8. 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 that are 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 equivalent (EDE) of about 0.9 mrem from radionuclides emitted to the atmosphere from all of the sources on the ORR in 2005; 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 EDE of about 0.4 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 EDE of about 0.5 mrem, an individual who consumed an average-weight goose containing the average ^{137}Cs concentration of could have received 0.02 mrem, and an individual who consumed an average-weight turkey containing the average ^{137}Cs concentration of could have received 0.02 mrem. In worst-case analyses, hypothetical persons who consume the heaviest deer, two geese, and two turkeys, each containing the maximum concentration of measured radionuclides, could have received an EDE of approximately 5 mrem.

8.1 Radiation Dose

Small quantities of radionuclides were released to the environment from operations at the ORR facilities during 2005. 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 dose equivalents, and environmental transport and dosimetry codes that also tend to overestimate the calculated dose equivalents. 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.

8.1.1 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 G. An important term to understand is “effective dose equivalent” (EDE). EDE is a risk-based dose equivalent 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 equivalence, 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, EDEs are usually expressed in millirem (mrem), which is one one-thousandth of a rem. (See Appendix G, Table G.2, for a comparison and description of various dose levels.)

8.1.2 Methods of Evaluation

8.1.2.1 Airborne Radionuclides

The radiological consequences of radionuclides released to the atmosphere from ORR operations during 2005 were characterized by calculating, for each plant and for the entire ORR, EDEs to maximally exposed off-site individuals, to on-site members of the public where no physical access controls are managed by DOE, and to the entire population residing within 50 miles of the center of the ORR. The dose calculations were made using the CAP-88 package of computer codes (Beres 1990), 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 Regulatory Guide 1.109 (NRC 1977) food-chain models to calculate radionuclide concentrations in foodstuffs (vegetables, meat, and milk) and subsequent intakes by humans.

A total of 48 emission points on the ORR, each of which includes one or more individual sources, was modeled during 2005. The total includes 8 points at the Y-12 Complex, 34 points at ORNL, and 6 points at ETTP. Table 8.1 is a list of the emission point parameter values and receptor locations used in the dose calculations.

Meteorological data used in the calculations for 2005 were in the form of joint frequency distributions of wind direction, wind speed class, and atmospheric stability category. (See Table 8.2 for a summary of tower locations used to model the various sources.) During 2005, rainfall, as averaged over the four rain gauges located on the ORR, was 1,146.2 mm. The average air temperature was 14.4°C, and the average mixing-layer height was 768 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 EDE estimates, production of beef, milk, and crops within 80 km of the ORR was calculated using production rates provided with CAP-88.

Results

Calculated EDEs from radionuclides emitted to the atmosphere from the ORR are listed in Table 8.3 (maximum individual) and Table 8.4 (collective). The hypothetical maximally exposed individual for the ORR was located about 1,120 m north-northeast of the main Y-12 National Security Complex release point, about 9,652 m north-northeast of the 7911 stack at ORNL, and about 13,236 m east-northeast of the TSCA Incinerator (stack K-1435) at the ETTP. This individual could have received an EDE of about 0.9 mrem, which is well below the NESHAP standard of 10 mrem and is 0.3% of the 300 mrem that the average individual receives from natural sources of radiation. The calculated collective EDE to the entire population within 80 km of the ORR (about 1,040,041 persons) was about 10.9 person-rem, which is approximately 0.004% 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

Table 8.1. 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			
					Plant maximum		ORR maximum	
X-1000 Lab Hoods	15		0	Ambient	5613	ENE	10019	NE
X-2026	22.9	1.05	10.65	Ambient	5296	E	9524	NE
X-2099	3.66	0.178	22.1	Ambient	5296	E	9524	NE
X-2523	7	0.3	7.61	Ambient	5339	E	9741	NE
X-3000 Lab Hoods	15	0	0	Ambient	5064	E	9378	NE
X-3018	61	4.11	0.23	Ambient	5125	E	9308	NE
X-3020	61	1.22	14.78	Ambient	5125	E	9308	NE
X-3039	76.2	2.44	13.28	Ambient	5060	E	9354	NE
X-3074 Group	4	0.25	0	Ambient	5125	E	9308	NE
X-3544	9.53	0.279	21.15	Ambient	5081	ENE	9613	NE
X-3597	1	0.19	0	Ambient	4916	E	9381	NE
X-3608 Air Stripper	10.97	2.44	0.57	Ambient	4966	ENE	9547	NE
X-3608 Filter Press	8.99	0.36	9.27	Ambient	4966	ENE	9547	NE
X-4000 Lab Hoods	15	0	0	Ambient	4633	E	9063	NE
X-5505M	11	0.305	2.83	Ambient	4361	E	8898	NNE
X-5505NS	11	0.96	0	Ambient	4361	E	8898	NNE
X-6000 Lab Hoods	15	0	0	Ambient	4164	E	8470	NNE
X-7000 Lab Hoods	15	0	0	Ambient	3212	NE	9636	NNE
X-7025	4	0.3	13.92	Ambient	3143	E	7558	NNE
X-7503	30.5	0.91	12.35	Ambient	4289	ENE	9369	NNE
X-7567	4.6	0.248	8.3	Ambient	4289	ENE	9369	NNE
X-7567 D&D	3.8	0.2	0	Ambient	4289	ENE	9369	NNE
X-7830	4.6	0.248	8.3	Ambient	5342	ENE	10840	NNE
X-7831-A	0.38	.69	0	Ambient	6637	ENE	11927	NNE
X-7856-CIP	18.29	0.483	13.32	Ambient	5342	ENE	10840	NNE
X-7877	13.9	0.406	13.56	Ambient	5342	ENE	10840	NNE
X-7911	76.2	1.52	13.18	Ambient	4259	ENE	9652	NNE
X-7966	6.1	0.292	10.11	Ambient	4259	ENE	9652	NNE
X-Decon Areas	15	0	0	Ambient	5060	E	9354	NE
X-HFIR Tank	0.38	0.3	0	Ambient	4250	ENE	9699	NNE
X-Soil & Sediment	0.38	0.2	0	Ambient	4289	ENE	9369	NNE
X-STP	7.6	0.203	12.73	Ambient	5219	ENE	9776	NE
X-SWSA-5 TRU	.305	.87	0	Ambient	5151	ENE	10212	NNE
X-T-1/T-2	.38	.357	0	Ambient	4289	ENE	9369	NNE
K-1407-U CNF	7.16	1.22	0.625	Ambient	1686	WSW	13497	ENE
K-1423 SWR	7.62	0.71	12.8	Ambient	1283	SW	13951	ENE
K-1435 Incinerator	30.5	1.37	5.64	79.76	1953	WSW	13236	ENE
K-1435 Tanks	18.29	0.2	0	Ambient	1953	WSW	13236	ENE
K-25 Guzzler	3.66	0.305	36.3	Ambient	1686	WSW	13497	ENE
K-25 Seg Shop 18A	18.3	1.37	2.56	Ambient	1028	SW	14234	ENE

