8. Dose

Activities on the Oak Ridge Reservation (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 0.2 mrem (0.002 mSv) from radionuclides emitted to the atmosphere from all of the sources on the ORR in 2003; 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 2 mrem (0.02 mSv), which is a small percentage (< 0.7%) of the individual dose attributable to natural sources of radiation. 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 67 h/year.

Calculations to determine possible doses from consumption of deer and geese harvested on or near the ORR resulted in the following: an individual who consumed an average-weight deer containing the average concentration of radionuclides could have received an EDE of about 0.7 mrem; an individual who consumed an average-weight goose containing the average concentration of radionuclides could have received 0.02 mrem. There were no turkey hunts on the ORR in 2003. In worst-case analyses, hypothetical persons who eat the heaviest deer and two geese, each containing the maximum concentration of measured radionuclides, could have received an EDE of 4 mrem.

8.1 RADIATION DOSE

Small quantities of radionuclides were released to the environment from operations at the ORR facilities during 2003. 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; they 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 F. 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 rem 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 1/1000 of a rem. (See Appendix F, Table F.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 2003 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 80 km (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 57 emission points on the ORR, each of which includes one or more individual sources, were modeled during 2003. This total includes 12 points at the Y-12 Complex, 34 points at ORNL, and 11 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 2003 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 2003, rainfall, as averaged over the four rain gauges located on the ORR, was 179 cm (70.5 in.). The average air temperature was 14.1°C (57.4°F), and the average mixing-layer height was 681.6 m (2236 ft). The mixing height is the depth of the atmosphere adjacent to the surface within which air is mixed.

For occupants of residences, the dose calculations assume that the occupant remained at home (actually, unprotected outside the house) during the entire year and obtained food according to the rural pattern defined in the NESHAP background documents (EPA 1989). This pattern specifies that 70% of the vegetables and produce, 44.2% of the meat, and 39.9% of the milk consumed are produced in the local area (e.g., a home garden). The remaining portion of each food is assumed to be produced within 80 km (50 miles) 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 5930 m (3.7 miles) south of the main Y-12 National Security Complex release point, about 4550 m (2.8 miles) east-northeast of the 7911 stack at ORNL, and about 11,340 m (7.0 miles) east of the TSCA Incinerator (stack K-1435) at the ETTP. This individual could have received an EDE of about 0.2 mrem (0.002 mSv), which is well below the NESHAP standard of 10 mrem (0.10 mSv) and is less than 0.1% of the 300 mrem (3 mSv) that the average individual receives from natural sources of radiation. The calculated collective EDE to the entire population within 80 km (50 miles) of the ORR (about 1,040,041 persons) was about 11 person-rem (0.11 person-Sv), which is approximately 0.004% of the 312,012 person-rem that this population received from natural sources of radiation.

The maximally exposed individual for the Y-12 National Security Complex was located about 2310 m (1.4 miles) east-northeast of the main Y-12 National Security Complex release

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	0	Ambient	5950	ENE	5950	ENE
X-2026	22.9	1.05	11.3	Ambient	5650	E	5650	E
X-2099	3.66	0.18	23.32	Ambient	5650	E	5650	E
X-2523	7	0.3	0	Ambient	5680	E	5680	E
X-3000 Lab Hoods	15	0	0	Ambient	5480	E	5480	E
X-3018	61	4.11	0.23	Ambient	5480	E	5480	E
X-3020	61	1.22	15.38	Ambient	5480	E	5480	E
X-3039	76.2	2.44	13.19	Ambient	5410	E	5410	E
X-3074 Group	4	0.25	0	Ambient	5480	E	5480	E
X-3544	9.53	0.28	15.57	Ambient	5420	E	5420	E
X-3608-1	10.97	2.44	0.57	Ambient	5300	E	5300	E
X-3608-2	8.99	0.36	13.91	Ambient	5300	E	5300	E
X-4000 Lab Hoods	15	0	0	Ambient	4980	E	4980	E
X-5505M	11	0.30	2.79	Ambient	4710	E	4710	E
X-5505NS	11	0.96	0	Ambient	4710	E	4710	E
X-6000 Lab Hoods	15	0	0	Ambient	4530	E	4530	E
X-7000 Lab Hoods	15	0	0	Ambient	3380	NE	3380	NE
X-7025	4	0.3	13.16	Ambient	3520	E	3520	E
X-7503	30.5	0.91	9.36	Ambient	4610	ENE	4610	ENE
X-7567	3.8	0.20	4.65	Ambient	4610	ENE	4610	ENE
X-OHF T-13	1	0.305	0	Ambient	5600	ENE	5600	ENE
X-OHF 1944	0.38	0.2	0	Ambient	5600	ENE	5600	ENE
X-7830	4.6	0.25	8.01	Ambient	5600	ENE	5600	ENE
X-7831-A	0.38	0.97	0	Ambient	5600	ENE	5600	ENE
X-7856-CIP	18.29	0.48	12.24	Ambient	5600	ENE	5600	ENE
X-7860	18.29	0.31	3.9	Ambient	5600	ENE	5600	ENE
X-7860 NHF D&D	0.38	0.2	0	Ambient	5600	ENE	5600	ENE
X-7877	13.9	0.41	13.56	Ambient	5600	ENE	5600	ENE
X-7911	76.2	1.52	14.31	Ambient	4550	ENE	4550	ENE
X-7935	14.6	0.46	14.2	Ambient	4550	ENE	4550	ENE
X-7966	6.1	0.29	8.18	Ambient	4550	ENE	4550	ENE
X-Decon Areas	15	NA	0	Ambient	5410	E	5410	E
X-SIOU	1	0.31	0	Ambient	5420	E	5420	E
X-STP	7.6	0.20	12.48	Ambient	5560	E	5560	E
K-1004-D	7.3	0	0	Ambient	1330	W	11780	E
K-1006-J	1	NA	0	Ambient	370	S	13090	E
K-1008-C	4.52	0.51	10.46	Ambient	1330	WSW	11860	E
K-1407-U	7.16	1.22	0.625	Ambient	1690	WSW	11670	E
K-1423 SWR	7.62	0.71	10.02	Ambient	1280	SW	12200	E
K-1425 A	1	0.5	0	Ambient	1920	WSW	11350	E

