8. Dose

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.

A hypothetical maximally exposed individual could have received a total effective dose equivalent (EDE) of about 0.3 mrem (less than 1 mrem) from radionuclides emitted to the atmosphere from all of the sources on the ORR in 2002; 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, 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 deer, geese, and wild turkeys 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 0.2 mrem; an individual who consumed an average weight goose containing the average concentration of radionuclides could have received 0.1 mrem; and a person who ate an average turkey could have received a dose of 0.02 mrem. In worst-case analyses, hypothetical persons who eat the heaviest deer, goose, or turkey, each containing the highest possible concentration of measured radionuclides, could have received EDEs of 4, 1, or 0.08 mrem, respectively.

8.1 RADIATION DOSE

Small quantities of radionuclides were released to the environment from operations at the ORR facilities during 2002. 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 2002 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 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 2002 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 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 57 emission points, each of which includes one or more individual sources, on the ORR was modeled during 2002. This total includes 11 points at the Y-12 Complex, 34 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 2002 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 2002, rainfall, as averaged over the four rain gauges located on the ORR, was 158.5 cm (62.4 in.). The average air temperature was 15.1°C (59.1°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 870 m (0.54 miles) northwest of the main Y-12 National Security Complex release point, about 8840 m (5.5 miles) north-northeast of the 7911 stack at ORNL, and about 12,210 m (7.6 miles) east-northeast of the TSCA Incinerator (stack K-1435) at the ETTP. This individual could have received an EDE of about 0.3 mrem (0.003 mSv), which is well below the NESHAP standard of 10 mrem (0.10 mSv) and is about 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 6 person-rem (0.06 person-Sv), which is approximately 0.002% of the 312,012 person-

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 LabHoods	15	0	0	Ambient	4290	SW	9110	NE
X-2001	15.24	0.66	7.44	Ambient	4650	SW	8730	NE
X-2026	22.9	1.05	11.22	Ambient	4780	SW	8610	NE
X-2099	3.658	0.1778	23.32	Ambient	4780	SW	8610	NE
X-2523	7	0.3	0	Ambient	4570	SW	8830	MME
X-3000 LabHoods	15	0	0	Ambient	4810	SW	8490	NNE
X-3018	61	4.11	0.23	Ambient	5000	SW	8400	NE
X-3020	61	1.2192	16.71	Ambient	5000	SW	8400	NE
X-3039	76.2	2.4384	13.28	Ambient	4960	SW	8450	NNE
X-3074 Group	4	0.254	0	Ambient	5000	SW	8400	NE
X-3544	9.53	0.2794	15.93	Ambient	4730	SW	8720	NNE
X-3608-1	10.97	2.44	0.57	Ambient	4810	SW	8660	NNE
X-3608-2	8.99	0.36	13.91	Ambient	4810	SW	8660	NNE
X-4000 Lab Hoods	15	0	0	Ambient	5290	SW	8180	NNE
X-4500NCL	9.144	0.3048	12.29	Ambient	5290	SW	8180	NNE
X-5505M	11	0.3	2.96	Ambient	5490	SW	8030	NNE
X-5505NS	11	0.96	0	Ambient	5490	SW	8030	NNE
X-6000 Lab Hoods	15	0	0	Ambient	5890	SW	7590	NNE
X-7000 Lab Hoods	15	0	0	Ambient	6460	WSW	8970	N
X-7025	4	0.3	12.83	Ambient	6940	SW	6730	NNE
X-7503	30.5	0.91	10.16	Ambient	5220	SW	8530	NNE
X-7567	3.8	0.2032	4.65	Ambient	5220	SW	8530	NNE
X-7830	4.6	0.24765	8.04	Ambient	4044	WSW	10010	NNE
X-7856-CIP	18.29	0.4826	13.19	Ambient	4040	WSW	10013	NNE
X-7860	18.29	0.31	3.9	Ambient	4040	WSW	10010	NNE
X-7877	13.9	0.4064	13.56	Ambient	4040	WSW	10010	NNE
X-7911	76.2	1.524	13.95	Ambient	5140	WSW	8840	NNE
X-7936T	0	0.254	0	Ambient	5140	WSW	8840	NNE
X-7966	6.096	0.2921	8.18	Ambient	5140	WSW	8840	NNE
X-Decon Areas	15	NA	0	Ambient	4960	SW	8450	NNE
X-OHF CG	1	0.305	0	Ambient	4040	WSW	10010	NNE
X-OHF D	1	0.305	0	Ambient	4040	WSW	10010	NNE
X-SIOU	1	0.3	0	Ambient	4730	SW	8720	NNE
X-STP	7.6	0.203	12.48	Ambient	4570	SW	8880	NNE
K-1004-D	7.3	0	0	Ambient	470	WNW	13020	ENE
K-1008-C	4.52	0.51	10.46	Ambient	390	SW	12840	ENE
K-1302	1	0.305	0	Ambient	660	S	12920	ENE
K-1407-U	7.16	1.22	0.625	Ambient	810	SW	12470	ENE
K-1423 CPF	3.96	0.305	3.23	Ambient	660	S	12920	ENE
K-1423 SWR	7.62	0.71	10.02	Ambient	660	S	12920	ENE
K-1435	30.5	1.37	5.26	79.1	1020	SW	12210	ENE
K-1435-C	18.29	0	0	Ambient	1020	SW	12210	ENE

