8. Dose

Setting:

Activities on the ORR have the potential to release small quantities of radionuclides and hazardous chemicals to the environment. These releases could result in exposures of members of the public to low concentrations of radionuclides or chemicals. Monitoring of materials released from the reservation and environmental monitoring and surveillance on and around the reservation provide data that are used to show that doses from released radionuclides and chemicals are in compliance with the law; the calculated doses are compared with existing state and federal criteria.

Update:

A hypothetical maximally exposed individual could have received a total of 0.73 mrem (less than 1 mrem) from radionuclides emitted to the atmosphere from all of the sources on the ORR in 1998; 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 exposure to waterborne radionuclides for all pathways combined (drinking water, eating fish, swimming, wading, shoreline use, etc.) gives a maximum individual dose of about 2.7 mrem, which is a small percentage of the individual dose attributable to natural background radiation (0.90%)

Calculations to determine possible doses from consumption of deer, geese, and wild turkey harvested on or near the ORR resulted in the following: an individual who consumed one average-weight deer containing the average concentration of radionuclides in 1998 could have received about 0.2 mrem; someone consuming a hypothetical goose containing the maximum concentration of radionuclides below the ORNL administrative limit could have received 0.5 mrem; and a person who ate an average turkey could have received a dose of 0.04 mrem. In a worst-possible-case analysis (i.e., the heaviest animal containing the highest possible concentration of radionuclides) the doses received could be as high as 4.3 mrem for deer, 1 mrem for two geese, and 0.4 mrem for consuming the heaviest, most contaminated turkey.

8.1 RADIATION DOSE

Small quantities of radionuclides were released to the environment from operations at the ORR facilities during 1998. Those releases are described, characterized, and quantified in previous chapters of this report. This chapter presents estimates of potential radiation doses to the public from the releases. The dose estimates are performed using monitored and estimated release data, environmental monitoring and surveillance data, estimated exposure conditions that tend to maximize the calculated dose equivalents, and environmental transport and dosimetry codes that also tend to overestimate the calculated dose equivalents. Thus, the dose estimates are intended to demonstrate that no member of the public received a dose during 1998 in excess of that allowed by relevant regulatory authorities. The estimates do not necessarily reflect doses received by typical people in the vicinity of the ORR.

8.1.1 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 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 effective dose equivalent (EDE) rem of any type of radiation has the same total radiological (in this case, also biological) risk effect. Because the doses being considered here are very small compared to the rem, EDEs are usually expressed in millirem (mrem), which is 1/1000 of a rem. (See Appendix A, Table A.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 1998 were characterized 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 the National Emission Standards for Hazardous Air Pollutants (NESHAP): Radionuclides, 40 CFR 61, Subpart H, which governs the emissions of radionuclides other than radon from DOE facilities. This package implements a steady-state Gaussian plume atmospheric dispersion model to calculate concentrations of radionuclides in the air and on the ground and uses Regulatory Guide 1.109 (NRC 1977) food-chain models to calculate radionuclide concentrations in foodstuffs (vegetables, meat, and milk) and subsequent intakes by humans.

A total of 54 emission points, each of which includes one or more individual sources, on the ORR was modeled during 1998. This total includes 6 points at the Y-12 Plant, 33 points at ORNL, and 15 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 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 1998 at the 60-m height on Tower MT6 for all sources at the Y-12 Plant; at the 100-m height on Tower MT2 for sources X-2001, X-2026, X-2099, X-2523, X-3018, X-3020, X-3039, X-3074, X-3505, X-3544, X-3608, X-5505, X-7025, X-7856, X-decommissioned lab hoods, X-minor grouped sources, X-STP sludge drier, X-GAAT tanks, X-EW-2, and X-W6/W7 at ORNL; at the 10-m height, with wind speeds adjusted to 30 m, on Tower MT4 for sources X-7500, X-7512, X-7567, X-7569, X-7830, X-7852, X-7860, X-7877, X-7911, X-7966 at ORNL; and at the 60-m height on Tower MT1 for all sources at the ETTP. During 1998, rainfall, as averaged over the four rain gauges located on the ORR, was 128 cm (50 in.). The average air temperature was 16°C (60°F), and the average mixing layer height was 1000 m (3280 ft).

The dose calculations are based on the assumptions 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.

Table 8.1. Emission point parameters and receptor locations used in dose calculations

Source	Type	Release height (m)	Diameter (m)	Gas exit velocity (m/s)	Gas exit temperature (°C)	Distance (m) and direction to MEI[a]			
						Plant		ORR	
X-2001	Point	15.24	0.66	9.9	Ambient	4,060	SSW	4,060	SSW
X-2026	Point	22.9	1.05	10.59	Ambient	4,060	SSW	4,060	SSW
X-2523	Point	7	0.3	5.96	Ambient	4,060	SSW	4,060	SSW
X-3018	Point	61	4.11	0.227	Ambient	4,060	SSW	4,060	SSW
X-3020	Point	61	1.96	6.37	Ambient	4,060	SSW	4,060	SSW
X-3039	Point	76.2	5.68	2.53	Ambient	4,060	SSW	4,060	SSW
X-3074	Point	4.89	0.26	10.2	Ambient	4,060	SSW	4,060	SSW
X-3505	Point	6.09	0.51	13.9	Ambient	4,060	SSW	4,060	SSW
X-3544	Point	9.53	0.27	26.3	Ambient	4,060	SSW	4,060	SSW
X-3608 Non-Rad WTP Air Stripper	Point	10.97	2.44	0.566	Ambient	4,060	SSW	4,060	SSW
X-3608 Non-Rad WTP Filter Press	Point	9	0.36	14	Ambient	4,060	SSW	4,060	SSW
X-2099	Point	3.658	0.152	23.876	Ambient	4,060	SSW	4,060	SSW
X-5505 Main Duct	Point	11	0.43	1.9	Ambient	4,060	SSW	4,060	SSW
X-5505 North/South Ducts	Point	11	1.07	15	Ambient	4,060	SSW	4,060	SSW
X-7025	Point	3.96	0.3	13.5	Ambient	5,710	SW	5,710	SW
X-7500	Point	9.14	1.61	3.19	Ambient	3,720	SW	3,720	SW
X-7512	Point	30.5	0.91	12.1	Ambient	3,720	SW	3,720	SW
X-7567	Point	3.81	0.31	2.01	Ambient	3,720	SW	3,720	SW
X-7569	Point	3.96	0.15	2.59	Ambient	3,720	SW	3,720	SW
X-7830	Point	4.6	0.21	11.1	Ambient	2,350	SW	2,350	SW
X-7852 Regular	Point	2.13	0.2	2.18	Ambient	2,350	SW	2,350	SW
X-7852 Remediation	Point	3.1	0.27	7	Ambient	2,350	SW	2,350	SW
X-7856 MVST	Point	18.29	0.58	11.7	Ambient	2,350	SW	2,350	SW
X-7860	Point	18.29	0.305	3.9	Ambient	2,350	SW	2,350	SW
X-7966	Point	6.1	0.25	0	Ambient	3,720	SW	3,720	SW
X-7877	Point	13.9	0.51	9.87	Ambient	2,350	SW	2,350	SW
X-7911	Point	76.2	3.43	3.05	Ambient	3,720	SW	3,720	SW
X-Decommissioned Lab Hoods	Point	15	NA	NA	Ambient	4,060	SSW	4,060	SSW
X-EW-2	Point	4.6	0.3	6.8	Ambient	3,470	SSW	3,470	SSW
X-GAAT Tanks	Point	1.22	0.16	13.6	Ambient	4,060	SSW	4,060	SSW
X-Minor Grouped Sources	Point	15	NA	NA	Ambient	4,060	SSW	4,060	SSW
X-STP Sludge Drier	Point	7.6	0.203	11.16	Ambient	3,470	SSW	3,470	SSW
X-W6/W7	Point	1.22	0.16	14	Ambient	4,060	SSW	4,060	SSW
Y-Monitored Stacks	Point	20	NA	NA	Ambient	1,080	NNE	12,200	SSW
Y-Minor Sources	Point	20	NA	NA	Ambient	1,080	NNE	12,200	SSW
Y-Lab Hoods	Point	20	NA	NA	Ambient	1,080	NNE	12,200	SSW
Y-ASO Union Valley	Point	4.27	0.747	13.352	ambient	2,410	WSW	15,000	SW
Y-9207	Point	10	NA	NA	Ambient	700	NW	13,100	S
Y-9204-3	Point	20	NA	NA	Ambient	1,100	N	12,100	SSW
K-1435 Incinerator	Point	30.5	1.37	5.62	80.28	5,180	WSW	6,460	SSE
K-1435 Tank Farm	Point	18.29	NA	NA	Ambient	5,180	WSW	6,460	SE
K-1435-A Lab Hoods	Point	3.05	NA	NA	Ambient	5,160	WSW	6,460	SE

