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 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 0.8 mrem from radionuclides emitted to the atmosphere from all of the sources on the ORR in 2006; 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 0.7 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 0.8 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. In worst-case analyses, if a hypothetical person consumed one deer (maximum actual deer) and two geese and two turkeys (each containing the maximum concentration of measured radionuclides and maximum weights), that person could have received an EDE of approximately 3 mrem. This calculation is conducted to provide an estimated upper-bound EDE from consuming wildlife harvested from the ORR.

8.1 Radiation Dose

Small quantities of radionuclides were released to the environment from operations at the ORR facilities during 2006. 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 2006 were characterized by calculating, for each major facility 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 41 emission points on the ORR, each of which includes one or more individual sources, was modeled during 2006. The total includes 8 points at the Y-12 Complex, 25 points at ORNL, and 8 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 2006 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 2006, rainfall, as averaged over the four rain gauges located on the ORR, was 1,267.9 mm. The average air temperature was 14.8°C, and the average mixing-layer height was 564.5 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 2,170 m east-northeast of the main Y-12 National Security Complex release point, about 10,429 m northeast of the 7911 stack at ORNL, and about 14,488 m east-northeast of the Toxic Substances Control Act (TSCA) Incinerator (stack K-1435) at the ETTP. This individual could have received an EDE of about 0.8 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 18.4 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).

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-Lab Hoods								
X-1000 Lab Hoods	15		0	Ambient	5613	ENE	11010	NE
X-3000 Lab Hoods	15		0	Ambient	5064	E	10358	NE
X-4000 Lab Hoods	15		0	Ambient	4633	E	10006	NE
X-6000 Lab Hoods	15		0	Ambient	4164	E	9402	NE
X-7000 Lab Hoods	15		0	Ambient	3212	NE	10133	NNE
X- 8920 Lab Hoods	15		0	Ambient	4273	ESE	7424	NE
X-2026	22.9	1.05	10.21	Ambient	5296	E	10526	NE
X-2099	3.66	0.178	22.1	Ambient	5296	E	10526	NE
X-2523	7	0.3	8.16	Ambient	5339	E	10721	NE
X-3018	61	4.11	0.23	Ambient	5125	E	10309	NE
X-3020	61	1.22	15.21	Ambient	5125	E	10309	NE
X-3039	76.2	2.44	13.5	Ambient	5060	E	10337	NE
X-3074 Group	4	0.25	0	Ambient	5125	E	10309	NE
X-3544	9.53	0.279	21.69	Ambient	5081	ENE	10563	NE
X-3608 Air Stripper	10.97	2.44	0.57	Ambient	4966	ENE	10485	NE
X-3608 Filter Press	8.99	0.36	9.27	Ambient	4966	ENE	10485	NE
X-5505								
X-5505M	11	0.305	3.05	Ambient	4361	E	9813	NE
X-5505NS	11	0.96	0	Ambient	4361	E	9813	NE
X-7025	4	0.3	13.36	Ambient	3143	E	8398	NE
X-7503	30.5	0.91	12.1	Ambient	4289	ENE	10201	NE
X-7830 Group	4.6	0.248	8.15	Ambient	5342	ENE	11632	NE
X-7856-CIP	18.29	0.483	12.91	Ambient	5342	ENE	11632	NE
X-7877	13.9	0.406	13.56	Ambient	5342	ENE	11632	NE
X-7880	27.43	1.52	13.99	Ambient	5342	ENE	11632	NE
X-7911	76.2	1.52	13.34	Ambient	4259	ENE	10429	NE
X-7966	6.096	0.292	10.11	Ambient	4259	ENE	10429	NE
X-8915	24.38	4.0	0.53	Ambient	4273	ESE	7424	ENE
X-Decon Areas	15	0	0	Ambient	5060	E	10337	NE
X-Soil & Sediment	0.38	0.2	0	Ambient	4289	ENE	10201	NE
X-STP	7.6	0.203	12.73	Ambient	5219	ENE	10729	NE
X-SWSA-5 TRU	.305	.87	0	Ambient	5151	ENE	11081	NE
K-1004-L Lab D&D	1.83	0.3	0	Ambient	2919	NE	15356	ENE
K-1066	3	2.54	0	Ambient	4073	ENE	16821	ENE
K-1407-U CNF	7.16	1.22	0.625	Ambient	2814	NE	14869	ENE
K-1420 Repack	0.456	0.31	0	Ambient	2051	NE	14703	ENE
K-1423 SWR	7.62	0.71	12.8	Ambient	2637	ENE	15359	ENE
K-1435 Incinerator	30.5	1.37	5.64	79.76	1940	NE	14488	ENE
K-1435-C Tanks	18.29	0.2	0	Ambient	1997	NE	14516	ENE
K-25 Seg Shop 18A	18.3	1.37	2.56	Ambient	2956	ENE	15691	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	478	NW	478	NW
Y-9616-7 Degas	12.2	0.2	4.36	Ambient	4037	ENE	4037	ENE
Y-9616-7 Lab Hood	12.2	0.25	0.69	Ambient	4037	ENE	4037	ENE
Y-9623 Lab Hood	8.5	0.254	0.64	Ambient	2350	ENE	2350	ENE
Y-Monitored	20	0	0	Ambient	2168	ENE	2168	ENE
Y-Union Valley Lab	4.27	0.762	13.08	Ambient	904	SW	904	SW
Y-Unmonitored Processes	20	0	0	Ambient	2168	ENE	2168	ENE
Y-Unmonitored Lab Hoods	20	0	0	Ambient	2168	ENE	2168	ENE