Table 8.1 (continued)

Source ID	Stack height (m)	Stack diameter (m)	Effective exit gas velocity (m/s)	Exit gas temperature (°C)	Distance (m) and direction to the maximally exposed individual			
					Plant maximum		ORR maximum	
K-33 SC	22.86	1.22	14.96	Ambient	1320	SE	13810	ENE
Y-9204-3	20	NA	0	Ambient	1140	NW	1140	NW
Y-9224	10	NA	0	Ambient	1480	W	1480	W
Y-9401-4	1	0.15	0	Ambient	1490	NNE	1490	NNE
Y-9422-22	3.96	0.153	0	Ambient	2910	W	2910	W
Y-9616-7 Hood	12.2	0.69	0	Ambient	1960	NNE	1960	NNE
Y-9623	8.5?	8.5	0.64	Ambient	970	NNW	970	NNW
Y-Minor	20	NA	0	Ambient	870	NW	870	NW
Y-Monitored	20	NA	0	Ambient	870	NW	870	NW
Y-OD-7	1	0.049	0	Ambient	1140	NW	1140	NW
Y-Union Valley Lab	4.267	0.762	13.076	Ambient	3360	WSW	3360	WSW
Y-Unmonitored Lab Hoods	20	NA	0	Ambient	870	NW	870	NW

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-33 SC
MT7	10	K-1435-C, K-1004-D, K-1008-C, K-1407-U, K-1423-CPF, K-1423-SWR, K-1775, K-1302, K-25 Guzzler
		ORNL
MT4	30	X-7503, X-7567, X-7830,X-7856-CIP, X-7860, X-7877, X-7911, X-7936T, X-7966, X-OHF CG, X-OHF D
MT2	100	X-3018, X-3020, and X-3039
MT2	30	X-2001, X-2026, X-2099, X-2523, X-3074 Group, X-3544, X-3608, X-4500NCL, X-5505, X-7025, X-Decon areas, X-LabHoods, 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 2002

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]	0.01 (0.0001)
Y-12	0.3 (0.003)[c]	0.27 (0.0027)
Entire ORR	*d*	0.29 (0.0029)[e]

[a]The maximally exposed individual was located 4960 m (3.1miles) SW of X-3039 and 5140 m (3.2 miles) WSW 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 870 m (0.5 miles) NW 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 2002

Plant	Effective dose equivalents[a]	
	(Person-rem)	(Person-Sv)
ORNL	2.2	0.022
ETTP	1.5	0.015
Y-12	2.0	0.020
Entire ORR	5.7	0.057

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

rem that this population received from natural sources of radiation.

The maximally exposed individual for the Y-12 National Security Complex was located about 870 m (0.54 miles) northwest of the main Y-12 National Security Complex release point. This individual could have received an EDE of about 0.3 mrem (0.003 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 2.0 person-rem (0.020 person-Sv), which is approximately 35% of the collective EDE for the ORR.