Table 8.1 (continued)

Source	Type	Release height (m)	Diameter (m)	Gas exit velocity (m/s)	Gas exit temperature (°C)	Distance (m) and direction to MEI[a]			
						Plant		ORR	
K-1008-C Respirator Cleaning Facility	Point	3.96	NA	NA	Ambient	4,360	WSW	6,720	SE
K-304-5 Deposit Removal Room	Point	1	NA	NA	Ambient	3,900	WSW	7,330	SE
K-1004-A/B/C/D Lab Hoods	Point	8.5	NA	NA	Ambient	4,340	W	6,390	SE
K-1066-E Yard UF_6 Cylinder Venting	Point	1	NA	NA	Ambient	3,160	WSW	7,470	ESE
K-Vault 16A Fissile Material Repack	Point	1	NA	NA	Ambient	3,900	WSW	7,330	SE
K-1423 Container Washing Operations	Point	6.1	0.152	NA	Ambient	4,270	WSW	7,230	SE
K-1423 Autoclave Piping Removal	Point	1	NA	NA	Ambient	4,270	WSW	7,230	SE
K-306-4 Incinerable Solids Repack	Point	3.05	0.61	10	Ambient	3,900	WSW	7,330	SE
K-1065-D TSCA Hatbox Downblend	Point	1	NA	NA	Ambient	2,770	WSW	8,440	SE
K-1407 CNF Air Stripper	Point	5.79	1.22	0.63	Ambient	4,590	WSW	6,880	SE
K-CO_2 Drum Blasting Operation	Point	5	0.334	15.23	Ambient	3,900	WSW	7,330	SE
KAFaD Rad-Laundry Facility	Point	3	NA	NA	60	3,540	WSW	7,250	SE

[a]MEI = Maximally exposed off-site individual.

Results

Calculated EDEs from radionuclides emitted to the atmosphere from the ORR are listed in Tables 8.2 (maximum individual) and 8.3 (collective). The hypothetical maximally exposed individual (MEI) for the ORR was located about 12,200 m (7.6 miles) south-southwest of the main Y-12 Plant release point, about 3720 m (2.3 miles) southwest of the X-7911 stack at ORNL, and about 6460 m (4.0 miles) southeast of the K-1435 (TSCA Incinerator) stack at the ETTP. This individual could have received an EDE of about 0.73 mrem (0.0073 mSv), which is well 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 calculated collective EDE to the entire population within 80 km (50 miles) of the ORR (about 879,546 persons) was about 12 person-rem (0.12 person-Sv), which is approximately 0.0045% of the 264,000 person-rem that this population could have received from natural sources of radiation.

The MEI for the Y-12 Plant was located about 1080 m (0.7 miles) north-northeast of the main Y-12 Plant release point. This individual could have received an EDE of about 0.53 mrem (0.0053 mSv). Inhalation and ingestion of uranium radioisotopes (i.e., ^{234}U, ^{235}U, ^{236}U, and ^{238}U) accounted for about 99% of the dose. 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 4.3 person-rem (0.043 person-Sv), which is approximately 35% of the collective EDE for the ORR.

The MEI for ORNL was located about 4060 m (2.5 miles) south-southwest of the X-3039 stack and 3720 m (2.3 miles) southwest of the X-7911 stack. This individual could have received an EDE of about 0.69 mrem (0.0069 mSv). About 40% of this dose is from immersion in airborne ^{41}Ar. Other radionuclides contributing 1% or more to the dose include ^{138}Cs (32%), ^{137}Cs (19%), and ^{212}Pb (1.7%).

Table 8.2. Calculated radiation doses to maximally exposed off-site individuals from airborne releases during 1998

Plant	Total effective dose equivalents [mrem (mSv)]	
	Plant max	ORR max
ORNL	0.69 (0.0069)[a]	0.69 (0.0069)
ETTP	0.068 (0.00068)[b]	0.013 (0.00013)
Y-12 Plant	0.53 (0.0053)[c]	0.019 (0.00019)
Entire ORR	*d*	0.73 (0.0073)[e]

[a]The maximally exposed individual was located 4060 m (2.5 miles) SSW of X-3039 and 3720 m (2.3 miles) SW of X-7911.

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

[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 ORNL maximally exposed individual.

Table 8.3. Calculated collective EDEs from airborne releases during 1998

Plant	Effective dose equivalents[a]	
	(Person-rem)	(Person-Sv)
ORNL	6.0	0.060
ETTP	2.0	0.020
Y-12 Plant	4.3	0.043
Entire ORR	12.3	0.123

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

The contribution of ORNL emissions to the collective EDE to the population residing within 80 km of the ORR was calculated to be about 6.0 person-rem (0.060 person-Sv), which is approximately 49% of the collective EDE for the ORR.