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

Tower	Height (m)	Source
		Y-12 Complex
MT6	60[a]	All Y-12 sources and SNS and 8920 Hoods (ORNL)
		ETTP
MT1	10	K-1435 Tanks
MT1	60	K-1435 Incinerator
MT7	10	K-1004L, K-1066, K-1407-U, K-1420, K-1423-SWR, K-1435C
MT7	30	K-25 Segmentation Shop 18A
		ORNL
MT4	10	X-7830, X-7966, X-SWSA-5 TRU, and X-Soils and Sediment
MT4	30	X-7503, X-7856-CIP, X-7877, X-7880, 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.

The maximally exposed individual for the Y-12 National Security Complex was located at 2,170 m east-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%) 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

Table 8.3. Calculated radiation doses to maximally exposed off-site individuals from airborne releases during 2006

Plant	Total effective dose equivalents [mrem (mSv)]	
	At plant max	At ORR max
ORNL	0.06 (0.0006)[a]	0.008 (0.00008)
ETTP	0.09 (0.0009)[b]	0.01 (0.0001)
Y-12	0.8 (0.008)[c]	0.8 (0.008)
Entire ORR	*d*	0.8 (0.008)[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 1940 m NE of K-1435.

[c]The maximally exposed individual is located 2168 m ENE 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 2006

Plant	Effective dose equivalents[a]	
	(Person-rem)	(Person-Sv)
ORNL	1.3	0.013
ETTP	4.9	0.049
Y-12	12.3	0.123
Entire ORR	18.4	0.184

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

12.3 person-rem, which is approximately 67% 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 0.06 mrem from ORNL emissions. Radionuclides contributing 1% or more to the dose include ^{138}Cs (57.6%), ^{212}Pb (9.0%), ^{41}Ar (5.4%), uranium radioisotopes (5.3%), ^{244}Cm (7.7%), ^{131}I (2.4%), ^{88}Kr (2.1%), ^{138}Xe (1.8%), ^{3}H (1.5%), ^{90}Sr (1.4%), and ^{137}Cs (1.2%). The contribution of ORNL emissions to the collective EDE to the population residing within 80 km of the ORR was calculated to be about 1.3 person-rem, approximately 6.8% of the collective EDE for the ORR.

The maximally exposed individual for the ETTP was located at a business about 1,940 m northeast of the TSCA Incinerator stack (K-1435). The EDE received by this individual was calculated to be about 0.09 mrem. About 84% of the dose is from ingestion and inhalation of uranium radioisotopes, about 10% is from ^{3}H, and about 5% is from thorium radioisotopes. The contribution of ETTP emissions to the collective EDE to the population residing within 80 km of the ORR was calculated to be about 4.9 person-rem, approximately 26.7% 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 0.06 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 0.08 and 0.9 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 monitoring 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 40 is

Table 8.5. Hypothetical effective dose equivalents from living at ORR and ETTP ambient-air monitoring stations during 2006

