.3 (0.003)[e]

[a]The maximally exposed individual was located 5060 m E of X-3039 and 4,259 m ENE of X-7911.

[b]The maximally exposed individual was located 685 m W of K-1435.

[c]The maximally exposed individual is located 2307 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, 2007

Plant	Collective effective dose[a]	
	Person-rem	Person-Sv
Oak Ridge National Laboratory	17.2	0.172
East Tennessee Technology Park	0.8	0.008
Y-12	1.5	0.015
Entire Oak Ridge Reservation (ORR)	19.5	0.195

[a]Collective effective dose to the 1,040,041 persons residing within 80 km of the ORR.

entire population within 80 km of the ORR (about 1,040,041 persons) was about 19.5 person-rem, which is approximately 0.006% of the 312,012 person-rem that this population received from natural sources of radiation (based on an individual dose of 300 mrem/year).

The maximally exposed individual for the Y-12 National Security Complex was located at about 2,310 m northeast of the main Y-12 National Security Complex release point. This individual could have received an ED of about 0.15 mrem from Y-12 National Security Complex 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 1.5 person-rem, which is approximately 8% of the collective ED for the ORR.

The maximally exposed individual for ORNL was located at a residence about 5,060 m east of the 3039 stack and 4,260 m east-northeast of the 7911 stack. This individual could have received an ED of about 0.26 mrem from ORNL emissions. Radionuclides contributing 1% or more to the dose include ^{41}Ar (54.2%), ^{138}Cs (22.9%), ^{212}Pb (12.2%), and ^{88}Kr (4.2%). The contribution of ORNL emissions to the collective ED to the population residing within 80 km of the ORR was calculated to be about 17.2 person-rem, approximately 88% of the collective ED for the ORR.

The maximally exposed individual for the ETTP was located at a business about 690 m west of the TSCA Incinerator stack (K-1435). The ED received by this individual was calculated to be about 0.02 mrem. About 79% of the dose is from ingestion and inhalation of uranium radioisotopes, about 16% is from ^{3}H, and 4% is from ^{99}Tc. The contribution of ETTP emissions to the collective ED to the population residing within 80 km of the ORR was calculated to be about 0.8 person-rem; approximately 4% 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 7.2). 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 0.005 and 0.1 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 0.04 and 0.3 mrem/year. EDs calculated using CAP-88 tended to be higher than EDs calculated using measured air concentrations (Table 7.5).

Table 7.5. Hypothetical effective doses from living at the Oak Ridge Reservation and the East Tennessee Technology Park ambient-air monitoring stations, 2007

Station	Calculated effective doses			
	Using air monitor data		Using CAP-88 and emission data	
	mrem/year	mSv/year	mrem/year	mSv/year
35	0.08	0.0008	0.08	0.0008
37	0.05	0.0005	0.07	0.0007
38	0.1	0.001	0.04	0.0004
39	0.005	0.00005	0.3	0.003
40	0.04	0.0004	0.3	0.003
42	0.03	0.0003	0.04	0.0004
46	0.01	0.0001	0.1	0.001
48	0.005	0.00005	0.1	0.001
52	0.003	0.00003	*a*	*a*
K2	0.04	0.0004	*a*	*a*
K6	0.01	0.0001	*a*	*a*
K9	0.004	0.00004	*a*	*a*
K11	0.04	0.0004	*a*	*a*

[a]Effective dose was not calculated using CAP-88 and emission data to the given ambient air monitor location.

An indication of doses from sources other than those on the ORR can be obtained from the ED calculated at the background air monitoring station (Station 52), which was 0.003 mrem/year. (The isotopes ^{7}Be and ^{40}K also were not included at the background air monitoring station calculation.) It should be noted that measured air concentrations of ^{7}Be was 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 0.04 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 second highest dose location for ORNL (in same wind direction but closer); the ED calculated using measured air concentrations was 0.005 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 0.04 mrem/year, greater than the ETTP maximally exposed individual annual dose of 0.02 mrem, estimated using CAP-88.