The MEI for the ETTP was located about 5180 m (3.2 miles) west-southwest of K-1435, the TSCA Incinerator stack. The EDE received by this individual was calculated to be about 0.068 mrem (0.00068 mSv). About 74% of this dose is from ingestion and inhalation of uranium radioisotopes, about 9.0% is from thorium radioisotopes, and about 24% 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 2.0 person-rem (0.020 person-Sv), which is approximately 16% 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 perimeter air monitoring stations (PAMs) (Fig. 7.3) and the remote air monitoring station (RAM). Hypothetical individuals assumed to reside at the PAMs could have received EDEs between 0.051 and 0.16 mrem/year (0.00051 and 0.0016 mSv/year); these EDEs include 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 EDE calculated at the remote air monitoring station (RAM), which was 0.066 mrem/year (0.00066 mSv/year). Between 11% and 79% of the EDE at the air monitoring stations are due to tritium, which, although emitted from the ORR, is a naturally occurring radionuclide.

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; the EDE calculated using measured air concentrations was 0.11 mrem/year (0.0011 mSv/year), which is about 21% of the 0.53 mrem/year (0.0053 mSv/year) calculated using CAP-88. PAM 39 is located at about the same distance as, but in a different wind direction from, the maximally exposed individual for ORNL; the EDE calculated using measured air concentrations was 0.016 mrem/year (0.00016 mSv/year), which is about 2.3% of the 0.69 mrem/year (0.0069 mSv/year) calculated using CAP-88. This result is not surprising because almost 80% of the dose from ORNL emissions is from emissions of noble gases, which would not be retained in the sampling media used at PAM 39. PAM 35 is located in the general direction of, but much closer to the ETTP emission points than, the maximally exposed individual for the ETTP; the EDE calculated using measured air concentrations at PAM 35 was 0.085 mrem/year (0.00085 mSv/year), which is greater than the 0.068 mrem/year (0.00068 mSv/year) modeled value to the maximally exposed individual.

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

8.1.2.2 Waterborne Radionuclides

Radionuclides discharged to surface waters from the ORR enter the Tennessee River system by way of the Clinch River and various feeder streams (see Sect. 1.4 for the surface water setting of the ORR). Discharges from the Y-12 Plant enter the Clinch River via Bear Creek and the East Fork of 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 (WOC) and White Oak Lake (WOL). 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. 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, if not all, radionuclides discharged from the ORR will be quantified and naturally occurring radionuclides will be either not considered or accounted for separately; the disadvantage is the use of models to estimate the concentrations of the radionuclides in water and fish. Using the two methods should allow the potential radiation dose to be bracketed.

Drinking Water

There are several water treatment plants along the Clinch and Tennessee river systems that could be affected by discharges from the ORR. For purposes of assessment, highly exposed individuals were assumed to drink 730 L of water during 1998; the average person, to 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 environmental monitoring plan (EMP) water sampling location CRK 58. A highly exposed individual could have received an EDE of about 0.56 mrem (0.0056 mSv) from drinking this water. The collective dose to the estimated 37,510 persons who drink this water could have been about 11 person-rem (0.11 person-Sv). Based on known radionuclide discharges to Melton Hill Lake, the highly exposed individual could have received an EDE of about 0.000089 mrem (0.00000089 mSv). (These dose estimates may be high because they are based on water samples taken before processing in the plants.)

The ETTP (Gallaher) water plant draws water from the Clinch River near CRK 23. Based on water samples taken in the plant and the assumption that workers drink half their annual water intake at work, a worker who drank 370 L of this water could have received an EDE of about

0.095 mrem (0.00095 mSv), and the collective EDE to the approximately 2000 ETTP workers could have been about 0.095 person-rem (0.00095 person-Sv). Based on water samples taken from the Clinch River (CRK 23), the worker could have received an EDE of about 0.35 mrem (0.0035 mSv), and the collective EDE could have been about 0.35 person-rem (0.0035 person-Sv). Using radionuclide discharge data, the maximum individual EDE was estimated to be 0.046 mrem (0.00046 mSv); the collective EDE was 0.046 person-rem (0.00046 person-Sv).

The Kingston municipal water plant draws water from the Tennessee River, just above its confluence with the Clinch River. Based on water samples taken in the plant, a highly exposed person could have received an EDE of about 0.19 mrem (0.0019 mSv), and the collective EDE to the estimated 7438 water users could have been about 0.73 person-rem (0.0073 person-Sv). No water samples are taken from the Tennessee River near the water plant. Using radionuclide discharge data, the maximum individual EDE was estimated to be 0.012 mrem (0.00012 mSv); the collective EDE was 0.046 person-rem (0.00046 person-Sv).

Several water treatment plants are located on tributaries of Watts Bar Lake and Chicamauga Lake. Persons drinking water from these plants could not have received EDEs greater than the 0.19 mrem (0.0019 mSv) or 0.012 mrem (0.00012 mSv) calculated for Kingston water. The estimated collective EDE, using discharge data, was about 1.1 person-rem (0.011 person-Sv).

Fish

Fishing is quite common on the Clinch and Tennessee river systems. For purposes of assessment, avid fish eaters were assumed to have consumed 21 kg of fish during 1998; the average person, to have consumed 6.9 kg of fish. EDEs were calculated using measured radionuclide contents in fish, and by using measured concentrations of radionuclides in water and calculated concentrations from discharges as input to the LADTAP XL code.

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 radionuclides that could have been discharged from the ORR, EDEs between 0.0021 and 0.018 mrem (0.000021 and 0.00018 mSv) from eating CRK 70 fish, between 0.013 and 0.032 mrem (0.13 and 0.32 μSv) from eating CRK 32 fish, and between 0.016 and 0.029 mrem (0.00016 and 0.00029 mSv) from eating CRK 16 fish. The collective EDE attributable to radionuclides that could have been released from the ORR could have been as much as 0.040 person-rem (0.00040 person-Sv).

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 Poplar Creek above and below the ETTP; and from East Fork Poplar Creek, just before it joins Poplar Creek. Based on analyses of these samples, avid fish eaters could have received, from radionuclides that could have been discharged from the ORR, EDEs between 0.50 and 2.1 mrem (0.0050 and 0.021 mSv) from fish taken from Melton Hill Lake; between 1.4 and 2.3 mrem (0.014 and 0.023 mSv) from fish taken from the Clinch River; and between 0.080 and 2.0 mrem (0.00080 and 0.020 mSv) from fish taken from Poplar Creek. The collective EDE could have been between 0.60 and 1.6 person-rem (0.0060 and 0.016 person-Sv). One sample taken at Melton Hill Lake sampling location CRK 66 showed a high content of ^{228}Ra (28 pCi/l). If this measurement was correct, the radium must have come from a source other than one on the ORR, because CRK 66 is upstream of significant inputs from the ORR. Regardless of the source of the radium, eating fish from water containing that much ^{228}Ra could have resulted in an EDE of 43 mrem (0.43 mSv).