Station	Calculated effective dose equivalent			
	Using air monitor data		Using CAP-88 and emission data	
	mrem/year	mSv/year	mrem/year	mSv/year
35	0.06	0.0006	0.2	0.002
37	0.01	0.0001	0.2	0.002
38	0.01	0.0001	0.08	0.0008
39	0.01	0.0001	0.2	0.002
40	0.03	0.0002	0.9	0.009
42	0.02	0.0002	0.07	0.0007
46	0.02	0.0002	0.2	0.002
48	0.02	0.0002	0.4	0.004
52	0.01	0.0001	*a*	*a*
K2	0.1	0.001	*a*	*a*
K6	0.02	0.0002	*a*	*a*
K9	0.1	0.001	*a*	*a*
K11	0.08	0.0008	*a*	*a*

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

located near the maximally exposed individual for the Y-12 Complex. The EDE calculated using measured air concentrations, assuming a business location, was 0.01 mrem/year, much less than the EDE of 0.9 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 EDE calculated using measured air concentrations was 0.01 mrem/year, less than the 0.2 mrem/year calculated using CAP-88. The K-2 Air Monitoring Station is located closer to ETTP than the maximally exposed individual (at a business) for ETTP; the EDE calculated using measured air concentrations was 0.06 mrem/year, less than the ETTP maximally exposed individual annual dose of 0.1 mrem, 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 0.02 and 0.1 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

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

	Drinking water	Eating fish	Other uses	Total[c]
Upstream of All ORR Discharge Locations (CRK 70 and CRK 66, City of Oak Ridge Water Plant)				
Individual EDE	0.003	0.03	0.000004	0.03
Collective EDE	0.04	0.002	0.000001	0.04
Melton Hill Lake (CRK 58, Knox Count Water Plant)				
Individual EDE	0.003	0.00007	0.00005	0.03
Collective EDE	0.04	0.002	0.00001	0.04
Upper Clinch River (CRK 23, Gallaher Water Plant, CRK 32)				
Individual EDE	0.01	0.7	0.00005	0.7
Collective EDE	0.009	0.1	0.00001	0.1
Lower Clinch River (CRK 16)				
Individual EDE	NA[d]	0.08	0.004	0.08
Collective EDE	NA[d]	0.03	0.01	0.04
Upper Watts Bar Lake, Kingston Municipal Water Plant				
Individual EDE	0.02	0.01	0.0006	0.03
Collective EDE	0.2	0.02	0.004	0.3
Lower System (Lower Watts Bar Lake and Chickamauga Lake)				
Individual EDE	0.02	0.01	0.0005	0.03
Collective EDE	2	0.1	0.04	2
Poplar Creek				
Individual EDE	NA[d]	0.3	0.006	0.3
Collective EDE	NA[d]	0.009	2E–7	0.009

[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.

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 detectable 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 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 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 2006, 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 66, which is located upstream of all ORR inputs, was estimated to be about 0.003 mrem. The collective EDE to the 29,981 persons who drink water from the city of Oak Ridge water plant could have been 0.04 person-rem. If naturally occurring radionuclides are included, the EDEs could have been 2 mrem and 31 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 0.003 mrem; the collective dose to the 48,316 persons who drink water from this plant could have been 0.06 person-rem. If naturally occurring radionuclides are included, the EDEs 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 EDE of about 0.01 mrem; the collective dose to the 1750 workers who drink water from this plant could have been about 0.009 person-rem. If naturally occurring radionuclides are included, the EDEs could have been about 4 mrem and 4 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 of about 0.02 mrem; the collective dose to the 23,551 persons who drink water from these plants could have been about 0.2 person-rem. If naturally occurring radionuclides are included, the EDEs could have been 0.7 mrem and 9 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 0.02 mrem calculated for drinking Kingston and Rockwood water. The collective dose to the 263,174 persons who drink water within the lower system could be about 3 person-rem. If naturally occurring radionuclides are included, the EDEs could have been 0.7 mrem and 73 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 assessment purposes, it was assumed that avid fish consumers would have eaten 21 kg of fish during 2006 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 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 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 0.03 mrem. If naturally occurring radionuclides are included, the EDE could have been 17 mrem.

Melton Hill Lake. An avid fish consumer who ate fish from Melton Hill Lake could have received an EDE of about 0.00007 mrem. The collective EDE to the 266 persons who could have eaten such fish could be about 0.000006 person-rem. If naturally occurring radionuclides are included, the EDEs could have been 9 mrem and 0.8 person-rem. (The EDEs including naturally occurring radionuclides ignore an elevated ^{40}K measurement in water at CRK 58. If this measurement is included, the EDEs could have been 47 mrem and 4 person-rem. This exclusion affects calculated maximum doses in all the downstream water bodies.)

