8. Dose

Setting

Activities on the Oak Ridge Reservation 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.

Update

A hypothetical maximally exposed individual could have received a total effective dose equivalent (EDE) of about 0.8 mrem (less than 1 mrem) from radionuclides emitted to the atmosphere from all of the sources on the ORR in 2001; 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 dose of about 4 mrem, which is a small percentage (~1%) 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 geese and wild turkey harvested on or near the ORR resulted in the following: an individual who consumed a hypothetical goose containing the maximum concentration of radionuclides below the ORNL administrative limit could have received 0.1 mrem; and a person who ate an average turkey could have received a dose of 0.02 mrem. In a worst-case analysis, a hypothetical person who eats two of the heaviest geese or the heaviest turkey, each containing the highest possible concentration of measured radionuclides, could have received EDEs of 0.3 mrem from the geese or 0.1 mrem from the turkey.

8.1 RADIATION DOSE

Small quantities of radionuclides were released to the environment from operations at the ORR facilities during 2001. 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. These dose estimates are intended to demonstrate that no member of the public received a dose during 2001 in excess of those allowed by relevant regulatory authorities. 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 and 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 2001 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 the National Emission Standards for Hazardous Air Pollutants (NESHAP): Radionuclides, 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 76 emission points, each of which includes one or more individual sources, on the ORR was modeled during 2001. This total includes 13 points at the Y-12 Complex, 51 points at ORNL, and 12 points at the 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 2001 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 2001, rainfall, as averaged over the four rain gauges located on the ORR, was 116.1 cm (45.7 in.). The average air temperature was 14.4°C (57.9°F), and the average mixing-layer height was 1000 m (3280 ft).

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 1120 m (0.69 miles) north-northeast of the main Y-12 National Security Complex release point, about 9650 m (5.9 miles) north-northeast of the 7911 stack at ORNL, and about 13,240 m (8.2 miles) east-northeast of the Toxic Substances Control Act (TSCA) Incinerator (stack K-1435) at the ETTP. This individual could have received an

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		ORR	
X-2001	15.24	0.66	7.44	Ambient	3820	SSW	9650	NE
X-2026	22.9	1.05	10.38	Ambient	3900	SSW	9520	NE
X-2099	3.658	0.254	8.6	Ambient	3900	SSW	9520	NE
X-2523	7	0.3	4.43	Ambient	3640	SSW	9740	NE
X-3018	61	4.11	0.23	Ambient	4090	SSW	9310	NE
X-3020	61	1.96	6.58	Ambient	4090	SSW	9310	NE
X-3039	76.2	5.68	2.44	Ambient	4010	SSW	9350	NE
X-3074 Group	4	0.26	10.2	Ambient	4090	SSW	9310	NE
X-3505	6.09	0.51	13.78	Ambient	3700	SSW	9610	NE
X-3544	9.53	0.27	12.99	Ambient	3700	SSW	9610	NE
X-3608-1	10.97	2.44	0.57	Ambient	3740	SSW	9550	NE
X-3608-2	8.99	0.36	13.91	Ambient	3740	SSW	9550	NE
X-5505NS	11	0.91	20.72	Ambient	4360	SSW	8900	NNE
X-5505M	11	0.29	4.02	Ambient	4360	SSW	8900	NNE
X-7025	4	0.3	12.63	Ambient	5700	SW	7560	NNE
X-7503	30.5	0.91	14.17	Ambient	3890	SW	9370	NNE
X-2026A	1	0.36	0	Ambient	3900	SSW	9520	NE
X-7567	3.8	0.31	2	Ambient	3890	SW	9370	NNE
X-7569	4	0.15	2.6	Ambient	3890	SW	9370	NNE
X-7830	4.6	0.21	11.53	Ambient	2480	SW	10840	NNE
X-7852	2.13	0.2	2.2	Ambient	2480	SW	10840	NNE
X-7860	18.29	0.31	3.9	Ambient	2480	SW	10840	NNE
X-7877	13.9	0.51	8.61	Ambient	2480	SW	10840	NNE
X-7911	76.2	3.43	2.72	Ambient	3680	SW	9650	NNE
X-7966	6.096	0.2921	12.17	Ambient	3680	SW	9650	NNE
X-Decon Areas	15	NA	0	Ambient	4010	SSW	9350	NE
X-GAAT Grout	1	0.36	0	Ambient	3700	SSW	9610	NE
X-SIOU	1	NA	NA	Ambient	3700	SSW	9610	NE
X-STP	4.572	0.2032	12.46	Ambient	3550	SSW	9780	NE
X-CDM Skid	1	0.91	0	Ambient	2480	SW	10840	NNE
X-7856-CIP	18.29	0.58	12.62	Ambient	2480	SW	10840	NNE
X-TH-4	1	0.36	0	Ambient	3640	SSW	9740	NE
X-W-1 Tank	1	0.36	0	Ambient	3550	SSW	9780	NE
X-W-1A	1	0.36	9.4	Ambient	3550	SSW	9780	NE
X-WC-3	1	0.36	0	Ambient	3980	SSW	9390	NE
X-WC-4	1	0.36	0	Ambient	3980	SSW	9390	NE
X-WC-9	1	0.36	0	Ambient	3700	SSW	9610	NE
X-WC-20	1	0.36	0	Ambient	2480	SW	10840	NNE
X-W-11	1	0.36	0	Ambient	3550	SSW	9780	NE
X-W-17	1	0.36	0	Ambient	3550	SSW	9780	NE
X-W-18	1	0.36	0	Ambient	3550	SSW	9780	NE

