6. Dose

Abstract

Activities on the Oak Ridge Reservation have the potential to release small quantities of radioisotopes and hazardous chemicals to the environment. Releases of radioisotopes or chemicals represent potential exposures (doses) to the public. Environmental monitoring and surveillance on the reservation provide data from which radiological and chemical assessments are performed. To ensure compliance with the law, the calculated doses are compared with state and federal criteria.

6.1 RADIATION DOSE

Small quantities of radionuclides were released to the environment from operations at the ORR facilities during 1996. Those releases are quantified and characterized in Chaps. 4, 5, and 7. This chapter presents estimates of the potential radiation doses to the public from the releases and describes the methods used to make the estimates.

6.1.1 Terminology

Most doses associated with radionuclide releases to the environment are caused by interactions between radiation emitted by the radionuclides and human tissue. These interactions involve the transfer of energy from the radiation to tissue, a process that may damage the tissue. The radiation may come from radionuclides located outside the body (in or on environmental media or objects) or from radionuclides deposited inside the body (by inhalation, ingestion, and, in a few cases, absorption through the skin).

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; internal exposures continue as long as the radionuclides remain inside the person. Also, external exposures may result in uniform irradiation of the entire body and all its components; internal exposures usually result in nonuniform irradiation of the body. (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 A. One of these is used repeatedly in this section, the effective dose equivalent (EDE), which is a risk-based dose equivalent that can be used to estimate health-effects risks to exposed persons. It is a weighted sum of dose equivalents to specified organs, expressed in rem or sieverts (1 rem = 0.01 Sv).

6.1.2 Methods of Evaluation

6.1.2.1 Airborne Radionuclides

Characterization of the radiological consequences of radionuclides released to the atmosphere from ORR operations during 1996 was accomplished by calculating, for each plant and for the entire ORR, EDEs to maximally exposed off-site individuals 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 Radionuclide-National Emission Standards for Hazardous Air Pollutants (Rad-NESHAP), 40 CFR 61, Subpart H. This package contains the EPA-approved version of the AIRDOS-EPA and DARTAB computer codes and the ALLRAD88 radionuclide data file. The AIRDOS-EPA computer code implements a steady-state Gaussian plume atmospheric dispersion model to calculate concentrations of radionuclides in the air and on the ground. It also 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.

The concentrations and human intakes are used by EPA's version of the DARTAB computer code to calculate EDEs from radionuclides released to the atmosphere. The dose calculations use the dose conversion factors (DCFs) contained in the ALLRAD88 data file (Beres 1990).

A total of 47 emission points, each of which includes one or more individual sources, on the ORR were modeled during 1996. This total includes 7 points at the Y-12 Plant; 27 points at ORNL; and 13 points at the ETTP. Table 6.1 is a list of the emission point parameter values and receptor locations used in the dose calculations.

Meteorological data used in the calculations were in the form of joint frequency distributions of wind direction, wind speed class, and atmospheric stability category. These data were derived from data collected during 1996 at the 60-m height on MT6 for all sources at the Y-12 Plant; at the 100-m height on MT2 for stacks 2000, 2026, 2523, 3018, 3020, 3039, 3074, 3544, 3608, 3610-T, 5505, 7025, the sludge drier, the minor lab hoods, LA-104, and the inactive lab hoods at ORNL; at the 30-m height on MT4 for stacks 7512, 7567, 7569, 7830, 7852, 7860, 7877, 7911, the In Situ Vitrification project, the lysimeter project, and the vial crusher at ORNL; and at the 10-m height, with wind speeds adjusted to 60-m, on MT1 for all sources at the ETTP. Average rainfall on the ORR during 1996, based on the four functioning rain gauges, was 154 cm (61 in.). The average air temperature was 14°C (56°F), and the average mixing layer height was 1000 m (3280 ft).

The dose calculations are based on the assumption that each person remained at home (actually, outside the house), unprotected, 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 by each person 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. For collective EDE estimates, production of beef, milk, and crops within 80 km of the ORR was calculated using the state-specific production rates provided with CAP-88.

Results

Calculated EDEs from radionuclides emitted to the atmosphere from the ORR are listed in Tables 6.2 (maximum individual) and 6.3 (collective). The EDE received by the hypothetical maximally exposed individual for the ORR was calculated to be about 0.45 mrem (0.0045 mSv), which is below the NESHAP standard of 10 mrem (0.10 mSv) and well below the 300 mrem (3 mSv) that the average individual receives from natural sources of radiation. The maximally exposed individual is located about 1080 m (0.7 miles) north-northeast of the Y-12 Plant release point, about 9300 m (5.8 miles) northeast of the 3039 stack at ORNL, and about 13,000 m (8.1 miles) east-northeast of the K-1435 (TSCA Incinerator) stack at the ETTP. The calculated collective EDE to the entire population within 80 km (50 miles) of the ORR (about 879,546 persons) was about 9.9 person-rem (0.099 person-Sv), which is approximately 0.004% of the 264,000 person-rem that this population could have received from natural sources of radiation.

The EDE received by the hypothetical maximally exposed individual for the Y-12 Plant was calculated to be 0.40 mrem (0.0040 mSv). This individual is located about 1080 m (0.7 miles) north-northeast of the Y-12 Plant release point. Essentially, all (93%) of this dose is from ingestion and inhalation of uranium, primarily ^{234}U, ^{235}U, and ^{238}U, and about 3% of the dose is attributed to ^{239}Pu. The contribution of Y-12 Plant emissions to the 50-year committed collective EDE to the population residing within 80 km of the ORR was calculated to be about 4.4 person-rem (0.044 person-Sv), which is approximately 44% of the collective EDE for the ORR.

The EDE received by the hypothetical maximally exposed individual for ORNL was calcu-

Table 6.1. Emission point parameters and receptor locations used in the dose calculations