Upper Clinch River. An avid fish consumer who ate fish from the Upper Clinch River could have received an EDE of about 0.7 mrem. The collective EDE to the 516 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 18 mrem and 3 person-rem.

Lower Clinch River. An avid fish consumer who ate fish from the Lower Clinch River (CRK 16) could have received an EDE of about 0.08 mrem. The collective EDE to the 1,204 persons who could have eaten such fish could have been about 0.03 person-rem. If naturally occurring radionuclides are included, the EDEs could have been 18 mrem and 7 person-rem.

Upper Watts Bar Lake. An avid fish consumer who ate fish from Upper Watts Bar Lake could have received an EDE about 0.01 mrem. The collective EDE to the 3,439 persons who could have eaten such fish could be about 0.02 person-rem. If naturally occurring radionuclides are included, the EDEs could have been 3 mrem and 4 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 34,276 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 3 mrem and 30 person-rem.

Poplar Creek. An avid fish consumer who ate fish from Poplar Creek could have received an EDE of about 0.3 mrem. Assuming 100 people could have eaten fish from Poplar Creek, the collective EDE is estimated to be about 0.009 person-rem. If naturally occurring radionuclides are included, the EDEs could have been 7 mrem and 0.2 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 2006, the estimated highly exposed individual EDEs were based on measured off-site surface water radionuclide concentrations and exclude naturally occurring radionuclides, 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

0.000004 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 0.00007 mrem. The collective EDE to the 34,706 other users could have been about 0.0004 person-rem. If naturally occurring radionuclides are included, the EDEs could have been 0.5 mrem and 3 person-rem.

Upper Clinch River. An other user of the Upper Clinch River could have received an EDE of about 0.00005 mrem. The collective EDE to the 516 other users could have been about 0.00001 person-rem. If naturally occurring radionuclides are included, the EDEs could have been 0.5 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 7,880 other users could have been about 0.01 person-rem. If naturally occurring radionuclides are included, the EDEs could have been 0.5 mrem and 1 person-rem.

Upper Watts Bar Lake. An other user of Upper Watts Bar Lake could have received an EDE of about 0.0006 mrem. The collective EDE to the 22,514 other users could have been about 0.004 person-rem. If naturally occurring radionuclides are included, the EDEs could have been 0.2 mrem and 1 person-rem.

Lower System. An other user of the Lower System could have received an EDE of about 0.0005 mrem. The collective EDE to the 224,392 other users could have been about 0.04 person-rem. If naturally occurring radionuclides are included, the EDEs could have been 0.1 mrem and 9 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 2E-7 person-rem. If naturally occurring radionuclides are included, the EDEs could have been 0.06 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 0.7 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 2.5 person-rem. These are small percentages of individual and collective doses attributable to natural background radiation, about 0.2% and 0.0008%, 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 at a distance from the ORR and at a remote location was found to contain low concentrations of ^{90}Sr (Sect. 7.5.3). At one location, tritium was detected in one sample. 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 between 0.05 and 0.08 mrem from drinking milk from the near locations and about 0.04 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 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 EDE of between 0.06 and 0.2 mrem, depending on garden location. Of this total, between 0.03 and 0.09 mrem could have come from eating tomatoes, between 0.01 and 0.08 mrem from eating lettuce, and between 0.03 and 0.1 mrem from eating turnips. The highest dose to a gardener could have been about 0.2 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 4 and 6 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 0.1 and 7 mrem. Of this total, between 0.005 and 7 mrem could have come from eating tomatoes, between 0.1 and 3 mrem from eating lettuce, and between 0.6 and 2 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 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 all sampling locations. Statistically significant concentrations were also found for ^{7}Be, ^{40}K, and ^{234}U at 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 between 0.3 and 2 mrem. Also, excluding the doses from ^{7}Be, ^{40}K, resulted in a maximum EDE of about 0.5 mrem for the hay samples collected from Area 7 (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 EDE from drinking milk and eating beef from Areas 1, 2, and 3; 2, 4, and 5; and 6 was estimated to be about 0.04 mrem. Excluding the unidentified activity of alpha-emitting radionuclides, the estimated EDE from drinking milk and eating beef from the background location (Area 7) was estimated to be about 0.002 mrem.

White-Tailed Deer

The Tennessee Wildlife Resources Agency (TWRA) conducted three 2-day deer hunts during 2006 on the Oak Ridge Wildlife Management Area, which is part of the ORR (see Sect. 7.7). During the hunts, 286 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). Two deer exceeded the limit for beta-particle activity in bone and were confiscated. The remaining 284 deer were released to the hunters.

