6. Dose

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Abstract

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 state and federal criteria.

6.1 RADIATION DOSE

Small quantities of radionuclides were released to the environment from operations at the ORR facilities during 1997. Those releases are quantified and characterized in Chaps. 4, 5, and 7. This chapter presents estimates of potential radiation doses to the public from the releases. The dose estimates, which use the monitored release and environmental monitoring and surveillance data, standard environmental transport codes, and exposure conditions that tend to maximize the calculated dose equivalents, are intended to demonstrate that during 1997, no member of the public received a dose in excess of that allowed by relevant regulatory authorities.

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 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).

6.1.2 Methods of Evaluation

6.1.2.1 Airborne Radionuclides

The radiological consequences of radionuclides released to the atmosphere from ORR operations during 1997 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: Radionuclides (Rad NESHAP), 40 CFR 61, Subpart H, which governs the emissions of radionuclides other than radon from DOE facilities. 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 42 emission points, each of which includes one or more individual sources, on the ORR were modeled during 1997. This total includes 6 points at the Y-12 Plant, 25 points at ORNL, and 11 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 1997 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 stacks X-2001, X-2026, X-2523, X-3018, X-3020, X-3039, X-3074, X-3544, X-3608, X-5505, X-7025, X-STP sludge drier, X-minor grouped sources, X-decommissioned lab hoods, X-Tank W-2X, X-GAAT tanks stack, and X-GAAT tanks vent at ORNL; at the 10-m height, with wind speeds adjusted to 30 m, on Tower MT4 for stacks X-7512, X-7567, X-7569, X-7830, X-7852, X-7860, X-7877, and X-7911 at ORNL; and at the 60-m height on Tower MT1 for all sources at the ETTP. During 1997, rainfall on the ORR was 132 cm (52 in.), as averaged over the four rain gauges located on the ORR. The average air temperature was 14°C (57°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.

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 0.41 mrem (0.0041 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 maximally exposed individual for the ORR is located about 12,200 m (7.6 miles) south-southwest of the 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. The calculated collective EDE to the entire population within 80 km (50 miles) of the ORR (about 879,546 persons) was about 10 person-rem (0.10 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

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

Source name	Type	Release height (m)	Diameter (m)	Gas exit velocity (m/s)	Gas exit temperature (°C)	Distance (m) and direction to maximally exposed individual			
						Plant		ORR	
X-2001	Point	15.24	0.66	8.32	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	0.23	Ambient	4,060	SSW	4,060	SSW
X-3020	Point	61	1.96	6.39	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	0.26	10.2	Ambient	4,060	SSW	4,060	SSW
X-3544	Point	9.53	0.27	23.17	Ambient	4,060	SSW	4,060	SSW
X-3608	Point	10.97	2.44	0.57	Ambient	4,060	SSW	4,060	SSW
X-5505	Point	11	0.3	7.92	Ambient	4,060	SSW	4,060	SSW
X-7025	Point	3.96	0.3	13.66	Ambient	5,710	SW	5,710	SW
X-7512	Point	30.5	0.91	10.43	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	4.55	0.21	12.51	Ambient	2,350	SW	2,350	SW
X-7852	Point	2.13	0.2	2.18	Ambient	2,350	SW	2,350	SW
X-7860	Point	18.29	0.305	3.9	Ambient	2,350	SW	2,350	SW
X-7877	Point	13.9	0.51	9.95	Ambient	2,350	SW	2,350	SW
X-7911	Point	76.2	3.43	2.85	Ambient	3,720	SW	3,720	SW
X-Decommissioned lab hoods	Point	15	NA	NA	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	1.52	0.203	2.91	Ambient	3,500	SSW	3,500	SSW
XW-2X	Point	4.6	NA	NA	Ambient	3,470	SSW	3,470	SSW
X-GAAT tanks stack	Point	1	NA	NA	Ambient	4,060	SSW	4,060	SSW
X-GAAT tanks vent	Point	1	NA	NA	Ambient	4,060	SSW	4,060	SSW
Y-Monitored stacks	Point	20	NA	NA	Ambient	1,080	NNE	12,200	SSW