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	
K-1435	30.5	1.37	5.26	79.1	1950	WSW	11340	E
K-1435-C	18.29	NA	0	Ambient	1950	WSW	11340	E
K-33 DD	22.86	1.72	0	Ambient	1020	S	13250	E
K-33 SC	11.58	1.22	14.96	Ambient	1020	S	13250	E
K-25 Guzzler	3.7	0.403	36.3	Ambient	1690	WSW	11670	E
Y-9204-3	20	NA	0	Ambient	2290	NE	5720	S
Y-9224	10	NA	0	Ambient	1330	NE	6440	S
Y-9401-4	1	NA	0	Ambient	3610	NE	5240	SSE
Y-9422-22	3.96	0.153	0	Ambient	610	NNW	6950	SSW
Y-9616-7 Hood	12.2	0.25	0.69	Ambient	4180	NE	5080	SSE
Y-9616-7 Degas	12.2	0.2	4.36	Ambient	4180	NE	5080	SSE
Y-9623	8.5	NA	0.64	Ambient	2500	NE	5730	S
Y-Monitored	20	NA	0	Ambient	2310	ENE	5930	S
Y-EMWMF	1	0.305	0	Ambient	5370	NE	4810	SSE
Y-Union Valley Lab	4.27	0.76	13.44	Ambient	730	WSW	7860	SSW
Y-Unmonitored	20	NA	0	Ambient	2310	ENE	5930	S
Y-Unmonitored Lab Hoods	20	NA	0	Ambient	2310	ENE	5930	S

point. This individual could have received an EDE of about 0.2 mrem (0.002 mSv) 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 (>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 5.5 person-rem (0.055 person-Sv), which is approximately 51% of the collective EDE for the ORR.

The maximally exposed individual for ORNL was located about 5410 m (3.4 miles) east of the 3039 stack and 4550 m (2.8 miles) east-northeast of the 7911 stack. This individual could have received an EDE of about 0.2 mrem (0.002 mSv) from ORNL emissions. Radionuclides contributing 1% or more to the dose include ^{138}Cs (48%), ^{41}Ar (18%), ^{241}Am (6.2%), ^{212}Pb (5.6%), ^{191}Os (3.2%), ^{233}U (2.9%), ^{234}U (2.9%), ^{138}Xe (2%), ^{88}Kr (1.5%), and ^{239}Pu (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 4.6 person-rem (0.046 person-Sv), which is approximately 43% of the collective EDE for the ORR.

The maximally exposed individual for the ETTP was located at a business about 1950 m (1.2 miles) west-southwest of the TSCA Incinerator stack (K-1435). The EDE received by this individual was calculated to be about 0.03 mrem (0.0003 mSv). About 91% of this dose is from ingestion and inhalation of uranium radioisotopes, about 7.2% is from thorium radioisotopes, and about 0.64% 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 0.7 person-rem (0.007 person-Sv), which is approximately 7% of the collective EDE for the reservation. As noted below, based on measured air concentrations of radionuclides at ETTP Station K9, the dose to the maximally exposed individual for ETTP is about 0.3 mrem/year (0.003 mSv/year), which takes into account part-time occupancy of a business location.

The reasonableness of the calculated radiation doses can be inferred by comparison with radiation doses that could be received from measured air concentrations of radionuclides

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

Tower	Height (m)[a]	Source
		Y-12 Complex
MT6	60	All sources
		ETTP
MT1	10	K-1435C
MT1	60	K-1435
MT7	30	K-33 SC
MT7	10	K-33 D&D, K-1004-D, K-1008-C, K-1407-U, K-1423-SWR, K-25 Guzzler, K-1425A, K-1066-J
		ORNL
MT4	10	X-7567, X-7830MV, X-7831-A, X-7966
MT4	30	X-7503, X-7856-CIP, X-7860, X-7860 D&D, X-7877, X-7911, X-7935, X-Lab Hoods (7000), X-T-13, X-1944
MT3	10	X-7025
MT3	30	X-Lab Hoods (6000)
MT2	100	X-3018, X-3020, and X-3039
MT2	30	X-2026, X-3544, X-5505, X-Decon areas, X-Lab Hoods (1000-5000), and X-SIOU
MT2	10	X-2099, X-2523, X-3074, X-3608, and X-STP

[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 2003

Plant	Total effective dose equivalents [mrem (mSv)]	
	Plant max	ORR max
ORNL	0.2 (0.002)[a]	0.2 (0.0019)
ETTP	0.03 (0.0003)[b]	0.003 (0.00003)
Y-12	0.2 (0.002)[c]	0.04 (0.0004)
Entire ORR	*d*	0.24 (0.0024)[e]

[a]The maximally exposed individual was located 5410 m (3.4 miles) E of X-3039 and 4550 m (2.8 miles) ENE of X-7911.

[b]The maximally exposed individual was located 1950 m (1.2 miles) WSW of K-1435.

[c]The maximally exposed individual is located 2310 m (1.4 miles) ENE of the Y-12 National Security Complex release point.

[d]Not applicable.

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

Table 8.4. Calculated collective effective dose equivalents from airborne releases during 2003

Plant	Effective dose equivalents[a]	
	(Person-rem)	(Person-Sv)
ORNL	4.6	0.046
ETTP	0.7	0.007
Y-12	5.5	0.055
Entire ORR	10.8	0.108

[a]Collective effective dose equivalents to the 1,040,041 persons residing within 80 km (50 miles) of the ORR.