The average ^{137}Cs concentration in tissue of the 284 released deer, as determined by field counting, was 0.68 pCi/g; the maximum ^{137}Cs concentration in a released deer was 2.04 pCi/g. Many of the ^{137}Cs concentrations were less than minimum detectable levels. The average weight was 91.26 lb, and the maximum weight of the released deer was 186 lb. The EDEs attributed to field-measured ^{137}Cs concentrations and actual field weights of the released deer ranged from 0.04 to 1.7 mrem. An individual who consumed one average-weight deer (91.3 lb), assuming

55% field weight is edible meat, containing the 2006 average concentration of ^{137}Cs (0.68 pCi/g) could have received an EDE of about 0.8 mrem.

In 2006, the maximum field-measured ^{137}Cs concentration was 2.04 pCi/g, and the maximum deer weight was 186 lb. A hypothetical hunter who consumed a deer of maximum weight and ^{137}Cs content could have received an EDE of about 4.7 mrem.

Tissue samples collected in 2006 from 12 deer (10 released and 2 retained) were subjected to laboratory analysis. Requested radioisotopic analyses included ^{137}Cs, ^{90}Sr, and ^{40}K radionuclides. Comparison of the field to analytical ^{137}Cs concentrations results found that the field concentrations were greater than the analytical results. 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 ^{137}Cs and ^{90}Sr (at the minimum detectable levels) analytical tissue data and actual deer weights, the estimated doses for these 12 deer ranged between 0.4 to 1.4 mrem.

The maximum estimated EDE from consuming venison from an actual released deer (based on field ^{137}Cs concentrations and weights) and including the maximum 2006 analytical ^{90}Sr result (0.18 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 EDE from consuming venison from deer harvested on the ORR in 2006 than estimating an EDE 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 EDE to an individual consuming venison from two or three deer was also evaluated. There were about 26 hunters who harvested two deer or more from the ORR. 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 0.7 to 3 mrem.

The collective EDE from eating all the harvested venison from ORR with a 2006 average field-derived ^{137}Cs concentration of 0.68 pCi/g and average weight of 91.3 lb is estimated to be about 0.2 person-rem.

Canada Geese

During the 2006 goose roundup, 203 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 0.17 pCi/g, with maximum ^{137}Cs concentration in the released geese of 0.49 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 8.4 lb (3.82 kg). The maximum goose weight was about 12.6 lb (5.7 kg). The EDEs 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 8.4 lb and an average ^{137}Cs concentration of 0.17 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 0.49 pCi/g and the maximum weight of 12.6 lb was about 0.07 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.

The two geese screened during the 2006 goose hunt had ^{137}Cs concentrations less than 0.2 pCi/g. Assuming maximum weight obtained during the roundup, the estimated EDE from consuming both geese would be about 0.06 mrem. In 2006, a muscle sample was analyzed for ^{40}K, ^{137}Cs, and ^{90}Sr from a seriously injured goose that had to be euthanized. The analytical results for ^{137}Cs and ^{90}Sr were less than MDA levels. Assuming MDA levels, excluding ^{40}K concentrations (naturally occurring radionuclide), and maximum weight from the goose roundup, the estimated dose from consuming this goose was about 0.08 mrem.

Eastern Wild Turkey

Two wild turkey hunts were held on the reservation in 2006, one on April 1 and 2 and the other on April 8 and 9. Thirty-nine birds were harvested, and none were retained. The average ^{137}Cs concentration measured in the released turkeys was 0.09 pCi/g, and the maximum ^{137}Cs concentration was 0.15 pCi/g. The average weight of the turkeys released was about 19.5 lb. The maximum turkey weight was about 23.5 lb.

If a person consumed a wild turkey with an average weight of 19.5 lb and an average ^{137}Cs concentration of 0.09 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 0.15 pCi/g and the maximum weight of 23.5 lb was about 0.04 mrem. It is assumed that approximately half the weight of a wild turkey is edible. In 2006, one hunter harvested two turkeys during the turkey hunt. The EDE from one person consuming both turkeys was estimated to be about 0.04 mrem. No tissue samples were analyzed in 2006.

The collective EDE from consuming all the harvested wild turkey meat (39 birds) with an average field-derived ^{137}Cs concentration of 0.09 pCi/g and average weight of 19.5 lb is estimated to be about 0.0008 person-rem.