Table 6.1 (continued)

Source name	Type	Release height (m)	Diameter (m)	Gas exit velocity (m/s)	Gas exit temperature (°C)	Distance (m) and direction to maximally exposed individual			
						Plant		ORR	
Y-Minor processes	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	9.75	0.8	10	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	5.39	79.76	3,650	SSW	6,460	SE
K-1435 waste feed tanks	Point	18.29	NA	NA	Ambient	3,650	SSW	6,460	SE
K-1435-A lab hoods	Point	3.05	NA	NA	Ambient	3,650	SSW	6,460	SE
K-1008-C lab hood	Point	3.96	NA	NA	Ambient	3,200	S	6,720	SE
K-304-5 deposit removal room	Point	0	NA	NA	Ambient	3,420	S	7,330	SE
K-1004-A,-B,-C lab hoods	Point	8.5	NA	NA	Ambient	2,770	SSW	6,390	SE
K-1066-E Yard UF_6 cylinder venting	Point	0	NA	NA	Ambient	2,920	SSE	7,470	ESE
K-1310-DC Rad vacuum cleaning facility	Point	0	0.31	NA	Ambient	2,920	SSE	7,470	ESE
K-1423 Waste mgt. drum crusher	Point	6.1	0.15	NA	Ambient	3,590	S	7,230	SE
K-1775 TVS project	Point	15.24	0.26	1.89	55.06	3,370	SSE	7,830	SE
K-1006 lab hoods	Point	7.62	NA	NA	Ambient	2,680	SSW	6,410	SE

calculated to be 0.33 mrem (0.0033 mSv). This individual is located about 1080 m (0.7 miles) north-northeast of the Y-12 Plant release point. Inhalation and ingestion of uranium radioisotopes (i.e., ^{234}U, ^{235}U, ^{236}U, and ^{238}U) account for about 92% of the dose. The only other radionuclides contributing 1% or more to the dose are ^{239}Pu (1.9%) and ^{239}Np (1.4%). 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 3.0 person-rem (0.030 person-Sv), which is approximately 30% of the collective EDE for the ORR.

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

Table 6.2. Calculated radiation doses to maximally exposed off-site individuals from airborne releases during 1997

Plant	Total effective dose equivalents [mrem (mSv)]	
	Plant max	ORR max
ORNL	0.38 (0.0038)[a]	0.38 (0.0038)
ETTP	0.059 (0.00059)[b]	0.014 (0.00014)
Y-12 Plant	0.33 (0.0033)[c]	0.015 (0.00015)
Entire ORR	*d*	0.41 (0.0041)[e]

[a]The maximally exposed individual is 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 is located 3650 m (2.3 miles) SW 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 6.3. Calculated collective EDEs from airborne releases during 1997

Plant	Effective dose equivalents[a]	
	(Person-rem)	(Person-Sv)
ORNL	5.8	0.058
ETTP	1.2	0.012
Y-12 Plant	3.0	0.030
Entire ORR	10.0	0.10

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

lated to be 0.38 mrem (0.0038 mSv). This individual is located 4060 m (2.5 miles) south-southwest of the X-3039 stack and 3720 m (2.3 miles) southwest of the X-7911 stack. About 76% of this dose is from immersion in airborne ^{41}Ar. Other radionuclides contributing 1% or more to the dose include ^{138}Cs (17%) and ^{212}Pb (1.7%). The contribution of ORNL emissions to the collective EDE to the population residing within 80 km of the ORR was calculated to be about 5.8 person-rem (0.058 person-Sv), which is approximately 58% of the collective EDE for the ORR.