(Table 7.2) at the ORR perimeter air monitoring stations (PAMs) and the remote air monitoring station (RAM) (Fig. 7.3). Hypothetical individuals assumed to reside at the PAMs could have received EDEs between 0.02 and 0.2 mrem/year (0.0002 and 0.002 mSv/year); these EDEs include contributions from naturally occurring (background) radionuclides, radionuclides released from the ORR, and radionuclides released from any other sources. If contributions from strictly naturally occurring radionuclides (^{7}Be and ^{40}K) are omitted, the EDEs range from about 0.01 to 0.1 mrem/year (0.0001 and 0.001 mSv/year) (Table 8.5). An indication of doses from sources other than those on the ORR can be obtained from the EDE calculated at the RAM (Station 52), which was less than 0.01 mrem/year (0.0001 mSv/year). (The isotopes ^{7}Be and ^{40}K were not included in the RAM calculation, either.)

Of particular interest is a comparison of doses calculated using measured air concentrations of radionuclides (except ^{7}Be and ^{40}K) that could have been emitted from the ORR at PAMs located near the maximally exposed individuals for each plant and doses calculated for those individuals using CAP-88 and measured emissions. PAM 40 is located near the maximally exposed individual for the Y-12 Complex; the EDE calculated using measured air concentrations was 0.04 mrem/year (0.0004 mSv/year), which is less than the 0.2 mrem/year (0.002 mSv/year) calculated using CAP-88. PAM 48 is located near the maximally exposed individual for ORNL (in an adjacent wind direction at a further distance), the EDE calculated using measured air concentrations was 0.15 mrem/year (0.0015 mSv/year), which is less than the 0.2 mrem/year (0.002 mSv/year) calculated using CAP-88. At PAM 39, which is located near the receptor location for the second highest exposed individual, the EDE calculated using measured air concentrations was 0.1 mrem/year (0.001 mSv/year), which is less than the 0.2 mrem/year (0.002 mSv/year) (rounded value) calculated using CAP-88. The EDE calculated using measured air concentrations at Station K9 was approximately 0.5 mrem/year (0.005 mSv/year) for full occupancy. Because the ETTP maximum location is a business, the actual dose would be about 0.3 mrem/year (0.003 mSv/year), which is about ten times higher than the modeled value of 0.03 mrem/year (0.0003 mSv/year).

The dose estimates based on calculated and measured radionuclide concentrations are in reasonable agreement, with the exception of Station K9, given the differences in distances and directions between maximally exposed individuals and the monitoring stations, and given that the CAP-88 model may overestimate doses by a factor of 2. Also, the ambient air monitors collect naturally occurring radionuclides and those emitted from non-ORR sources.

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 and various feeder streams (see Sect. 1.4 for the surface water setting of the ORR). Discharges from the Y-12 Complex enter the Clinch River via Bear Creek and East Fork Poplar Creek, both of which enter Poplar Creek before it enters the Clinch River, and by discharges from Rogers Quarry into McCoy Branch and then into Melton Hill Lake. Discharges from ORNL enter the Clinch River via White Oak Creek. 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.

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) that were determined by laboratory analyses of actual water and fish samples (see Sects. 7.4 and 7.9). The second method estimates radionuclide concentrations in water and fish that were calculated from measured radionuclide discharges and known or estimated stream flows. The advantage of the first method is the use of radionculide concentrations actually measured in water and fish; disadvantages are the inclusion of naturally occurring radionuclides especially in gross alpha- and beta-activity measurements, the possibility that some radionuclides of ORR origin might be present in quantities too low to be

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

Station	Effective dose equivalent [a]	
	mrem/year	mSv/year
35	0.1	0.001
37	0.02	0.0002
38	0.04	0.0004
39	0.1	0.001
40	0.04	0.0004
42	0.1	0.001
46	0.03	0.0003
48	0.02	0.0002
52	0.01	0.0001
K2	0.3	0.003
K6	0.9	0.009
K9	0.5	0.005
K10	0.2	0.002

[a] Assumes full-time occupancy; for business location the estimated EDE is half of the EDE.

measured, and the possibility that the presence of some radionuclides might be overstated (e.g., present in a quantity below the detection limit). 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. However, using the two methods should allow the potential radiation doses to be bounded.

Drinking Water

Several water treatment plants along 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 measurements taken away from the processing plants. For purposes of assessment, it was assumed that maximally exposed individuals would drink 730 L of water during 2003 and that the average person would drink 370 L.

The only water treatment plant located on Melton Hill Lake that could be affected by discharges from the ORR is a Knox County plant. Water from this plant is not sampled. However, the plant is located near surface water sampling location CRK 58. Based on detected concentrations of identifiable radionuclides that could have come from the ORR, no individual should have received an EDE above background levels. If unidentified alpha and beta activities, which are believed to be due to naturally occurring radionuclides, are taken into account, a highly exposed individual could have received an EDE of about 5E-11 mrem (5E-13 mSv) from drinking this water. Based on known radionuclide discharges to Melton Hill Lake, a highly exposed individual could have received an EDE of about 3E-7 mrem (3.7E-9 mSv), even if unidentified alpha and beta activities are included.

The ETTP (Gallaher) water plant draws water from the Clinch River near CRK 23. For assessment purposes, we assume that workers obtain half their annual water (370 L) intake at work. No in-plant water-sampling data are available. Based on water samples taken above the water plant's intake, workers could have received EDEs as high as 0.3 mrem (0.003 mSv), and the collective EDE to the approximately 2500 workers could have been about 0.7 person-rem (0.007 person-Sv). If the unidentified alpha and beta activities are included, the EDEs could have been 0.7 mrem and 2 person-rem (0.007 mSv and 0.02 person-Sv). Using radionuclide discharge data, the maximum individual EDE was estimated to be 1E-4 mrem (1E-6 mSv); the collective EDE was 2E-4 person-rem (2E-6 person-Sv). Including unidentified alpha and beta activities increases the hypothetical doses to 2E-4 mrem and 2E-4 person-rem (2E-6 mSv and 2E-6 person-Sv).

The Kingston and Rockwood municipal water plants draw water from the Tennessee River not very far from its confluence with the Clinch River. No water samples are taken from the Tennessee River near these plants. Radionuclide discharge data and Clinch River water sample data were used to estimate the maximum individual EDE as 0.1 mrem (0.001 mSv); the collective EDE to the estimated 21,068 water users could have been about 2 person-rem (0.02 person-Sv). Including

unidentified alpha and beta activities could increase these dose estimates to 0.3 mrem and 3 person-rem (0.003 mSv and 0.03 person-Sv).