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 numerous locations on and off the ORR. The average exposure rate at PAMs around the ORR during 2006 was about 5.5 μR/h. This rate corresponds to an EDE rate of about 36 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 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 2006.

As described in Sect. 4.10, the UF_6 cylinder storage yards and K-770 Scrap Yard at ETTP are potential sources of direct gamma and neutron radiation exposure to the public. Measured exposure rates and a hypothetical model of a maximally exposed individual were used to calculate theoretical doses. The calculated EDEs were based on gamma and neutron dose rates measured at the K-1066-J and K-1066-E Cylinder Yards along the near bank of Poplar Creek, the parking lot adjacent to the K-1066-K Cylinder Yard, and the near bank of the Clinch River in the vicinity of the K-770 Scrap Yard.

The potential maximally exposed individual model used for exposure from the K-1066-J or K-1066-E Cylinder Yard is a hypothetical fisherman assumed to have spent 250 h/year near the point of average exposure. This hypothetical individual could have received an EDE above background of about 0.25 mrem from gamma radiation and 0.50 mrem from neutron radiation (0.75 mrem gamma and neutron) along the bank of Poplar Creek near the K-1066-E Cylinder Yard during 2006. This section of the creek runs through the ETTP plant and is used at times by fishermen; however, it is very unlikely that anyone would fish this stretch of Poplar Creek for 250 h/year. At the time of the January surveys, no cylinders were being stored in the K-1066-J Cylinder Yard, and consequently there was no potential dose above background levels at this location.

General area dose rates were recorded in the vicinity of the K-770 Scrap Yard, along the near bank of the Clinch River. A hypothetical fisherman assumed to have spent 250 h/year near the point of average exposure along the bank of the Clinch River near the K-770 Scrap Yard could have received an EDE above background of about 0.50 mrem from gamma radiation and no dose from neutron radiation during 2006.

The parking lot adjacent to the K-1066-K Cylinder Yard is used by workers and the public. This parking lot is intended for employees and has no public facilities. A potential maximally exposed individual is someone assumed to have spent 30 min per work day (125 h/year) waiting in the parking lot at the point of average exposure along the edge closest to the K-1066-K Cylinder Yard. This hypothetical individual could have received an EDE above background of no dose from gamma radiation and 0.13 mrem from neutron radiation during 2006. At the time of the survey, no cylinders were being stored in the K-1066-K Cylinder Yard.

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 1.21), 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 10 different sampling locations:

- Melton Branch (MEK 0.2),
- White Oak Creek (WCK 1.0 and 2.6),
- First Creek,
- Fifth Creek,
- Raccoon Creek,
- Northwest Tributary, and
- Clinch River (CRK 32, 58, and 66).

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 (maximum concentrations and using default parameters for BCGs). At WCK 1.0 and WCK 2.6, 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/day at all 12 sampling locations.

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

- SWHISS Station 9422-1 (Station 17),
- Discharge Point S24, Bear Creek at BCK 9.4
- Station 304, Bear Creek at Hwy. 95
- Discharge Point S17 (unnamed tributary to the Clinch River),
- Rogers Quarry Discharge Point S19
- outfall 512
- outfall 520,

- outfall 550, and
- Central Mercury Treatment Unit (outfall 551).

All but four locations passed the general screening phase (maximum water concentrations and default parameters for BCGs). These four locations: S24 Bear Creek, outfall 512, Station 304 Bear Creek, and SWHISS Station 9422-1, passed using average water concentrations. This resulted in absorbed dose rates to aquatic organisms below the DOE aquatic dose limit of 1 rad/day at all nine Y-12 locations.

At ETTP, doses to aquatic organisms were estimated from surface water concentrations at eight 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), 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/day at all eight sampling locations.

8.1.3.2 Terrestrial Biota

In 2006, a terrestrial biota sampling strategy that considers 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. Sampling for terrestrial dose assessment was initiated in 2007.

As a result of CERCLA and the programs initiated to remediate the effects of hazardous waste disposal on the ORR, a substantial amount of radiological data in various media (e.g., soils, sediment, and surface water) have been collected and reported in Remedial Investigation (RI) reports and numerous other documents. In addition, baseline ecological risk assessments (BERAs) were conducted between 1997 and 2000 for all major disposal sites at the three DOE facilities on the ORR, including Bethel Valley and Melton Valley at the Oak Ridge National Laboratory, Bear Creek Valley, and upper East Fork Poplar Creek at the Y-12 National Security Complex, and the ETTP. In some cases, additional BERAs were conducted for specific waste sites (e.g., selected disposal ponds and burial grounds at ETTP in 1995, sitewide residual contamination in soils and Mitchell Branch at ETTP in 2006, and Melton Valley Watershed in 2004). The results of these BERAs serve as a basis for identifying ORR sampling locations. The ORR sampling program focuses initially on unremediated areas, such as floodplains and selected upland areas. Floodplains are often downstream of contaminant source areas and are dynamic systems where soils are eroding in some area and being deposited in others.