Source name	Type	Release height (m)	Inner diameter (m)	Gas exit velocity (m/s)	Gas exit temperature (°C)	Distance (m) and direction to maximally exposed individual			
						Plant		ORR	
				Y-12 Plant					
Minor process sources	Point	20			Ambient	1,080	NNE	1,080	NNE
Monitored stacks	Point	20			Ambient	1,080	NNE	1,080	NNE
Unmonitored room exhausts	Point	20			Ambient	1,080	NNE	1,080	NNE
Lab hoods	Point	20			Ambient	1,080	NNE	1,080	NNE
9207	Point	20			Ambient	700	NW	700	NW
9204-3	Point	20			Ambient	1,100	N	1,100	N
ASO	Point	9.75	0.8	10	Ambient	2,410	WSW	2,410	WSW
				ORNL					
2000	Point	15.24	0.66	8.32	Ambient	4,970	SW	9,300	NE
7025	Point	3.96	0.3	13.74	Ambient	6,910	SW	7,550	NNE
2523	Point	7	0.3	7.5	Ambient	4,970	SW	9,300	NE
LA-104	Point	1			Ambient	4,970	SW	9,300	NE
3074	Point	4	0.26	10.2	Ambient	4,970	SW	9,300	NE
7860	Point	18.29	0.31	3.9	Ambient	3,860	WSW	10,990	NNE
7852	Point	2.13	0.2	2.18	Ambient	3,860	WSW	10,990	NNE
2026	Point	22.9	1.05	10.41	Ambient	4,970	SW	9,300	NE
In Situ Vitrification Project	Point	0			Ambient	3,370	SW	10,920	NE
3020	Point	61	1.96	6.29	Ambient	4,970	SW	9,300	NE
3039	Point	76.2	5.68	2.53	Ambient	4,970	SW	9,300	NE
7512	Point	30.5	0.91	7.96	Ambient	5,160	WSW	9,640	NNE
7911	Point	76.2	3.43	2.85	Ambient	5,160	WSW	9,640	NNE
5505	Point	11	0.3	7.92	Ambient	4,970	SW	9,300	NE
3018	Point	61	4.11	0.2	Ambient	4,970	SW	9,300	NE
3544	Point	9.53	0.27	28.18	Ambient	4,970	SW	9,300	NE
Inactive lab hoods	Point	15			Ambient	4,970	SW	9,300	NE
7830	Point	4.55	0.21	12.86	Ambient	3,860	WSW	10,990	NNE
7567	Point	3.81	0.31	2.01	Ambient	5,160	WSW	9,640	NNE
7569	Point	3.96	0.15	2.59	Ambient	5,160	WSW	9,640	NNE
7877	Point	13.9	0.51	11.4	Ambient	3,860	WSW	10,990	NNE
3608	Point	10.97	2.44	0.57	Ambient	4,970	SW	9,300	NE
STP sludge drier	Point	1.52	0.2	2.91	Ambient	4,460	SW	9,760	NE
3610-T	Point	0.61			Ambient	4,970	SW	9,300	NE

Table 6.1 (continued)

Source name	Type	Release height (m)	Inner diameter (m)	Gas exit velocity (m/s)	Gas exit temperature (°C)	Distance (m) and direction to maximally exposed individual			
						Plant		ORR	
Lysimeter project	Point	0			Ambient	3,160	WSW	11,330	NNE
7654 vial crusher	Point	1.2			Ambient	3,860	WSW	10,990	NNE
Minor lab hoods	Point	15			Ambient	4,970	SW	9,300	NE
				ETTP					
K1435 incinerator	Point	30.5	1.37	5.46	80.55	5,180	WSW	13,000	ENE
K1435-A	Point	3.05			Ambient	5,180	WSW	13,000	ENE
K1435 Tanks	Point	2			Ambient	5,180	WSW	13,000	ENE
K1004-L	Point	13.41			Ambient	4,340	W	14,000	ENE
K1006	Point	7.62			Ambient	4,240	W	14,000	ENE
K1008-C	Point	3.96			Ambient	4,360	WSW	13,900	ENE
K1015	Point	3.7			Ambient	4,340	WSW	14,000	ENE
K1037	Point	10.5	1.07	6.34	Ambient	4,820	WSW	13,250	ENE
K1423	Point	6.1	0.1524		Ambient	4,270	WSW	14,000	ENE
K1310-DC	Point	1	0.305		Ambient	3,160	WSW	15,060	ENE
K304-5	Point	1			Ambient	3,900	WSW	14,300	ENE
UF_6 cylinder project	Point	1			Ambient	3,160	WSW	15,060	ENE
K1004 A-D	Point	8.5			Ambient	4,340	W	14,000	ENE

lated to be 0.24 mrem (0.0024 mSv). This individual is located 4970 m (3.1 miles) southwest of the 3039 stack and 5160 m (3.2 miles) west-southwest of the 7911 stack. About 48% of this dose is from ingestion and inhalation of ^{138}Cs and about 29% is from immersion in noble gases (primarily ^{41}Ar). Other nuclides contributing 1% or more to the dose include ^{131}I (5.7%), ^{3}H (5.4%), ^{185}W (5.4%), and ^{212}Pb (3.3%). The contribution of ORNL emissions to the collective EDE to the population residing within 80 km of the ORR was calculated to be about 3.1 person-rem (0.031 person-Sv), which is approximately 32% of the collective EDE for the ORR.

The EDE received by the hypothetical maximally exposed individual for the ETTP was calculated to be 0.056 mrem (0.00056 mSv). This individual is located about 5180 m (3.2 miles) west-southwest of the TSCA Incinerator (K-1435) stack. About 95% of this dose is from ingestion and inhalation of uranium, about 2.0% is from thorium, and about 1.1% is from plutonium. 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 24% of the collective EDE for the reservation.

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 at the ORR PAMs and RAMs (Fig. 5.3). Hypothetical individuals assumed to reside at the PAMs could have received EDEs between 0.11 and 0.19 mrem/year (0.0011 and 0.0019 mSv/year); these EDEs in-

Table 6.2. Calculated radiation doses to maximally exposed off-site individuals from airborne releases during 1996

Plant	Total effective dose equivalents [mrem (mSv)]	
	Plant max	ORR max
ORNL	2.4E–01 (2.4E–03)[a]	3.6E–02 (3.6E–04)
ETTP	5.6E–02 (5.6E–04)[b]	1.1E–02 (1.1E–04)
Y-12 Plant	4.0E–01 (4.0E–03)[c]	4.0E–01 (4.0E–03)
Entire ORR	*d*	4.5E–01 (4.5E–03)[e]

[a]The maximally exposed individual is located 4970 m (3.1 miles) SW of the 3039 stack and 5160 m (3.2 miles) WSW of the 7911 stack.

[b]The maximally exposed individual is located 5180 m (3.2 miles) WSW of the K-1435 stack.

[c]The maximally exposed individual is located 1080 m (0.7 miles) NNE of the Y-12 Plant release point.

[d]Not applicable.

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

Table 6.3. Calculated collective EDEs from airborne releases during 1996

Plant	Effective dose equivalents[a]	
	Person-rem	Person-Sv
ORNL	3.1	0.031
ETTP	2.4	0.024
Y-12 Plant	4.4	0.044
ORR	9.9	0.099

[a]The collective effective dose equivalents to the 879,546 persons residing within 80 km (50 miles) of the ORR.

clude contributions from naturally occurring (background) radionuclides, radionuclides released from the ORR, and radionuclides released from any other sources. An indication of doses from sources other than those on the ORR can be obtained from the EDEs calculated at the two RAMs, which averaged 0.080 mrem/year (0.00080 mSv/year). Between 27 and 49% of the calculated EDEs at the PAMs are attributable to tritium, some of which was produced naturally.

Of particular interest is a comparison of doses calculated using measured air concentrations 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 Plant and the entire ORR. The EDE calculated at PAM 46 was 0.17 mrem/year (0.0017 mSv/year), which is about 38% of the 0.45 mrem/year (0.045 mSv/year) to the maximally exposed individual modeled by the CAP-88 code. PAM 39 is located near the maximally exposed individual for ORNL. The EDE calculated at PAM 39 was 0.12 mrem/year (0.0012 mSv/year), which is about half the 0.24 mrem/year (0.0024 mSv/year) based on CAP-88 code modeling. PAM 35 is located near the maximally exposed individual for the ETTP. The EDE calculated at PAM 35 was 0.19 mrem/year (0.0019 mSv/year), which is about three times higher than the 0.056 mrem/year (0.00056 mSv/year) modeled value to the maximally exposed individual.