Table 8.1 (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		ORR maximum	
Y-9422-22 Air Stripper	3.96	0.153	0	Ambient	2018	W	2018	W
Y-9616-7 Degas	12.2	0.2	4.36	Ambient	2855	NE	2855	NE
Y-9616-7 Lab Hood	12.2	0.25	0.69	Ambient	2855	NE	2855	NE
Y-9623 Lab Hood	8.5	0.25	0.64	Ambient	1341	NNE	1341	NNE
Y-Monitored	20	0	0	Ambient	1120	NNE	1120	NNE
Y-Union Valley Lab	4.27	0.762	13.08	Ambient	2362	WSW	2362	WSW
Y-Unmonitored Processes	20	0	0	Ambient	1120	NNE	1120	NNE
Y-Unmonitored Lab Hoods	20	0	0	Ambient	1120	NNE	1120	NNE

Table 8.2. Summary of ORR meteorological towers, sampling heights, and sources

Tower	Height (m)	Source
		Y-12 Complex
MT6	60[a]	All sources
		ETTP
MT1	10	K-1435 Tanks
MT1	60	K-1435 Incinerator
MT7	10	K-1407-U CNF, K-1423-SWR, and K-25 Guzzler
MT7	30	K-25 Segmentation Shop 18A
		ORNL
MT4	10	X-7567, X-7567 D&D, X-7830, X-7831-A, X-7966, X-HFIR Tank, X-SWSA-5 TRU, X-T-1/T-2, and X-Soil and Sediment
MT4	30	X-7503, X-7856-CIP, X-7877, X-7911, and X-7000 Lab Hoods
MT3	10	X-7025
MT3	30	X-6000 Lab Hoods
MT2	10	X-2099, X-2523, X-3074, X-3544, X-3597,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.

Table 8.3. Calculated radiation doses to maximally exposed off-site individuals from airborne releases during 2005

Plant	Total effective dose equivalents [mrem (mSv)]	
	At plant max	At ORR max
ORNL	0.1 (0.001)[a]	0.02 (0.0002)
ETTP	0.04 (0.0004)[b]	0.008 (0.00008)
Y-12	0.8 (0.008)[c]	0.8 (0.008)
Entire ORR	*d*	0.9 (0.009)[e]

[a]The maximally exposed individual was located 5,060 m E of X-3039 and 4,259 m ENE of X-7911.

[b]The maximally exposed individual was located 1,953 m WSW of K-1435.

[c]The maximally exposed individual is located 1,120 m NNE of the Y-12 National Security Complex release point.

[d]Not applicable.

[e]The maximally exposed individual for the entire ORR is the Y-12 maximally exposed individual.

Table 8.4. Calculated collective effective dose equivalents from airborne releases during 2005

Plant	Effective dose equivalents[a]	
	(Person-rem)	(Person-Sv)
ORNL	2.7	0.027
ETTP	1.4	0.014
Y-12	6.8	0.068
Entire ORR	10.9	0.109

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

a residence about 1,120 m north-northeast of the main Y-12 National Security Complex release point. This individual could have received an EDE of about 0.8 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 (more than 99.5%) of the dose. The contribution of Y-12 Complex emissions to the 50-year committed collective EDE to the population residing within 80 km of the ORR was calculated to be about 6.8 person-rem, which is approximately 63% of the collective EDE 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 EDE of about 0.1 mrem from ORNL emissions. Radionuclides contributing 1% or more to the dose include ^{138}Cs (37.2%), ^{41}Ar (31.6%), ^{212}Pb (9.2%), uranium radioisotopes (3.6%) ^{244}Cm (3.1%), ^{241}Am (1.7%), ^{3}H (1.7%), ^{88}Kr (1.3%), ^{131}I (1.2%), and ^{138}Xe (1.1%). The contribution of ORNL emissions to the collective EDE to the population residing within 80 km of the ORR was calculated to be about 2.7 person-rem, which is approximately 25% of the collective EDE for the ORR.

The maximally exposed individual for the ETTP was located at a business about 1,950 m west-southwest of the TSCA Incinerator stack (K-1435). The EDE received by this individual was calculated to be about 0.04 mrem. About 56% of the dose is from ingestion and inhalation of uranium radioisotopes, about 30% is from thorium radioisotopes, and about 11% is from ^{3}H. The contribution of ETTP emissions to the collective EDE to the population residing within 80 km of the ORR was calculated to be about 1.4 person-rem, which is approximately 13% of the collective EDE for the reservation.

The reasonableness of the estimated radiation doses can be inferred by comparing EDEs estimated from measured radionuclide air concentrations with EDEs 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 EDEs between 0.01 and 0.08 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 EDEs between 0.1 and 0.7 mrem/year. EDEs calculated using CAP-88 tended to be higher than EDEs calculated using measured air concentrations (Table 8.5).

An indication of doses from sources other than those on the ORR can be obtained from the EDE calculated at the background air monitoring station (Station 52), which was 0.01 mrem/year. (The isotopes ^{7}Be and ^{40}K also were not included at the background air monitor-

Table 8.5. Hypothetical effective dose equivalents from living at ORR and ETTP ambient-air monitoring stations during 2005

Station	Calculated effective dose equivalent			
	Using air monitor data		Using CAP-88 and emission data	
	mrem/year	mSv/year	mrem/year	mSv/year
35	0.08	0.0008	0.2	0.002
37	0.02	0.0002	0.3	0.003
38	0.01	0.0001	0.2	0.002
39	0.05	0.0005	0.2	0.002
40	0.04	0.0004	0.7	0.007
42	0.02	0.0002	0.1	0.001
46	0.03	0.0003	0.6	0.006
48	0.01	0.0001	0.1	0.001
52	0.01	0.0001	*a*	*a*
K2	0.09	0.0009	*a*	*a*
K6	0.1	0.001	*a*	*a*
K9	0.2	0.002	*a*	*a*

[a]EDEs were not calculated using CAP-88 and emission data.

ing station calculation). It should be noted that measured air concentrations of ^{7}Be and ^{40}K were similar at the PAM stations and at the background air monitoring station.