The maximally exposed individual for ORNL was located about 4960 m (3.1 miles) southwest of the 3039 stack and 5140 m (3.2 miles) west-southwest of the 7911 stack. This individual could have received an EDE of about 0.1 mrem (0.001 mSv) from ORNL emissions. Radionuclides contributing 1% or more to the dose include ^{138}Cs (40%), ^{41}Ar (18%), ^{233}U (8.2%), ^{234}U (8.2%), ^{212}Pb (5.6%), ^{138}Xe (2.2%), ^{88}Kr (2.2%), ^{135m}Xe (1.9%), ^{131}I (1.9%), ^{238}U (1.7%), and ^{60}Co (1.7%). The contribution of ORNL emissions to the collective EDE to the population residing within 80 km of the ORR was calculated to be about 2.2 person-rem (0.022 person-Sv), which is approximately 38% of the collective EDE for the ORR.

The maximally exposed individual for the ETTP was located at a business about 1020 m (0.63 miles) southwest of the TSCA Incinerator stack (K-1435). The EDE received by this individual was calculated to be about 0.1 mrem (0.001 mSv). About 90% of this dose is from ingestion and inhalation of uranium radioisotopes, about 4.6% is from thorium radioisotopes, about 2.0% is from ^{238}Pu, and about 1.8% is from ^{3}H. The contribution of ETTP emissions to the collective EDE to the population residing within 80 km of the ORR was calculated to be about 1.5 person-rem (0.015 person-Sv), which is approximately 27% 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 0.5 mrem/year (0.005 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 between 0.4 and 0.5 mrem/year (0.004 and 0.005 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 are about 0.3 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 0.2 mrem/year (0.002 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 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 0.3 mrem/year (0.003 mSv/year), which agrees with the 0.3 mrem/year (0.003 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 0.3 mrem/year (0.003 mSv/year), which is higher than the 0.1 mrem/year (0.001 mSv/year) calculated using CAP-88. The EDE calculated using measured air concentrations at Station K2 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 0.2 mrem/year (0.002 mSv/year), which is about two times higher than the modeled value of 0.1 mrem/year (0.001 mSv/year).

The 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. Also, the ambient air monitors collect naturally occurring radionuclides and those emitted from non-ORR sources.

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	0.34	0.0034
37	0.25	0.0025
38	0.26	0.0026
39	0.28	0.0028
40	0.27	0.0027
42	0.28	0.0028
46	0.26	0.0026
48	0.25	0.0025
52	0.24	0.0024
K2	0.45	0.0045
K6	0.56	0.0056
K9	0.32	0.0032
K10	0.28	0.0028
K11	0.67	0.0067

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

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 highly exposed individuals would drink 730 L of water during 2002 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 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 2E–06 mrem (2E–08 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 0.2 mrem (0.002 mSv), and the collective EDE to the approximately 2500 workers could have been about 0.3 person-rem (0.003 person-Sv). If the unidentified alpha and beta activities are included, the EDEs could have been 2 mrem and 3 person-rem (0.02 mSv and 0.03 person-Sv). Using radionuclide discharge data, the maximum individual EDE was estimated to be 5E–05 mrem (5E–07 mSv); the collective EDE was 7E–05 person-rem (7E–07 person-Sv). Including unidentified alpha and beta activities increases the hypothetical doses to 2E–04 mrem and 2E–04 person-rem (2E–06 mSv and 2E–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 0.04 mrem (4E–04 mSv); the collective EDE to the estimated 21,241 water users could have been about 0.4 person-rem (0.004 person-Sv). Including unidentified alpha and beta activities could increase these dose estimates to 0.5 mrem and 5 person-rem (0.005 mSv and 0.05 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 0.04 mrem (4E–04 mSv) calculated for Kingston and Rockwood water.