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		ORR	
X-W-19	1	0.36	0	Ambient	3940	SSW	9400	NE
X-W-20	1	0.36	0	Ambient	3940	SSW	9400	NE
X-1000 LabHoods	15	0	0	Ambient	3410	SSW	10020	NE
X-3000 LabHoods	15	0	0	Ambient	3980	SSW	9390	NE
X-4000 Lab Hoods	15	0	0	Ambient	4220	SSW	9060	NE
X-6000 Lab Hoods	15	0	0	Ambient	4790	SSW	8470	NNE
X-7000 Lab Hoods	15	0	0	Ambient	4690	WSW	9640	NNE
K-BNFL-W	22.86	1.37	0	Ambient	1320	SE	14840	ENE
K-1004-D	7.3	NA	0	Ambient	470	WNW	14040	ENE
K-1008-C	4.52	0.51	10.46	Ambient	390	SW	13870	ENE
K-1407-U	7.16	1.22	0.625	Ambient	810	SW	13500	ENE
K-1423 CPF	3.96	0.305	0	Ambient	660	S	13950	ENE
K-1423 Repack	7.62	0.71	10.02	Ambient	660	S	13950	ENE
K-1435	30.5	1.37	5.74	80.61	1020	SW	13240	ENE
K-1435-C	18.29	NA	0	Ambient	1020	SW	13240	ENE
K-1435-A	3.96	NA	0	Ambient	1020	SW	13240	ENE
K-1202-N	1	0.91	0	Ambient	810	SW	13500	ENE
K-1420-A	1	0.91	0	Ambient	810	SW	13500	ENE
K-BNFL-C	22.86	1.22	14.96	Ambient	1320	SE	14840	ENE
Y-Monitored	20	NA	0	Ambient	1120	NNE	1120	NNE
Y-Minor	20	NA	0	Ambient	1120	NNE	1120	NNE
Y-Unmonitored Lab Hoods	20	NA	0	Ambient	1120	NNE	1120	NNE
Y-Union Valley Lab	4.27	0.762	13.1	Ambient	2350	WSW	2350	WSW
Y-9616-7 Degas	12.2	0.2	4.36	Ambient	2860	NE	2860	NE
Y-9616-7 Hood	12.2	NA	0.69	Ambient	2860	NE	2860	NE
Y-9623	8.5	NA	0	Ambient	1340	NNE	1340	NNE
Y-9422-22	4	0.15	0	Ambient	2020	W	2020	W
Y-9204-3	20	NA	0	Ambient	1300	N	1300	N
Y-9224	10	NA	0	Ambient	820	NW	820	NW
Y-9401-4	1	0.91	0	Ambient	2320	NE	2320	NE
Y-OD-9	1	0.091	0	Ambient	1300	N	1300	N
Y-OD-10	1	0.091	0	Ambient	1300	N	1300	N

EDE of about 0.8 mrem (8E–03 mSv), which is well below the NESHAP standard of 10 mrem (0.10 mSv) and is about 0.3% 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 8 person-rem (0.08 person-Sv), which is approximately 0.003% 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 1120 m (0.7 miles) north-northeast of the main Y-12 National Security Complex release point. This individual could have received an EDE

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

Tower	Height (m)	Source
		Y-12 Complex
MT6	60[a]	All sources
		ETTP
MT1	60	K-1435
MT7	30	K-BNFL-C
MT7	10	K-BNFL-W, K-1004-D, K-1008-C, K-1407-U, K-1423-CPF, K-1423 repack, K-1435-C, K-1435-A, K-1202-N, K-1420-A
		ORNL
MT4	30	X-7503, X-7567, X-7569, X-7830, X-7852,X-7856, X-7860, X-7877, X-7911, X-7966, X-WC-20, X-CDM Skid
MT2	100	X-3018, X-3020, and X-3039
MT2	30	X-2001, X-2026, X-2099, X-2523, X-3074, X-3505, X-3544, X-3608, X-3082, X-5505, X-7025, X-TH-4, X-W-1, X-W-1A, X-W-2, X-WC-1, X-WC-3, X-WC-4, X-WC-9, X-W-11, X-W-17, X-W-18, X-W-19, X-W-20, X-F501, X-W1I, X-GAAT grout, X-decon areas, X-Lab hoods, X-SIOU, 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 2001

Plant	Total effective dose equivalents [mrem (mSv)]	
	Plant max	ORR max
ORNL	0.1 (0.001)[a]	0.02 (0.0002)
ETTP	0.1 (0.001)[b]	0.02 (0.0002)
Y-12	0.7 (0.007)[c]	0.74 (0.0074)
Entire ORR	*d*	0.78 (0.0078)[e]

[a]The maximally exposed individual was located 4010 m (2.5 miles) SSW of X-3039 and 3680 m (2.3 miles) SW of X-7911.