Of particular interest is a comparison of doses calculated using measured air concentrations of radionuclides at PAMs located near the maximally exposed individuals for each plant and doses calculated for those individuals using CAP-88 and measured emissions. PAM 46 is located near the maximally exposed individual for the Y-12 Complex. The EDE calculated using measured air concentrations was 0.6 mrem/year, which is similar to the EDE of 0.9 mrem/year calculated using CAP-88 at the maximally exposed individual location for the Y-12 complex. PAM 39 is located near the second highest dose location for ORNL (in same wind direction at a closer in distance); the EDE calculated using measured air concentrations was 0.05 mrem/year, which is similar to the 0.1 mrem/year calculated using CAP-88. PAM 35 is located near the maximally exposed individual (at a business) for ETTP; the EDE calculated using measured air concentrations, adjusted for a business exposure, was 0.04 mrem/year, which was essentially the same dose estimated using CAP-88.

Several air monitors also were located on the ETTP site (see Fig. 4.9). EDEs calculated from air concentrations of radionuclides at these monitors were between 0.09 and 0.2 mrem/ year.

8.1.2.2 Waterborne Radionuclides

Radionuclides discharged to surface waters from the ORR enter the Tennessee River system by way of the Clinch River (see Sect. 1.5 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. 7.4 and 7.6). 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, the possibility that some radionuclides of ORR origin might be present in quantities too low to be measured, and the possibility that the presence of some radionuclides might be misstated (e.g., present in a quantity below the detection limit). 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 EDE 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 EDEs estimated by both methods, in each of the surface water segments are provided in Appendix G.

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 its 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 EDE. As explained in Appendix G, EDEs were calculated from measured concentrations of radionuclides in water and from radionuclide concentrations in water that were calculated using measured radionuclide discharges and streamflow data. At all locations in 2005, estimated maximum EDEs 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. For reference purposes, the EDE to a hypothetical highly exposed person drinking water at CRK 70, which is located upstream of all ORR inputs, was estimated to be about 0.05 mrem. The collective EDE to the 29,315 persons who drink water from the city of Oak Ridge water plant could have been 0.7 person-rem. If naturally occurring radionuclides are included, the EDEs could have been 2 mrem and 26 person-rem.

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 EDE of about 0.05 mrem; the collective dose to the 48,120 persons who drink water from this plant could have been 0.7 person-rem. If naturally occurring radionuclides are included, the EDEs could have been 2 mrem and 48 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 EDE of about 0.05 mrem; the collective dose to the 1,750 workers who drink water from this plant could have been about 0.05 person-rem. If naturally occurring radionuclides are included, the EDEs could have been 3 mrem and 2 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 EDE about 0.04 mrem; the collective dose to the 21,303 persons who drink water from these plants could have been about 0.4 person-rem. If naturally occurring radionuclides are included, the EDEs could have been 0.5 mrem and 5 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 EDEs greater than about 0.03 mrem calculated for Kingston and Rockwood water. The collective dose to the 258,193 persons who drink water within the lower system could be about 3.5 person-rem. If naturally occurring radionuclides are included, the EDEs could have been 0.5 mrem and 47 person-rem.

Poplar Creek. There are no drinking water intake locations on Poplar Creek.

Eating Fish

Fishing is quite common on the Clinch and Tennessee River systems. For purposes of assessment, it was assumed that avid fish consumers would have eaten 21 kg of fish during 2005 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 EDE will be based on either the first method, measured radionuclide concentrations in fish, or by the second method, which calculates possible radionuclide concentrations fish from measured radionuclide discharges and known or estimated stream flows and exclude naturally occurring radionuclides (e.g., ^{40}K). The EDEs estimated by both methods, in each of the surface water segment, are provided in Appendix G.

Melton Hill Lake above all possible ORR inputs. For reference purposes, a hypothetical avid fish consumer who ate fish caught at CRK 70, which is above all possible ORR inputs, could have received an EDE of about 0.08 mrem. If naturally occurring radionuclides are included, the EDE could have been 8 mrem.

Melton Hill Lake. An avid fish consumer who ate fish from Melton Hill Lake could have received an EDE of about 0.08 mrem. The collective EDE to the 876 persons who could have eaten such fish could be about 0.003 person-rem. If naturally occurring radionuclides are included, the EDEs could have been 9 mrem and 0.3 person-rem.

Upper Clinch River. An avid fish consumer who ate fish from the Upper Clinch River could have received an EDE of about 0.3 mrem. The collective EDE to the 700 persons who could have eaten such fish could have been about 0.06 person-rem. If naturally occurring radionuclides are included, the EDEs could have been 10 mrem and 2 person-rem. (The EDEs including naturally occurring radionuclides ignore an unusually high ^{40}K measurement in water at CRK 23. If this measurement is included, the EDEs could have been 63 mrem and 11 person-rem. This exclusion affects calculated maximum doses in all the downstream water bodies. Actual radionuclide concentration measurements in fish collected at CRKs 16, 32, and 70 indicate the dose from eating fish to be between 1 and 3 mrem.)

Lower Clinch River. An avid fish consumer who ate fish from the Lower Clinch River (CRK 16) could have received an EDE of about 0.1 mrem. The collective EDE to the 1634 persons who could have eaten such fish could have been about 0.05 person-rem. If naturally occurring radionuclides are included, the EDEs could have been 10 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 EDE about 0.02 mrem. The collective EDE to the 2,335 persons who could have eaten such fish could be about 0.009 person-rem. If naturally occurring radionuclides are included, the EDEs could have been 2 mrem and 1 person-rem.

Lower System. An avid fish consumer who ate fish from Lower System could have received an EDE of about 0.01 mrem. The collective EDE to the 45,030 persons who could have eaten such fish could have been about 0.1 person-rem. If naturally occurring radionuclides are included, the EDEs could have been 2 mrem and 18 person-rem.