The EDE received by the hypothetical maximally exposed individual for the ETTP was calculated to be 0.059 mrem (0.00059 mSv). This individual is located about 3650 m (2.3 miles) south-southwest of the TSCA Incinerator (K-1435) stack. About 87% of this dose is from ingestion and inhalation of uranium radioisotopes, about 9.0% is from thorium radioisotopes, and about 1.3% 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 1.2 person-rem (0.012 person-Sv), which is approximately 12% 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 remote air monitoring station (RAM) (Fig. 5.3). Hypothetical individuals assumed to reside at the PAMs could have received EDEs between 0.11 and 0.32 mrem/year (0.0011 and 0.0032 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 RAM, which was 0.13 mrem/year (0.0013 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. The EDE calculated at PAM 46 was 0.18 mrem/year (0.0018 mSv/year), which is about 55% of the 0.33 mrem/year (0.033 mSv/year) to the maximally exposed individual modeled by the CAP-88 code. 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 at PAM 39 was 0.17 mrem/year (0.0017 mSv/year), which is about half the 0.38 mrem/year (0.0038 mSv/year) calculated for the maximally exposed individual. This result is not surprising because almost 80% of the dose from ORNL emissions is from emissions of noble gases, which would be not retained in the sampling media used at the PAMs. PAM 35 is located in the direction of, but much closer to, the emission points than is the maximally exposed individual for the ETTP. The EDE calculated at PAM 35 was 0.11 mrem/year (0.0011 mSv/year), which is about twice the 0.059 mrem/year (0.00059 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.

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 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 WOC and 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. For convenience of assessment, surface waters potentially affected by the ORR are divided into six segments that are distinguished by proximity to the ORR and by changes in water flow. These segments are Melton Hill Lake, Upper Clinch River (between Melton Hill Dam and the mouth of Poplar Creek), Lower Clinch River (between Poplar Creek and the Tennessee River), Upper Watts Bar Lake (the Kingston area), the Lower System (the rest of Watts Bar Lake and Chicamauga Lake), and Poplar Creek.

Two types of data are used to estimate potential radiation doses to the public. The first method uses radionuclide concentrations in water and fish that were determined by laboratory analyses of 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 not be considered; 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 1997; the average person, to drink 370 L.

Melton Hill Lake. The only water treatment plant located on Melton Hill Lake that could be affected by discharges from the ORR is a Knox County plant near CRK 58. Water from this plant is not sampled. However, the plant is located near EMP water sampling location CRK 58. A highly exposed individual could have received an EDE of about 0.096 mrem (0.00096 mSv) from drinking this water. The collective dose to the estimated 37,510 persons who drink this water could have been about 1.8 person-rem (0.018 person-Sv). These doses are about 300 times higher than those calculated from radionuclide discharges from the ORR to Melton Hill Lake. (These dose estimates may be high because they are based on water samples taken before processing in the plants.) Individuals drinking water that was sampled upstream of ORR radionuclide inputs could have received EDEs slightly higher than persons drinking water sampled at CRK 58.

Upper Clinch River. The ETTP (Gallaher) water plant draws water from this portion of the Clinch River. Based on water samples taken in the plant, a worker who drank 370 L (half of the worker's total annual water consumption) of this water could have received an EDE of about 0.15 mrem (0.0015 mSv), and the collective EDE to the approximately 2000 ETTP workers could have been about 0.29 person-rem (0.0029 person-Sv). Based on water samples taken from the Clinch River (CRK 23), the worker could have received an EDE of about 0.16 mrem (0.0016 mSv), and the collective EDE could have been about 0.31 person-rem (0.0031 person-Sv). Using radionuclide discharge data, the maximum individual EDE was estimated to be 0.025 mrem (0.00025 mSv); the collective EDE was 0.050 person-rem (0.00050 person-Sv).

Lower Clinch River. There are no water treatment plants that draw water from this segment.

Upper Watts Bar Lake. The Kingston municipal water plant is located near this segment; it 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 0.40 mrem (0.0040 mSv), and the collective EDE to the estimated 7438 water users could have been about 1.5 person-rem (0.015 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 0.015 mrem (0.00015 mSv); the collective EDE was 0.12 person-rem (0.0012 person-Sv). About half the EDEs from drinking sampled water are from ^{238}Pu. The source of this material is puzzling, especially because the Kingston water intake is on the Tennessee River, upstream from its convergence with the Clinch River.