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 the 0.09 mrem (0.0009 mSv) calculated for Kingston and Rockwood water.

Using the maximum EDE derived by either method (measured water concentration or modeled from discharges) and using the community and noncommunity drinking water populations served (Oak Ridge to Chattanooga), the estimated collective EDE from all drinking water locations was about 12 person-rem (0.12 person-Sv).

Fish

Fishing is quite common on the Clinch and Tennessee River systems. For purposes of assessment, it was assumed that avid fish eaters would have consumed 21 kg of fish during 2003 and that the average person would have consumed 6.9 kg of fish. EDEs were calculated from measured radionuclide contents in fish (see Sect. 7.9), the measured concentrations of radionuclides in water, and the calculated concentrations from discharges as input to the LADTAP XL code (Hamby 1991).

Fish samples were collected from Melton Hill Lake above all ORR inputs (CRK 70), from the upper part of the Clinch River (CRK 32), and from the Clinch River below all ORR inputs (CRK 16). Based on these samples, avid fish consumers could have received, from statistically significant detected radionuclides that could have been discharged from the ORR, a 50-year committed EDE between 0 and 0.1 mrem (0 and 0.001 mSv), depending on type of fish and harvest location, excluding ^{40}K (a naturally occurring radionuclide) and unidentified alpha and beta activities. Consuming catfish taken from CRK 70 could have resulted in an EDE of 0.01 mrem (0.0001 mSv), whereas eating sunfish from that location could have resulted in no EDE. Eating catfish taken from CRK 32 could have resulted in an EDE of 0.05 mrem (0.0005 mSv); eating sunfish from that location could have resulted in an EDE of 0.1 mrem (0.001 mSv). Eating catfish taken from CRK 16 could have resulted in an EDE of 0.01 mrem (0.0001 mSv); eating sunfish from that location also could have resulted in an EDE of 0.03 mrem (0.0003 mSv). The presence of naturally occurring ^{40}K adds between 1 and 2 mrem (0.001 and 0.002 mSv) to the above doses.

Unidentified beta and alpha activities were detected in many of the fish samples. Excess beta and alpha activities were estimated by subtracting activities of identified beta- and alpha-particle-emitting radionuclides from the corresponding unidentified activities. If the excess unidentified beta and alpha activities were from the naturally occurring radionuclides ^{234}Th and ^{226}Ra, respectively, the hypothetical avid fish consumer could have received an EDE between zero and 0.6 mrem (0.006 mSv). Eating catfish taken from CRK 70 could have resulted in an EDE of 0.2 mrem (2E-03 mSv), 91% of which is due to excess beta activity; eating sunfish from that location could have resulted in no EDE from radionuclides other than ^{40}K, a naturally occurring radionuclide. Eating catfish taken from CRK 32 could have resulted in an EDE of 0.2 mrem (0.002 mSv), 77% of which is due to excess beta activity; eating sunfish from that location could have resulted in an EDE of 0.6 mrem (0.006 mSv), 81% of which is due to excess alpha and beta activity. Eating catfish taken from CRK 16 could have resulted in an EDE of 0.3 mrem (0.003 mSv), 96% of which is due to excess beta activity; eating sunfish from that location could have resulted in an EDE of 0.03 mrem (0.0003 mSv), none of which is due to excess alpha or beta activity. It is believed that essentially all of the excess activities are due to naturally occurring radionuclides, not to radionuclides that were discharged from the ORR.

Water samples were collected from Melton Hill Lake (CRK 70, 66, and 58); from the Clinch River below Melton Hill Dam (CRK 32, 23, and 16); from East Fork Poplar Creek, just before it joins Poplar Creek (EFK 0.1) and downstream of its floodplain (EFK 5.4); and from Poplar Creek, after it is formed by East Fork Poplar Creek and prior to its joining the Clinch River. Based on water concentrations of identified radionuclides that could have come from the ORR in these samples, avid fish consumers could have received

EDEs of about 2E-11 mrem (2E-11 mSv) from fish taken from Melton Hill Lake and between 3E-4 to 1 mrem (3E-6 to 0.01 mSv) from the Clinch River; between 0.04 and 1 mrem (0.0004 and 0.01 mSv) from fish taken from Poplar Creek; and between 0.1 and 2 mrem (0.001 and 0.02 mSv) from fish taken from East Fork Poplar Creek. It should be noted that catching and consuming fish from East Fork Poplar Creek is discouraged strongly by state of Tennessee postings banning such activities. Thus, we do not consider consumption of fish from East Fork Poplar Creek to be a credible exposure pathway.

If the unidentified alpha and beta activities are included, the above EDEs could be about 2 mrem (0.002 mSv) from Melton Hill Lake fish; between 3E-4 and 3 mrem (3E-6 and 0.03 mSv) from Clinch River fish; about 1 mrem (0.01 mSv) from fish taken from Poplar Creek; and between 2 and 3 mrem (0.02 and 0.03 mSv) from fish taken from East Fork Poplar Creek. Radium-226 was detected in two water samples, though not above the quantified limit, collected at CRK 16 (by a method not recommended by the EPA). If these ^{226}Ra concentrations were into account, the estimated EDE from consuming fish at CRK 16 would be about 9 mrem (0.09 mSv).

Based on radionuclide discharges to Melton Hill Lake, the Clinch River, and the Poplar Creek system, maximum EDEs to avid fish consumers could have been 5E-7 mrem (5E-9 mSv), 3E-4 mrem (3E-6 mSv), and 1 mrem (0.01 mSv), respectively.

Using the maximum EDE derived from either method (fish tissue or modeled from water concentrations) and taking into account fish harvest data from Melton Hill, Watts Bar, and Chickamauga reservoirs, the collective EDE from eating fish from the above locations and from the Tennessee River system down to Chattanooga could have been 3 person-rem (0.03 person-Sv).