The estimated collective EDE from all drinking water locations was about 4 person-rem (0.04 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 2002 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 0.3 mrem (0 and 0.003 mSv), depending on type of fish and harvest location. Eating catfish taken from CRK 70 could have resulted in an EDE of 0.005 mrem (0.00005 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 0.02 mrem (0.0002 mSv); eating sunfish from that location could have resulted in an EDE of 0.3 mrem (0.003 mSv). Eating catfish taken from CRK 16 could have resulted in an EDE of 0.03 mrem (0.0003 mSv); eating sunfish from that location also could have resulted in an EDE of 0.04 mrem (0.0004 mSv). The presence of naturally occurring ^{40}K adds between 1 and 2 mrem (0.001 and 0.002 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 0.02 and 0.4 mrem (2E-04 and 0.004 mSv). Eating catfish taken from CRK 70 could have resulted in an EDE of 0.04 mrem (4E-04 mSv), 87% of which is due to excess beta activity; eating sunfish from that location could have resulted in an EDE of approximately 0.2 mrem (0.002 mSv); all of which is due to the excess beta activity. Eating catfish taken from CRK 32 could have resulted in an EDE of 0.2 mrem (0.002 mSv), 85% of which is due to excess beta activity; eating sunfish from that location could have resulted in an EDE of 0.4 mrem (0.004 mSv), 30% of which is due to excess beta activity. Eating catfish taken from CRK 16 could have resulted in an EDE of 0.07 mrem (0.0007 mSv), 59% of which is due to excess beta activity; eating sunfish from that location could have resulted in an EDE of 0.04 mrem (0.0004 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 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–14 mrem (1E–16 mSv) from fish taken from Melton Hill Lake; between 0 and 0.2 mrem (0 and 0.002 mSv) from fish taken from the Clinch River; between 0.05 and 0.08 mrem (5E–04 and 5E-08 mSv) from fish taken from Poplar Creek; and between 0.1 and 0.2 mrem (0.001 and 0.002 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 range between 0.9 and 4 mrem (0.009 and 0.04 mSv) from Melton Hill Lake fish; between 0.2 and 4 mrem

(0.002 and 0.04 mSv) from Clinch River fish; between 0.03 and 3 mrem (3E–04 and 0.03 mSv) from fish taken from Poplar Creek; and between 3 and 6 mrem (0.03 and 0.06 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 3E–06 mrem (3E–8 mSv), 3E–04 mrem (3E–06 mSv), and 2 mrem (0.02 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 (0.006 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 3E–05 and 0.08 mrem (3E–07 and 8E–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 range between 1E-04 and 4E–04 mrem (1E-06 and 4E–06 mSv) from using Melton Hill Lake, between 1E–04 and 0.08 mrem (1E–06 and 8E–04 mSv) from using the Clinch River, between 3E–04 and 0.1 mrem (3E–06 and 0.001 mSv) from using Poplar Creek, and between 6E–04 and 0.4 mrem (6E–06 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 9E–08 and 0.07 mrem (9E–10 and 7E–04 mSv). Including unidentified alpha and beta activities produces an EDE between 4E-07 and 1 mrem (4E-09 and 0.01 mSv).

The maximum collective EDE from all other water uses could have been 0.2 person-rem (0.002 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 2 mrem (0.02 mSv) to persons obtaining their full annual complement of fish from Poplar Creek. The maximum collective EDE to the 50-mile population could be as high as 6 person-rem (0.06 person-Sv). These are small percentages of individual and collective doses attributable to natural background radiation, about 2% and 0.002%, respectively.

8.1.2.3 Radionuclides in Other Environmental Media

The CAP-88 computer codes are used to calculate radiation doses from ingestion of meat, milk, and vegetables that contain radionuclides released to the atmosphere. These doses are included in the dose calculations for airborne radionuclides. However, some environmental media, including the three mentioned, are sampled as part of the surveillance program. The following dose estimates are based on environmental sampling results and may include contributions from radionuclides occurring in the natural environment, released from the ORR, or both.

Milk

Milk collected at two locations near the ORR and at a remote location was found to contain small quantities of radio-strontium and ^{3}H (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 0.05 (0.0005 mSv) from drinking milk from the near locations and about 0.04 mrem (0.004 mSv) from the remote location.