Lower System. Several water treatment plants are located on tributaries of the remainder of Watts Bar Lake and Chicamauga Lake. Persons drinking water from these plants could not have received EDEs greater than about 0.014 mrem (0.00014 mSv). The estimated collective EDE, using discharge data, was about 1.4 person-rem (0.014 person-Sv).

Poplar Creek. There are no water treatment plants that draw water from this segment.

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 1997; the average person, to have consumed 6.9 kg of fish. Measured concentrations of radionuclides in water and calculated concentrations from discharges were input to the LADTAP XL code to calculate EDEs from eating fish.

Melton Hill Lake. Samples of fish were collected at one location (CRK 70) on Melton Hill Lake. Based on analyses of these samples, an avid fish eater could have received an EDE of about 0.040 mrem (0.00040 mSv); the collective EDE could have been 0.017 person-rem (0.00017 person-Sv). Water samples were collected at three locations (CRKs 70, 66, and 58) on Melton Hill Lake. Based on analyses of these samples, an avid fish eater could have received an EDE as high as 0.55 mrem (0.0055 mSv); the collective EDE could have been as high as 0.23 person-rem (0.0023 person-Sv). Based on radionuclide discharges to Melton Hill Lake, an avid fish eater could have received an EDE of 0.00042 mrem (0.0000042 mSv); the collective EDE could have been 0.00017 person-rem (0.0000017 person-Sv).

Upper Clinch River. Samples of fish were collected at one location (CRK 32) on the Upper Clinch River. Based on analyses of these samples, an avid eater could have received an EDE of about 0.034 mrem (0.00034 mSv); the collective EDE could have been 0.0098 person-rem (0.000098 person-Sv). Water samples were collected at two locations (CRK 32 and 23) on Upper Clinch River. Based on analyses of these samples, an avid fish eater could have received an EDE as high as 0.96 mrem (0.0096 mSv); the collective EDE could have been as high as 0.27 person-rem (0.0027 person-Sv). Based on radionuclide discharges to Melton Hill Lake, an avid fish eater could have received an EDE of 0.072 mrem (0.00072 mSv); the collective EDE could have been 0.020 person-rem (0.00020 person-Sv).

Lower Clinch River. Samples of fish were collected at one location (CRK 16) on the Lower Clinch River. Based on analyses of these samples, an avid fish eater could have received an EDE of about 0.045 mrem (0.00045 mSv); the collective EDE could have been 0.013 person-rem (0.00013 person-Sv). Water samples were collected at CRK 16. Based on analyses of these samples, an avid fish eater could have received an EDE as high as 0.31 mrem (0.0031 mSv); the collective EDE could have been as high as 0.088 person-rem (0.00088 person-Sv). Based on radionuclide discharges, an avid fish eater could have received an EDE of 0.068 mrem (0.00068 mSv); the collective EDE could have been 0.019 person-rem (0.00019 person-Sv).

Upper Watts Bar Lake. No fish or water samples were collected from this segment. Discharge data indicate that an avid fish eater could have received an EDE of about 0.020 mrem (0.00020 mSv); the collective EDE could have been 0.051 person-rem (0.00051 person-Sv).

Lower System. No fish or water samples were collected from this segment. Discharge data indicate that an avid fish eater could have received an EDE as high as 0.019 mrem (0.00019 mSv); the collective EDE could have been 0.095 person-rem (0.00095 person-Sv).

Poplar Creek. No fish samples were collected from Poplar Creek. Water samples were taken from locations above and below the ETTP and from East Fork Poplar Creek, just before it joins Poplar Creek. Based on analyses of these samples, an avid fish eater could have received an EDE as high as 0.93 mrem (0.0093 mSv); the collective EDE could have been as high as 0.016 person-rem (0.00016 person-Sv). Based on radionuclide discharges, an avid fish eater could have received an EDE of 0.62 mrem (0.0062 mSv); the collective EDE could have been 0.018 person-rem (0.00018 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.