The sampling strategy consists of two phases: (1) initial sampling to estimate doses based on the radionuclide concentrations in soil, and (2) follow-up, which involves site-specific sampling of biota if the benchmark of 0.1 rad per day is exceeded. Doses in the initial sampling will be estimated for soil invertebrates and small mammals, such as shrews and mice. Doses to wide-ranging, terrestrial wildlife species are unlikely to exceed 0.1 rad per day. Where there are recent data in areas of interest (e.g., ETTP BERA 2006 data) these data will be used.

The soil sampling is initially focusing 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. Suggested soil sampling locations and soil radionuclide analytes are identified below:

1. *White Oak Creek floodplain between the lower boundary of the Intermediate Pond and White Oak Creek*. Hazard quotients greater than 1 have been estimated for soil invertebrates and shrews and mice in this floodplain area. Suggested soil radionuclide analytes include ^{137}Cs, ^{60}Co, ^{90}Sr, ^{239}Pu/^{240}Pu, ^{241}Am, and ^{244}Cm.

2. *Bear Creek Valley floodplain.* Although data indicate that radionuclide concentrations in the soils are low, the results are based on a relatively small number of samples. Suggested soil radionuclide analytes include ^{234}U, ^{238}U, ^{241}Am, and ^{238}Pu.

3. *West Bethel Valley in the vicinity of the Contractor's Landfill and station SWSA 3-3.* Potential ecological risks to terrestrial biota were identified. Suggested soil radionuclide analyte is ^{137}Cs.

4. *Select areas near the ETTP Powerhouse, North Trash Slope, and the Mitchell Branch Habitat Area.* Suggested soil radionuclide analytes include ^{234}U, ^{238}U and ^{239}Pu.

8.1.4 Current-Year Summary

A summary of the maximum EDEs to individuals by pathway of exposure is given in Table 8.7. In the very unlikely event that any person were irradiated by all of those sources and pathways for the duration of 2006, that person could have received a total EDE of about 9 mrem. Of that total, 0.8 mrem would have come from airborne emissions, 0.7 mrem from waterborne emissions, (0.02 mrem from drinking water from the Watts Bar Lake, 0.7 mrem from consuming fish from the Clinch River, and 0.004 mrem from other water uses), and 0.8 mrem from direct radiation while fishing on Poplar Creek inside the ETTP. This dose is about 3% of the annual dose (300 mrem) from background radiation. The EDE of 6 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 3 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 2006 maximum EDE should not have exceeded about 6 mrem, or about 6% of the limit given in DOE Order 5400.5. (For further information, see Table G.2 in Appendix G, which summarizes 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 21 person-rem. This dose is about 0.007% of the 312,012 person-rem that this population received from natural sources during 2006.

8.1.5 Five-Year Trends

Dose equivalents associated with selected exposure pathways for the years from 2001 to 2006 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 doses to members of the public who also could have been affected by releases from these facilities. Eight facilities responded to the DOE request. Based on these responses, no member of the public should have received an EDE greater than 3.7 mrem due to airborne releases from these facilities. The maximally exposed individual dose of 15.3 mrem/year was estimated at the boundary of one of the facilities. Four facilities responded stating that there had been no air or 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). 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 8.9, HQs were less than 1 for detected chemical analytes for which there are reference doses or maximum contaminant levels.

Table 8.7. Summary of maximum potential radiation dose equivalents to an adult during 2006 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	0.8	0.008	0.8	18.4	0.184	1,040,041[b]	
Liquid effluents:							
Drinking water	0.02	0.0002	0.02	2	0.02	369,153[c]	
Eating fish	0.7	0.007	0.7	0.4	0.004	39,931[d]	
Other activities	0.004	0.0004	0.004	0.04	0.0004	290,107[d]	
Eating deer	3	0.03[e]	3.0	0.2	0.002	284	
Eating geese	0.2	0.002[f]	0.2	*G*	*g*		
Eating turkey	0.04	0.0004[h]	0.04	0.0008	8E–6	39	
Direct radiation	0.8	0.008[i]	0.8	0.08	0.0008	100	
All pathways	6	0.06	6	21	0.21	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 population within 80 km and fraction of fish harvested in Melton Hill, Watts Bar, and Chickamauga reservoirs. Melton Hill recreational information obtained from TVA (TVA 2006).