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 0.00013 (0.0000013), 0.075 (0.00075), and 0.48 (0.0048) mrem (mSv), respectively. The collective EDE from eating fish from the above locations and from the Tennessee River system down to Chattanooga could have been 0.18 person-rem (0.0018 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 hours/year, boat for 63 hours/year, and use the shoreline for 67 hours/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 to 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 between 0.0081 and 0.012 mrem (0.000081 and 0.00012 mSv) from using Melton Hill Lake; of 0.011 (0.00011 mSv) from using the Clinch River; and between 0.000026 and 0.0029 mrem (0.00000026 and 0.000029 mSv) from using Poplar Creek. The collective EDE from using all water bodies could have been between 0.029 and 0.059 person-rem (0.00029 and 0.00059 person-Sv).

Based on radionuclide discharges to the Clinch River–Poplar Creek system, a user could have received an EDE between 0.00000086 and 0.00090 mrem (0.0000000086 and 0.0000090 mSv); the collective EDE could have been 0.0031 person-rem (0.000031 person-Sv).

Summary

Table 8.4 is a summary of potential EDEs from waterborne radionuclide discharges. Adding worst-case EDEs for all pathways in a water-body segment gives a maximum imaginable individual EDE of about 2.7 mrem (0.027 mSv). The maximum imaginable collective EDE to the 50-mile population was estimated to be about 48 person-rem (0.48 person-Sv). These are small percentages of individual and collective doses attributable to natural background radiation, 0.90% and 0.018%, 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 three locations near the ORR was found to contain small quantities of radiostrontium, ^{3}H, ^{7}Be, ^{40}K, and ^{131}I. All of these radionuclides are found in the natural environment, and all but ^{7}Be and ^{40}K also are emitted from the ORR. The sample data were used to calculate potential EDEs to hypothetical persons who drank 310 L of sampled milk during the year.

These hypothetical persons could have received an EDE between 0.053 and 0.099 mrem (0.53 and 0.99 µSv) from radionuclides that could have been emitted from the ORR; the average EDE could have been 0.069 mrem (0.69 µSv). The average EDE associated with just total strontium and ^{131}I in milk in EPA Region 4 is about 0.090 mrem (0.90 µSv) (EPA 1993). Drinking milk collected several tens of miles to the south of the ORR, beyond its range of measurable influence, could have resulted in an EDE of about 0.077 mrem (0.77 µSv).

For perspective, the doses resulting from the naturally occurring ^{7}Be and ^{40}K in the sampled milk could be between 7.5 and 7.8 mrem (75 and 78 µSv).

Food Crops

Samples of two types of vegetables (tomatoes, lettuce, and turnip greens) were collected from five gardens around the ORR during 1998. These vegetable types are representative of fruit-bearing and leafy vegetables. The samples were found to contain small quantities of ^{7}Be, ^{40}K, ^{60}Co, ^{137}Cs, ^{234}U, ^{235}U, and ^{238}U. All of these radionuclides are found in the natural environment and in commercial fertilizers, and all but ^{7}Be and ^{40}K also are emitted from the ORR. No root crops were sampled this year. The sampling results were used to calculate potential EDEs to persons eating these foods.

Nationwide Food Consumption Survey (NFCS) data were used to estimate consumption rates and potential EDEs for eating home-

Table 8.4. Summary of annual maximum individual EDEs (mrem)[a] from waterborne radionuclides

Type of sample	Drinking water	Eating fish	Other uses	Total of highest
		Melton Hill Lake, CRK 70		
Fish		0.018		
Water	0.56	2.1	0.012	2.7
Discharge	0.000089	0.00013	0.00000086	0.00022
		Upper Clinch River, Gallaher Water Plant, CRK23		
Drinking water	0.095			
Fish		0.032		
Water	0.35	2.3	0.011	2.6
Discharge	0.046	0.075	0.00019	0.12
		Lower Clinch River, CRK 16		
Fish		0.029		
Water		1.7	0.012	1.7
Discharge		0.063	0.00016	0.064
		Upper Watts Bar Lake, Kingston Municipal Water Plant		
Drinking water	0.19			
Discharge	0.012	0.017	0.000044	0.029
		Lower System (Lower Watts Bar Lake and Chicamauga Lake)		
Discharge	0.012	0.017	0.000045	0.029
		Poplar Creek		
Water		2.0	0.0029	2.0
Discharge		0.48	0.00090	0.48

[a]1 mrem = 0.01 mSv.

produced foods (EPA 1997). A home gardener was assumed to have eaten 32 kg (71 lb) of home grown tomatoes and 10 kg (22 lb) of homegrown leafy vegetables during the year.

Based on the sampling data and the assumed food consumption rates, a person who ate home grown produce could have received EDEs between 0.0063 and 0.066 mrem (0.063 and 0.66 µSv) from eating leafy vegetables and between 0.0011 and 0.0031 mrem (0.011 and 0.031 µSv) from eating tomatoes. Thus, a person receiving the maximum potential dose from both types of produce could have received a total EDE of about 0.069 mrem (0.69 µSv) from radionuclides that could have been released from the ORR.

If the doses from the naturally occurring ^{7}Be and ^{40}K are included, the maximum potential dose could have been about 3.3 mrem (33 µSv).

Hay

Another environmental pathway that was evaluated using sampling data is eating beef and drinking milk obtained from bovines that ate hay harvested from the ORR. Hay was collected from one background or reference location and from six ORR locations. Hay from the six ORR locations was combined into three samples. Statistically significant concentrations were found only for ^{7}Be, ^{40}K, and ^{137}Cs. Essentially all of the dose to humans (about 99.9 %) from eating beef and drinking milk from cattle that eat hay was from the naturally occurring ^{40}K and ^{7}Be. Including the contribution from ^{40}K and ^{7}Be, the EDE from drinking milk and eating beef was estimated to be about 14 mrem (0.14 mSv); excluding ^{40}K and

^{7}Be, the EDE was estimated to be about 0.021 mrem (2.1E-4 mSv).