Poplar Creek. An avid fish consumer who ate fish from Poplar Creek could have received an EDE of about 0.09 mrem. Assuming 100 people could have eaten fish from Poplar Creek, the collective EDE is estimated to be about 0.003 person-rem. If naturally occurring radionuclides are included, the EDEs could have been 8 mrem and 0.3 person-rem.

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 EDEs from these activities. At all locations in 2005, the estimated highly exposed individual EDEs were based on measured off-site surface water radionuclide concentrations and exclude naturally occurring radionucides, such as ^{40}K. When compared with EDEs from eating fish from the same waters, the EDEs from these other uses are relatively insignificant.

Melton Hill Lake above all possible ORR inputs. For reference purposes, an individual other user of Melton Hill Lake above ORR inputs could have received an EDE of about 0.0004 mrem. If naturally occurring radionuclides are included, the EDE could have been 0.1 mrem.

Melton Hill Lake. An individual other user of Melton Hill Lake could have received an EDE of about 0.0003 mrem. The collective EDE to the 4,428 other users could have been about 0.00006 person-rem. If naturally occurring radionuclides are included, the EDEs could have been 0.1 mrem and 0.03 person-rem.

Upper Clinch River. An other user of the Upper Clinch River could have received an EDE of about 0.0005 mrem. The collective EDE to the 700 other users could have been about 0.0002 person-rem. If naturally occurring radionuclides are included, the EDEs could have been 0.1 mrem and 0.02 person-rem. (Inclusion of the unusually high ^{40}K measurement could raise the EDEs to 0.3 mrem and 0.09 person-rem.)

Lower Clinch River. An other user of the Lower Clinch River could have received an EDE of about 0.004 mrem. The collective EDE to the 8,263 other users could have been about 0.01 person-rem. If naturally occurring radionuclides are included, the EDEs could have been 0.1 mrem and 0.4 person-rem.

Upper Watts Bar Lake. An other user of Upper Watts Bar Lake could have received an EDE of about 0.0007 mrem. The collective EDE to the 11,804 other users could have been about 0.003 person-rem. If naturally occurring radionuclides are included, the EDEs could have been 0.02 mrem and 0.1 person-rem.

Lower System. An other user of the Lower System could have received an EDE of about 0.0006 mrem. The collective EDE to the 227,637 other users could have been about 0.04 person-rem. If naturally occurring radionuclides are included, the EDEs could have been 0.02 mrem and 2 person-rem.

Poplar Creek. An other user of Poplar Creek could have received an EDE of about 0.006 mrem. The collective EDE to the 100 other users could have been about 0.00000005 person-rem. If naturally occurring radionuclides are included, the EDEs could have been 0.07 mrem and 0.000001 person-rem.

Summary

Table 8.6 is a summary of potential EDEs from identified waterborne radionuclides around the ORR. Adding worst-case EDEs for all pathways in a water-body segment gives a maximum individual EDE of about 0.4 mrem to a person obtaining his or her full annual complement of fish, drinking water, and participation in other water uses from the Upper Clinch River. The maximum collective EDE to the 50-mile population could be as high as 5.8 person-

Table 8.6. Summary of annual maximum individual (mrem) and collective (person-rem) effective dose equivalents from waterborne radionuclides[a,b]

	Drinking water	Eating fish	Other uses	Total[c]
Upstream of All ORR Discharge Locations CRK 70				
Individual EDE	0.05	0.08	0.0004	0.1
Collective EDE	0.7	0.003	9E–5	0.7
Melton Hill Lake CRK 70,CRK 66, CRK 58				
Individual EDE	0.05	0.08	0.0003	0.1
Collective EDE	0.7	0.003	6E–5	0.7
Upper Clinch River, CRK 23, Gallaher Water Plant, CRK 32				
Individual EDE	0.05	0.3	0.0005	0.4
Collective EDE	0.05	0.06	0.0002	0.1
Lower Clinch River, CRK 16				
Individual EDE	NA[d]	0.1	0.004	0.1
Collective EDE	NA[d]	0.05	0.01	0.06
Upper Watts Bar Lake, Kingston Municipal Water Plant				
Individual EDE	0.04	0.02	0.0007	0.05
Collective EDE	0.4	0.009	0.003	0.4
Lower System (Lower Watts Bar Lake and Chickamauga Lake)				
Individual EDE	0.03	0.01	0.0006	0.05
Collective EDE	3.5	0.1	0.04	3.7
Poplar Creek				
Individual EDE	NA[d]	0.09	0.006	0.1
Collective EDE	NA[d]	0.003	5E–8	0.003

[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.

rem. These are small percentages of individual and collective doses attributable to natural background radiation, about 0.1% and 0.003%, respectively.

8.1.2.3 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 the three mentioned, 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.

Milk

Milk collected at two locations near the ORR and at a remote location was found to contain small quantities of radio-strontium and tritium (Sect. 7.5.3). The sample data were used to calculate potential EDEs to hypothetical persons who drank 310 L (NRC 1977) of sampled milk during the year.

These hypothetical persons could have received an EDE of about 0.07 mrem from drinking milk from the near locations and about 0.06 mrem from the remote location, excluding the contribution from ^{40}K, a naturally occurring radionuclide.

Food Crops

The food-crop sampling program is described in Sect. 7.5. Samples of tomatoes, lettuce, and turnips were obtained from six local gardens. These vegetable types are representative of 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 certain 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 EDE of between 0.04 and 0.07 mrem, depending on garden location. Of this total, between 0.00007 and 0.002 mrem could have come from eating tomatoes, between 0.04 and 0.06 mrem from eating lettuce, and between 5×10^{-8} and 7×10^{-8} mrem from eating turnips. The highest dose to a gardener could have been about 0.07 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. (Potassium-40 actually accounts for all the beta activity found in leafy-vegetable samples.) The presence of ^{40}K in the samples adds, on average, about 1 mrem to the hypothetical home gardener's EDE.

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 EDE of between 0.004 and 2 mrem. Of this total, between 0.002 and 0.004 mrem could have come from eating tomatoes, between 0.5 and 2 mrem from eating lettuce, and between 1×10^{-7} and 8×10^{-7} 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.