Dose estimates based on calculated and measured nuclide concentrations for the Y-12 Plant and ORNL are in good agreement, given that the CAP-88 model typically overestimates doses by a factor of 2. The dose estimate based on measured nuclide concentrations near ETTP is somewhat higher than would be expected with respect to the estimate based on calculated concentrations.

6.1.2.2 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. Discharges from the Y-12 Plant enter the Clinch River by way of Bear Creek and EFPC, both of which enter Poplar Creek before it enters the Clinch River, and by direct discharge from Rogers Quarry into Melton Hill Lake. Discharges from ORNL enter the Clinch River by way of WOC and WOL. Discharges from the ETTP enter the Clinch River by way of Poplar Creek. This section discusses the potential radiological impacts of these discharges to persons who drink water, eat fish, swim, boat, and use the shoreline at various locations along the Clinch and Tennessee rivers.

Measured, annual-average concentrations of radionuclides in water samples taken at the ETTP (Gallaher) water plant and at the Kingston municipal water plant were used to calculate potential maximum individual EDEs from drinking water. A worker who drank 365 L (half of the worker's total water consumption) of ETTP water during 1996 could have received an EDE of about 0.22 mrem (0.0022 mSv); a person who drank 730 L of Kingston water could have received about 0.32 mrem (0.0032 mSv).

There are other water treatment plants that are not sampled along the Clinch and Tennessee river systems. Six plants are located above Melton Hill Dam, and others are located on tributaries of Watts Bar and Chicamauga lakes. Three of the upstream plants draw water from near sampling points CRK 84, CRK 66, and CRK 58. Two draw water from unsampled areas near CRK 120 and CRK 74. The remaining plant draws water from Bull Run Creek. Persons drinking 730 L of water per year from the three plants near sampling points could receive EDEs of 0.12, 0.24, and 0.24 mrem (0.0012, 0.0024, and 0.0024 mSv), respectively. (These dose estimates may be high because they are based on water samples taken before processing in the plants.) Persons drinking water from the Watts Bar and Chicamauga plants should receive EDEs lower than the 0.32 mrem calculated for the Kingston water treatment plant.

A program initiated during 1993 involves collecting samples of water and fish at selected locations along the Clinch River, Poplar Creek, and near the intake of the Kingston city water plant on the Tennessee River. The results of this sampling program were used to illustrate potential radiation doses from radionuclides found in waters above and below inputs from the ORR.

Measured concentrations of radionuclides in water at the selected locations were input to the LADTAP XL computer code to calculate potential EDEs to maximally exposed individuals who are assumed to eat 21 kg of fish/year, to swim or wade for 27 hours/year, to boat for 63 hours/year, and to use the shoreline for 67 hours/year at the sampled location. Also, fish sampling data were used to calculate maximum individual EDEs from eating 21 kg of fish. Table 6.4 is a summary of the potential EDEs. Eating fish and shoreline usage are the only significant contributors to potential EDEs. Doses attributable to swimming or wading and boating are negligibly small.

EDEs from eating fish also are estimated using measured concentrations of radionuclides in fish. Because of differences in the radionuclides reported as present, doses calculated using concentrations in water exceeded those calculated using concentrations in fish tissue. The results are presented in Table 6.4.

Calculated EDEs ranged from 0.20 to 1.0 mrem (0.0020 to 0.010 mSv) per year. High and low dose estimates are found both above and below DOE inputs. Dose estimates for eating fish range from 0.0002 to 0.99 mrem (0.000002 to 0.0099 mSv) per year, and doses resulting from shoreline exposures ranged from 0.000031 to 0.030 mrem (0.00000031 to 0.00030 mSv) per year. The highest EDEs were calculated at a location (CRK 16) downstream from all DOE inputs.

An alternative method to estimate potential EDEs from radionuclides discharged to surface waters is to use measured discharge quantities and water body flow rates in the LADTAP code. The highest individual EDE calculated by using this method was 1.2 mrem (0.012 mSv) to an individual eating 21 kg of fish caught from lower Poplar Creek. All other individual EDEs were less than 0.15 mrem (0.0015 mSv). The collective EDE from drinking water, eating fish, swimming, boating, and using the shoreline from Melton Hill Lake to Chicamauga Dam was estimated to be 2.0 person-rem (0.020 person-Sv).

Table 6.4. Potential maximum individual EDEs (mrem)[a,b] from use of off-site waters based on measured radionuclide concentrations

Location	Eating fish	Swimming or wading	Boating	Using shoreline	Total
Clinch River above all DOE input (CRK 84)	1.6E–1 1.9E–4	3.7E–5	3.9E–5	3.0.E–2	1.6E–1
Clinch River at Oak Ridge Marina (CRK 80)	3.1E–1 3.4E–4	2.0E–4	2.0E–4	1.5E–2	3.2E–1
Clinch River above Oak Ridge city water intake (CRK 66)	2.5E–1 1.8E–4	1.4E–4	1.5E–4	1.2E–2	2.6E–1
Clinch River at Knox County water intake (CRK 58)	5.1E–1	1.5E–4	1.6E–4	1.3E–2	5.1E–1
Clinch River below ORNL (CRK 32)	2.8E–1 3.3E–2	1.4E–5	2.1E–7	3.1E–5	2.8E–1
Clinch River at ETTP water intake (CRK 23)	4.9E–1	1.7E–4	1.4E–4	1.1E–2	5.0E–1
Clinch River below all DOE inputs (CRK 16)	9.9E–1 4.1E–4	2.4E–4	2.3E–4	1.8E–2	1.0E+0
Tennessee River at Kingston Water Plant intake (TRK 915)	2.8E–1	1.5E–5	1.6E–5	1.4E–3	2.8E–1
Poplar Creek above union with East Fork Poplar Creek (PCK 22)	1.9E–1	*c*	9.4E–5	7.1E–3	2.0E–1
Poplar Creek below the ETTP (PCK 2.2)	3.5E–1 3.0E–4	*c*	2.3E–7	3.6E–5	3.5E–1

[a]1 mrem = 0.01 mSv.
[b]All values are based on measured concentrations of radionuclides in water except the second set of values for eating fish, which are based on measured concentrations of radionuclides in fish.
[c]Not applicable; no one has ever been observed swimming or wading at these locations.

When all pathways are considered, the maximum EDE resulting from waterborne radionuclide discharges could have been about 1.5 mrem (0.015 mSv): 1.2 mrem (0.012 mSv) from use of off-site waters plus 0.3 mrem (0.003 mSv) from drinking Kingston water. The collective EDE to the 50-mile population was estimated to be about 2.0 person-rem (0.02 person-Sv). These are small percentages of individual and collective doses attributable to natural background radiation, 0.5% and 0.0008%, respectively.

6.1.2.3 Radionuclides in Other Environmental Media

The CAP-88 computer codes 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 of these media are sampled as part of the surveillance program. The following dose estimates are based on sampling results.