[b]The maximally exposed individual was located 1020 m (0.6 miles) SW of K-1435.

[c]The maximally exposed individual is located 1120 m (0.7 miles) NNE of the Y-12 National Security Complex release point.

[d]Not applicable.

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

Table 8.4. Calculated collective EDEs from airborne releases during 2001

Plant	Effective dose equivalents[a]	
	(Person-rem)	(Person-Sv)
ORNL	1.5	0.015
ETTP	2.4	0.024
Y-12	4.5	0.045
Entire ORR	8.4	0.084

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

of about 0.7 mrem (7E–03 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 more than 95% of the dose; other radionuclides contributed the remaining 5%. 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 4.5 person-rem (0.045 person-Sv), which is approximately 54% of the collective EDE for the ORR.

The maximally exposed individual for ORNL was located about 4010 m (2.5 miles) south-southwest of the 3039 stack and 3680 m (2.3 miles) southwest of the 7911 stack. This individual could have received an EDE of about 0.1 mrem (1E–03 mSv) from ORNL emissions. Radionuclides contributing 1% or more to the dose include ^{138}Cs (59%), ^{212}Pb (11%), ^{244}Cm (6.4%), ^{135m}Xe (5.4%), ^{131}I (4.6%), ^{138}Xe (2.7%), ^{233}U (1.9%), ^{234}U (1.9%), ^{238}Pu (1.0%), and ^{3}H (1.0%). The contribution of ORNL emissions to the collective EDE to the population residing within 80 km of the ORR was calculated to be about 1.5 person-rem (0.015 person-Sv), which is approximately 18% of the collective EDE for the ORR.

The maximally exposed individual for the ETTP was located at a business about 1020 m (0.6 miles) southwest of the TSCA Incinerator stack (K-1435). The EDE received by this individual was calculated to be about 0.1 mrem (1E–03 mSv). About 72% of this dose is from ingestion and inhalation of uranium radioisotopes, about 13% is from thorium radioisotopes, and about 14% 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 2.4 person-rem (0.024 person-Sv), which is approximately 29% of the collective EDE for the reservation. As noted below, based on measured air concentrations of radionuclides at ETTP Station K2, the dose to the maximally exposed individual for ETTP is about 0.4 mrem/year (0.004 mSv/year).

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 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 of about 0.2 mrem/year (2E–03 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 between 0.04 and 0.1 mrem/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, which was 0.03 mrem/year (3E–04 mSv/year). (The isotopes ^{7}Be and ^{40}K were not included in the RAM calculation, either.)

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

Station	Effective dose equivalent	
	mrem/year	mSv/year
35	0.08	0.0008
37	0.04	0.0004
38	0.06	0.0006
39	0.04	0.0004
40	0.08	0.0008
42	0.11	0.0011
46	0.07	0.0007
48	0.05	0.0005
52	0.03	0.0003
K2	0.72	0.0072
K6	0.55	0.0055
K9	0.56	0.0056
K10	0.36	0.0036

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 to those individuals using CAP-88 and measured emissions. PAM 46 is located near the maximally exposed individual for the Y-12 Complex; the EDE calculated using measured air concentrations was 0.07 mrem/year (7E–04 mSv/year), which is about 9% of the 0.8 mrem/year (8E–03 mSv/year) calculated using CAP-88. PAM 39 is located at about the same distance as, but in an adjacent wind direction from, the maximally exposed individual for ORNL; the EDE calculated using measured air concentrations was 0.04 mrem/year (4E–04 mSv/year), which is about 40% of the 0.1 mrem/year (1E–03 mSv/year) calculated using CAP-88. The EDE calculated using measured air concentrations at Station K2 was approximately 0.7 mrem/year (0.007 mSv/year) for full occupancy. Because the ETTP maximum location is a business, the actual dose would be less than 0.4 mrem/year (0.004 mSv/year). This dose is about four times higher than the modeled value of 0.1 mrem/year (0.001 mSv/year).

Except for the ETTP, dose estimates based on calculated and measured radionuclide concentrations are in reasonable agreement, given the differences in distances and directions between maximally exposed individuals and the monitoring stations, and the fact that the CAP-88 model typically overestimates doses by a factor of 2.

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 uses 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 measured concentrations of radionuclides in water and fish; disadvantages are the inclusion of naturally occurring radionuclides in total alpha- and beta-activity measurements, 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 overstated. (If the analytical laboratory looks for the presence of a given nuclide, a quantity will be reported for that nuclide even if the nuclide is not really present or is present at 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

There are several water treatment plants along the Clinch and Tennessee River systems that could be affected by discharges from the ORR. No in-plant radionuclide concentration data are available for any of these plants. For purposes of assessment, it was assumed that highly exposed individuals would drink 730 L of water during 2001 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 the Environmental Monitoring Plan 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 2 mrem (0.02 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 1E–06 mrem (1E–08 mSv), 1E–04 mrem (1E–06 mSv) if unidentified alpha and beta activities are included. (These dose estimates may be high because they are based on water samples taken before processing in the plants.)