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 27 h/year, boat for 63 h/year, and use the shoreline for 67 h/year. Measured and calculated concentrations of radionuclides in water and the LADTAP XL code were used to estimate potential EDEs from these activities. When compared with EDEs from eating fish from the same waters, the EDEs from these other uses are relatively insignificant.

Based on the above-noted water samples, highly exposed other users could have received EDEs less than 7E-4 mrem (7E-6 mSv) from using Melton Hill Lake, between 1E-05 and 0.3 mrem (1E-07 and 3E-03 mSv) from using the Clinch River, between 3E-03 and 0.1 mrem (3E-05 and 1E-3 mSv) from using Poplar Creek, and between 5E-04 and 0.4 mrem (5E-06 and 0.004 mSv) from using East Fork Poplar Creek. If the unidentified alpha and beta activities are included, the above EDEs could be about 9E-4 mrem (9E-6 mSv) from using Melton Hill Lake, between 3E-5 and 0.3 mrem (3E-7 and 0.003 mSv) from using the Clinch River, between 3E-3 and 0.1 mrem (3E-5 and 0.001 mSv) from using Poplar Creek, and between 7E-4 and 0.4 mrem (7E-6 and 0.004 mSv) from using East Fork Poplar Creek.

Based on radionuclide discharges to the Clinch River-Poplar Creek system, a user could have received an EDE between 1E-8 and 0.03 mrem (1E-10 and 3E-4 mSv).

Using the EDEs derived from exposure to identified radionuclides and estimates of populations boating, wading, and using the shoreline, the maximum collective EDE from all other water uses could have been about 5 person-rem (0.05 person-Sv).

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 2 mrem (0.02 mSv) to a person obtaining his or her full annual complement of fish, drinking water, and participation in other water uses from the Clinch River. The maximum collective EDE to the 50-mile population could be as high as 20 person-rem (0.20 person-Sv). These are small percentages of individual and collective doses attributable to natural background radiation, about 0.7% and 0.006%, respectively.

Table 8.6. Summary of annual maximum individual effective dose equivalents from waterborne radionuclides (mrem)[a]

Type of sample	Drinking water	Eating fish	Other uses	Total of highest
Melton Hill Lake, CRK 70, CRK 66, CRK 58				
Fish[b]		0.01		
Water[c]	5E-11	2E-11	7E-4	7E-4
Discharge[d]	3E-7	5E-7	1E-8	8E-7
Maximum	3E-7	0.01	7E-4	0.01
Upper Clinch River, CRK 23, Gallaher Water Plant, CRK 32				
Fish[b]		0.1		
Water[c]	0.5	1	0.3	2
Discharge[d]	1E-4	3E-4	2E-5	4E-4
Maximum	0.5	1	0.3	2
Lower Clinch River, CRK 16				
Fish[b]		0.03		
Water[c]	NA[e]	1	0.3	1
Discharge[d]	NA[e]	3E-4	2E-5	3E-4
Maximum	NA[e]	1	0.3	1
Upper Watts Bar Lake, Kingston Municipal Water Plant				
Water[c]	0.1	0.3	0.07	0.5
Discharge[d]	3E-5	7E-5	7E-6	1E-4
Maximum	0.1	0.3	0.07	0.5
Lower System (Lower Watts Bar Lake and Chickamauga Lake)				
Water[c]	0.09	0.2	0.06	0.4
Discharge[d]	3E-5	6E-5	6E-6	1E-4
Maximum	0.09	0.2	0.06	0.4
Poplar Creek				
Water[c]	NA[e]	0.9	0.1	1
Discharge[d]	NA[e]	1	0.03	1
Maximum	NA[e]	1	0.1	1

[a] 1 mrem = 0.01 mSv.
[b] Doses based on measured radionuclide concentrations in fish tissue.
[c] Doses based on measured radionuclide concentrations in water.
[d] Doses based on measured discharges of radionuclides from on-site outfalls.
[e] Not at drinking water supply locations.

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 (Sect. 7.6.3). 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 0.04 mrem (0.0004 mSv) from drinking milk from the near locations and about 0.05 mrem (0.005 mSv) 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. 7.6.2. 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 (71 lb) of homegrown tomatoes, 10 kg (22 lb) of homegrown lettuce, and 37 kg (82 lb) of homegrown turnips. The hypothetical gardener could have received a 50-year committed EDE of between 0.01 and 0.1 mrem (0.0001 and 0.001 mSv), depending on garden location. Of this total, between 0.02 and 0.04 mrem (0.0002 and 0.0004 mSv) could have come from eating tomatoes, between 0.01 and 0.05 mrem (0.0001 and 0.0005 mSv) from eating lettuce, and between 0.02 and 0.05 mrem (0.0002 and 0.0005 mSv) from eating turnips. The highest dose to a gardener could have been about 0.1 mrem (0.001 mSv) from consuming all three types of homegrown vegetables.

Many of the samples contained detected activities of unidentified beta- and alpha-particle-emitting radionuclides. By subtracting identified activities of beta- and alpha-particle-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 ^{90}Sr and ^{210}Po, respectively, a hypothetical home gardener could have received an EDE of between 4 and 10 mrem (0.04 and 0.1 mSv). Of this total, between 1 and 9 mrem (0.01 and 0.09 mSv) could have come from eating tomatoes, between 0.1 and 0.6 mrem (0.001 and 0.006 mSv) from eating lettuce, and between 0.8 and 4 mrem (0.008 and 0.04 mSv) 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.

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, around 4 mrem (0.04 mSv) to the hypothetical home gardener's EDE.

White-Tailed Deer

The TWRA conducted three 2-day deer hunts during 2003 on the Oak Ridge Wildlife Management Area, which is part of the ORR, as described in Sect. 7.8. A total of 256 deer were killed during these hunts and were brought to the TWRA checking station. At the station, a bone

sample and a tissue sample were taken from each deer. These samples were field-counted for radioactivity to ensure that the deer met release criteria—that is, less than 20 pCi/g (0.74 Bq/g) of beta-particle activity in bone or 5 pCi/g (0.19 Bq/g) of ^{137}Cs in edible tissue. Two of the deer exceeded the limit for beta-particle activity in bone and were confiscated. The remaining 254 deer were released to the hunters.