Milk

Milk collected at five locations near the ORR was sampled for strontium, tritium, and ^{131}I. Only strontium was detected in the milk samples. The sampling results were used to calculate potential EDEs to a hypothetical person who drank 310 L of the sampled milk during the year. Such a person could have received EDEs between 0.05 and 0.1 mrem (0.0005 and 0.001 mSv); the average EDE to such persons could have been 0.08 mrem (0.0008 mSv). The average EDE associated with drinking milk in EPA Region 4 is about 0.09 mrem (0.0009 mSv) (EPA 1993a).

Honey

Three bee colonies are located on the ORR. The honey produced in these hives was sampled, and the sampling results were used to calculate potential EDEs to a hypothetical person who consumed 1 kg (2.2 lb) of the sampled honey during the year. That person could have received an EDE between 0.009 and 0.08 mrem (0.00009 and 0.0008 mSv). However, a significant part of the dose is attributable to ^{40}K, which is strictly a naturally occurring radionuclide. Correcting for the contribution of ^{40}K, the EDE to the hypothetical person could be between 0 and 0.06 mrem (0 and 0.0006 mSv).

The average adult likely consumes less than 1 kg of honey per year. The total production of honey in Anderson, Loudon, and Roane counties during 1992 (the latest available data) was approximately 1500 kg (3200 lb). In the extremely unlikely event that all the honey produced in the three counties contained the sampled concentration of radionuclides that gives the highest individual EDE, the resulting collective EDE could have been 0.1 person-rem (0.001 person-Sv).

Crops

Another environmental pathway for ingestion that was evaluated separately is eating vegetables. In 1996, three types of vegetables were sampled: tomatoes, lettuce, and turnips. These vegetable types were chosen as representative of fruit-bearing, leafy, and root vegetables. Tomatoes, lettuce, and turnips were sampled from all nine plots, which are located at the ORR PAMs.

To calculate potential EDEs from eating the sampled vegetables, it was assumed that a person ate 32 kg (71 lb) of homegrown tomatoes, 10 kg (22 lb) of homegrown leafy vegetables, and 37 kg (82 lb) of homegrown root vegetables during the year. Nationwide Food Consumption Survey (NFCS) data were used to estimate consumption rates for home-produced foods (USDA 1994). The U.S. Department of Agriculture conducts the NFCS every 10 years to analyze the food consumption behavior and dietary status of Americans. Based on these assumptions, the average individual's EDE from eating all three vegetable types could have been about 4 mrem (0.04 mSv), about 1.8 mrem (0.018 mSv) from fruit-bearing vegetables, about 0.6 mrem (0.006 mSv) from leafy vegetables, and about 1.7 mrem (0.017 mSv) from root vegetables (Table 6.5). Essentially all (about 99.9%) of these doses are attributed to ^{40}K, which is strictly a naturally occurring radionuclide. If the contribution of ^{40}K is excluded, the annual individual EDE is 0.005 mrem (5E–5 mSv). The reduced EDE is attributed to other radionuclides detected in the vegetables, including ^{238}U, ^{234}U, ^{235}U, ^{60}Co, and ^{137}Cs. Although these radionuclides are measured in emissions from the ORR, uranium isotopes also occur naturally in soil and fertilizers that are spread on gardens, and

Table 6.5. Average EDEs from ingesting vegetables grown at ORR ambient air monitoring stations, 1996

Vegetable	EDE [mrem (mSv)]	
	All reported radionuclides	Excluding ^{40}K
Tomatoes	1.8E+00 (1.8E–02)	7.8E-04 (7.8E–06)
Lettuce	6.0E–01 (6.0E–03)	8.5E-04 (8.5E–06)
Turnips	1.7E+00 (1.7E–02)	3.0E-03 (3.0E–05)
Total	4.1E+00 (4.1E–02)	5.0E-03 (5.0E–05)

^{137}Cs exists in the environment because of weapons testing. Therefore, most of the radioactivity found in the vegetables and the associated radiation annual EDEs may not be attributable to ORR operations. The estimated EDEs for ingesting vegetables grown at the ORR monitoring sites are summarized in Table 6.5.

Hay samples were collected from one background location and from six ORR locations. The six ORR samples were combined into three samples. Statistically significant concentrations were found only for ^{7}Be and ^{40}K, both of which are naturally occurring radionuclides. Essentially all (about 99.99%) of the dose to humans from eating beef and drinking milk from cattle that eat hay was from the naturally occurring ^{40}K. Including the contribution from ^{40}K, the EDE from drinking milk and eating beef was estimated to be about 21 mrem (0.21 mSv); excluding ^{40}K, the EDE attributed to ^{7}Be was estimated to be about 1.7E–03 mrem (1.7E–05 mSv). No statistically significant concentrations of radionuclides emitted from the ORR were found in the hay samples.

White-Tailed Deer

Several deer hunts were held on the ORR during 1996. A total of 464 deer were killed, of which 2 were confiscated because their radionuclide content potentially exceeded the ^{90}Sr in-bone release limit (1.5 times background, which is about 20 pCi/g). The remaining 462 deer had an average field-dressed weight of about 37 kg (81 lb). Assuming 55% of the dressed weight is edible, the average deer would yield about 20 kg (45 lb) of meat. Therefore, based on the average weight, the total harvest of edible meat was about 9,330 kg (20,580 lb).

All deer were surveyed at the TWRA inspection station to estimate the ^{137}Cs content in tissue and total strontium in bone. Based on field measurements, the average ^{137}Cs concentration in the 462 released deer was 0.19 pCi/g (0.007 Bq/g). Laboratory analyses of muscle and liver samples resulted in statistically significant concentrations of only ^{137}Cs and ^{40}K. In 11 of 27 muscle and liver samples collected, the average ^{137}Cs was 0.09 pCi/g (0.003 Bq/g), which is lower than the field average ^{137}Cs concentration. Potassium-40 (^{40}K) was detected in all 27 muscle and liver samples and the average concentration was 2.5 pCi/g (0.09 Bq/g). However, ^{40}K is a naturally occurring radionuclide. The EDE for an individual consuming one average weight deer with the average field concentration of ^{137}Cs (0.19 pCi/g) was estimated to be 0.2 mrem (0.002 mSv). The collective EDE from eating all the harvested deer meat with an average ^{137}Cs concentration of 0.19 pCi/g could have been about 0.09 person-rem (9E–4 person-Sv).

EDEs were estimated for the hunter with the highest potential intake (in terms of concentration and field-dressed weight) who harvested two deer. When actual field-derived ^{137}Cs concentrations (0.74 pCi/g and 0.71 pCi/g) and field-dressed weights (90 lb and 81 lb) are used, and it is assumed that one individual consumed all the deer meat, the highest EDE was calculated to be about 1.5 mrem (0.015 mSv).

Canada Geese

During 1996 whole-body gamma scans were conducted on about 83 geese. The geese were collected from ORNL (18), ETTP (42), and Melton Hill Dam (23). Of the 83 geese screened, ^{60}Co was detected in only one goose, which was confiscated. The average ^{137}Cs concentration was 0.12 pCi/g (4.4E–3Bq/g). The maximum ^{137}Cs concentration was 1.8 pCi/g (7 E–2 Bq/g).