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 0.1 mrem (1E–03 mSv), and the collective EDE to the approximately 1000 workers could have been about 0.1 person-rem (1E–03 person-Sv). If the unidentified alpha and beta activities are included, the EDEs could have been 2 mrem and 2 person-rem (0.02 mSv and 0.02 person-Sv). Using radionuclide discharge data, the maximum individual EDE was estimated to be 8E–05 mrem (8E–07 mSv); the collective EDE was 8E–05 person-rem (8E–07 person-Sv). Including unidentified alpha and beta activities increases the hypothetical doses to 3E–04 mrem and 3E–04 person-rem (3E–06 mSv and 3E–06 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; it was estimated to be 0.03 mrem (3E–04 mSv); the collective EDE to the estimated 22,028 water users could have been about 0.3 person-rem (3E–03 person-Sv). Including unidentified alpha and beta activities could increase these dose estimates to 0.4 mrem and 4 person-rem (4E–03 mSv and 0.04 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 0.03 mrem (3E–04 mSv) calculated for Kingston and Rockwood water. The estimated collective EDE was about 2 person-rem (2E–02 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 2001 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 eaters could have received, from statistically significant detected radionuclides that could have been discharged from the ORR, a 50-year committed EDE between 0 and 4E–02 mrem (0 and 4E–04 mSv), depending on type of fish and harvest location. Eating catfish taken from CRK 70 could have resulted in an EDE of 1E–03 mrem (1E–05 mSv); eating sunfish from that location could have resulted in an EDE of approximately 0 mrem (0 mSv). Eating catfish taken from CRK 32 could have resulted in an EDE of 4E–02 mrem (4E–04 mSv); eating sunfish from that location could have resulted in an EDE of 3E–02 mrem (3E–04 mSv). Eating catfish taken from CRK 16 could have resulted in an EDE of 3E–02 mrem (3E–04 mSv); eating sunfish from that location also could have resulted in an EDE of 3E–02 mrem (3E–04 mSv). The presence of naturally occurring ^{40}K adds between 0.3 and 2 mrem (3E–03 and 2E–02 mSv) to the above doses.

Many of the fish samples contained detected activities of unidentified beta and alpha activities. 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 ^{234}Th and ^{226}Ra, respectively, the hypothetical avid fish eater could have received an EDE between 0 and 2 mrem (0 and 2E–02 mSv). Eating catfish taken from CRK 70 could have resulted in an EDE of 0.2 mrem (0.002 mSv), 99% of which is due to excess beta activity; eating sunfish from that location could have resulted in an EDE of approximately 0 mrem (0 mSv). Eating catfish taken from CRK 32 could have resulted in an EDE of 3E–01 mrem (3E–03 mSv), 84% of which is due to excess beta activity; eating sunfish from that location could have resulted in an EDE of 3E–02 mrem (3E–04 mSv), none of which is due to excess alpha or beta activity. Eating catfish taken from CRK 16 could have resulted in an EDE of 3E–02 mrem (3E–04 mSv), none of which is due to excess alpha or beta activity; eating sunfish from that location could have resulted in an EDE of 2 mrem (0.02 mSv), 98% of which is due to excess alpha 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 concentrations of identified radionuclides that could have come from the ORR in these samples, avid fish eaters could have received EDEs of less than 1E–10 mrem (1E–12 mSv) from fish taken from Melton Hill Lake; between 6E–04 and 0.1 mrem (6E–06 and 1E–03 mSv) from fish taken from the Clinch River; about 0.2 mrem (2E–03 mSv) from fish taken from Poplar Creek; and about 0.2 mrem (2E–03 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.

If the unidentified alpha and beta activities are included, the above EDEs could become about 4 mrem (0.04 mSv) from Melton Hill Lake fish; between 9E–04 and 4 mrem (9E–06 and 0.04 mSv) from Clinch River fish; between 0.07 and 3 mrem (7E–04 and 0.03 mSv) from fish taken from Poplar Creek; and between 6 and 9 mrem (0.06 and 0.09 mSv) from fish taken from East Fork Poplar Creek.

Based on radionuclide discharges to Melton Hill Lake, the Clinch River, and the Poplar Creek system, maximum EDEs to avid fish eaters could have been 2E–06 mrem (2E–8 mSv), 7E–04 mrem (7E–06 mSv), and 4 mrem (0.04 mSv), respectively. The collective EDE from eating fish from the above locations and from the Tennessee River system down to Chattanooga could have been 0.6 person-rem (6E–03 person-Sv).

Other Uses

Other uses 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 of less than 8E–17 mrem (8E–19 mSv) from using Melton Hill Lake, between 5E–05 and 0.02 mrem (5E–07 and 2E–04 mSv) from using the Clinch River, between 2E–04 and 9E–04 mrem (2E–06 and 9E–06 mSv) from using Poplar Creek, and about 6E–04 mrem (6E–06 mSv) from using East Fork Poplar Creek.