White-Tailed Deer

The Tennessee Wildlife Resources Agency (TWRA) conducted three 2-day deer hunts during 1998 on the Oak Ridge Wildlife Management Area, which is part of the ORR. A total of 336 deer was killed during these hunts and were brought to the TWRA checking station. At the station, a bone 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 less than 20 pCi/g (0.74 Bq/g) of beta-particle activity in bone or 5 pCi/g (0.19 Bq/g) of ^{137}Cs in edible tissue. Three of the deer exceeded the limit for beta-particle activity in bone and were confiscated. The remaining 333 deer were released to the hunters.

The released deer had an average field-dressed weight of about 38.6 kg (85 lb). Because about 55% of the dressed weight is edible meat, the average deer would yield about 21 kg (46.8 lb) of meat. Therefore, based on the average weight, the total harvest of edible meat was about 7062 kg (15,568 lb).

The average ^{137}Cs concentration in tissue of the 333 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 3.3 pCi/g (0.12 Bq/g). No tissue samples from the released deer were subjected to laboratory analysis, which is required to quantitatively determine ^{90}Sr concentrations in the tissue. Therefore, the maximum concentration of ^{90}Sr found in tissue samples from deer harvested on the ORR during 1990–97 was used to estimate potential maximum EDEs from eating deer harvested during 1998. The maximum ^{90}Sr concentration in released deer was 0.4 pCi/g (0.015 Bq/g).

An individual who consumed one average-weight deer containing the 1998 average concentration of ^{137}Cs (0.2 pCi/g) could have received an EDE of about 0.2 mrem (0.002 mSv). The maximum EDE to a hunter who harvested and consumed a deer from the ORR in 1998 was estimated to be 4.3 mrem, based on a ^{137}Cs concentration of 3.33 pCi/g and a maximum ^{90}Sr concentration of 0.4 pCi/g.

The maximum EDE to an individual consuming venison from two or more deer was also evaluated. There were about 20 hunters (individuals or members of a household) who harvested two or three deer from the ORR in 1998. The maximum EDE to a hunter who consumed two harvested deer could have been 2.3 mrem (1 mrem from ^{137}Cs and 1.3 mrem ^{90}Sr). There were two cases where three deer were harvested by hunters within the same household. The maximum EDE to an individual consuming all of the venison from three deer could have been 2.9 mrem (1.6 mrem resulting from ^{137}Cs and 1.3 mrem ^{90}Sr). The collective EDE from eating all the harvested venison with a 1998 average field-derived ^{137}Cs concentration of 0.2 pCi/g (0.007 Bq/g) is estimated to be about 0.07 person-rem (0.0007 person-Sv).

Canada Geese

During the 1998 goose roundup, 112 geese (58 from ORNL, 25 from the ETTP, 4 from the Y-12 Plant, 21 from the Oak Ridge Marina, and 4 from Melton Hill Dam) were weighed and subjected to whole-body gamma scans. Concentrations of ^{137}Cs concentrations detected in 38 geese collected near Building 1505 and the sludge lagoon exceeded the ORNL administrative limit of 5 pCi/g. All of these geese were retained, and an environmental sampling plan was initiated to identify potential sources of the contamination. The estimated EDEs resulting from one individual consuming the meat from any one of the retained geese ranged from 2.3 to 3.9 mrem.

Seventy-four geese did not exceed the administrative limit and were released. The maximum estimated EDE to an individual who consumed a hypothetical released goose with the maximum ^{137}Cs concentration of 3.6 pCi/g and the maximum weight (5.32 kg) was 0.5 mrem (0.005 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, geese of the maximum weight with the highest measured concentration of ^{137}Cs, that person could have received an EDE of about 1 mrem (0.01 mSv).

Eastern Wild Turkey

Two wild turkey hunts were held on the ORR during 1998. A total of 48 birds were harvested; none were retained. The average weight of the turkeys was 8.5 kg (19 lb), and their average ^{137}Cs concentration was 0.2 pCi/g (0.007 Bq/g). A person who ate an average turkey (assuming 50% of weight was edible tissue) could have received an EDE of about 0.04 mrem (0.0004 mSv). The maximum weight of a released turkey was 10.7 kg (23.5 lb), and the maximum ^{137}Cs concentration in a turkey (not the heaviest turkey) was 1.6 pCi/g (0.06 Bq/g). A person who ate a hypothetical turkey (a combination of the heaviest turkey and the highest ^{137}Cs concentration) could have received an EDE of about 0.4 mrem (0.004 mSv). The collective EDE from eating all of the harvested turkey meat with a 1998 average field-derived ^{137}Cs concentration of 0.2 pCi/g (0.007 Bq/g) and average weight of 8.5 kg (19 lb) is estimated to be about 0.002 person-rem (0.00002 person-Sv).

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 1998 was about 5.3 µR/hour. This rate corresponds to an EDE rate of about 36 mrem/year (0.36 mSv/year). Except for two locations, all measured exposure rates at or near 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 1997, 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 8.4 µR/hour (down from 13 µR/hour in 1987) and ranged between 6.9 and 9.3 µR/hour (3.5 and 18 µR/hour in 1987). This corresponds to an average exposure rate of about 2 µR/hour (0.001 mrem/hour) above background.

A potential maximally exposed individual is a hypothetical fisherman who was assumed to have spent 5 hours/week (250 hours/year) near the point of average exposure. This hypothetical maximally exposed individual could have received an EDE of about 0.25 mrem (0.0025 mSv) during 1998.

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. Dose rate measurements taken at nine locations along the creek bank during 1997 ranged between 3.5 and 9.5 µR/hour, which corresponds to an EDE rate between 0.0026 to 0.0071 mrem/hour (between 0.000026 and 0.000071 mSv/hour). The average dose rate was about 6.1 µR/hour, which corresponds to an EDE rate of 0.0046 mrem/hour (0.000046 mSv/hour). A 4-hour fishing trip could have resulted in an EDE of 0.02 mrem (0.0002 mSv). If the hypothetical Clinch River fisherman is used, the 250-hour/year exposure time could have resulted in 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.

8.1.3 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 (see Appendix A for definition of absorbed dose and the rad). 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 8.5 lists average and maximum total dose rates to aquatic organisms from waterways at ORNL, the Y-12 Plant, and the ETTP.