The average weight of the Canada geese scanned during the roundup was about 3 kg (8 lb), half of which is assumed to be edible. A person eating a Canada goose with the average ^{137}Cs concentration could have received an EDE of about 0.01 mrem (1E–04 mSv). A person eating a Canada goose with the maximum ^{137}Cs concentration and the maximum weight of a goose surveyed [4 kg (9 lb)] could receive an EDE of about 0.2 mrem (2E–03 mSv). If it is assumed that one person consumed 8 geese, each with an average ^{137}Cs concentration [0.12 pCi/g (4E–03 Bq/g)], the estimated EDE would be about 0.08 mrem (8E–04 mSv). This is a conservative assumption because most hunters harvest on average one to two geese per hunting season (USFWS 1995).

Approximately 1,077 geese were harvested in the four surrounding counties—Anderson, Knox, Loudon, and Roane. This number is based on a University of Tennessee telephone survey of permit holders taken between September 5 and 15, 1995, and total late season (January 1996, October and December 1996, and January 1997) harvest tag data. Tag data were obtained from one published report (TWRA 1996) and from unpublished data supplied by TWRA staff. September 1996 harvest data were not available; however, the 1995 harvest data indicate the greater number of geese harvested during that hunting period than during later hunting seasons. Of the total number of geese harvested in the four counties, it is estimated that about 460 of these geese could have spent time on the ORR. The annual average collective EDE from consuming 460 geese is estimated to be about 0.005 person-rem (5E–05 person-Sv), assuming all were contaminated at the average ^{137}Cs concentration of 0.12 pCi/g (4E–3 Bq/g).

In 1995, eleven geese were sacrificed and tissue, bone, and thyroid samples were collected and analyzed. In addition, six background geese also were sacrificed, and samples were collected and analyzed. The 1995 average ^{90}Sr concentration in tissue was 6.8 pCi/g (0.25 Bq/g). If one person consumes one goose with average 1996 field and 1995 analytical concentrations of ^{137}Cs and ^{90}Sr, respectively, the annual individual EDE is estimated to be about 2 mrem (0.02 mSv). Taking into account the maximum 1996 field and 1995 analytical concentrations of ^{137}Cs and ^{90}Sr detected in the goose samples, 1.8 pCi/g (0.02 Bq/g) and 11 pCi/g (0.41 Bq/g), respectively, and the maximum goose weight of 4 kg (9 lb), the EDE is estimated to be about 4 mrem (0.04 mSv).

Eastern Wild Turkey

Eight eastern wild turkeys were collected on the ORR in 1996. Whole-body gamma scans were conducted on these turkeys, and ^{137}Cs was detected in only one turkey. The ^{137}Cs concentration in the turkey was 0.09 pCi/g (3.3E–3 Bq/g). Based on this ^{137}Cs concentration and turkey weight of 7.3 lb (3.3 kg), the EDE to a person consuming this turkey is estimated to be about 0.007 mrem (7E–5 mSv). All eight turkeys were released in Roane County.

Direct Radiation

External exposure rates from background sources in the state of Tennessee average about 6.4 µR/hour and range from 2.9 to 11 µR/hour. 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 1995 was about 7.5 µR/hour. This equals a dose rate of about 50 mrem/year (0.50 mSv/year). Except for two locations, all measured exposure rates beyond the ORR boundaries are near background levels. The two exceptions are a stretch of bank along the Clinch River and a section of Poplar Creek that flows through the ETTP.

During 1987, external exposure rate measurements were taken along a 1.7-km (1.1-mile) length of Clinch River bank. Measured exposure rates along this stretch of bank averaged 13 µR/hour and ranged between 3.5 and 18 µR/hour. These measured exposure rates were attributed to radiation emanating from a nearby field that contained the remnants of a ^{137}Cs seeding experiment. The experimental plots were remediated during 1994, but new measurements of the exposure rate along the Clinch River have not been performed. Therefore, we assume the exposure rate along the Clinch River caused by the cesium plots was the same as reported last year, about 8 µR/hour (0.006 mrem/hour) above background.

A potential maximally exposed individual is a hypothetical fisherman who was assumed to spend 5 hours/week (250 hours/year) near the point of average exposure. This hypothetical maximally exposed individual could have received an EDE of about 1 mrem (0.01 mSv) during 1995. This dose estimate likely is high, because most of the ^{137}Cs was removed from the experimental fields in 1994.

The radiation field along Poplar Creek emanates from storage areas within the ETTP. The section of the creek affected by this area runs through the plant and is used at times by fishermen. Exposure rate measurements, corrected for background, at the creek bank ranged between 3.9 and 8.3 μR/hour, which is equivalent to an EDE rate from 0.003 to 0.006 mrem/hour (between 0.00003 and 0.00006 mSv/hour). The average exposure rate was about 5.1 μR/hour, which corresponds to an EDE rate of 0.004 mrem/hour (0.00004 mSv/hour). A 4-hour fishing trip could have resulted in reception of an EDE between 0.01 to 0.02 mrem (0.0001 to 0.0002 mSv). If the hypothetical Clinch River fisherman is used, the 250-hour/year exposure time could have resulted in reception of an EDE of about 1 mrem (0.01 mSv). It is extremely unlikely that anyone would fish this stretch of Poplar Creek for 250 hours/year.

6.1.3 Doses to Aquatic Biota

DOE Order 5400.5, Chapter II, sets an interim absorbed dose rate limit of 1 rad/day (0.01 Gy/day) to native aquatic organisms. To demonstrate compliance with this limit, absorbed dose rates to fish, crustacea (e.g., crayfish), and muskrats were calculated using the computer code CRITR2 (Baker and Soldat 1993). Fish and crustacea are considered to be primary aquatic organisms, those that reside in the aquatic ecosystem. Muskrats are considered to be secondary organisms, those that subsist on aquatic plants. Maximum and average concentrations of radionuclides measured in surface waters on and around the ORR are used to estimate dose rates from internal and external exposures. Internal dose rates are calculated using organism- and nuclide-specific bioaccumulation factors and absorbed energy fractions. External dose rates are calculated for submersion in water and irradiation from bottom sediments. Exposure to sediments is particularly meaningful for crawling or fixed organisms (such as crayfish and mollusks). Direct radiation doses from sediment are estimated from water concentrations using factors such as a geometry roughness factor, sediment deposition transfer factor, and nuclide-specific ground-surface irradiation dose factors.

Table 6.6 lists average and maximum total dose rates to aquatic organisms from waterways at the Y-12 Plant, ORNL, and the ETTP. The doses for ORNL are based on water concentrations associated with nine different sampling locations: Melton Branch (Outfalls X-13 and 2), WOC (Outfall X-14), WOD (Outfall X-15), First Creek, Fifth Creek, Raccoon Creek, Northwest Tributary, and at the 7500 Bridge. The results from these calculations indicate that absorbed dose rates to aquatic biota are less than 1 rad/day (0.01 Gy/day). At ORNL the highest dose rates, which were associated with maximum concentrations of radionuclides in water, occurred at Melton Branch (X13): 3E–3 rad/day (3E–5 Gy/day) to fish, 3E–2 rad/day (3E–4 Gy/day) to crustacea, and 7E–3 rad/day (7E–5 Gy/day) to muskrats. Even with maximum radionuclide concentrations at these locations, the absorbed doses were significantly less than the limit of 1 rad/day (0.01 Gy/day).