If the unidentified alpha and beta activities are included, the above EDEs could become 4E–04 mrem (4E–06 mSv) from using Melton Hill Lake, between 2E–04 and 0.02 mrem (2E–06 and 2E–04 mSv) from using the Clinch River, between 9E–04 and 0.1 mrem (9E–06 and 1E–03 mSv) from using Poplar Creek, and between 2E–03 and 0.4 mrem (2E–05 and 4E–03 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 3E–07 and 0.7 mrem (3E–09 and 7E–03 mSv); the maximum collective EDE could have been 0.3 person-rem (3E–03 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 imaginable individual EDE of about 4 mrem (0.04 mSv). The maximum collective EDE to the 50-mile population was estimated to be about 4 person-rem (0.04 person-Sv). These are small percentages of individual and collective doses attributable to natural background radiation, about 1% and 0.001%, respectively.

Table 8.6. Summary of annual maximum individual EDEs 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]		1E-03		
Water[c]	0	1E-14	8E-17	1E-14
Discharge[d]	1E-06	1E-06	7E-08	3E-06
Maximum	1E-06	1E-03	7E-08	1E-03
Upper Clinch River, CRK 23, Gallaher Water Plant, CRK 32				
Fish[b]		4E-02		
Water[c]	1E-01	1E-02	1E-04	1E-02
Discharge[d]	8E-05	3E-04	5E-05	5E-04
Maximum	1E-01	4E-02	1E-04	1E-01
Lower Clinch River, CRK 16				
Fish[b]		3E-02		
Water[c]	NA	1E-01	2E-02	1E-01
Discharge[d]	NA	7E-04	5E-05	8E-04
Maximum	NA	1E-01	2E-02	1E-01
Upper Watts Bar Lake, Kingston Municipal Water Plant				
Water[c]	3E-02	2E-02	4E-03	5E-02
Discharge[d]	3E-05	1E-04	1E-05	2E-04
Maximum	3E-02	2E-02	4E-03	5E-02
Lower System (Lower Watts Bar Lake and Chickamauga Lake)				
Water[c]	2E-02	2E-02	4E-03	5E-02
Discharge[d]	3E-05	1E-04	1E-05	2E-04
Maximum	2E-02	2E-02	4E-03	5E-02
Poplar Creek				
Water[c]	NA	8E-02	9E-04	8E-04
Discharge[d]	NA	2	6E-02	2
Maximum	NA	2	6E-02	2
Lower East Fork Poplar Creek				
Water[c]	NA	2E-01	6E-04	2E-01
Discharge[d]	NA	4	9E-02	4
Maximum	NA	4	9E-02	4

[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.

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, ^{3}H, and ^{131}I (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 5E–02 (5E–04 mSv) from drinking milk from the near locations and about 4E–02 mrem (4E–04 mSv) from the remote location. The average EDE associated with just total strontium and ^{131}I in milk in EPA Region 4 has been determined to be about 9E–02 mrem (9E–04 mSv) (EPA 1993).

Food Crops

The food-crop sampling program is described in Sect. 7.6.2. Samples of tomatoes were obtained from six local gardens and one remote garden, lettuce from the six local gardens, and turnip greens and turnips from one local garden. 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.

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 and 10 kg (22 lb) of homegrown lettuce. Coupling these ingestion rates with statistically significant detected concentrations in vegetables of identified radionuclides that could have been emitted from the ORR, the hypothetical gardener could have received a 50-year committed EDE between 0.02 and 0.1 mrem (2E–04 and 1E–03 mSv), depending on garden location. Of this total, between 6E–03 and 0.02 mrem (6E–05 and 2E–04 mSv) could have come from eating tomatoes and between 7E–03 and 0.1 mrem (7E–05 and 1E–03 mSv) from eating lettuce. Turnips and turnip greens were sampled from one garden. Assuming consumption of 37 kg (82 lb) of homegrown turnips and 10 kg (22 lb) of homegrown turnip greens, the gardener could have received an additional EDE of 0.02 mrem (2E–04 mSv), 0.01 mrem from turnips and 7E–03 mrem from turnip greens. This particular gardener could have received about 0.04 mrem (4E–04) from consuming all four 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, the hypothetical home gardener could have received an EDE between 1 and 5 mrem (0.01 and 0.05 mSv). Of this total, between 9E–03 and 2 mrem (9E–05 and 0.02 mSv) could have come from eating tomatoes and between 1 and 3 mrem (0.01 and 0.03 mSv) from eating lettuce. Similarly, the one turnip grower could have received an EDE of about 3 mrem (0.03 mSv), essentially all from the 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 2 mrem (0.02 mSv) to the hypothetical home gardener's EDE.

Hay

Another environmental pathway that was evaluated using sampling data is eating beef and drinking milk obtained from cows that ate hay harvested from the ORR. Statistically significant concentrations were found only for ^{7}Be and ^{40}K, both naturally occurring radionuclides. Therefore, all of the dose to humans from eating beef and drinking milk from cattle that eat hay was due to naturally occurring ^{40}K and ^{7}Be. The average EDE from drinking milk and eating beef from Areas 1, 2, and 3; 2, 4, and 5; and 6 (see Sect. 7.6.1 and Fig. 7.6) was estimated to be about 10 mrem (0.10 mSv). The hay samples collected from Area 8, the background location, resulted in the maximum EDE of about 25 mrem (0.025 mSv) from eating beef and drinking milk due primarily to measured ^{40}K concentrations.