Three other air monitors also were located on the ETTP site (see Fig. 3.21). EDs calculated from air concentrations of radionuclides at these monitors were between 0.004 and 0.04 mrem/year.

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) 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 without and with 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 should allow the potential radiation doses to be bounded.

In the following drinking water and fish subsections, the estimated maximum ED is based on either the first method, which uses radionuclide concentrations measured in the medium of interest (i.e., in water and fish), or by the second method, which calculates possible radionuclide concentrations in water and 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.

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 2007, estimated maximum EDs to a person drinking water were calculated using measured radionuclide concentrations in off-site surface water and exclude naturally occurring radionuclides such as ^{40}K.

Melton Hill Lake above all possible ORR inputs. Since no radionuclides, other than naturally occurring ones, were found in samples taken from Melton Hill Lake above possible ORR inputs [at Clinch River kilometer (CRK) 70 and CRK 66], no EDs to a hypothetical highly exposed person drinking such water was estimated. Also, a collective ED to the 29,981 persons who drink water from the city of Oak Ridge water plant could not be calculated. If naturally occurring radionuclides are included, individual and collective EDs could have been 2 mrem and 29 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 highly exposed individual could have received an ED of about 0.0007 mrem; the collective dose to the 48,316 persons who drink water from this plant could have been 0.02 person-rem. If naturally occurring radionuclides are included, the EDs could have been 2 mrem and 50 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 1000 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 3 mrem and 1 person-rem.

Lower Clinch River. There are no drinking water intake locations in this river segment (from the confluence with Poplar Creek to the confluence with 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 highly exposed individual could have received an ED of about 0.04 mrem; the collective dose to the 24,165 persons who drink water from these plants could have been about 0.5 person-rem. If naturally occurring radionuclides are included, the EDs could have been 0.6 mrem and 8 person-rem.

Lower System. Several water treatment plants are located on tributaries of Watts Bar Lake and Chickamauga Lake. Based on discharge and Clinch River water data, persons drinking water from these plants could not have received EDs greater than about 0.04 mrem calculated for drinking Kingston and Rockwood water. The collective dose to the 263,976 persons who drink water within the lower system could be about 4 person-rem. If naturally occurring radionuclides are included, the EDs could have been 0.7 mrem and 71 person-rem.

Poplar Creek. There are no drinking water intake locations on Lower East Fork Poplar Creek or on 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 2007 and that the average person, who is used for collective dose calculations, would have consumed 6.9 kg of fish. As mentioned above, 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 and excludes naturally occurring radionuclides (e.g., ^{238}U, ^{232}Th, ^{40}K). The EDs estimated by both methods, in each of the surface water segment, are provided in Appendix F.

Melton Hill Lake above all possible ORR inputs. For reference purposes, a hypothetical avid fish consumer who ate fish caught at CRK 70 or CRK 66, which are above all possible ORR inputs, could have received an ED of about 0.03 mrem. If naturally occurring radionuclides are included, the ED could have been 7 mrem.

Melton Hill Lake. An avid fish consumer who ate fish from Melton Hill Lake could have received an ED of about 0.001 mrem. The collective ED to the 139 persons who could have eaten such fish could be about 0.00005 person-rem. If naturally occurring radionuclides are included, the EDs could have been 8 mrem and 0.4 person-rem.

Upper Clinch River. An avid fish consumer who ate fish from the Upper Clinch River could have received an ED of about 0.1 mrem. The collective ED to the 732 persons who could have eaten such fish

could have been about 0.03 person-rem. If naturally occurring radionuclides are included, the EDs could have been 9 mrem and 2 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 0.08 mrem. The collective ED to the 1,708 persons who could have eaten such fish could have been about 0.04 person-rem. If naturally occurring radionuclides are included, the EDs could have been 7 mrem and 4 person-rem.

Upper Watts Bar Lake. An avid fish consumer who ate fish from Upper Watts Bar Lake could have received an ED about 0.03 mrem. The collective ED to the 4,880 persons who could have eaten such fish could be about 0.04 person-rem. If naturally occurring radionuclides are included, the EDs could have been 2 mrem and 3 person-rem.