At the Y-12 Plant, doses to aquatic organisms were estimated from concentrations of radionuclides in water obtained from EFPC at SWHISS house 9422-1 (Station 17), Bear Creek at BCK 4.55 (formerly Outfall 304), and Rogers Quarry discharge point S-19 (formerly Outfall 302). At Bear Creek (BCK 4.55), the maximum dose rates to fish, crustacea, and muskrats were ascertained: 7E–04 rad/day (7E–06 Gy/day), 2E–03 rad/day (2E–05Gy/day), and 1E–01 rad/day (1E–03 Gy/day), respectively. A maximum dose rate of 2 E–03 rad/day (2E–05 Gy/day) was also estimated for crustacea at EFPC. For muskrat, the dominant radionuclide contributor to the internal dose rate was ^{228}Ra, a decay product of ^{232}Th, a naturally occurring radionuclide.

Similar analyses were conducted at the ETTP. The waterways evaluated were Mitchell Branch at K-1700, Poplar Creek at K-1007B, K-716 (downstream of ETTP), K-1710 (upstream of ETTP), and at K-901A, which was located at Clinch River. At Mitchell Branch (K-1700), the maximum dose rates to fish, crustacea, and muskrats from measured uranium and ^{99}Tc concentrations

Table 6.6. 1996 total dose rate for aquatic organisms (rad/day)[a,b]

Measurement location	Fish		Crustacea		Muskrat	
	Av	Max	Av	Max	Av	Max
			ORNL			
Melton Branch (X13)	1E–3	3E–3	1E–2	3E–2	3E–3	7E–3
White Oak Creek (X14)	8E–4	1E–3	6E–3	9E–3	2E–3	3E–3
White Oak Dam (X15)	9E–4	1E–3	7E–3	1E–2	2E–3	3E–3
7500 Road Bridge	4E–4	6E–4	3E–3	5E–3	9E–4	1E–3
First Creek	3E–4	1E–3	3E–3	1E–2	8E–4	3E–3
Fifth Creek	9E–5	5E–4	9E–4	4E–3	2E–4	9E–4
Melton Branch 2	2E–5	6E–5	1E–4	4E–4	4E–5	1E–4
Northwest Tributary	4E–4	7E–4	3E–3	4E–3	7E–4	1E–3
Raccoon Creek	4E–5	1E–4	4E–4	1E–3	1E–4	3E–4
			Y-12 Plant			
East Fork Poplar Creek (Station 17)	1E–4	6 E–4	7E–4	2E–3	2E–4	4E–2
Bear Creek (BCK 4.55)[c]	1E–4	7E–4	8E–4	2E–3	3E–3	1E–1
Rogers Quarry (Outfall S19)[d]	3E–5	3E–4	2E–4	1E–3	3E–5	4E–2
			ETTP			
Mitchell Branch (K-1700)	2E–5	4E–5	1E–4	3E–4	8E–5	1E–4
Poplar Creek (K-1007B)	2E–6	5E–6	1E–5	1E–4	6E–6	1E–5
Poplar Creek (K-1710) upstream of ETTP	2E–6	1E–5	1E–5	2E–4	9E–6	3E–5
Poplar Creek (K-716) downstream of ETTP	3E–6	8E–6	6E–6	1E–4	1E–5	3E–5
Clinch River (K-901-A)	5E–6	1E–5	5E–5	2E–4	2E–5	4E–5

[a]Total dose rate includes the contribution of internally deposited radionuclides, sediment exposure (derived from water concentrations), and water immersion.
[b]To convert from rad/day to Gy/day divide by 100.
[c]Formerly NPDES Outfall 304.
[d]Formerly NPDES Outfall 302. Renamed S19 in current permit.

were 4E–5 rad/day (4E–7 Gy/day), 3E–4 rad/day (3E–6 rad/day), and 1E–4 rad/day (1E–6 Gy/day), respectively. Even with maximum radionuclide concentrations at these locations, the absorbed doses were significantly less than the limit of 1 rad/day (0.01 Gy/day).

Absorbed doses estimated from maximum radionuclide water concentrations determined on the ORR resulted in doses that were less than the 1 rad/day (0.01 Gy/day) limit prescribed in DOE Order 5400.5.

6.1.4 Current-Year Summary

A summary of the maximum EDEs to individuals by several pathways of exposure is given in Table 6.7. It is unlikely (if not impossible) that any real person could have been irradiated by all

Table 6.7. Summary of estimated radiation dose equivalents to an adult during 1996 at locations on the ORR of maximum exposure

Pathway	Location	Effective dose equivalent (mrem)[a]
Gaseous effluents	Maximally exposed resident to	
Inhalation plus direct	Y-12 Plant	0.40
radiation from air,	ORNL	0.24
ground, and food chains	ETTP	0.056
	ORR	0.45
Liquid effluents		
Drinking water	Kingston Water Plant	0.32
Eating fish	Lower Poplar Creek	1.2
Other activities	Lower Clinch River, CRK 16	0.018
Eating deer		1.5
Eating geese		0.08
Direct radiation	Clinch River shoreline	1.0[b]
	Poplar Creek (ETTP)	1.0

[a]1 mrem = 0.01 mSv.

[b]This likely is an overestimate of the potential dose because the source of direct radiation was remediated during 1994.

of these sources and pathways for a period of one year; however, if the resident who received the highest EDE [0.45 mrem (0.0045 mSv)] from gaseous effluents also drank water from the Kingston plant [0.32 mrem (0.0032 mSv)], ate fish from Poplar Creek [1.2 mrem (0.012 mSv)], and fished the Clinch River near the cesium field or Poplar Creek inside the ETTP [1 mrem (0.01 mSv)], he or she could have received a total EDE of about 3.0 mrem (0.030 mSv), or about 1.0% of the annual dose [300 mrem (3 mSv)] from background radiation. If the above person also was the person who received the highest EDE [1.5 mrem (0.015 mSv)] from eating deer harvested on the ORR, that person could have received a committed EDE of about 4.5 mrem (0.045 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 one year. As described in the preceding paragraph, the 1996 maximum EDE could have been about 4.5 mrem (0.045 mSv), or about 4.5% of the limit given in DOE Order 5400.5. For further information, see Table A.2, which provides a summary of dose levels associated with a wide range of activities.

6.1.5 Five-Year Trends

Dose equivalents associated with selected exposure pathways for the years from 1992 to 1996 are given in Table 6.8. The variations in values over this five-year period likely are not statistically significant. The dose estimates for direct irradiation along the Clinch River have been corrected for background.

6.1.6 Potential Contributions from Off-Site Sources

Four off-site facilities were identified as potential contributors to radiation exposure of the public around the ORR. These facilities include a

Table 6.8. Trends in total effective dose equivalent for selected pathways

Pathway	Effective dose equivalent (mrem)[a]				
	1992	1993	1994	1995	1996
All air	1.3	1.4	1.7	0.5	0.45
Fish consumption	0.4	0.2	1.6	0.9	1.2
Drinking water (Kingston)	0.05	0.07	0.04	0.15	0.32
Direct radiation (Clinch River)	1[b]	1[b]	1[b,c]	1[b,c]	1[b,c]
Direct radiation (Poplar Creek)	11[b]	1[b]	1[b]	1[b]	1[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.