White-Tailed Deer

No deer hunts, which are typically managed by DOE and the Tennessee Wildlife Resources Agency, were held on the ORR during the final quarter of 2001. The hunts were canceled due to security concerns.

Canada Geese

During the 2001 goose roundup, 113 geese were weighed and subjected to whole-body gamma scans. None of these geese exceeded the administrative limit. If a person consumed a goose with an average weight of 3.66 kg (8.1 lb) and an average ^{137}Cs concentration of 0.2 pCi/g (0.007 Bq/g), the estimated EDE would be about 0.02 mrem (0.0002 mSv). The maximum estimated EDE to an individual who consumed a hypothetical released goose with the maximum ^{137}Cs concentration of 0.88 pCi/g (0.033 Bq/g) and the maximum weight of 5.2 kg (11.5 lb) was about 0.1 mrem (0.001 mSv). It is assumed that approximately half the weight of a goose is edible.

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 0.25 mrem (0.0025 mSv).

To follow up on a special study initiated in 1998, muscle samples were analyzed from four geese sacrificed in 2001. Requested radioisotopic analyses, in addition to the routine analyses of ^{137}Cs, ^{60}Co, and ^{90}Sr, included uranium (^{234}U, ^{235}U, and ^{238}U) and transuranics, such as plutonium (^{238}Pu, ^{239}Pu), ^{241}Am, and ^{244}Cm. 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 0.006 to 0.086 mrem (0.00006 to 0.00086 mSv). The goose collected at ORNL (as in 2000) resulted in the higher EDE, due primarily to elevated ^{137}Cs concentrations.

Eastern Wild Turkey

During the two wild turkey hunts held on the reservation April 7–8, 2001, and April 28–29, 2001, 54 birds were harvested and only one exceeded the administrative release limits established for radiological contamination. The average ^{137}Cs concentration in the released turkeys was 0.11 pCi/g (0.004 Bq/g), and the maximum ^{137}Cs concentration was 0.4 pCi/g (0.015 Bq/g).

It is assumed that about 50% of the field weight is edible meat; therefore, the average turkey would yield about 8.8 lb (4 kg) of meat. If a person consumed a turkey with an average weight of 7.98 kg (17.6 lb) and an average ^{137}Cs concentration of 0.11 pCi/g (0.004 Bq/g), the estimated EDE would be about 0.02 mrem (0.0002mSv). The maximum estimated EDE to an individual who consumed a hypothetical released turkey with the maximum ^{137}Cs concentration of 0.4 pCi/g (0.015 Bq/g) and the maximum weight of 11.16 kg (24.6 lb) was about 0.1 mrem (0.001 mSv).

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 2001 was about 5.2 μR/h. This rate corresponds to an EDE rate of about 36 mrem/year (0.36 mSv/year). Except for three locations, all measured exposure rates at or near the ORR boundaries are near background levels. The exceptions are a stretch of bank along the Clinch River, a section of Poplar Creek that flows through the ETTP, and a parking lot adjacent to the K-1066-K cylinder yards.

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 2001.

As described in Sect. 4.12, potential above-background annual EDEs to hypothetically exposed individuals were 0.50 mrem along Poplar Creek near the K-1066-J cylinder yard, 1.75 mrem along Poplar Creek near the K-1066-E cylinder yard, and 1.13 mrem in the parking lot near the K-1066-K cylinder yard.

8.1.3 Doses to 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 radiation or radioactive material releases into the aquatic environment (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, a companion electronic calculational tool to the proposed DOE technical standard entitled *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota* (DOE 2002e).

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. Based on this observation, 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., crustraceans 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 includes (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. If sediment concentrations, are not available, the Radionuclide Biota Concentration Guide Calculator will estimate sediment guides from the surface water concentrations. Surface water sampling data were used for this aquatic dose assessment.

At ORNL, doses to aquatic organisms are based on surface water concentrations at seven different sampling locations: Melton Branch kilometer (MEK) 0.2, White Oak Creek kilometer (WCK) 1.0 and 2.6, First Creek, Fifth Creek, Raccoon Creek, and Northwest Tributary. All of these locations, with the exception of MEK 0.2 and WCK 1.0 and 2.6 passed the initial general screening (using default parameters for biota concentration guides). At MEK 0.2 and WCK 1.0 and 2.6, the default bioaccumulation factors for ^{137}Cs and ^{90}Sr in fish were adjusted to reflect on-site bioaccumulation of these radionuclides in fish. Riparian organisms are the limiting receptor for ^{137}Cs and ^{90}Sr in surface water; however, the best available bioaccumulation data for Melton Branch and 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 and ^{90}Sr in riparian organisms. This resulted in the absorbed dose rates to aquatic organisms at all locations to be below the DOE aquatic dose limit of 1 rad/day.

At the Y-12 Complex, doses to aquatic organisms were estimated from surface concentrations of radionuclides in water obtained from 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 512, and Outfall 520. The Radiological Biota Concentration Guide Calculator, revision 2, was used to determine that all of the sites passed the initial general screening (in which default biota contamination guides were used), due primarily to the revision in the ^{226}Ra and ^{228}Ra aquatic system water concentration limits.