Lower System. An avid fish consumer who ate fish from Lower System could have received an ED of about 0.03 mrem. The collective ED to the 41,780 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 2 mrem and 26 person-rem.

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 0.9 mrem. Assuming 100 people could have eaten fish from Poplar Creek, the collective ED is estimated to be about 0.03 person-rem. If naturally occurring radionuclides are included, the EDs could have been 5 mrem and 0.2 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 2007, the estimated highly 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 are relatively insignificant.

Melton Hill Lake above all possible ORR inputs. Since no radionuclides, other than naturally occurring ones, were found in samples taken from Melton Hill Lake above possible ORR inputs (at CRK 70 and CRK 66), no EDs to hypothetical other users water were estimated. Also, a collective ED to the 10,412 other users was not calculated. If naturally occurring radionuclides are included, individual and collective EDs could have been 0.2 mrem and 0.5 person-rem, respectively.

Melton Hill Lake. An individual other user of Melton Hill Lake could have received an ED of about 0.00005 mrem. The collective ED to the 24,294 other users could have been about 0.0003 person-rem. If naturally occurring radionuclides are included, the EDs could have been 0.3 mrem and 2 person-rem.

Upper Clinch River. An other user of the Upper Clinch River could have received an ED of about 0.02 mrem. The collective ED to the 3,866 other users could have been about 0.005 person-rem. If naturally occurring radionuclides are included, the EDs could have been 0.3 mrem and 0.07 person-rem.

Lower Clinch River. An other user of the Lower Clinch River could have received an ED of about 0.1 mrem. The collective ED to the 9,020 other users could have been about 0.03 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 other user of Upper Watts Bar Lake could have received an ED of about 0.03 mrem. The collective ED to the 25,772 other users could have been about 0.05 person-rem. If naturally occurring radionuclides are included, the EDs could have been 0.06 mrem and 0.5 person-rem.

Lower System. An other user of the Lower System could have received an ED of about 0.005 mrem. The collective ED to the 356,704 other users could have been about 0.4 person-rem. If naturally occurring radionuclides are included, the EDs could have been 0.06 mrem and 5 person-rem.

Poplar Creek. An other user of Lower East Fork Poplar Creek, above its confluence with Poplar Creek, could have received an ED of about 0.01 mrem. The collective ED to the 100 other users could

have been about 0.0005 person-rem. If naturally occurring radionuclides are included, the EDs could have been 0.2 mrem and 0.008 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 0.9 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 6 person-rem. These are small percentages of individual and collective doses attributable to natural background radiation, about 0.3% and 0.002%, respectively.

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 (CRK 70 and CRK 66, City of Oak Ridge Water Plant)				
Individual ED	0.0	0.03	0.0	0.03
Collective ED	0.0	0.001	0.0	0.001
Melton Hill Lake (CRK 58, Knox County Water Plant)				
Individual ED	0.0007	0.001	0.00005	0.002
Collective ED	0.02	0.00005	0.0003	0.02
Upper Clinch River (CRK 23, Gallaher Water Plant, CRK 32)				
Individual ED	0.2	0.1	0.02	0.3
Collective ED	0.08	0.03	0.005	0.1
Lower Clinch River (CRK 16)				
Individual ED	NA[d]	0.08	0.1	0.2
Collective ED	NA[d]	0.04	0.03	0.08
Upper Watts Bar Lake, Kingston Municipal Water Plant				
Individual ED	0.04	0.03	0.03	0.09
Collective ED	0.5	0.04	0.05	0.6
Lower System (Lower Watts Bar Lake and Chickamauga Lake)				
Individual ED	0.04	0.03	0.005	0.07
Collective ED	4	0.3	0.4	5
Poplar Creek (near Lower East Fork Poplar Creek)				
Individual ED	NA[d]	0.9	0.01	0.9
Collective ED	NA[d]	0.03	0.0005	0.03

[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]Rounded difference between individual pathway doses and total.