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]		5E–03		
Water[c]	0	1E–16	8E–17	1E–16
Discharge[d]	2E–06	3E–06	9E–08	5E–06
Maximum	2E–06	5E–03	9E–08	5E–03
Upper Clinch River, CRK 23, Gallaher Water Plant, CRK 32				
Fish[b]		3E–01		
Water[c]	2E–01	2E–01	7E–04	4E–01
Discharge[d]	5E–05	2E–04	3E–05	3E–04
Maximum	2E–01	3E–01	7E–04	5E–01
Lower Clinch River, CRK 16				
Fish[b]		4E–02		
Water[c]	NA	2E–01	8E–02	3E–01
Discharge[d]	NA	3E–04	3E–05	3E–04
Maximum	NA	2E–01	8E–02	3E–01
Upper Watts Bar Lake, Kingston Municipal Water Plant				
Water[c]	4E–02	4E–02	2E–02	8E–02
Discharge[d]	2E–05	6E–05	1E–05	9E–05
Maximum	4E–02	4E–02	2E–02	1E–01
Lower System (Lower Watts Bar Lake and Chickamauga Lake)				
Water[c]	3E–02	3E–02	2E–02	7E–02
Discharge[d]	1E–05	5E–05	9E–06	7E–05
Maximum	3E–02	3E–02	2E–02	9E–02
Poplar Creek				
Water[c]	NA	8E–02	9E–04	8E–02
Discharge[d]	NA	2	4E–02	2
Maximum	NA	2	4E–02	2

[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.

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 and lettuce were obtained from six local gardens, and turnips were obtained from five 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.

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. 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 0.03 and 0.1 mrem (0.0003 and 0.001 mSv), depending on garden location. Of this total, between 0.003 and 0.007 mrem (0.00003 and 0.00007 mSv) could have come from eating tomatoes, between 0.01 and 0.04 mrem (0.0001 and 0.0004 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) 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 between 2 and 7 mrem (0.02 and 0.07 mSv). Of this total, between 0.5 and 4 mrem (0.005 and 0.04 mSv) could have come from eating tomatoes, between 0.2 and 5 mrem (0.002 and 0.05 mSv) from eating lettuce, and between 0.05 and 0.2 mrem (0.0005 and 0.002 mSv). 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 3 mrem (0.03 mSv) to the hypothetical home gardener's EDE.

White-Tailed Deer

The TWRA conducted three 2-day deer hunts during 2002 on the Oak Ridge Wildlife Management Area, which is part of the ORR, as described in Sect. 7.8. A total of 421 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 and were field-counted for radioactivity to ensure that the deer met release criteria; that is, they contained about 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. Three of the deer exceeded the limit for beta-particle activity in bone and were confiscated. The remaining 418 deer were released to the hunters.

The average ^{137}Cs concentration in tissue of the 418 released deer, as determined by field counting, was 0.2 pCi/g (0.007 Bq/g); the maximum ^{137}Cs concentration in a deer was 1.7 pCi/g (0.06 Bq/g). In 2002, no tissue samples from the released deer were subjected to laboratory analysis.

An individual who consumed one average-weight deer (93.7 lb (42.5 kg)) containing the 2002 average concentration of ^{137}Cs (0.2 pCi/g) could have received an EDE of about 0.2 mrem (0.002 mSv). The maximum hypothetical EDE to a hunter who consumed a deer harvested from the ORR in 2002 was estimated to be 4.4 mrem, based on a ^{137}Cs concentration of 1.69 pCi/g and a maximum weight of 211 lb (95.7 kg). The maximum EDE to an individual consuming venison from two deer was also evaluated. There were about eleven hunters (those from the same household) who harvested two deer from the ORR in 2002. The maximum EDE, based on ^{137}Cs concentrations determined by field counting, to a hunter who consumed two harvested deer was estimated to be about 1 mrem. The collective EDE from eating all the harvested venison from ORR with a 2002 average field-derived ^{137}Cs concentration of 0.2 pCi/g (0.007 Bq/g) and average weight of 93.7 lb (42.5 kg) is estimated to be about 0.1 person-rem (0.001 person-Sv).

This year, the tissue from four roadkill deer were analyzed. The deer were collected from four different locations on and near the ORR: (1) Oak Ridge Turnpike near the Highway 95 and Highway 58 intersection, (2) Bethel Valley Road near the east portal entrance, (3) the intersection of Edgemoor Road and Highway 62 near the Solway Bridge, and (4) on the ORNL site. 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), thorium (^{228}Th, ^{230}Th, and ^{232}Th), and transuranics, such as plutonium (^{238}Pu, ^{239}Pu), ^{241}Am, ^{2371}Np, and ^{244}Cm.