At ETTP, doses to aquatic organisms were estimated from surface water concentrations at ten different sampling locations. The waterways evaluated were Mitchell Branch at K1700 and at Mitchell Branch kilometer (MIK) 1.4 (upstream location), Poplar Creek at K-716 (downstream), K1007-B and K-1710 (upstream location), Clinch River kilometer (CRK) 16 (downstream of all DOE outfalls), K901-A (downstream of ETTP operations), K-1407-J (the Central Neutralization Facility), and East Fork Poplar Creek (kilometers 0.1 upstream on East Fork Poplar Creek) and kilometer 5.4 (downstream of the East Fork Poplar Creek floodplain). All of these locations, with the exception of K-1407-J, the discharge from the Central Neutralization Facility, passed the initial general screening (using default parameters for biota concentration guides). For the Central Neutralization Facility outfall, the default bioaccumulation factor for ^{137}Cs in fish was adjusted to reflect site-specific bioaccumulation. This resulted in the absorbed dose rates to aquatic organisms at all locations to be below the DOE aquatic dose limit of 1 rad/day.

A pilot study to evaluate the terrestrial biota dose screening tool in the proposed standard, "Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota," was conducted using Bear Creek Watershed soil data. The soil concentrations used in this pilot study were those used in the Bear Creek Valley Remedial Investigation ecological risk assessment. Maximum soil concentrations and default parameters in the Radionuclide Biota Concentration Guide calculator were used. At the screening level, the results of the pilot study indicate that the doses to terrestrial organisms in the Bear Creek Watershed would be less than 0.1 rad/day, the proposed dose limit for terrestrial organisms.

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 2001; however, if someone were, that person could have received a total EDE of about 7 mrem (0.07 mSv): 0.8 mrem (8E–03 mSv) from airborne emissions, 0.1 mrem (1E–03 mSv) from drinking ETTP water, 4 mrem (0.04 mSv) from eating fish from Lower East Fork Poplar Creek, 2 mrem (0.02 mSv) from fishing on Poplar Creek inside the ETTP, and 0.09 mrem (9E–04 mSv) from other water uses on Lower East Fork Poplar Creek. This dose is about 2% 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 0.4 mrem (4E–03 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 2001 maximum EDE could not conceivably have exceeded about 7 mrem (0.07 mSv), or about 7% 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 12 person-rem (0.12 person-Sv). This dose is about 0.004% of the 312,012 person-rem (3123 person-Sv) that this population received from natural sources during 2001.

Table 8.7. Summary of maximum potential radiation dose equivalents to an adult during 2001 and locations of the maximum exposures

Pathway	Dose to maximally exposed individual (mrem)	Dose to maximally exposed individual (mSv)	% of DOE 100 mrem/yr limit	Estimated population dose (person-rem)	Estimated population dose (person-Sv)	Population within 80 km	Estimated background radiation population dose (person-rem)
Airborne effluents: All pathways	0.8	0.008	0.8	8	0.08	1,040,041	312,012
Liquid effluents:							
drinking water	0.1	0.001	0.1	3	0.03	338,832	101,650
eating fish	3.5	0.035	3.5	0.6	0.006	50,688	15,206
other activities	0.09	0.0009	0.09	0.3	0.003	771,001	231,300
Eating deer	NA[b]		NA[b]	NA[b]			
Eating geese	0.3	0.003[c]	0.3				
Eating turkey	0.1	0.001[d]	0.1				
Direct radiation	1.8	0.018	1.8	0.2	0.002		
All pathways	6.7	0.067	6.7	12	0.12	1,040,041	312,012

[a]1 mrem = 0.01 mSv.

[b]No deer hunts were conducted during 2001.

[c]From consuming two hypothetical worst-case geese, each a combination of the heaviest goose harvested and the highest measured concentrations of ^{137}Cs and ^{90}Sr in released geese.

[d]From consuming a hypothetical worst-case turkey, a combination of the heaviest turkey harvested and the highest measured concentration of ^{137}Cs in turkey.

8.1.5 Five-Year Trends

Dose equivalents associated with selected exposure pathways for the years from 1996 to 2001 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 operated 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. The DOE requested from these facilities information pertaining to potential radiation dose to members of the public that also could have been affected by releases from the ORR. Six facilities responded to the DOE request. Based on these responses, no member of the public should have received an EDE greater than 1.0 mrem (1E–02 mSv) due to airborne releases from these facilities. No information was provided about releases, if any, from these facilities to water.

8.1.7 Findings

The maximally exposed off-site individual could have received a 50-year committed EDE of about 0.8 mrem (8E–03 mSv) from airborne effluents from the ORR. This dose is below 10 mrem (0.10 mSv) per year, the limit specified in the Clean Air Act for DOE facilities. No individual EDE could have exceeded the 100-mrem/year (1.0-mSv/year) limit prescribed by DOE. The estimated collective committed EDE to the approximately 1,040,041 persons living within 50 miles (80 km) of the ORR was about 8 person-rem (0.08 person-Sv) for 2001 airborne emissions. This represents about 0.003% of the 312,012 person-rem (3120 person-Sv) that the surrounding population would receive from all sources of natural radiation.