Melton Hill Lake. Based on the water samples collected at CRKs 70, 66, and 58, a highly exposed other user could have received an EDE as high as 0.015 mrem (0.00015 mSv); the collective EDE could have been as high as 0.032 person-rem (0.00032 person-Sv). Based on radionuclide discharges to Melton Hill Lake, a user could have received an EDE of 0.0000030 mrem (0.000000030 mSv); the collective EDE could have been 0.0000014 person-rem (0.000000014 person-Sv).

Upper Clinch River. Based on the water samples collected at CRKs 32 and 23, a highly exposed other user could have received an EDE as high as 0.014 mrem (0.00014 mSv); the collective

EDE could have been as high as 0.0023 person-rem (0.000023 person-Sv). Based on measured radionuclide discharges from the ORR, a user could have received an EDE of 0.00014 mrem (0.0000014 mSv); the collective EDE could have been 0.000021 person-rem (0.00000021 person-Sv).

Lower Clinch River. Based on the water samples collected at CRK 16, a highly exposed other user could have received an EDE as high as 0.0040 mrem (0.000040 mSv); the collective EDE could have been as high as 0.0034 person-rem (0.000034 person-Sv). Based on measured radionuclide discharges from the ORR, a user could have received an EDE of 0.00012 mrem (0.0000012 mSv); the collective EDE could have been 0.00010 person-rem (0.0000010 person-Sv).

Upper Watts Bar Lake. No water samples were collected from this segment. Discharge data indicate that a highly exposed other user could have received an EDE of about 0.000035 mrem (0.00000035 mSv); the collective EDE could have been 0.00026 person-rem (0.0000026 person-Sv).

Lower System. No water samples were collected from this segment. Discharge data indicate that a highly exposed other user could have received an EDE of about 0.000034 mrem (0.00000034 mSv); the collective EDE could have been 0.0020 person-rem (0.000020 person-Sv).

Poplar Creek. Based on the water samples taken from Poplar Creek and from the lower end of East Fork Poplar Creek, a highly exposed other user could have received an EDE as high as 0.0033 mrem (0.000033 mSv); the collective EDE could have been as high as 0.000035 person-rem (0.00000035 person-Sv). Based on radionuclide discharges, a user could have received an EDE of 0.00061 mrem (0.0000061 mSv); the collective EDE could have been 0.000017 person-rem (0.00000017 person-Sv).

Summary

Table 6.4 is a summary of potential EDEs from waterborne radionuclide discharges. Adding worst-case EDEs for all pathways and all segments indicates that the maximum imaginable EDE could have been about 1.4 mrem (0.014 mSv): 0.4 mrem (0.004 mSv) from drinking Kingston water, plus 0.96 mrem (0.0096 mSv) from eating Upper Clinch River fish, plus 0.015 mrem (0.00015 mSv) from other uses on Melton Hill Lake. The maximum imaginable collective EDE to the 50-mile population was estimated to be about 5.7 person-rem (0.057 person-Sv). These are small percentages of individual and collective doses attributable to natural background radiation, 0.46% and 0.0022%, respectively.

6.1.2.3 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 sampled for total strontium, ^{3}H, ^{40}K, and ^{131}I. Only strontium and ^{40}K were detected in the milk samples. All of these radionuclides are found in the natural environment, and all but ^{40}K are emitted from the ORR. The sampling results seem to be biased high this year, possibly as a result of a change in the method of reporting detection limits. Most of the strontium reported in the samples was below the detection limits and may not have actually been present in the milk. Nevertheless, the sample data were used to calculate potential EDEs to a hypothetical person who drank 310 L of sampled milk during the year.

This hypothetical person could have received an EDE between 0.66 and 1.5 mrem (0.0066 and 0.015 mSv); the average EDE could have been 0.95 mrem (0.0095 mSv) from strontium in milk.