[d]Not at 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

Milk collected at two locations at a distance from the ORR contained detected ^{90}Sr concentrations (Sect. 6.5.3). At all three locations, tritium was detected in the samples. The sample data were used to calculate potential EDs to hypothetical persons who drank 310 L (NRC 1977) of sampled milk during the year. These hypothetical persons could have received an ED of about 0.07 mrem from drinking milk from the near locations and about 0.007 mrem from the remote location, excluding the contribution from ^{40}K, a naturally occurring radionuclide.

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 eight local gardens. 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 32 kg of homegrown tomatoes, 10 kg of homegrown lettuce, and 37 kg of homegrown turnips. The hypothetical gardener could have received a 50-year committed ED of between 0.007 and 0.1 mrem, depending on garden location. Of this total, between 0 and 0.05 mrem could have come from eating tomatoes, between 0.007 and 0.04 mrem from eating lettuce, and between 0.02 and 0.09 mrem from eating turnips. The highest dose to a gardener could have been about 0.1 mrem from consuming all three types of homegrown vegetables.

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 2 and 7 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 2 and 9 mrem. Of this total, between 0.04 and 1 mrem could have come from eating tomatoes, between 0.7 and 4 mrem from eating lettuce, and between 1 and 5 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, not radionuclides discharged from the ORR. One tomato sample had an elevated gross alpha result. The sample was recounted and the result was still elevated. Another aliquot of the original sample was also counted and resulted in a gross alpha result similar to that seen in other tomato samples. An isotopic analyses (^{228}Th, ^{230}Th, ^{232}Th, ^{226}Ra, ^{234}U, ^{235}U, ^{238}U, and ^{210}Po) of the original sample was conducted to identify the possible contributor to the elevated gross alpha result, and none of the isotopes significantly contributed to the initial gross alpha result. It is believed that the original tomato sample aliquot may have been compromised.

7.1.2.3.3 Hay

Another environmental pathway that was evaluated using sampling data is eating beef and drinking milk obtained from hypothetical cows that ate hay harvested from the ORR. Statistically significant concentrations of ^{7}Be, ^{40}K, and uranium (^{234}U and ^{238}U) were detected at most sampling locations. Statistically significant concentrations were also found for ^{7}Be, ^{40}K, ^{234}U, and ^{238}U at the background location. Excluding the doses from ^{7}Be and ^{40}K (both naturally occurring), the average ED from drinking milk and eating beef from Areas 1, 2, and 3; 2, 4, and 5; and 6 (see Sect. 6.5.1 and Fig. 6.5) was estimated to be between 0.002 and 1 mrem. Also, excluding the doses from ^{7}Be and ^{40}K resulted in a maximum ED of about 1.5 mrem for the hay samples collected from Area 8 (the background location). The samples also contained small amounts of detected activities of primarily unidentified alpha-emitting radionuclides. By further subtracting unidentified activities of alpha- and beta-; the estimated average ED from drinking milk and eating beef from Areas 1, 2, and 3; 2, 4, and 5; and 6 was estimated to be about 0.005 mrem. Excluding the unidentified activity of alpha-emitting radionuclides, the estimated ED from drinking milk and eating beef from the background location (Area 8) was estimated to also be about 0.005 mrem.

7.1.2.3.4 White-Tailed Deer

The Tennessee Wildlife Resources Agency (TWRA) conducted three 2-day deer hunts during 2007 on the Oak Ridge Wildlife Management Area, which is part of the ORR (see Sect. 6.7). During the hunts, 361 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 and 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 confiscated. The remaining 358 deer were released to the hunters.

The average ^{137}Cs concentration in tissue of the 358 released deer, as determined by field counting, was 0.65 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. The average weight was 86.2 lb, and the maximum weight of the released deer was 179 lb. The EDs attributed to field-measured ^{137}Cs concentrations and actual field weights of the released deer ranged from 0.01 to 1.8 mrem.