Based on statistically significant radionuclide concentrations (excluding ^{40}K, a naturally occurring radionuclide) and the estimated weights of the deer, the estimated EDEs to an individual consuming one of these deer, ranged from about 0.8 to 2.3 mrem (0.008 to 0.023 mSv).

Canada Geese

During the 2002 goose roundup, 105 geese were weighed and subjected to whole-body gamma scans. The average ^{137}Cs concentration in the released geese was 1.3 pCi/g (0.048 Bq/g). The maximum ^{137}Cs concentration in the released geese was 7.5 pCi/g (0.28 Bq/g). The average weight of the geese screened during the roundup was about 9.04 lb (4.1 kg). The maximum goose weight was about 13.7 lb (6.2 kg). If a person consumed a released goose with an average weight of 9.04 lb (4.1 kg) and an average ^{137}Cs concentration of 1.3 pCi/g (0.048 Bq/g), the estimated EDE would be about 0.13 mrem (0.0013 mSv). The maximum estimated EDE to an individual who consumed a hypothetical released goose with the maximum ^{137}Cs concentration of 7.5 pCi/g (0.3 Bq/g) and the maximum weight of 13.7 lb (6.2 kg) was about 1.2 mrem (0.012 mSv). However, the gosling with the maximum ^{137}Cs concentration (which weighed 3.5 kg), if consumed, would have resulted in an EDE of about 0.7 mrem (0.007 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 2.5 mrem (0.025 mSv). This year, the three geese that exceeded the administrative limit of 5 pCi/g (based on consumption of venison from one deer) were released because they were still goslings. They were banded should future studies be required.

To follow up on a special study initiated in 1998, muscle samples were analyzed from three geese sacrificed during the 2002 roundup. A goose from ETTP, ORNL (sewage treatment pond area), and the Oak Ridge Marina 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 0.06 to 0.16 mrem (0.0006 to 0.0016 mSv).

Eastern Wild Turkey

During the two wild turkey hunts held on the reservation April 6–7 and April 13–14, 2002, 38 birds were harvested and none exceeded the administrative release limits established for radiological contamination in wildlife. The average ^{137}Cs concentration in the released turkeys was 0.1 pCi/g (0.004 Bq/g), and the maximum ^{137}Cs concentration was 0.3 pCi/g (0.01 Bq/g).

If a person consumed a wild turkey with an average weight of 18.6 lb (8.4 kg) and an average ^{137}Cs concentration of 0.1 pCi/g (0.004 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 turkey with the maximum ^{137}Cs concentration of 0.3 pCi/g (0.01 Bq/g) and the maximum weight of 10.3 kg (22.8 lb) was about 0.08 mrem (0.0008 mSv). It is assumed that approximately half the weight of a wild turkey is edible. The collective EDE from eating all the harvested wild turkey meat (38 birds) with an average field-derived ^{137}Cs concentration of 0.1 pCi/g (0.004 Bq/g) and an average weight of 18.6 lb (8.4 kg) is estimated to be about 0.0008 person-rem (8E-6 person-Sv)

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 2002 was about 5.4 μR/h. This rate corresponds to an EDE rate of about 35 mrem/year

(0.35 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 2002.

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 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 calculational 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. 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. Surface water sampling data were primarily used for this aquatic dose assessment, with the exception of 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 of these locations, with the exception of 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 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 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. Discharge Point 502 (the West End Treatment Facility) did not pass the initial general screening, in which the default biota contamination guides were used. All other locations passed the general screening. For Discharge Point 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. 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 the absorbed dose rates to aquatic organisms at all locations to be below the DOE aquatic dose limit of 1 rad/day.

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 MIK 1.4 (upstream location) and MIK 0.4, 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). All of these locations passed the initial general screening (using default parameters for biota concentration guides).