[c]This is an overestimate of the potential dose because the source of the direct radiation was remediated during 1993 and 1994.

waste processing facility located on Bear Creek Road, a depleted uranium processing facility located on Illinois Avenue, a decontamination facility located on Flint Road in Oak Ridge, and a waste processing facility located on Gallaher Road in Kingston.

Airborne emissions from these facilities (based on information supplied by the facilities) should not cause any individual to receive an EDE greater than 3.8 mrem (0.038 mSv). When combined with impacts caused by emissions from the ORR, no individual should receive an EDE in excess of EPA or DOE limits. No information was obtained about waterborne releases, if any, from these facilities.

6.1.7 Findings

The maximally exposed off-site individual could have received a 50-year committed EDE of about 0.45 mrem (0.0045 mSv) from airborne effluents from the ORR. This dose is below 10 mrem (0.10 mSv) per year, the limit specified in the CAA for DOE facilities. The estimated collective committed EDE to the about 880,000 persons living within 80 km (50 miles) of the ORR was about 9.9 person-rem (0.099 person-Sv) for 1996 airborne emissions. This represents about 0.004% of the 264,000 person-rem (2,640 person-Sv) that the surrounding population would receive from all sources of natural radiation.

6.2 CHEMICAL DOSE

6.2.1 Terminology

The following terms are pertinent to the understanding of chemical exposure. See Appendix B for further explanation of terms and methodology.

- Slope factor (SF). A plausible upper-bound estimate of the probability of a response per unit intake of a chemical over a lifetime. The SF is used to estimate an upper-bound probability of an individual developing cancer as a result of lifetime exposure to a particular level of a potential carcinogen. Units are expressed as mg kg^{-1} day^{-1}.
- Maximum contaminant level (MCL). EPA National Interim Primary and National Pri-

mary Drinking Water regulation concentrations that apply to all community or public water systems.

- Reference dose (RfD). An estimate of the daily exposure to the human population, including sensitive individuals, that is likely to be without an appreciable risk of deleterious effects during a lifetime.
- Secondary maximum contaminant level (SMCL). EPA National Secondary Drinking Water regulation concentrations that apply to public water systems. The EPA SMCLs are unenforceable criteria that apply to aesthetic water quality; however, Tennessee SMCLs, which are the same as the federal SMCLs, are enforceable.

RfDs, which are used to evaluate potential health effects from noncarcinogens, are derived from doses of chemicals that result in no adverse effect or the lowest dose that showed an adverse effect on humans or laboratory animals. (See Appendix B.) The EPA maintains the Integrated Risk Information System (IRIS) data base, which contains verified RfDs and SFs and up-to-date health risk and EPA regulatory information for numerous chemicals.

For chemicals for which RfDs are not available, MCL and SMCL concentrations, expressed in milligrams per liter, are converted to RfD values by multiplying by 2 L (the average daily adult water intake) and dividing by 70 kg (the reference adult body weight). The result is a dose expressed in mg kg^{-1} day^{-1}. Table 6.9 lists the RfDs and SFs used in this analysis.

SFs are used to evaluate carcinogenic impacts. The SF converts the estimated daily intake averaged over a lifetime exposure to the incremental risk of an individual developing cancer. Because it is unknown whether a threshold (a dose below which no adverse effect occurs) exists for carcinogens, units for carcinogens are set in terms of risk. For potential carcinogens at the ORR, a risk of developing cancer during a human lifetime of 1 in 100,000 (10^{-5}) was used to establish acceptable levels of exposure. That is, the EPA estimates that a certain concentration of a chemical, if ingested, could cause a risk of one additional cancer case for every 100,000 exposed persons.

6.2.2 Methods of Evaluation

6.2.2.1 Airborne Chemicals

Air permits issued by TDEC allow release of permitted quantities of chemicals. No air monitoring data amenable to human exposure analysis were available. (See Sect. 4.1, “Airborne Discharges.”)

6.2.2.2 Waterborne Chemicals

Current risk assessment methodologies use the term “hazard quotient” (HQ) to evaluate noncarcinogenic health effects. Intakes, calculated in mg kg^{-1} day^{-1} in the HQ methodology, are expressed in terms of dose. For carcinogens, the estimated dose (I) from ingestion of water or fish is divided by the chronic daily intake (CDI), which corresponds to a 10^{-5} lifetime risk of developing cancer. See Appendix B for a more detailed discussion.

6.2.2.3 Drinking Water

HQ ratios for chemical concentrations found in surface water are summarized in Table 6.10. The tilde (~) indicates that estimated values and/or detection limits were used in estimating the average concentration of a chemical. This symbol is listed beside the estimated HQ ratio to indicate the type of data used.

To evaluate the drinking water pathway, HQs were estimated at current drinking water supply locations (CRKs 23 and 58) both below and above the ORR. The Gallaher Water Station (CRK 23) is located near the water intake for the ETTP and is below the ORNL effluent discharge point. The Knox county water supply intake (CRK 58) is located above the ORR discharge points. In addition, the drinking water pathway was evaluated at the Anderson County Filtration Plant (CRK 84), which is above all DOE inputs, and at CRK 16, which is a location downstream of all DOE inputs.

Table 6.9. Chemical reference doses and slope factors used in drinking water and fish intake analysis

Chemical	Reference dose or slope factor[a]	Reference[b]
Acetone	1.0E–01	RfD
Aluminum	6.0E–03	SMCL
Arsenic	3.0E–04	RfD
Barium	7.0E–02	RfD
Beta-BHC	4.0E–05	TN WQC
2-Butanone	6.0E–01	RfD
Carbon disulfide	1.0E–01	RfD
Chlordane (alpha, gamma)	6.0E–05	RfD
Chloride	7.1E+00	SMCL
Chromium (VI)	5.0E–03	RfD
Copper	4.0E–02	MCL
4,4′-DDE	3.4E–01	SF
4,4′-DDT	5.0E–04	RfD
1,2 Dichloroethene	9.0E–03	RfD
Dieldrin	1.6E+01	SF
Endosulfan I, II	6.0E–03	RfD
Endosulfan sulfate	2.1E–03	TN WQC
Endrin	3.0E–04	RfD
Fluoride	6.0E–02	RfD
Heptachlor	5.0E–04	RfD
Heptachlor epoxide	1.3E–05	RfD
Iron	9.0E–03	SMCL
Lead	4.0E–04	MCL
Manganese	4.7E–02	RfD (water)
Mercury	5.7E–05	MCL
Methoxychlor	5.0E–04	RfD
Nickel (soluble salts)	2.0E–02	RfD
Nitrate	1.6E+00	RfD
PCBs	2.0E+00	SF (mixed)
Selenium	5.0E–03	RfD
Strontium	6.0E–01	RfD
Sulfate	1.4E+01	MCL
Thallium	8.0E–05	RfD
Toluene	2.0E–01	RfD
Trichloroethene	1.4E–04	MCL
Uranium (soluble salts)	3.0E–03	RfD
Vanadium	7.0E–03	RfD
Vinyl chloride	1.9E+00	SF
Xylene	2.0E+00	RfD
Zinc	3.0E–01	RfD

[a]RfD: reference dose (mg kg^{-1} day^{-1}); SF: slope factor (risk per mg kg^{-1} day^{-1}).