At ORNL, doses to aquatic organisms are based on water concentrations at nine different sampling locations (see Table 8.5): Melton Branch (kilometer 0.2), WOC (kilometers 1.0, 2.6, and 6.8), First Creek, Fifth Creek, Raccoon Creek, Ish Creek, and Northwest Tributary. The results from these calculations indicate that absorbed dose rates to aquatic biota are less than 1 rad/day (0.01 Gy/day). The highest dose rate to fish and crustacea (based on maximum radionuclide concentrations in water) occurred at both Melton Branch (MEK 0.2) and White Oak Creek (WOC 1.0): 2E–3 rad/day (2E–5 Gy/day) and 6E–4 rad/day (6E–6 Gy/day), respectively. The highest dose rate of 6E-3 rad/day (6E-5 Gy/day) to muskrats was associated with the maximum radionuclide concentrations in water at Melton Branch (MEK 0.2). 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 East Fork Poplar Creek at SWHISS 9422-1 (formerly Station 17), Bear Creek at BCK 4.55 (formerly Outfall 304), and Rogers Quarry discharge point S-19 (formerly Outfall 302). At Y-12, the highest dose rates to fish, crustacea, and muskrats (based on maximum radionuclide concentrations in water) occurred at SWHISS 9422-1: 6E–4 rad/day (6E–6 Gy/day) , 3E–3 rad/day (3E–5 Gy/day), and 1E–1 rad/day (1E–2 Gy/day), respectively. The dominant radionuclide contributor to the muskrat dose 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-1007-B and K-1710, Clinch River at K-901-A, and East Fork Poplar Creek (kilometers 0.1 and 5.4). At Mitchell Branch (K-1700), the maximum dose rates to fish, crustacea, and muskrats were 2E–4 rad/day (2E–6 Gy/day), 6E–4 rad/day (6E–6 Gy/day), and 6E–4 rad/day (6E–6 Gy/day), respectively. Even with maximum radionuclide concentrations at these locations, the absorbed doses were 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.

8.1.4 Current-Year Summary

A summary of the maximum EDEs to individuals by pathway of exposure is given in Table 8.6. 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 1998; however, if someone was, that person could have received a total EDE of about 4.2 mrem (0.042 mSv): 0.73 mrem (0.0073 mSv) from airborne emissions, 0.19 mrem (0.0019 mSv) from drinking water from the Kingston plant, 2.3 mrem (0.023 mSv) from eating fish from Upper Clinch River, 1.0 mrem (0.010 mSv) from fishing on Poplar Creek inside the ETTP, and 0.012 mrem (0.00012 mSv) from other water uses on Melton Hill Lake. This dose is about 1.4% 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 5.7 mrem (0.057 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 1998 maximum EDE could not have exceeded about 9.9 mrem (0.099 mSv), or about 9.9% of the limit given in DOE Order 5400.5. For further information, see Table A.2 in Appendix A, which

Table 8.5. 1998 total dose rate for aquatic organisms (rad/day)[a,b]

Measurement location	Fish		Crustacea		Muskrat	
	Av	Max	Av	Max	Av	Max
ORNL						
Upstream locations						
White Oak Creek (WCK 6.8)	3E–8	2E–5	3E–8	4E–5	4E–8	5E–6
On-site stream locations						
Fifth Creek (FIFTHCK 0.1)	NA[c]	1E–4	NA[c]	6E–5	NA[c]	3E–4
First Creek (1STCK 0.1)	6E–8	9E–4	6E–8	2E–4	8E–8	3E–3
Northwest Tributary (NWTK 0.1)	NA[c]	2E–4	NA[c]	7E–5	NA[c]	5E–4
Downstream locations						
Melton Branch (MEK 0.2)	1E–3	2E–3	3E–4	6E–4	4E–3	6E–3
Northwest Tributary (NWTK0.1)	NA[c]	2E–4	NA[c]	7E–5	NA[c]	5E–4
White Oak Creek (WCK 2.6)	3E–4	6E–4	6E–5	3E–4	7E–4	2E–3
White Oak Creek (WCK 1.0)	6E–4	2E–3	2E–4	6E–4	2E–3	3E–3
Ish Creek (ICK 0.7)	2E–5	3E–5	4E–6	5E–6	8E–6	1E–5
Raccoon Creek (RCK 2.0)	NA[c]	2E–4	NA[c]	3E–5	NA[c]	6E–4
Y-12 Plant						
On-site stream locations						
East Fork Poplar Creek (SWHISS 9422-1)	1E–4	6E–4	5E–4	3E–3	1E–2	1E–1
Bear Creek (BCK 4.55)[d]	1E–4	4E–4	7E–4	2E–3	8E–3	5E–2
Rogers Quarry (Outfall S19)[e]	3E–5	3E–4	2E–4	9E–4	2E–5	9E–2
Downstream location						
Bear Creek (BCK 0.6)	1E–5	4E–5	1E–5	6E–5	6E–5	7E–5
ETTP						
Upstream locations						
Poplar Creek (K-1710)	4E–6	2E–5	5E–5	3E–4	2E–5	5E–5
East Fork Poplar Creek (EFK 0.1)	NA[c]	6E–6	NA[c]	6E–6	NA[c]	3E–6
East Fork Poplar Creek (EFK 5.4)	2E–5	3E–5	4E–5	5E–5	6E–6	4E–5
On-site stream location						
Mitchell Branch (K-1700)	4E–5	2E–4	2E–4	6E–4	2E–4	6E–4
Downstream locations						
Poplar Creek (K-1007B)	3E–6	8E–6	8E–5	3E–4	8E–6	2E–5
Clinch River (K-901-A)	6E–6	1E–5	1E–4	3E–4	2E–5	3E–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]Not available; the average radionuclide concentrations were not significantly greater than zero.

[d]Formerly NPDES Outfall 304.

[e]Formerly NPDES Outfall 302.

Table 8.6. Summary of maximum potential radiation dose equivalents to an adult during 1998 and locations of the maximum exposures

Pathway	Location	Effective dose equivalent (mrem)[a]
Gaseous effluents:	Maximally exposed resident to	
Inhalation, immersion, direct radiation from ground, and food chains	Y-12 Plant	0.53
	ORNL	0.69
	ETTP	0.068
	ORR	0.73
Liquid effluents		
Drinking water	Kingston Water Plant	0.19
Eating fish	Clinch River, CRK 23	2.3
Other activities		0.012
Eating deer		4.3[b]
Eating geese		1.0[c]
Eating turkey		0.4[d]
Direct radiation	Clinch River shoreline	0.25
	Poplar Creek (ETTP)	1.0

[a]1 mrem = 0.01 mSv.

[b]From consuming a hypothetical worst possible deer, a combination of the heaviest deer harvested and the highest measured concentrations of ^{137}Cs and ^{90}Sr found in any deer.

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

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

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

The highest imaginable total collective EDE to the population living within a 50-mile (80-km) radius of the ORR was estimated to be about 60 person-rem (0.60 person-Sv). This dose is about 0.023% of the 264,000 person-rem (2640 person-Sv) that this population received from natural sources during 1998.

8.1.5 Five-Year Trends

Dose equivalents associated with selected exposure pathways for the years from 1994 to 1998 are given in Table 8.7. 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 Off-Site Sources

Four off-site facilities could contribute to radiation doses received by members of the public around the ORR. These facilities include a waste processing facility located on Bear Creek Road, a depleted uranium processing facility located on Kerr Hollow Road, a decontamination facility located on Flint Road in Oak Ridge, and a waste processing facility located on Gallaher Road in Kingston.