An individual who consumed one average-weight deer (86.2 lb), assuming 55% field weight is edible meat, containing the 2007 average field-measured concentration of ^{137}Cs (0.65 pCi/g) could have received an ED of about 0.7 mrem. The maximum field-measured ^{137}Cs concentration was 1 pCi/g, and the maximum deer weight was 179 lb. A hypothetical hunter who consumed a deer of maximum weight and ^{137}Cs content could have received an ED of about 2.3 mrem.

Tissue samples collected in 2007 from 12 deer (9 released and 3 retained) were subjected to laboratory analysis. Requested radioisotopic analyses included ^{60}Co, ^{137}Cs, ^{90}Sr, and ^{40}K radionuclides. Comparison of the field to analytical ^{137}Cs concentrations results found that the field concentrations were greater than the analytical results with the exception of one retained deer. All were less than the administrative limit of 5 pCi/g. The ^{90}Sr concentrations analyzed in these tissue samples were all less than the minimum detectable levels. Using ^{60}Co, ^{137}Cs and ^{90}Sr (at the minimum detectable levels and excluding ^{40}K, a naturally-occurring radionuclide) analytical tissue data and actual deer weights, the estimated doses for these 12 deer ranged between 0.4 to 1 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 2007 analytical ^{90}Sr result (0.16 pCi/g, which was at the minimum detectable level) is estimated to be about 3 mrem. This estimate is considered a more realistic evaluation of a maximum ED from consuming venison from deer harvested on the ORR in 2007 than estimating an ED from consumption of venison with maximum ^{137}Cs concentrations, maximum weight, and maximum ^{90}Sr concentration found in historical data, as conducted in the previous evaluations.

The maximum ED to an individual consuming venison from two or three deer was also evaluated. There were about 45 hunters who harvested two 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 0.5 to 2 mrem.

The collective ED from eating all the harvested venison from ORR with a 2007 average field-derived ^{137}Cs concentration of 0.6 pCi/g and average weight of 86.2 lb is estimated to be about 0.3 person-rem.

7.1.2.3.5 Canada Geese

During the 2007 goose roundup, 202 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 0.19 pCi/g, with maximum ^{137}Cs concentration in the released geese of 0.4 pCi/g. Most of the ^{137}Cs concentrations were less than minimum detectable activity levels. The average weight of the geese screened during the roundup was about 8.2 lb. The maximum goose weight was about 11 lb. The EDs attributed to field-measured ^{137}Cs concentrations and actual field weights of the geese ranged from 0 to 0.02 mrem. If a person consumed a released goose with an average weight of 8.2 lb and an average ^{137}Cs concentration of 0.19 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 0.4 pCi/g and the maximum weight of 11 lb was about 0.05 mrem.

It is possible that one 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 geese of maximum weight with the highest measured concentration of ^{137}Cs, that person could have received an ED of about 0.1 mrem.

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 less than 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 was about 0.3 mrem.

7.1.2.3.6 Eastern Wild Turkey

Two wild turkey hunts were held on the reservation in 2007, one on March 31–April 1 and the other on April 14–15. Thirty-one 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 0.21 pCi/g. The average weight of the turkeys released was about 18.9 lb. The maximum turkey weight was about 23.2 lb.

If a person consumed a wild turkey with an average weight of 18.9 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 0.21 pCi/g and the maximum weight of 23.2 lb was about 0.06 mrem. It is assumed that approximately half the weight of a wild turkey is edible. The ED from one person consuming two average weight turkeys with average ^{137}Cs concentrations was estimated to be about 0.04 mrem. No tissue samples were analyzed in 2007.

The collective ED from consuming all the harvested wild turkey meat (31 birds) with an average field-derived ^{137}Cs concentration of 0.1 pCi/g and average weight of 18.9 lb is estimated to be about 0.0007 person-rem.

7.1.2.3.7 Direct Radiation

External exposure rates from background sources in the state of Tennessee average about 6.4 μR/h and range from 2.9 to 11 μR/h (Myrick 1981). External radiation exposure rates are measured at numerous locations on and off the ORR. The average exposure rate at PAMs around the ORR during 2007 was about 7.8 μR/h. This rate corresponds to an ED rate of about 49 mrem/year. All measured exposure rates at or near the ORR boundaries are near background levels.