Table 8.8. Trends in total effective dose equivalent for selected pathways

Pathway	Effective dose equivalent (mrem)[a]				
	1997	1998	1999	2000	2001
All air	0.41	0.73	0.7	0.4	0.8
Fish consumption	0.96	2.3	4	1	0.2
Drinking water (Kingston)	0.40	0.19	0.16	No data	0.03
Direct radiation (Clinch River)	0.4[b]	0.4[b]	0.4[b]	0.4[b]	0.4[b]
Direct radiation (Poplar Creek)	1[b]	1[b]	2[b]	1[b]	2[b]

[a]1 mrem = 0.01 mSv.
[b]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.

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, chemical analytes were only measured in surface water samples collected at CRK 70 and CRK 16. Located upstream of all DOE discharge points is CRK 70, and located downstream of all DOE discharge points is CRK 16. As shown in Table 8.10, HQs were less than one for detected chemical analytes for which there are RfDs or MCLs.

Table 8.9. 2001 chemical hazard quotients for drinking water[a]

Chemical	Hazard quotient	
	CRK 70[a]	CRK 16[b]
Barium	0.02	0.02
Manganese	0.04	0.04
Acetone	0.004	

[a]Melton Hill Reservoir above city of Oak Ridge input.
[b]Clinch River downstream of all DOE inputs.

8.2.2 Fish Consumption

Chemicals in water can be accumulated by aquatic organisms that may be eaten by humans. To evaluate the potential health effects from the fish consumption pathway, hazard quotients (HQs) were estimated for the consumption of noncarcinogens, and intake/chronic-daily-intake ratios I/I(10^{-5}) 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. The fish consumption rate of 60 g/day is similar to the EPA default locally caught fish ingestion rate of 54 g/day fish (EPA 1991). TDEC uses a method developed by EPA to establish fish consumption advisories for carcinogenic pollutants [as described in TDEC 1200-4-3-.03 (j)]. Using the mean daily consumption rate of 6.5 g/day would reduce both the HQ values and the I/I(10^{-5}) values by a factor of approximately 10. Refer to Appendix G for a detailed description of the chemical dose methodology.

As shown in Table 8.10, for consumption of sunfish, an HQ greater than one was calculated for Beta-BHC at CRK 32, and values greater than one were calculated for Aroclor-1260 at all three locations. For consumption of catfish, HQ values greater than one were calculated for Aroclor-1260 at all three locations. In addition, HQs greater than

Table 8.10. 2001 chemical hazard quotients (HQs) and estimated dose/chronic daily intake I/I(10^{-5}) 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						
Chromium	~0.2					
Copper		~0.009				
Mercury	~0.1	0.2	0.6	0.1	0.2	0.7
Zinc	0.04	0.03	0.04	0.02	0.04	0.01
HQs for pesticides and Aroclors						
Aldrin				0.4		0.5
Aroclor-1260	~1.8	~2.7	~2.1	12	14	J4.5
BHC						
alpha				9.7		
beta		~5.3		2.7		3.7
delta				2.7		3.7
gamma (lindane)				2.0		2.7
Chlordane						
alpha				0.3	0.04	0.5
gamma					J0.01	0.03
4,4'-DDT				0.04		0.06
Dieldrin						0.6
Endosulfan I				0.002		0.003
Endosulfan II				0.004		0.005
Endosulfan sulfate				0.007		0.009
Endrin				0.07		0.1
Endrin aldehyde				0.9		1.4
Heptochlor				0.02		0.03
Heptochlor epoxide				0.8		1.1
Methyloxychlor				0.02		0.03
I/I(10^{-5}) for carcinogens						
Aldrin				7.8		11
Chlordane						
alpha				2.5	0.3	3.5
gamma					J0.1	0.2
4,4 DDD				0.2		0.3
4,4' DDE				0.3		0.4
4,4' DDT				0.3		0.4
Dieldrin						20

Table 8.10 (continued)

Parameters	Sunfish			Catfish		
	CRK 70[b]	CRK 32[c]	CRK 16[d]	CRK 70[b]	CRK 32[c]	CRK 16[d]
Heptochlor				2.0		2.9
Heptchlor epoxide				4.2		5.8
PCBs (mixed)[f]	~3	~4.7	~3.7	21	25	J7.8
Toxaphene				7.8		11

[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]Detected below detection limits therefore value was estimated.
[f]Mixed PCBs consists of the summation of Aroclors detected or estimated.

one were estimated for BHC (beta, delta, and gamma) at both CRK 70 (upstream of all DOE inputs) and CRK 16 (downstream of all DOE inputs). An HQ greater than one was also calculated for endrin aldehyde and heptachlor epoxide at CRK 16.

For carcinogens in catfish, I/I(10^{-5}) ratios greater than one indicate a cancer risk greater than 10^{-5}. I/I(10^{-5}) ratios greater than one were calculated for the intake of Aroclor-1260 found in sunfish and catfish collected at all three locations. In catfish, I/I(10^{-5}) ratios greater than one were calculated for aldrin, chlordane, heptachlor, heptachlor epoxide and toxaphene at CRK 70 (upstream of all DOE inputs) and at CRK 16 (downstream of all DOE inputs). However, in catfish, an I/I(10^{-5}) ratio greater than one was calculated for dieldrin at CRK 16. 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 1993).