These facilities submit annual reports to demonstrate compliance with NESHAP regulations. These reports indicate that no individual located in the vicinity of the ORR should have received in EDE in excess of 2.0 mrem (0.020 mSv) because of airborne emissions from these facilities. When combined with doses that could have been caused by emissions from the

Table 8.7. Trends in total effective dose equivalent for selected pathways

Pathway	Effective dose equivalent (mrem)[a]				
	1994	1995	1996	1997	1998
All air	1.7	0.5	0.45	0.41	0.73
Fish consumption	1.6	0.9	1.2	0.96	2.3
Drinking water (Kingston)	0.04	0.15	0.32	0.40	0.19
Direct radiation (Clinch River)	1[b,c]	1[b,c]	1[b,c]	0.25[b]	0.25[b]
Direct radiation (Poplar Creek)	1[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.

ORR, no individual should have received an EDE in excess of EPA or DOE annual limits. No information was obtained about waterborne releases, if any, from these facilities.

8.1.7 Findings

The maximally exposed off-site individual could have received a 50-year committed EDE of about 0.73 mrem (0.0073 mSv) from airborne effluents from the ORR. This dose is below 10 mrem (0.10 mSv) per year, the limit specified in the Clean Air Act for DOE facilities. No individual EDE was calculated that even approaches the 100-mrem/year (1.0-mSv/year) limit prescribed by DOE. The estimated collective committed EDE to the approximately 880,000 persons living within 50 miles (80 km) of the ORR was about 12 person-rem (0.12 person-Sv) for 1998 airborne emissions. This represents about 0.0045% of the 264,000 person-rem (2640 person-Sv) that the surrounding population would receive from all sources of natural radiation.

8.2 CHEMICAL DOSE

8.2.1 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 Primary Drinking Water regulation concentrations that apply to all community 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.

- Tennessee Water Quality Criteria (TN-WQC). Water quality criteria regulations that apply to the control of pollution in various waters or in different sections of the same waters in Tennessee.

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) database, 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, SMCL, and TN-WQC 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 8.8 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.

8.2.2 Methods of Evaluation

8.2.2.1 Airborne Chemicals

Research and facility operations result in the release of small quantities of chemicals to the atmosphere. These releases are allowed under air pollution control rules and do not pose a threat to human health or the environment.

8.2.2.2 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 or intake (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.

Drinking Water

Most chemicals of concern were not detected in Clinch River water, although samples were collected monthly during 1998 (12 samples at each of 3 locations on the Clinch River). Results of the analyses for metals of concern indicated that except for lead, which was detected at 0.13 ppm in one sample (out of 12) at CRK 70, and zinc, which was detected in three samples at CRK 70 and one sample at CRK 16, only aluminum, iron, barium, manganese, and strontium were detected at all locations. Most volatile organic compounds detected were detected at levels below the designated analytical detection limits, and therefore, reported concentrations were estimates with a greater than usual uncertainty.

Hazard Quotient (HQ) ratios for chemical concentrations found in Clinch River surface water are summarized in Table 8.9. The tilde (~) indicates that estimated values and/or detection limits (as a maximum possible value) were used to estimate the average concentration of a chemical in water. 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 both upstream and downstream of the ORR discharge points. Upstream of all DOE

Table 8.8. Chemical reference doses and slope factors used in drinking water and fish intake analysis (1998)

Chemical	Reference dose or slope factor[a]	Reference[b]
Aluminum	5.7E-03	SMCL[c]
Aroclor-1260	1.4E-05	TN-WQC
Arsenic	3.0E-04	RfD
	1.5E+00	SF
Barium	7.0E-02	RfD
Benzene	1.4E-04	MCL
	2.9E-02	SF
Beryllium	2.0E-03	RfD
Boron	9.0E-02	RfD
Copper	3.7E-02	MCL[d]
4,4′-DDE	3.4E-01	SF
Dieldrin	5.0E-05	RfD
	1.6E+01	SF
Endosulfan I, II	6.0E-03	RfD
Ethylbenzene	1.0E-01	RfD
Iron	8.6E-03	SMCL
Lead	4.0E-04	MCL[d]
Manganese	4.7E-02	RfD
Mercury	1.0E-04	RfD[e]
PCBs (mixed)	2.0E+00	SF[f]
Selenium	5.0E-03	RfD
Strontium	6.0E-01	RfD
Tetrachlorothene	1.0E-02	RfD
1,1,1-Trichloroethane	5.7E-03	MCL
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.

[c]Based on the TN SMCL of 0.2 mg/L; the federal SMCL is a range of 0.05–0.2 mg/L.

[d]This is not a true MCL, but an “action level.” When the “action level” of 0.015 mg/L for lead or 1.3 mg/L for copper (measured in the 90th percentile at the consumer’s tap) is exceeded, corrosion control studies and treatment requirements are applicable.

[e]Interim Reference Dose.

[f]The cancer potency of PCB mixtures is determined using a three-tiered approach. This value is the upper bound slope factor for the High Risk and Persistence Tier.

Table 8.9. 1998 chemical hazard quotients for drinking water[a]

Chemical	Hazard quotient		
	CRK 70[b]	CRK 23[c]	CRK 16[d]
Metals			
Aluminum	~1.6	~1.5	~1.5
Barium	~2E–2	~2E–2	~2E–2
Iron	1	1	1
Lead	~6E+0		
Manganese	4E–2	3E–2	3E–2
Strontium	4E–3	4E–3	4E–3
Zinc	~4E–3		~4E–3
Volatile organics			
Benzene			~1.5[e]
Ethylbenzene			~2E-3
Tetrachloroethene		~2E-2	
1,1,1-Trichloroethane	~4E-2		
Toluene		~1E-3	~1E-3

[a]A tilde (~) indicates that estimated values and/or detection limits were used in the calculation, and a blank space indicates the parameter was undetected.
[b]Melton Hill Reservoir above city of Oak Ridge input.
[c]Water supply intake for the ETTP.
[d]Clinch River downstream of all DOE inputs.
[e]Benzene is also considered to be a carcinogen; the I/CDI ratio is ~ 0.3.

discharge points is CRK 70. The Gallaher Water Station (CRK 23), a current drinking water supply intake location for the ETTP, is below the ORNL effluent discharge point, and CRK 16 is a location downstream of all DOE discharge points.