External exposure rate measurements taken during 1997 along a 1.7-km length of Clinch River shoreline averaged 8.4 μR/h and ranged between 6.9 and 9.3 μR/h. This corresponds to an average exposure rate of about 2.0 μR/h (0.0014 mrem/h) above background. A potential maximally exposed individual would be a hypothetical fisherman assumed to have spent 5 h/week (250 h/year) near the point of average exposure on the Clinch River shoreline. This hypothetical maximally exposed individual could have received an ED of about 0.4 mrem above background during 2007.

In previous years, the UF_6 cylinder storage yards and K-770 Scrap Yard at ETTP were potential sources of direct gamma and neutron radiation exposure to the public. All remaining UF_6 cylinders stored at ETTP were shipped in December 2006 to the Portsmouth site for disposition; direct dose measurements in the vicinity of each empty storage yard confirmed that the cylinder yards are no longer sources of potential dose to the public above background levels.

All remaining contaminated scrap was shipped from the K-770 Scrap Yard to the EMWMF in early 2007. General area dose rates were recorded in the vicinity of the K-770 Scrap Yard, along the near bank of the Clinch River on February 26, 2007. As per Sect. 3.6.3, these measurements confirmed that the K-770 Scrap Yard is no longer a source of potential dose to the public above background levels.

7.1.3 Doses to Aquatic and Terrestrial Biota

7.1.3.1 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 the rad). To demonstrate compliance with this limit, the aquatic organism assessment was conducted using the RESRAD-Biota code (Version 1.21), 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 "next-generation" biota dose evaluation tool and uses the screening (i.e., biota concentration guides [BCGs]) and analysis methods in the technical standard.

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 the limiting organisms for the general screening phase of the graded approach for aquatic organisms. 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 nine different sampling locations:

- Melton Branch (Melton Branch kilometer [MEK] 0.2),
- White Oak Creek (White Oak Creek kilometer [WCK] 1.0 and 2.6),
- First Creek,
- Fifth Creek,
- Raccoon Creek,
- Northwest Tributary, and
- Clinch River (CRK 32 and 66).

All but one location, WCK 1.0 (White Oak Creek at the dam) passed the initial screening phase (maximum concentrations and using default parameters for BCGs). At WCK 1.0, 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 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 12 sampling locations.

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

- SWHISS Station 9422-1 (Station 17),
- Discharge Point S24, Bear Creek at BCK 9.4
- Discharge Point S17 (unnamed tributary to the Clinch River),
- Outfall 502 West End Treatment Facility
- Outfall 512 and
- Central Mercury Treatment Unit (Outfall 551).

All but two locations passed the general screening phase (maximum water concentrations and default parameters for BCGs). Station 17 and Surface Water Hydrological Information Support System (SWHISS) 9422-2 both passed using average water concentrations and for Station 17, also using site-specific sediment concentrations. This resulted in absorbed dose rates to aquatic organisms below the DOE aquatic dose limit of 1 rad/d at all six Y-12 locations.

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

- Mitchell Branch at K1700, MIK 0.7, 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.

7.1.3.2 Terrestrial Biota

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 was developed.

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 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; 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.

To evaluate impacts on biota, as per DOE Order 450.1A, the terrestrial organism assessment was conducted using the RESRAD-Biota code (Version 1.21), a companion tool for implementing the DOE technical standard, *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota* (DOE 2002). At all soil sampling locations, with the exception of samples collected on the White Oak Creek floodplain (e.g., confluence of Melton Branch and White Oak Creek and White Oak Creek floodplain upstream from White Oak Dam), samples passed either the initial-level screening, (using default parameters and maximum soil concentrations) or second-level screening (using default parameters and average soil concentrations). Cesium-137 is the primary dose contributor in the soil samples collected on the White Oak floodplain. Radiological risk to wildlife associated with ^{137}Cs on the White Oak Creek floodplain is known and will be addressed in future CERCLA RODs. However, based on the results of the terrestrial biota soil sampling, site-specific sampling of biota in the White Oak floodplain is anticipated.