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 2002; however, if someone were, that person could have received a total EDE of about 5 mrem (0.05 mSv): 0.3 mrem (0.003 mSv) from airborne emissions, 0.2 mrem (0.002 mSv) from drinking ETTP water, 2.4 mrem (0.024 mSv) from eating fish from Poplar Creek, 1.8 mrem (0.018 mSv)

Table 8.7. Summary of maximum potential radiation dose equivalents to an adult during 2002 and locations of the maximum exposures

Pathway	Dose to maximally exposed individual		% of DOE 100 mrem/ year limit	Estimated population dose		Population within 80 km	Estimated background radiation population dose (person-rem)
	mrem	mSv		person-rem	person-Sv		
Airborne effluents: All pathways	0.3	0.003	0.3	6	0.06	1,040,041	312,012
Liquid effluents:							
drinking water	0.2	0.002	0.2	4.3	0.043	356,375	106,913
eating fish	2.4	0.024	2.4	0.6	0.006	31,543	9,463
other activities	0.08	0.0008	0.08	1.5	0.015	772,369	231,711
Eating deer	4.4	0.044[a]	4.4	0.1	0.001	1,684	505
Eating geese	2.5	0.025[b]	2.5				
Eating turkey	0.08	0.0008[c]	0.08	0.0008	0.000008	152	45
Direct radiation	1.8	0.018	1.8	0.2	0.002		
All pathways	11.8	0.118	11.8	12	0.12	1,040,041	312,012

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

[b]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.

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

from fishing on Poplar Creek inside the ETTP, and 0.08 mrem (8E–04 mSv) from other water uses on the lower Clinch River. This dose is about 3% 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 7 mrem (0.07 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 2002 maximum EDE could not conceivably have exceeded about 12 mrem (0.12 mSv), or about 12% 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 2002.

8.1.5 Five-Year Trends

Dose equivalents associated with selected exposure pathways for the years from 1998 to 2002 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. One facility reported a fenceline external dose of about 80 mrem/year (0.80 mSv/year); however, based on location, no member of the public should receive a dose that high. When corrected for background, this dose is reduced by about 38 mrem/year (0.38 mSv/year).

8.1.7 Findings

The maximally exposed off-site individual could have received a 50-year committed EDE of about 0.3 mrem (0.003 mSv) from airborne

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

Pathway	1998	1999	2000	2001	2002
All air	0.73	0.7	0.4	0.8	0.3
Fish consumption (Clinch River)	2.3	4	1	0.2	0.3
Drinking water (Kingston)	0.19	0.16	No data	0.03[b]	0.04[b]
Direct radiation (Clinch River)	0.4[c]	0.4[c]	0.4[c]	0.4[c]	0.4[c]
Direct radiation (Poplar Creek)	1[c]	2[c]	1[c]	2[c]	2[c]

[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.

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 6 person-rem (0.06 person-Sv) for 2002 airborne emissions. This represents about 0.002% of the 312,012 person-rem (3120 person-Sv) that the surrounding population would receive from all sources of natural radiation.

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 and 2001, 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 8.9, HQs were less than one for detected chemical analytes for which there are reference doses or maximum contaminant levels.

Table 8.9. 2002 chemical hazard quotients for drinking water[a]

Chemical	Hazard quotient	
	CRK 70[b]	CRK 16[c]
Barium	0.02	0.02
Manganese	0.04	0.04
Zinc	~0.006	

[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 city of Oak Ridge input.

[c]Clinch River downstream of all DOE inputs.

8.2.2 Fish Consumption

Chemicals in water can be accumulated by aquatic organisms that may be eaten by humans. To evaluate the potential health effects from the fish consumption pathway, 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 general population 95th percentile of long-term intake rate of 63 g/day fish (EPA 1997). 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. (See 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 Aroclor-1260 at all three locations. For consumption of catfish, HQ values greater than one were calculated for Aroclor-1260 at all three locations.

For carcinogens in sunfish and 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, a $I/I(10^{-5})$ ratio greater than one was calculated for aldrin at CRK 16 (downstream of all DOE inputs). 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).

Table 8.10. 2002 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						
Mercury	0.09	0.1	0.3	0.3	0.2	0.8
Zinc	0.02	0.03	0.03	0.01	0.02	0.02
HQs for pesticides and Aroclors						
Aldrin						~0.2
Aroclor-1260	~1.3	~2.2	~2.5	24.2	7	30.0
I/I(10^{-5}) for carcinogens						
Aldrin						~4.8
4,4' DDE		~0.3				
PCBs (mixed)[e]	~2.2	~3.7	~4.3	41.6	12	51.4

[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.