[e]The maximum EDE from consumption of a deer harvested on the ORR in 2006 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 few geese (2) were brought to checking station during the goose hunt.

[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.

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.

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. This 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

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

Pathway	2002	2003	2004	2005	2006
All air	0.3	0.2	0.4	0.9	0.8
Fish consumption (Clinch River)	0.3	1	0.2	0.3	0.7
Drinking water (Kingston)	0.04[b]	0.1	0.04	0.03	0.02
Direct radiation (Clinch River)	0.4[c]	0.4	0.4	0.4	0.5[d,e]
Direct radiation (Poplar Creek)	2[c]	2[d]	3[d]	1[d]	0.8[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. 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, in previous years (e.g., 2002 to 2005), the direct radiation measurements were from an area near Jones Island.

Table 8.9. Chemical hazard quotients and estimated risks for drinking water, 2006[a]

Chemical	Hazard quotient	
	CRK 70[b]	CRK 16[c]
Antimony		~0.03
Arsenic	~0.1	~0.2
Acetone	~0.0001	~0.0001
Barium	~0.005	0.005
Boron	0.002	0.002
Chromium	~0.01	~0.01
Lead	0.1	
Manganese	0.01	0.009
Molybdenum	0.005	0.004
Nickel	0.002	0.002
Strontium	0.005	0.005
Thallium	~0.2	~0.2
Tetrachloroethene	~0.002	~0.0001
Uranium	0.002	0.003
Vanadium	~0.01	~0.008
Zinc	0.0006	0.0004
Risk for carcinogens		
Arsenic	~7E–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.

except for arsenic and Aroclor-1260. For arsenic, HQ values greater than one were estimated at all three locations for both sunfish and catfish.An HQ greater than one for Aroclor-1260 was estimated in sunfish in two locations (CRK 32 and 16) and in catfish at all three locations.

For carcinogens, risk values greater than 10^{-5} were calculated for the intake of arsenic foundin sunfish and catfish collected at all three locations. For catfish, risk values greater than 10^{-5} were also calculated for the intake of Aroclor-1260 collected at all three locations. At CRK 70, the risk value for dieldrin in catfish was greater than 10^{-5}; however, dieldrin was not detected at the other 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, 2006[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						
Arsenic	1.6	1.6	1.6	1.2	1.3	1.3
Barium	0.0006	0.0009	0.0004	0.0002	0.00009	0.00008
Cadmium		0.01	~0.01	~0.01	0.01	~0.01
Chromium	0.02	0.02	0.01	0.02	0.02	0.01
Lead	0.6	~0.5	0.4	0.6	0.5	0.3
Manganese	0.006	0.004	0.004	0.001	0.001	0.002
Mercury	0.1	0.2	0.5	0.3	0.3	0.6
Molybdenum	~0.003	0.006	~0.004	0.01	~0.003	~0.003
Selenium	0.3	0.2	0.2	0.1	0.1	0.1
Strontium	0.002	0.003	0.001	0.0001	0.00006	0.0002
Thallium	0.07	0.09	0.06	0.03	0.04	0.05
Uranium	0.0003	0.0002	0.0002	0.0006	0.0002	0.0003
Zinc	0.05	0.04	0.04	0.02	0.02	0.02
Hazard quotient for pesticides and Aroclors						
Aroclor-1260	~0.5	~0.95	0.98	7.4	18.5	2.8
BHC, delta	~0.2		~0.07			
Chlordane, alpha				0.01	0.004	
Chlordane, gamma				0.01	~0.002	
Dieldrin				~0.08		
Heptachlor epoxide				~0.1		
Risks for carcinogens						
Arsenic	3E-4	3E-4	3E-4	2E-4	3E-4	3E-4
Aroclor-1260	~8E-6	~2E-5	2E-5	1E-4	3E-4	5E-5
Chlordane, alpha				1E-6	3E-7	
Chlordane, gamma				8E-7	2E-7	
Dieldrin				~3E-5		
PCBs (mixed)[e]	~8E-6	~2E-5	2E-5	1E-4	3E-4	5E-5

[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.