7.1.4 Current-Year Summary

A summary of the maximum EDs to individuals by pathway of exposure is given in Table 7.7. In the very unlikely event that any person was irradiated by all of those sources and pathways for the duration of 2007, that person could have received a total ED of about 4 mrem. Of that total, 0.3 mrem would have come from airborne emissions, 1 mrem from waterborne emissions, (0.2 mrem from drinking water from the Watts Bar Lake, 0.9 mrem from consuming fish from Lower East Fork Poplar creek near its confluence with Poplar Creek, and 0.1 mrem from other water uses along the Lower Clinch River), and 0.4 mrem from direct radiation while fishing on Clinch River. This dose is about 1.3 % of the annual dose (300 mrem) from background radiation. The ED of 4 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 2007 maximum ED should not have exceeded about 4 mrem, or about 4 % of the limit given in DOE Order 5400.5. (For further information, see Table F.2 in Appendix F which summarizes dose levels associated with a wide range of activities.)

The total collective ED to the population living within a 80-km radius of the ORR was estimated to be about 26 person-rem. This dose is about 0.008% of the 312,012 person-rem that this population received from natural sources during 2007.

7.1.5 Five-Year Trends

Dose equivalents associated with selected exposure pathways for the years from 2003 to 2007 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 irradiation along the Clinch River have been corrected for background.

Table 7.7. Summary of maximum potential radiation effective dose to an adult and locations of the maximum exposures, 2007

Pathway	Dose to maximally exposed individual		Percentage of U.S. Department of Energy 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	19.5	0.195	1,040,041[b]	
Liquid effluents:							
Drinking water	0.2	0.002	0.2	5	0.05	367,438[c]	
Eating fish	0.9	0.009	0.9	0.5	0.005	49,455[d]	
Other activities	0.1	0.001	0.1	0.5	0.005	489,023[d]	
Eating deer	2[e]	0.02	2	0.3	0.003	358	
Eating geese	0.1[f]	0.001	0.1	*g*	*g*		
Eating turkey	0.1[h]	0.001	0.1	0.0007	0.000007	31	
Direct radiation	0.4[i]	0.004	0.4				
All pathways	4	0.04	4	26	0.26	1,040,041	312,012

[a]Estimated background population dose is based on 300 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 were obtained from the Tennessee Valley Authority (TVA 2006 and TVA 2007).

[e]From consuming one hypothetical worst-case deer, each a combination of the heaviest deer harvested and the highest measured concentrations of ^{137}Cs in released deer on the ORR in 2007 and the population dose is 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 two 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 number of hunters that harvested turkey.

[i]Direct radiation dose estimate based on exposure to a fisherman on the Clinch River.

7.1.6 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 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. Six facilities responded to the DOE request. Based on these responses, no member of the public should have received an ED greater than 2 mrem due to airborne releases from these facilities. A maximally exposed individual dose of 15.4 mrem/year due to direct radiation was estimated at the boundary of one of the facilities. Two facilities responded stating that there had been no air or water releases.

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

Pathway	2003	2004	2005	2006	2007
All air	0.2	0.4	0.9	0.8	0.3
Fish consumption (Clinch River)	1	0.2	0.3	0.7	0.9
Drinking water (Kingston)	0.1[b]	0.04	0.03	0.02	0.04
Direct radiation (Clinch River)	0.4[c]	0.4	0.4	0.5[d,e]	0.4[f]
Direct radiation (Poplar Creek)	2[d]	3[d]	1[d]	0.8[d]	NA

[a]1 mrem = 0.01 mSv.

[b]Based on water samples from the Clinch River System.

[c]These values have been corrected by removing the contribution of natural background radiation and by using International Commission on Radiological Protection recommendations for converting external exposure to effective dose equivalent.

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

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

[f] From 2003 to 2005 and 2007, the direct radiation measurements are from an area near Jones Island.