Table 6.4. Summary of maximum individual EDEs (mrem)[a] from waterborne radionuclides

Type of sample	Drinking water	Eating fish	Other uses	Total of highest
		Melton Hill Lake		
Fish		0.040		
Water	0.096	0.55	0.015	0.66
Discharge	0.00032	0.00042	0.0000014	0.00074
		Upper Clinch River		
Drinking water	0.15			
Fish		0.034		
Water	0.16	0.96	0.014	1.1
Discharge	0.025	0.072	0.00014	0.12
		Lower Clinch River		
Fish		0.045		
Water		0.31	0.0040	0.31
Discharge		0.068	0.00012	0.068
		Upper Watts Bar Lake		
Drinking water	0.40			0.40
Discharge	0.015	0.020	0.000035	0.035
		Lower System (Lower Watts Bar Lake and Chicamauga Lake)		
Discharge	0.014	0.019	0.000034	0.033
		Poplar Creek		
Water		0.93	0.0033	0.93
Discharge		0.62	0.00061	0.62

[a]1 mrem = 0.01 mSv.

The average EDE associated with drinking milk in EPA Region 4 is about 0.09 mrem (0.0009 mSv) (EPA 1993a). However, drinking milk collected several tens of miles to the south, beyond the range of measurable influence of the ORR could have resulted in an EDE of about 2.6 mrem (0.026 mSv).

For perspective, the hypothetical person could have received an EDE of about 200 mrem (2.0 mSv) from the ^{40}K in milk. This EDE seems unrealistically high, largely because the reported concentrations of potassium seem too high when considered in terms of expected doses from naturally occurring radionuclides.

Honey

The honey sampling program was discontinued in 1997. Previous sampling campaigns indicated that any doses received from honey would be low. For example, a hypothetical person who consumed 1 kg (2.2 lb) of honey during 1996 could have received an EDE of between 0 and 0.06 mrem (0 and 0.0006 mSv) from radionuclides that could have been emitted from ORR facilities.

Food Crops

Samples of three types of vegetables (tomatoes, lettuce, and turnips) were collected from five representative gardens surrounding the ORR during 1997. These vegetable types are representative of fruit-bearing, leafy, and root vegetables. 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-produced foods (EPA 1997). A home gardener was assumed to have eaten 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.

Based on the sampling data and the assumed food consumption rates, a typical home gardener who ate all three vegetable types could have received an EDE of about 3.4 mrem (0.034 mSv), about 1.2 mrem (0.012 mSv) from fruit-bearing vegetables, about 0.7 mrem (0.007 mSv) from leafy vegetables, and about 1.5 mrem (0.015 mSv) from root vegetables (Table 6.5). Essentially all (about 99.8%) of these doses result from the presence of ^{40}K, which is strictly a naturally occurring radionuclide in foods. Excluding the EDE from ^{40}K, the home gardener could have received an EDE of about 0.008 mrem (0.00008 mSv). This EDE is attributed to the other radionuclides detected in the vegetables, including ^{238}U, ^{7}Be, ^{60}Co, and ^{137}Cs. Although these radionuclides are measured in emissions from the ORR, the uranium isotopes and ^{7}Be also occur naturally in soil and fertilizers that are spread on gardens, and ^{60}Co and ^{137}Cs also are present in the environment because of weapons testing. No weapons testing has ever occurred in the Oak Ridge area. Most of the radioactivity found in the vegetables and the associated radiation doses may be attributable to radionuclides found in the environment, not radionuclides emitted by operations on the ORR.