Measured aluminum, iron, and benzene surface water concentrations resulted in HQ values greater than 1 (HQs less than 1 are desirable). HQs greater than 1 for aluminum were observed in both upstream and downstream locations. Only at the upstream location (CRK 70) was an HQ greater than 1 observed for lead, which was reported as detected in only one sample (out of 12 collected). The derivation of the reference dose for both aluminum and iron were the SMCLs (see Appendix B for a discussion of SMCLs used as reference doses). The SMCLs control contaminants in drinking water that primarily affect aesthetic qualities, such as taste and odor. An HQ slightly greater than 1 was estimated for benzene at CRK 16 (Table 8.9). Tildes associated with HQ and I/CDI ratios shown in Table 8.9 indicate that estimated values and/or detection limits were used in the calculation of these surface water chemical concentrations.

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 were analyzed for a number of metals, pesticides, and PCBs. Table 8.10 is a summary of the HQ values and I/CDI ratios derived from average concentrations of chemicals detected in fish samples taken both upstream and downstream from the ORR. A tilde (~) indicates that an estimated value was included in the calculation of the average chemical concentration in fish tissue. This symbol is listed beside the reported HQ values or

Table 8.10. 1998 chemical hazard quotients (HQs) and estimated dose/chronic daily intake (I/CDIs) 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	3E–1	~2E–1	5E-1	1E+0	1E+0	2E+0
Zinc	3E–2	4E–2	3E–2	4E–2	2E–2	2E–2
	HQs for pesticides and Aroclors					
Aroclor-1260	~3E+0	~5E+0	~3E+0	2E+1	9E+0	2E+1
Dieldrin	~2E-1	~2E-1	~1E+0			
Endosulfan I	~1E-3	~9E-4				
	I/CDIs for carcinogens					
4,4′-DDE				5E-1	1E+0	4E-1
Dieldrin	~7E+0	~8E+0	~5E+1			
Total Aroclor (Aroclor -1260)	~4E+0	~6E+0	~4E+0	3E+1	1E+2	3E+1

[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.

I/CDI ratios to indicate the type of data used in the calculation.

In the current assessment, a fish consumption rate of 60 g/day (21 kg/year) is assumed for both the noncarcinogenic and carcinogenic pollutants; this is the same fish consumption rate used in the estimation of the maximally exposed radiological dose from consumption of fish. The fish consumption rate of 60 g/day is similar to the EPA adult reasonable maximum exposure ingestion rate of 54 g/day fish (90th percentile) (EPA 1991a and EPA 1995). The Tennessee Department of Environment and Conservation (TDEC) uses a method developed by the EPA to establish fish consumption advisories for carcinogenic pollutants [as described in TDEC 1200-4-3-.03 (j)]. One of the main differences between the method used in the current assessment and the TDEC fish consumption advisory method is the consumption rate value used to estimate intake. In the TDEC fish consumption advisory method, a default mean daily consumption rate of 6.5 g/day is recommended, unless there is better site-specific consumption rate information. Using the mean daily consumption rate of 6.5 g/day would reduce both the HQ values and the I/CDI values summarized in Table 8.10 by a factor of approximately 10.

For perspective, a recommended mean value for a fish serving size is about 129 g/day (about 5 oz./day), and it is assumed that the average individual eats three to five fish servings per month (EPA 1997). This serving size and the number of fish servings per month results in an annual average consumption rate that ranges between about 5 kg/year to 8 kg/year, considerably less than the 21 kg/year used in this assessment. To examine a worst-case scenario in agreement with the radiological calculations, the carcinogenic effects calculated here using a consumption rate of 21 kg per year assume that the individual consumes 156 5-oz. servings of contaminated fish every year for 70 years. Individuals who subsist on fish caught in local rivers and lakes may in fact have a greater number of fish servings per month as compared to the average individual. However, the majority of individuals that catch fish in the Clinch River are considered to be recreational anglers rather than subsistence anglers.

No HQ values greater than 1 were calculated for consumption of sunfish with the exception of Aroclor 1260. For consumption of catfish, HQ values greater than 1 were calculated for mercury and Aroclor-1260. Only mercury and Aroclor-1260 were detected in catfish tissue at levels of concern, and they were detected in catfish tissue collected at all locations, both upstream and downstream of the ORR. Mercury is known to be a contaminant of potential concern for the fish consumption pathway in the Clinch River (DOE 1996). However, almost 68% of all fish advisories issued in the Unites States are a result of mercury contamination in fish and shellfish (EPA 1999a). Mercury was also used in large quantity at the Y-12 Plant in the past. However, for perspective, according to the most recent EPA information (EPA 1999a), solid waste incineration and fossil fuel combustion facilities contribute approximately 87% of the emissions of mercury in the United States. Except for mercury and zinc, no metals were detected in fish taken from the Clinch River. However, arsenic and selenium have also been identified as contaminants of potential concern in the Clinch River from fish consumption. For these two metals, current analytical detection limits are too high to permit calculation of HQ values less than 1.

Therefore, we are currently pursuing more sensitive analytical procedures to obtain better detection limits. Better detection limits would allow better definition of HQ values for these metals.

Aroclor-1260, a well-known PCB, was detected in catfish tissue at levels that resulted in HQ values greater than 1. An HQ of 20 was calculated for fish taken at CRK 16, below all inputs from the ORR, but an HQ of 20 was also calculated for catfish collected at CRK 70, well above any input from the ORR. Although banned from further production in 1979, Aroclor-1260, as all other types of PCBs, is highly persistent in the environment, and Aroclor-1260, in particular, is a known contaminant of concern for catfish consumption from the entire Clinch River system (DOE 1996).

For carcinogens, I/CDI ratios greater than 1 indicate a cancer risk greater than 10^{-5}. I/CDI ratios greater than 1 were calculated for intake of dieldrin and PCBs (Aroclor-1260) found in sunfish collected both upstream and downstream of the ORR. However, average dieldrin and PCB concentrations were estimated in sunfish tissue from values below the reported analytical detection limits of the instruments. Therefore, actual I/CDI ratios could be less, perhaps much less, than the calculated I/CDI ratios. I/CDI ratios greater than 1 were calculated for PCBs (Aroclor-1260) in catfish collected both upstream and downstream of the ORR. An I/CDI ratio value of 100 was estimated for catfish collected at CRK 32. This I/CDI ratio value means that a fisherman who consumes a 5-oz. portion of catfish from the Clinch River, each portion of which is contaminated with 1.6 ppm of PCBs, and he consumes this three times a week every week for 70 years, increases his cancer risk from 1 in 100,000 to 1 in 1000. This corresponds to an excess cancer risk of approximately 10^{-3} rather than 10^{-5}. 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) . For perspective, as of 1998, 37 states have issued 679 advisories for PCBs. These advisories inform the public that high concentrations of PCBs have been found in local fish at levels of public health concern (EPA 1999b).