For the 2003 deer hunts, a new counting system was installed at the field counting station. This counting system provides better specific isotopic information as compared to the previous field counting system. The average ^{137}Cs concentration in tissue of the 254 released deer, as determined by field counting, was 0.7 pCi/g (0.026 Bq/g); the maximum ^{137}Cs concentration in a deer was 1.9 pCi/g (0.063 Bq/g). In 2003, tissue samples from three deer were submitted for laboratory analysis.

Based on field analysis data for the deer harvested in 2003, an individual who consumed a deer harvested on the ORR could have received an average EDE of about 0.7 mrem (0.007 mSv). The maximum EDE to a hunter who consumed a deer harvested from the ORR in 2003 was estimated to be 4 mrem (0.04 mSv). About 19 hunters (one hunter or more from the same household) harvested two deer from the ORR in 2003. In two cases three deer were harvested by members of the same household. The maximum EDE, based on ^{137}Cs concentrations determined by field analyses, to a hunter who consumed three harvested deer was estimated to be about 2 mrem (0.02 mSv).

The collective EDE from eating all the harvested venison from the ORR with a 2003 average field-derived ^{137}Cs concentration of 0.7 pCi/g (0.026 Bq/g) and an average weight of 76.9 lb (34.9 kg) is estimated to be about 0.2 person-rem (0.002 person-Sv).

Canada Geese

During the 2003 goose roundup, 95 geese were weighed and subjected to whole-body gamma scans. The average ^{137}Cs concentration in the released geese was 0.24 pCi/g (0.009 Bq/g). The maximum ^{137}Cs concentration in the released geese was 0.97 pCi/g (0.036 Bq/g). The average weight of the geese screened during the roundup was about 8.68 lb (3.9 kg). The maximum goose weight was about 12.59 lb (5.7 kg). If a person consumed a released goose with an average weight of 8.68 lb (3.9 kg) and an average ^{137}Cs concentration of 0.24 pCi/g (0.009 Bq/g), the estimated EDE would be about 0.024 mrem (0.00024 mSv). The maximum estimated EDE to an individual who consumed a hypothetical released goose with the maximum ^{137}Cs concentration of 0.97 pCi/g (0.036 Bq/g) and the maximum weight of 12.6 lb (5.7 kg) was about 0.1 mrem (0.001 mSv). As mentioned above, a new counting system was installed at the field counting station, thereby providing better specific isotopic information than had been obtained by the previous field counting system.

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 hypothetical geese of maximum weight with the highest measured concentration of ^{137}Cs, that person could have received an EDE of about 0.3 mrem (0.003 mSv).

To follow up on a special study initiated in 1998, muscle samples were analyzed from four geese sacrificed during the 2003 roundup. One goose each from ETTP, ORNL (sewage treatment pond area), the Oak Ridge Marina, and Clark Center Park were sacrificed and the tissue 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 0.05 to 0.1 mrem (0.0005 to 0.001 mSv).

Eastern Wild Turkey

No wild turkey hunts were held on the ORR in 2003 due to security concerns.

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 (0.42 mSv/year) and range between 19 and 72 mrem/year, or 0.19 and 0.72 mSv/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 2003 was about 5.3 μR/h. This rate corresponds to an EDE rate of about 33 mrem/year (0.47 mSv/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 (1.1-mile) 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 (1.5E-03 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 (4E-03 mSv) above background during 2003.

As described in Sect. 4.12, the potential above-background annual EDE to a hypothetical maximally exposed individual would be about 1 mrem from gamma radiation and 0 mrem from neutron radiation along the bank of Poplar Creek near the K-1066-J Cylinder Yard; 2 mrem (1.25 mrem from gamma radiation and 0.75 mrem from neutron radiation) along the bank of Poplar Creek near the K-1066-E Cylinder Yard; about 1 mrem from neutron radiation attributable to the K-770 Scrap Yard, which is along the near bank of the Clinch River; and about 5 mrem (1.75 mrem from gamma radiation and 3 mrem from neutron radiation) in the parking lot along the edge closest to the K-1066-K Cylinder Yard. However, the parking lot is for employees and has no public facilities.

8.1.3 Doses to Aquatic Biota

8.1.3.1 Aquatic Biota

DOE Order 5400.5, Chapter II, sets an absorbed dose rate limit of 1 rad/day (0.01Gy/day) to native aquatic organisms from exposure to radioactive material in liquid wastes discharged to natural waterways (see Appendix F for definitions of absorbed dose and the rad). To demonstrate compliance with this limit, absorbed dose rates to aquatic organisms were calculated using the Radionuclide Biota Concentration Guide Calculator (Rev 2.0), a companion electronic calculation tool to the DOE technical standard entitled *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota* (DOE 2002b).

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 mollusks) or riparian organisms (e.g., raccoons) are often 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 biota concentration guides, 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 biota concentration guidelines using default parameters. This aquatic dose assessment was based primarily on surface water sampling data except at two locations at Y-12 where both surface water and sediment sampling data were available.

At ORNL, doses to aquatic organisms are based on surface water concentrations at seven different sampling locations: MEK 0.2, WCK 1.0 and 2.6, First Creek, Fifth Creek, Raccoon Creek, and Northwest Tributary. All but two of these locations, WCK 1.0 (White Oak Creek at the Dam) and WCK 2.6, passed the initial general screening (using default parameters for biota concentration guides). At WCK 1.0 and 2.6, the default bioaccumulation factors for ^{137}Cs in fish were adjusted to reflect on-site bioaccumulation of these radionuclides in fish. Riparian organisms are the limiting receptor for ^{137}Cs 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 ^{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 seven ORNL locations.