Hay

Another environmental pathway that was evaluated using sampling data is eating beef and drinking milk obtained from cows that ate hay harvested from the ORR. Statistically significant concentrations were found for ^{7}Be and ^{40}K and uranium (^{234}U and ^{238}U) at all sampling locations, including the background location. Excluding the doses from ^{7}Be and ^{40}K (both naturally occurring), the average EDE from drinking milk and eating beef from Areas 1, 2, and 3; 2, 4, and 5; and 6 (see Sect. 7.5.1 and Fig. 7.5) was estimated to be about 0.01 mrem. Also, excluding the doses from ^{7}Be and ^{40}K resulted in a maximum EDE of about 0.004 mrem for the hay samples collected from Area 7 (the background location). It should be noted that hay is no longer sold for off-site use.

White-Tailed Deer

The TWRA conducted three 2-day deer hunts during 2005 on the Oak Ridge Wildlife Management Area, which is part of the ORR (see Sect. 7.7). During the hunts, 350 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 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 347 deer were released to the hunters.

The average ^{137}Cs concentration in tissue of the 347 released deer, as determined by field counting, was 0.48 pCi/g; the maximum ^{137}Cs concentration in a released deer was 0.82 pCi/g. The average weight was 84.53 lb, and the maximum weight of the released deer was 176.9 lb. The EDEs attributed to field-measured ^{137}Cs concentrations and actual field weights of the released deer ranged from 0.008 to 1.2 mrem. An individual who consumed one average-weight deer (84.5 lb), assuming 55% field weight is edible meat, containing the 2005 average concentration of ^{137}Cs (0.48 pCi/g) could have received an EDE of about 0.5 mrem.

In 2005, the maximum field-measured ^{137}Cs concentration was 0.82 pCi/g, and the maximum deer weight was 176.9 lb. A hypothetical hunter who consumed a deer of maximum weight and ^{137}Cs content could have received an EDE of 2 mrem. Accounting for the maximum field measured ^{137}Cs concentration of 0.82 pCi/g, a maximum weight of 176.9 lb, and the maximum ^{90}Sr concentration of 0.4 pCi/g measured in deer (released and retained) tissue (ORNL 1999), the maximum hypothetical EDE to a hunter who consumed a deer harvested from the ORR in 2005 was estimated to be 4.6 mrem.

Tissue samples collected in 2004 from 20 deer (10 released and 10 retained) were subjected to laboratory analysis. Requested radioisotopic analyses included ^{137}Cs, ^{90}Sr, and ^{40}K radionuclides. Comparison of the field to analytical ^{137}Cs concentrations results found that the field ^{137}Cs concentrations where either greater than or within the statistical range of the ^{137}Cs analytical results. All were less than the administrative limit of 5 pCi/g. The ^{90}Sr concentrations measured in these tissue samples ranged from 0.003 and 0.1 pCi/g.

The maximum EDE to an individual consuming venison from two deer was also evaluated. There were about 49 hunters who harvested two deer or more from the ORR. There were four cases where three or four deer were harvested per a household in 2005. Based on ^{137}Cs concentrations determined by field counting and actual field weight, the EDE range to a hunter who consumed two or more harvested deer was estimated to range between 0.3 to 2.5 mrem.

The collective EDE from eating all the harvested venison from ORR with a 2005 average field-derived ^{137}Cs concentration of 0.48 pCi/g and average weight of 84.5 lb is estimated to be about 0.2 person-rem.

Canada Geese

During the 2005 goose roundup, 167 geese were weighed and subjected to whole-body gamma scans. The average ^{137}Cs concentration in the released geese was 0.23 pCi/g. The maximum ^{137}Cs concentration in the released geese was 0.79 pCi/g. The average weight of the geese screened during the roundup was about 3.53 kg. The maximum goose weight was about 5.1 kg. The EDEs attributed to field-measured ^{137}Cs concentrations and actual field weights of the geese ranged from 0.0003 to 0.03 mrem. If a person consumed a released goose with an average weight of 3.53 kg and an average ^{137}Cs concentration of 0.23 pCi/g, the estimated EDE would be about 0.02 mrem. It is assumed that approximately half the weight of a Canada goose is edible. The maximum estimated EDE to an individual who consumed a hypothetical released goose with the maximum ^{137}Cs concentration of 0.79 pCi/g and the maximum weight of 5.1 kg was about 0.1 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 EDE of about 0.2 mrem.

In a follow-up on a special study initiated in 1998, muscle samples were analyzed from three geese sacrificed during the 2005 roundup. One goose each from ETTP, ORNL (West End), and Clark Center Park were sacrificed, and the tissue was analyzed. Requested radioisotopic analyses, in addition to the routine analyses of ^{137}Cs and ^{90}Sr, included uranium (^{234}U and ^{238}U) and transuranics, such as ^{239}Pu and ^{241}Am. Based on statistically significant radionuclide concentrations (excluding ^{40}K, a naturally occurring radionuclide) and the actual weights of the geese, the estimated EDEs ranged from about 0.06 to 0.07 mrem.

Eastern Wild Turkey

Two wild turkey hunts were held on the reservation, one on April 9 and 10 and the other on April 16 and 17, 2005. Thirty-eight birds were harvested, and one exceeded the administrative release limits established for radiological contamination in wildlife. The average ^{137}Cs concentration in the measured in the released turkeys was 0.1 pCi/g, and the maximum ^{137}Cs concentration was 0.3 pCi/g.

If a person consumed a wild turkey with an average weight of 8.3 kg and an average ^{137}Cs concentration of 0.1 pCi/g, the estimated EDE would be about 0.02 mrem. The maximum estimated EDE to an individual who consumed a hypothetical released turkey with the maximum ^{137}Cs concentration of 0.3 pCi/g and the maximum weight of 10.9 kg was about 0.08 mrem. It is assumed that approximately half the weight of a wild turkey is edible. The collective EDE from eating all the harvested wild turkey meat (37 birds) with an average field-derived ^{137}Cs concentration of 0.1 pCi/g and average weight of 8.3 kg is estimated to be about 0.0008 person-rem.

A radioisotopic analysis was conducted on the tissue of the retained turkey; this included ^{137}Cs, ^{90}Sr, uranium (^{234}U and ^{238}U), thorium (^{228}Th, ^{230}Th, and ^{232}Th), and transuranics, such as ^{239}Pu and ^{241}Am. Based on statistically significant radionuclide concentrations (excluding ^{40}K, a naturally occurring radionuclide) and the actual weight of the turkey, the estimated EDE was 0.1 mrem.