[b]The maximum contaminant level (MCL), secondary maximum contaminant level (SMCL), and Tennessee Water Quality Criteria (TN WQC) are in units of mg/L. To convert the concentration to a RfD (mg kg^{-1} day^{-1}), multiply by the consumption rate (2 L/day), and divide by the mass of a reference man, 70 kg.

Table 6.10. 1996 chemical hazard quotients for drinking water[a]

Chemical	Hazard quotient			
	CRK 84[b]	CRK 58[c]	CRK 23[d]	CRK 16[e]
		Metals		
Aluminum	6E–01	2E+00	1E+00	6E+00
Barium	1E–02	1E–02	1E–02	2E–02
Iron	5E–01	2E+00	7E–01	3E+00
Manganese	4E–02	6E–02	3E–02	
Mercury	~5E–02	~6E–02	~7E–02	
Uranium	~1E–03	2E–03	2E–03	2E–03
Vanadium		~1E–02		~1E–02
Zinc	~1E–03	~8E–04	~5E–04	~8E–04
		Anions		
Chloride	2E–02	2E–02	2E–02	2E–02
Fluoride	~8E–02			~7E–02
Nitrate	6E–02	5E–02	5E–02	4E–02
Sulfate	4E–02	4E–02	4E–02	3E–02
		Volatile organics		
2-Butanone	~4E–04	~3E–04	~2E–04	~2E–04
Acetone	~2E–03	~3E–03	~3E–03	~2E–03
Carbon disulfide			~1E–03	~1E–03
Toluene		~6E–04	~6E–04	
Xylene		~7E–05	~6E–05	

[a]A tilde (~) indicates that estimated values and/or detection limits were used in the calculation.
[b]Melton Hill Reservoir above all DOE inputs.
[c]Water supply intake for Knox County.
[d]Water supply intake for ETTP.
[e]Clinch River downstream of all DOE inputs.

With the exception of aluminum and iron, the HQ values at all water sampling locations were less than one (HQ < 1 is desirable). The derivation of the reference dose for both aluminum and iron were the SMCLs. The SMCLs control contaminants in drinking water that primarily affect aesthetic qualities, such as taste and odor. Elevated aluminum and iron HQs were estimated both upstream and downstream of the ORR.

6.2.2.4 Fish Consumption

Chemicals in water can be accumulated by aquatic organisms that may be eaten by humans. Sunfish and catfish collected from the Clinch River and sunfish collected from Poplar Creek were analyzed for a number of metals, pesticides, and PCBs. Table 6.11 summarizes the HQ and I/CDI ratios derived on average chemical concentrations in fish samples found both upstream and downstream locations from the ORR. Arsenic,

Table 6.11. 1996 chemical hazard quotients (HQs) for metals and estimated dose/chronic daily intake (I/CDIs) for carcinogens in fish[a]

Parameters	Sunfish						Catfish	
	CRK 84[b]	CRK 80[c]	CRK 66[d]	CRK 32[e]	CRK 16[f]	PCK 2.2[g]	CRK 32[e]	CRK 16[f]
				HQs for metals				
Arsenic	~4E+00	~4E+00						
Chromium	~3E–02		~1E–02					7E–02
Copper	7E–03	1E–02	6E–03	~6E–03		~9E–03	8E–03	1E–02
Lead								1E+01
Mercury	~2E+00			~2E+00	2E+00	1E+00	2E+00	5E+00
Nickel								1E–01
Selenium		~1E–01	~1E–01	~4E–01				
Silver								
Thallium	8E–02	9E–02	8E–02		~2E–01	~2E–01	5E–01	
Uranium								
Zinc	5E–02	4E–02	4E–02	6E–02	6E–02	6E–02	2E–02	2E–02
				HQs for pesticides				
Alpha chlordane				~8E–02	~8E–02	~8E–02	3E+00	2E–01
Gamma chlordane					~3E–01		~1E+00	7E–02
Beta-BHC					~2E–01	~2E–01		
4,4'-DDT					~2E–02			4E–02
Endosulfan I					~1E–03			
Endosulfan II				~2E–03	~2E–03	~1E–03	8E–02	
Endosulfan sulfate							~1E–02	
Endrin				~4E–02	~3E–02	~4E–02	~9E–01	
Endrin ketone						~4E–02		
Heptachlor					~1E–02			
Heptachlor epoxide				~4E–01	~4E–01	~3E–01		
Methoxychlor				~1E–01				
				I/CDIs for carcinogens (pesticides and PCBs)				
4,4'-DDE				~1E–01	~1E–01	~8E–02	~5E+00	
Dieldrin				~5E+00	~8E+00			8E+00
Polychlorinated Biphenyls (PCBs)								
Aroclor-1248								
Aroclor-1254					~1E+01	~6E+00		
Aroclor-1260		~8E+00	~9E+00	~3E+00	~1E+01	~6E+00		

[a]A tilde (~) indicates that estimated values and/or detection limits were used in the calculation.
[b]Melton Hill Reservoir, above all DOE inputs, Anderson Country Filtration Plant.
[c]Melton Hill Reservoir, Oak Ridge Marina, above ORNL.
[d]Melton Hill Reservoir, above the city of Oak Ridge intake.
[e]Clinch River, downstream of ORNL.
[f]Clinch River, downstream of all DOE inputs.
[g]Poplar Creek, downstream of the ETTP.

lead, and mercury concentrations in fish tissue resulted in HQs greater than one. HQs greater than one for mercury were found in sunfish upstream and downstream of the ORR, catfish downstream of the ORR, and in sunfish found in Poplar Creek (PCK 2.2). An HQ greater than one for arsenic was estimated only for sunfish collected upstream from all DOE and ORNL discharge points; however, an HQ greater than one for lead was calculated for catfish collected from CRK 16, which is downstream from all DOE inputs. Hazard quotients greater than one for chlordane (alpha and gamma) were estimated in catfish samples collected at CRK 32; however, no catfish samples were collected upstream of DOE and ORNL discharge points. In many cases, the hazard quotients, especially for pesticides in sunfish, were estimated using concentrations estimated at or below the analytical detection limit. Because of analytical detection limitations, the actual fish tissue concentrations are unknown.

For carcinogens, I/CDI ratios greater than one indicate a risk greater than 10^{-5}. In sunfish collected upstream and downstream of ORR, I/CDIs greater than one were estimated for Aroclor-1260, a PCB. In sunfish collected downstream of ORR, I/CDIs greater than one were also estimated for 4,4′-DDE, dieldrin, and Aroclor-1254, also a PCB. For catfish, I/CDIs greater than one were estimated for 4,4′-DDE, dieldrin, and Aroclor-1254 and Aroclor-1260 (PCK 2.2). In many cases, the tissue concentrations of PCBs, 4,4′-DDE, and dieldrin were estimated at or below the analytical detection limit. Because of analytical detection limitations, the actual fish tissue concentrations are unknown (an exception is the average dieldrin concentration in the catfish tissue samples collected at CRK 16).