At the Y-12 Complex, doses to aquatic organisms were estimated from surface water concentrations at eight different sampling locations: East Fork Poplar Creek at Surface Water Hydrological Information Support System Station 9422-1 (Station 17), Bear Creek kilometer (BCK) 4.55 (formerly Outfall 304), Rogers Quarry Discharge Point S19 (formerly Outfall 302), Discharge Point S17 (tributary to the Clinch River), Outfall 501 (Central Pollution Control Facility), Outfall 502, Outfall 512, and Outfall 551. With the exception of Outfall 502, all locations passed the general screening. For Outfall 502, the default bioaccumulation factors for ^{137}Cs in fish were adjusted to reflect ORR bioaccumulation of these radionuclides in fish. Riparian organisms are the limiting receptors for ^{137}Cs in surface water, and the best available bioaccumulation data for East Fork Poplar Creek are for fish. This resulted in absorbed dose rates to aquatic organisms below the DOE aquatic dose limit of 1 rad/day at all eight Y-12 locations.

At ETTP, doses to aquatic organisms were estimated from surface water concentrations at nine different sampling locations: Mitchell Branch at K1700 and at MIK 1.4 (upstream location) and MIK 0.4, Poplar Creek at K-716 (downstream), K1007-B and K-1710 (upstream location), K901-A (downstream of ETTP operations), K-1407-J (the Central Neutralization Facility), and East Fork Poplar Creek (0.1 km upstream on East Fork Poplar Creek). All of these locations passed the initial general screening (using default parameters for biota concentration guides).

8.1.3.2 Terrestrial Biota

DOE Order 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 Cs-137 driving risks for all receptors. In 5 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 2004b) 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 Plant property boundary and becomes Lower East Fork Poplar Creek. The baseline ecological risk assessment addresses only surface water and sediment exposures to contaminants in Upper East Fork Poplar Creek, Lake Reality, wetlands and seep associated with the East End carbon tetrachloride plume because the characterization area includes no substantial habitat for terrestrial biota. Risks were estimated from radionuclides measured in surface water collected from sampling stations within the Upper East Fork Poplar Creek characterization area. Radionuclide concentrations in Upper East Fork Poplar Creek surface water do not appear to present a significant risk to any of the assessment endpoints. Dose rates were below the recommended limits for fish, benthic invertebrates, and piscivorous wildlife (mink and belted kingfisher).

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 semi-aquatic 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 all of the dose for all receptors. External exposures were determined to be inconsequential.

At ETTP data were aggregated within subwatersheds and used to evaluate possible risks to fish and other aquatic organisms, piscivorous wildlife, terrestrial plants, soil invertebrates, and terrestrial wildlife receptors (BJC 2004d, 2004e). 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. Maximum PCB concentrations in fish from K-1007 P1 were an order of magnitude higher than in fish from the K-901 Pond or Mitchell Branch. Dose rate calculations for fish, benthic invertebrates, and piscivorous wildlife indicated radionuclides in surface water and sediment were unlikely to be a concern for these receptors.

While all subwatersheds 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 subwatershed, the K-25 North Trash Slope within the K-27/K-29/K-1064 subwatershed, and portions of the habitat area along Mitchell Branch in the Mitchell Branch subwatershed appear to pose the greatest likelihood of unacceptable risks to terrestrial receptors. These same areas also had radionuclide levels potentially resulting in doses above threshold levels for one or more terrestrial receptors. In all cases internal exposures to uranium isotopes were identified as the primary contributors to elevated radiation dose levels. Dose rates from soil at the K-901/K-1070-A, Duct Island, K-1007, Contractor's Spoil, and K-33 subwatersheds were below dose rate limits for all receptors.

The DOE Environmental Management Program is in the process of planning an ORR-wide ecological risk assessment and monitoring

Table 8.7. Summary of maximum potential radiation dose equivalents to an adult during 2003 and locations of the maximum exposures

Pathway	Dose to maximally exposed individual		Percentage of DOE 100 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	0.2	0.002	0.2	10.8	0.108	1,040,041[a]	
Liquid effluents:							
drinking water	0.5	0.005	0.5	12	0.12	346,692[b]	
eating fish	1	0.01	1	3	0.03	37,739[c]	
other activities	0.3	0.003	0.3	5	0.05	771,146[d]	
Eating deer	4	0.04[e]	4	0.2	0.002	256	
Eating geese	0.3	0.003[f]	0.3	*g*	*g*		
Direct radiation	2	0.02[h]	2	0.2	0.002		
All pathways	8	0.08	8	31	0.31	1,040,041	312,012

[a] Estimated background population dose is based on 300 mrem/year individual dose and the population within 80 km (50 miles) of the ORR.

[b] Population based on 2000 census data.

[c] Population estimates based on community and non-community drinking water supply data from TDEC, Division of Water.

[d] Population estimates based on the number of fish harvested in Melton Hill, Watts Bar, and Chickamuaga Reservoirs.

[e] The maximum EDE from consumption of a deer harvested on the ORR in 2003 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] Direct radiation dose estimate based on exposure to a fisherman on Poplar Creek.

strategy to provide consistent and comprehensive protection of ecological resources on the ORR.

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 2003; however, if someone were, that person could have received a total EDE of about 4 mrem (0.4 mSv); of this total, 0.2 mrem (0.002 mSv) would have come from airborne emissions, 0.5 mrem (0.005 mSv) from drinking Clinch River water, 1 mrem (0.01 mSv) from eating fish from the Clinch River, 2 mrem (0.02 mSv) from fishing on Poplar Creek inside the ETTP, and 0.3 mrem (0.003 mSv) from other water uses on the Clinch River. This dose is about 1% of the annual dose [300 mrem (3 mSv)] from background radiation. If this person also was the person who received the highest EDEs from eating wildlife harvested on the ORR, that person could not have received an additional committed EDE greater than about 4 mrem (0.04 mSv).

DOE Order 5400.5 limits to no more than 100 mrem (1 mSv) the EDE that an individual may receive from all exposure pathways from all radionuclides released from the ORR during 1 year. As described in the preceding paragraph, the 2003 maximum EDE should not have exceeded about 6 mrem (0.6 mSv), or about 6% of the limit given in DOE Order 5400.5. For further information, see Table F.2 in Appendix F, which

provides a summary of dose levels associated with a wide range of activities.