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. These exposure rates translate into annual EDE rates that average 42 mrem/year and range between 19 and 72 mrem/year (Myrick et al. 1981). External radiation exposure rates are measured at a number of locations on and off the ORR. The average exposure rate at PAMs around the ORR during 2005 was about 5.4 μR/h. This rate corresponds to an EDE rate of about 34 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 (0.0015 mrem/h) above background. A potential maximally exposed individual would be a hypothetical fisherman who was 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 EDE of about 0.4 mrem above background during 2005.

The potential above-background annual EDE to a hypothetical maximally exposed individual (hypothetical fisherman who is assumed to fish 250 h/year near the point of average exposure) would be about 0.25 mrem from gamma radiation and 0.25 mrem from neutron radiation (total EDE of 0.5 mrem from both gamma and neutron radiation) along the bank of Poplar Creek near the K-1066-J Cylinder Yard and 0.75 mrem from gamma radiation and 0.5 mrem from neutron radiation (total EDE of 1.25 mrem from both gamma and neutron radiation) along the bank of Poplar Creek near the K-1066-E Cylinder Yard. That section of the creek runs through the ETTP plant and is used at times by fisherman; however, it is very unlikely that anyone would fish it 250 h/year. The gamma and neutron dose rates along the near bank of the Clinch River in the vicinity of the K-770 Scrap Yard would be about 0.25 mrem from gamma radiation and 0.25 mrem from neutron radiation (total EDE of 0.5 mrem from both gamma and neutron radiation). The estimated annual dose to a hypothetical individual assumed to spend 30 min per work day in the parking lot adjacent to the K-1066-K Cylinder Yard could be about 0.75 mrem from gamma radiation and 0.25 mrem from neutron radiation (total EDE of 1.25 mrem from both gamma and neutron radiation).

8.1.3 Doses to Aquatic and Terrestrial Biota

8.1.3.1 Aquatic Biota

DOE Order 5400.5, Chap. II, sets an absorbed dose rate limit of 1 rad/day to native aquatic organisms from exposure to radioactive material in liquid wastes discharged to natural waterways (see Appendix G 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 1.0), 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 contained 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 ten different sampling locations:

- Melton Branch (MEK 0.2),
- White Oak Creek (WCK 1.0, 2.6, and 6.8),
- First Creek,
- Fifth Creek,
- Raccoon Creek, and
- Clinch River (CRK 32).

Two additional surface water sampling locations on the ORR were also evaluated: Bear Creek (BCK 0.6) and East Fork Poplar Creek (EFK 5.4) All but two of these locations, WCK 1.0 (White Oak Creek at the dam) and White Oak Creek (WCK 2.6), passed the screening phase (using default parameters for BCGs). At WCK 1.0 and WCK 2.6, the default bioaccumulation factors for both ^{137}Cs and ^{90}Sr in fish 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/day at all twelve sampling locations.

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

- Station 9422-1 (Station 17), Bear Creek at BCK 4.55 (formerly outfall 304) and at BCK 0.6,
- Rogers Quarry Discharge Point S19 (formerly outfall 302),
- Discharge Point S17 (unnamed tributary to the Clinch River),
- West End Treatment Facility (outfall 502),
- outfall 512,
- outfall 520,
- Central Pollution Control Facility (discharge point 501), and
- Central Mercury Treatment Unit (outfall 551).

All locations passed the general screening. This resulted in absorbed dose rates to aquatic organisms below the DOE aquatic dose limit of 1 rad/day at all ten Y-12 locations.

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

- Mitchell Branch at K1700 and at MIK 1.4 (upstream location),
- Poplar Creek at K-716 (downstream),
- K1007-B and K-1710 (upstream location),
- K901-A (downstream of ETTP operations),
- K-700, K-1407-J (the Central Neutralization Facility), and
- Clinch River (CRK 16 and CRK 23).

All of these locations passed the initial general screening (using default parameters for BCGs).

8.1.3.2 Terrestrial Biota

DOE Orders 450.1 and 5400.5 include requirements to demonstrate radiation protection of biota within terrestrial systems as well as aquatic systems.

As required by CERCLA, baseline ecological risk assessments have been conducted for a number of watershed areas on the ORR. The results of these assessments provide the basis for selection of future terrestrial biota sampling locations on the ORR. The ecological impacts identified in the assessments for the following sites are summarized below.

ORNL is divided into two watershed areas, the Bethel Valley watershed and the Melton Valley watershed. The Bethel Valley watershed, as approached in the baseline ecological risk assessment, was divided into four geographical areas: the Raccoon Creek area, West Bethel Valley, Central Bethel Valley, and East Bethel Valley. Based on the results of the assessment for Bethel Valley (DOE 1999b), the only area where there appear to be potential risks to terrestrial organisms exposed to radiological contaminants was West Bethel Valley, but the risks were not widespread. Potential risks from exposure to radionuclides in surface soil were identified for soil invertebrates and all wildlife receptors (e.g., soil invertebrates, shrews, white-footed mice, red fox, deer, red-tailed hawk, turkey, and mink) except plants. Cesium-137 was the risk driver for all receptors. Uranium-234 was an additional radionuclide of concern for turkeys at this location.

In the Melton Valley watershed ecological assessment (DOE 1997a), ecological risks were estimated for plants, soil invertebrates, and terrestrial wildlife exposed to radionuclide contaminants in surface soil within each subbasin in the watershed for which surface soil data were available. Radiological data were available for 28 subbasins. Radionuclide exposures resulted in potential risks to terrestrial biota at 16 subbasins. Radionuclide risks were highest in the East Seep subbasin, with ^{137}Cs driving risks for all receptors. In five subbasins, calculated dose rates were above limits for plants. Estimated doses exceeded dose limits for soil invertebrates in 7 subbasins and for wildlife receptors (e.g., shrews and mice) in 16 subbasins. However, doses to piscivorous wildlife (e.g., mink, kingfisher, great blue heron) were below dose limits to all piscivorous receptors. The data collected for a recent Melton Valley ecological monitoring report (DOE 2004) indicate that the ecological contaminants of concern in Melton Valley surface soil, surface water, and sediment pose little or no risk to wildlife receptors. This report suggests that the earlier ecological risk assessment overestimated the exposure and risk to wildlife receptors.