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). (See Appendix G for a detailed description of the chemical dose methodology.) Chemical analytes were measured in surface water samples collected at CRK 70 and CRK 16. CRK 70 is located upstream of all DOE discharge points, and 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 from 10^{-4} to 10^{-6}. Risk values greater than 10^{-5} were calculated for the intake of arsenic in water collected at both upstream and downstream 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/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. An HQ greater than one for Aroclor-1260 was estimated in catfish at all three locations (CRK 16, 32, and 70). For sunfish, the HQ was either near to or exceeded 1 at all three locations. An HQ greater than 1 for Aroclor-1254 was estimated in catfish at all three locations.

For carcinogens, risk values greater than 10^{-5} were calculated for the intake of Aroclor-1254 found in catfish collected at all three locations. For both sunfish and catfish, risk values greater than 10^{-5} were also calculated for the intake of Aroclor-1260 collected at all three locations. TDEC has issued a fish advisory

Table 7.9. Chemical hazard quotients and estimated risks for drinking water, 2007[a]

Chemical	Hazard quotient[b]	
	CRK 70[c]	CRK 16[d]
Antimony	~0.04	
Arsenic	~0.2	~0.2
Acetone	~0.0002	~0.0001
Barium	0.005	0.005
Boron	0.003	0.003
Chromium	~0.01	~0.01
Lead	~0.1	~0.1
Manganese	0.008	0.01
Molybdenum	0.009	0.005
Nickel	0.003	0.002
Strontium	0.006	0.006
Thallium	~0.2	~0.2
Uranium	0.003	0.003
Zinc	0.0006	0.0008
Risk for carcinogens		
Arsenic	~7E–5	~3E–5
Methylene chloride		~1E–6

[a]Abbreviation:
CRK = Clinch River kilometer

[b]A tilde (~) indicates that estimated values were used in the calculation.

[c]Melton Hill Reservoir above the city of Oak Ridge Water Plant.

[d]Clinch River downstream of all U.S. Department of Energy inputs.

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 (TDEC 2002).

Table 7.10. Chemical hazard quotients and estimated risks for carcinogens in fish, 2007[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		~0.2	~0.1	~0.2	0.2	0.2
Barium	0.0006	0.0005	0.0005	0.0001	0.00008	0.0001
Cadmium	~0.01		0.03			
Chromium	~0.02	0.02	0.02	0.02	0.02	0.02
Lead	0.3	0.3	0.3	0.3	0.3	0.3
Manganese	0.005	0.004	0.006	0.0009	0.001	0.001
Mercury	0.07	0.06	0.2	0.2	0.2	0.5
Selenium	0.3	0.2	0.2	0.1	0.1	0.1
Silver				~0.002		
Strontium	0.002	0.001	0.0009	0.00009	0.00009	0.0001
Thallium	0.1	0.1	0.1	0.09	0.09	0.07
Uranium	0.0001	0.0001	0.0002	0.0001	0.00009	0.0002
Zinc	0.04	0.04	0.04	0.02	0.02	0.02
Hazard quotient for pesticides and Aroclors						
Aroclor-1254				2.5	9.5	3
Aroclor-1260	0.95	0.99	1.2	7	10	6
Chlordane, alpha	~0.0007	~0.001	~0.001	0.03	0.03	0.02
Chlordane, gamma				0.01		
4,4'-DDT			~0.006			
Risks for carcinogens						
Aroclor-1254				4E–5	2E–4	5E–5
Aroclor-1260	2E–5	2E–5	2E–5	1E–4	2E–4	1E–4
Benzene hexachloride , alpha		~2E–6	~9E–13			
Chlordane, alpha	~5E–8	~1E–7	~8E–8	2E–6	2E–6	1E–6
Chlordane, gamma				1E–6		
4,4'-DDE		~1E–7	~1E–7	~8E–7	2E–6	1E–6
4,4'-DDT			~5E–7			
Dieldrin						
PCBs (mixed)[e]	2E–5	2E–5	2E–5	2E–4	4E–4	2E–4

CRK=Clinch River kilometer

[a]A tilde (~) indicates that estimated values were used in the calculation, 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.