The total collective EDE to the population living within a 50-mile (80-km) radius of the ORR was estimated to be less than 31 person-rem (0.31 person-Sv). This dose is about 0.01% of the 312,012 person-rem (3123 person-Sv) that this population received from natural sources during 2003.

8.1.5 Five-Year Trends

Dose equivalents associated with selected exposure pathways for the years from 1999 to 2003 are given in Table 8.8. The variations in values over this 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. Seven facilities responded to the DOE request. Based on these responses, no member of the public should have received an EDE greater than 3.3 mrem (3.3E-02 mSv) due to airborne releases from any of these facilities. The maximally exposed individual dose of 3.3 mrem/year was estimated at one of the facilities boundary. Three facilities responded regarding water releases; two facilities had no water releases, and one facility had releases to the sanitary sewer system that complied with site, state, and NRC regulatory requirements.

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 (see Table 8.9 and refer to Appendix G for a detailed description of the chemical dose methodology). As in 2000 through 2002, 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.

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 (~0.13 lb/day) [21 kg/year (46 lb/year)] is assumed for both the noncarcinogenic and carcinogenic pollutants; this is the same fish consumption rate used in the estimation of the maximally exposed radiological dose from consumption of fish. TDEC uses a method developed by EPA to establish fish consumption advisories for carcinogenic pollutants [as described in TDEC 1200-4-3-.03 (j) (TDEC 2004)]. Using the mean daily consumption rate of 6.5 g/day would reduce both the HQ values and the risk values by a factor of approximately 10. (See Appendix G for a detailed description of the chemical dose methodology.)

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

Pathway	1999	2000	2001	2002	2003
All air	0.7	0.4	0.8	0.3	0.2
Fish consumption (Clinch River)	4	1	0.2	0.3	1
Drinking water (Kingston)	0.16	No data	0.03[b]	0.04[b]	0.1
Direct radiation (Clinch River)	0.4[c]	0.4[c]	0.4[c]	0.4[c]	0.4
Direct radiation (Poplar Creek)	2[c]	1[c]	2[c]	2[c]	2[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.

Table 8.9. 2003 chemical hazard quotients and estimated risks for drinking water[a]

Chemical	Hazard quotient	
	CRK 70[b]	CRK 16[c]
Antimony	~0.01	0.009
Arsenic	~0.2	~0.2
Acetone	~0.0002	~0.0001
Barium	0.01	0.02
Beryllium	~0.0006	0.0008
Boron	0.005	0.005
Cadmium	~0.003	~0.004
Chromium	~0.007	~0.01
Lead	0.1	~0.2
Manganese	0.01	0.01
Mercury	~0.006	~0.008
Molybdenum	0.004	0.003
Nickel	0.002	0.002
Selenium	0.009	0.009
Silver	~0.0005	~0.00006
Strontium	0.6	0.004
Thallium	0.1	0.08
Uranium	0.002	~0.003
Vanadium	~0.005	~0.005
Zinc	~0.0006	0.003
Risk for carcinogens		
Arsenic	~9E-5	~4E-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.

Table 8.10. 2003 chemical hazard quotients (HQs) and estimated risks for carcinogens in fish[a]

Parameters	Sunfish			Catfish		
	CRK 70[b]	CRK 32[c]	CRK 16[d]	CRK 70[b]	CRK 32[c]	CRK 16[d]
HQs for metals						
Antimony			~0.1			
Arsenic	0.36	0.24	0.3	0.3	0.2	~0.3
Barium	0.003	0.004	0.004	0.0008	0.0006	0.0005
Beryllium	0.0007	0.001	0.006	~0.0007	~0.0002	
Cadmium			~0.02	0.02	~0.01	~0.01
Chromium	0.03	0.03	0.03	0.02		~0.005
Lead		0.2	~0.2	0.2	~0.2	0.1
Manganese	0.009	0.008	0.01	0.001	0.0009	0.001
Mercury	0.07	0.3	0.3	0.6	0.4	0.2
Nickel	0.001	~0.0008	~0.0008	~0.002		
Selenium	0.2	0.2	0.1	0.05	0.04	0.06
Silver				~0.005		
Strontium	0.002	0.003	0.003	0.0002	0.0002	0.0002
Thallium	0.1	0.1	0.1	0.06	0.05	0.07
Uranium	0.0001	0.0002	0.0003	0.0001	0.0001	0.0001
Vanadium	~0.002	~0.002	~0.003			
Zinc	0.05	0.05	0.04	0.02	0.02	0.02
HQs for pesticides and Aroclors						
Aroclor-1254				1.6	~2.6	1.2
Aroclor-1260	0.98	~0.78	0.95	7.8	30.4	5.8
Chlordane,gamma				0.002	~0.003	0.005
Endosulfan sulfate						0.0005
Heptaclor epoxide						~0.2
Risks for carcinogens						
Arsenic	7E-5	5E-5	5E-5	5E-5	4E-5	~6E-5
Aroclor-1254				3E-5	~5E-5	2E-5
Aroclor-1260	2E-5	~1E-5	2E-5	1E-4	5E-4	9.9E-5
Chlordane, gamma				2E-7	~2E-7	4E-7
Heptaclor epoxide						~7E-6
PCBs (mixed)[e]	2E-5	~1E-5	2E-5	2E-4	6E-4	1E-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.

As shown in Table 8.10, for consumption of sunfish, HQ values of less than 1 were calculated for the detected analytes at all three locations. For consumption of catfish, HQ values were less than 1 for all detected analytes except for Aroclor-1254 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. In catfish, risk values greater than 10^{-5} were calculated for Aroclor-1254 and Aroclor-1260 at all three collection locations. TDEC has issued a fish advisory that states that catfish should not be consumed from Melton Hill Reservoir (in its entirety) because of PCB contamination and has issued a precautionary fish consumption advisory for catfish in the Clinch River arm of Watts Bar Reservoir (TDEC 2002).