The Y-12 site was divided into two watershed areas, Upper East Fork Poplar Creek and Bear Creek. In the Upper East Fork Poplar Creek watershed, the characterization area encompasses Upper East Fork Poplar Creek, Lake Reality, the main industrialized part of the Y-12 Plant, and the East End carbon tetrachloride plume (which extends into Union Valley) (DOE 1998). Upper East Fork Poplar Creek extends from its headwaters at the North/South Pipe downstream to Station 17, where it crosses the Y-12 Complex property boundary and becomes Lower East Fork Poplar Creek. The baseline ecological risk assessment addressed only surface water and sediment exposures to contaminants in Upper East Fork Poplar Creek, Lake Reality, wetlands, and seeps associated with the East End carbon tetrachloride plume because the characterization area includes no substantial habitat for terrestrial biota. In 2005 a sampling project was conducted in the northwest part of the industrialized Y-12 Complex. A data set was collected for purposes of characterizing an area for new construction. To evaluate whether the soil concentrations could result an absorbed dose of 0.1 rad/day, the RESRAD-Biota for Windows (Version 1.0), which is a companion tool for implementing DOE technical standard entitled *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota* (DOE 2002), was used. Maximum radionuclide soil concentrations, regardless of sample interval depth, were used in the screening. These maximum radionuclide concentrations passed the initial general terrestrial biota screening.

The Bear Creek watershed consists of Bear Creek from its confluence with Lower East Fork Poplar Creek to the headwaters at the western edge of the Y-12 Plant, the associated floodplain and tributaries, and the source area in upper Bear Creek Valley (DOE 1997b). The primary sources considered in the ecological assessment were the waste and secondary contamination at the S-3 Ponds, the Bone Yard/Burn Yard, Sanitary Landfill 1, and Bear Creek Burial Grounds. No detectable radiation effects are anticipated for individual terrestrial biota (plant, earthworm, terrestrial, or semiaquatic wildlife receptors) frequenting Bear Creek, its floodplain, or source area sites. The overall current dose rate was below the effects thresholds for all receptors at all of these sites. Alpha radiation exposures related to ingestion of contaminated prey accounted for virtually the entire dose for all receptors. External exposures were determined to be inconsequential.

At ETTP data were aggregated within geographic areas and were used to evaluate possible risks to fish and other aquatic organisms, piscivorous wildlife, terrestrial plants, soil invertebrates, and terrestrial wildlife receptors (BJC 2004b, BJC 2004c). The primary areas of concern for aquatic organisms appear to be the K-901-A Holding Pond, the K-1007 P1 Pond, and Mitchell Branch. Potential risks to aquatic organisms or piscivorous or aerial insectivorous wildlife receptors were evident or likely in these three water bodies while potential risks at other ETTP water bodies (the K-720 Slough, K-770 Embayment, K-1007 P3, P4, and P5 Ponds, and upper reach of Mitchell Branch) were considerably lower and less extensive. Dose rate calculations for fish, benthic invertebrates, and piscivorous wildlife indicated that radionuclides in surface water and sediment were unlikely to be a concern for those receptors.

All geographic areas included at least one surface soil analyte with a maximum concentration exceeding benchmark levels for at least one terrestrial receptor; metals and/or PCBs in the K-770 Scrapyard within the Powerhouse area, the K-25 North Trash Slope within the K-27/K-29/K-1064 process area, and portions of the habitat area along Mitchell Branch in the Mitchell Branch support area appear to pose the greatest likelihood of unacceptable risks to terrestrial receptors.

8.1.4 Current-Year Summary

A summary of the maximum EDEs to individuals by pathway of exposure is given in Table 8.7. It is very unlikely (if not impossible) that any real person could have been irradiated by all of these sources and pathways for the duration of 2005; however, if someone were, that person could have received a total EDE of about 8 mrem. Of that total, 0.9 mrem would have come from airborne emissions, 0.4 mrem from waterborne emissions, (0.05 mrem from drinking water from the Clinch River, 0.3 mrem from consuming fish from the Clinch River, and 0.004 mrem from other water uses), and 1.3 mrem from direct radiation while fishing on Poplar Creek inside the ETTP. This dose is about 1% of the annual dose (300 mrem) from background radiation. The EDE of 8 mrem includes the person who received the highest EDEs 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 2.6 mrem.

DOE Order 5400.5 limits the EDE 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 2005 maximum EDE should not have exceeded about 8 mrem, or about 8% of the limit given in DOE Order 5400.5. (For further information, see Table G.2 in Appendix G, which provides a summary of dose levels associated with a wide range of activities.)

The total collective EDE to the population living within a 80-km radius of the ORR was estimated to be about 13.2 person-rem. This dose is about 0.005% of the 312,012 person-rem that this population received from natural sources during 2005.

8.1.5 Five-Year Trends

Dose equivalents associated with selected exposure pathways for the years from 2001 to 2005 are given in Table 8.8. 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.

8.1.6 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 dose to members of the public who also could have been affected by releases from these facilities. Five facilities responded to the DOE request. Based on these responses, no member of the public should have received an EDE greater than 2.7 mrem due to airborne releases from these facilities. The maximally exposed individual dose of 1.9 mrem/year was estimated at the

Table 8.7. Summary of maximum potential radiation dose equivalents to an adult during 2005 and locations of the maximum exposures

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	0.9	0.009	0.9	10.9	0.109	1,040,041[b]	
Liquid effluents:							
Drinking water	0.05	0.0005	0.5	5.4	0.054	358,681[c]	
Eating fish	0.3	0.003	0.3	0.1	0.003	51,652[d]	
Other activities	0.004	0.0004	0.004	0.01	0.0006	774,820[d]	
Eating deer	4.6	0.046[e]	4.6	0.2	0.002	347	
Eating geese	0.2	0.002[f]	0.2	*g*	*g*		
Eating turkey	0.2	0.002[h]	0.2	0.0008	8E–6	37	
Direct radiation	1.3	0.013[i]	1.3	0.13	0.0013	100	
All pathways	8	0.08	8	17	0.17	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 ORR.

[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 the number of fish harvested in Melton Hill, Watts Bar, and Chickamauga reservoirs.

[e]The maximum EDE from consumption of a deer harvested on the ORR in 2005 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 there are no goose hunts on the ORR.

[h]From consuming two hypothetical worst-case turkey, each 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 released turkeys.

[i]Direct radiation dose estimate based on exposure to a fisherman on Poplar Creek.

Table 8.8. Trends in total effective dose equivalent (mrem)[a] for selected pathways

Pathway	2001	2002	2003	2004	2005
All air	0.8	0.3	0.2	0.4	0.9
Fish consumption (Clinch River)	0.2	0.3	1	0.2	0.3
Drinking water (Kingston)	0.03[b]	0.04[b]	0.1	0.04	0.03
Direct radiation (Clinch River)	0.4[c]	0.4[c]	0.4	0.4	0.4
Direct radiation (Poplar Creek)	2[c]	2[c]	2[d]	3[d]	1[d]

[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.

boundary of one of the facilities. Four facilities responded stating that there had been no water releases.

8.2 Chemical Dose

8.2.1 Drinking Water Consumption

To evaluate the drinking water pathway, hazard quotients (HQs) were estimated upstream and downstream of the ORR discharge points (Table 8.9). (See Appendix H for a detailed description of the chemical dose methodology). As in 2000 through 2004, chemical analytes were measured only 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 8.9, 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.

Table 8.9. Chemical hazard quotients and estimated risks for drinking water, 2005[a]

Chemical	Hazard quotient	
	CRK 70[b]	CRK 16[c]
Antimony	~0.03	~0.03
Arsenic	~0.2	~0.2
Acetone	~0.0002	~0.0002
Barium	~0.02	0.02
Beryllium		~0.001
Boron	0.002	0.005
Cadmium	~0.005	~0.005
Chromium	~0.01	~0.01
Lead	0.1	0.1
Manganese	0.02	0.01
Molybdenum	~0.005	~0.003
Nickel	0.002	0.002
Selenium	~0.01	0.01
Silver	~0.0009	~0.0009
Strontium	0.005	0.004
Thallium	~0.2	0.2
Toluene	~0.0001	~0.0001
Uranium	0.002	0.003
Vanadium	~0.01	~0.01
Zinc	0.0006	0.0006
Risk for carcinogens		
Arsenic	~8E–5	~3E–5

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

[b]Melton Hill Reservoir above city of Oak Ridge input.

[c]Clinch River downstream of all DOE inputs.

8.2.2 Fish Consumption

Chemicals in water can be accumulated by aquatic organisms that may be consumed by humans. To evaluate the potential health effects from the fish consumption pathway, HQs were estimated for the consumption of noncarcinogens, and risk values were estimated for the consumption of carcinogens detected in sunfish and catfish collected both upstream and downstream of the ORR discharge points. In the current assessment, a fish consumption rate of 60 g/day (21 kg/year) is assumed for both the noncarcinogenic and carcinogenic pollutants. It is the same fish consumption rate used in the estimation of the maximum exposed radiological dose from consumption of fish. (See Appendix H for a detailed description of the chemical dose methodology.)

As shown in Table 8.10, for consumption of sunfish and catfish, HQ values of less than 1 were calculated for the all detected analytes except for arsenic and Aroclor-1260 at all three locations.

For carcinogens in sunfish and catfish, risk values greater than 10–5 were calculated for the intake of arsenic and Aroclor-1260 found in sunfish and catfish collected at all three locations. For catfish, risk values greater than 10–5 were also calculated for the intake of Aroclor-1254 collected at all three locations. The Tennessee Department of Environment and Conservation (TDEC) has issued a fish advisory that states that catfish should not be consumed from Melton Hill Reservoir (in its entirety) because of PCB contamination and has issued a precautionary fish consumption advisory for catfish in the Clinch River arm of Watts Bar Reservoir (TDEC 2002).

Table 8.10. Chemical hazard quotients and estimated risks for carcinogens in fish, 2005[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						
Arsenic	1.2	1.2	1.1	1.0	1.2	1.1
Barium	0.002	0.002	0.0008	0.00007	0.0001	0.0001
Beryllium		~0.0007				
Boron	0.0003	0.0002	0.0003	0.0002	0.0003	0.0003
Chromium	0.03	0.03	0.02	0.01	0.02	0.02
Lead	0.3	~0.3	~0.2	0.2	2.5	
Manganese	0.01	0.02	0.007	0.0009	0.001	0.001
Mercury	0.1	0.1	0.7	0.2	0.3	0.6
Molybdenum	0.006	0.008	0.01	~0.005	~0.005	0.006
Nickel	0.001					
Selenium	0.2	0.1	0.1	0.07	0.04	0.04
Silver	0.003	0.002	0.003			~0.003
Strontium	0.004	0.004	0.002	0.00007	0.00009	0.0001
Thallium	0.09	0.1	0.1	0.03	0.04	0.03
Uranium	0.0004	0.0004	0.0004	0.0003	0.0002	0.0003
Vanadium	0.002	0.002	~0.001		~0.002	
Zinc	0.05	0.05	0.04	0.02	0.02	0.02
Hazard quotient for pesticides and Aroclors						
Aroclor-1254				2.8	3.9	5.3
Aroclor-1260	0.98	~0.6	~0.8	9.0	9.5	11.9
Chlordane, alpha				0.01	0.02	0.01
Chlordane, gamma				0.008	0.01	0.007
Risks for carcinogens						
Arsenic	2E-4	2E-4	2E-4	2E-4	2E-4	2E-4
Aroclor-1254				5E-5	7E-5	9E-5
Aroclor-1260	2E-5	~1E-5	~1E-5	2E-4	2E-4	2E-4
Chlordane, alpha				9E-7	1E-6	9E-7
Chlordane, gamma				6E-7	8E-7	5E-7
4,4’-DDD				~4E-7		7E-7
4, 4′-DDE	~1E-7	~1E-7	~2E-7	8E-7	2E-6	2E-6
PCBs (mixed)[e]	2E-5	~1E-5	~1E-5	2E-4	2E-4	3E-4

[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 Oak Ridge city input.

[c]Clinch River, downstream of ORNL.

[d]Clinch River, downstream of all DOE inputs.

[e]Mixed PCBs consists of the summation of Aroclors detected or estimated.