Table 6.5. Average EDEs from ingesting vegetables grown at ORR ambient air monitoring stations, 1997

Vegetable	EDE [mrem (mSv)]	
	All reported radionuclides	Excluding ^{40}K
Tomatoes	1.2E+00 (1.2E–02)	3.0E-03 (3.0E–05)
Lettuce	7.0E–01 (7.0E–03)	1.9E-03 (1.9E–05)
Turnips	1.5E+00 (1.5E–02)	3.0E-03 (3.0E–05)
Total	3.4E+00 (3.4E–02)	8.0E-03 (8.0E–05)

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 location and from six ORR locations. Hay from six ORR locations were combined into three samples. Statistically significant concentrations were found only for ^{7}Be and ^{137}Cs. Beryllium-7 is a naturally occurring radionuclide, and ^{137}Cs may be present from previous weapons testing. (Note that no ^{137}Cs was found in sampled milk.) The EDE from drinking milk and eating beef during 1997 was estimated to be about 0.1 mrem (0.001 mSv), mostly from the presence of ^{137}Cs. In previous years, ^{40}K, a naturally occurring radionuclide that was not measured in 1997, was the primary contributor to the EDE from drinking milk and eating beef from bovines that consumed ORR-grown hay.

White-Tailed Deer

The TWRA conducted three 2-day deer hunts during 1997 on the Oak Ridge Wildlife Management Area, which is part of the ORR. A total of 438 deer were 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. Nine of the deer exceeded the limit for beta-particle activity in bone and were confiscated. The remaining 429 deer were released to the hunters.

The released deer had an average field-dressed weight of about 37 kg (82 lb). Because about 55% of the dressed weight is edible meat, the average deer would yield about 20 kg (44 lb) of meat. Therefore, based on the average weight, the total harvest of edible meat was about 8600 kg (18,960 lb).

The average ^{137}Cs concentration in tissue of the 429 released deer, as determined by field counting, was 0.07 pCi/g (0.003 Bq/g); the maximum ^{137}Cs concentration in a deer was 1.37 pCi/g (0.05 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 during 1996 was used to estimate EDEs from eating deer harvested during 1997. This concentration was 0.002 pCi/g (0.00007 Bq/g).

An individual who consumed one average-weight deer containing the 1997 average concentration of ^{137}Cs (0.07 pCi/g) could have received an EDE of about 0.07 mrem (0.00007 mSv). The maximum likely EDE could be to a hunter who harvests and consumes two deer. During 1997, such a hunter could have received an EDE of about 1 mrem (0.01 mSv) from consuming two deer that had field-dressed weights of 80.5 and 85.5 lb (36.5 and 38.9 kg) and field-determined ^{137}Cs concentrations of 0.57 and 0.48 pCi/g (0.037 and 0.018 Bq/g). The maximum hypothetical EDE, about 3 mrem (0.03 mSv), would result from consuming a hypothetical deer, namely, the heaviest deer harvested containing the highest field-determined concentration of ^{137}Cs (1.37 pCi/g) and the maximum 1996 ^{90}Sr concentration.

The collective EDE from eating all the harvested deer meat with an 1997 average field-derived ^{137}Cs concentration of 0.07 pCi/g (0.003 Bq/g) is estimated to be about 0.03 person-rem (0.0003 person-Sv).

Canada Geese

During the 1997 goose roundup, 83 geese (39 from ORNL, 28 from the ETTP, and 16 from Melton Hill Dam) were weighed and subjected to whole-body gamma scans. Only one goose was retained. The average weight of the scanned geese was about 4 kg (9 lb); the heaviest goose weighed 5.2 kg (11.4 lb). Approximately half the weight of a goose is edible. The average ^{137}Cs concentration was 0.07 pCi/g (0.003 Bq/g); the maximum concentration was 0.69 pCi/g (0.03 Bq/g).

No ^{90}Sr analyses were performed during 1997. However, in 1995, 11 local geese and 6 geese from a background location were sacrificed and tissue, bone, and thyroid samples were collected and analyzed. The 1995 average ^{90}Sr concentration in tissue was approximately 7 pCi/g (0.3 Bq/g); the maximum concentration was 11 pCi/g (0.41 Bq/g).

If one person consumed an average-weight goose that contained the 1997 average concentration of ^{137}Cs and the 1995 average concentration of ^{90}Sr, that person could have received an EDE of about 2 mrem (0.02 mSv). The highest possible EDE, from eating a hypothetical goose (a combination of the heaviest goose and the maximum ^{137}Cs and ^{90}Sr concentrations), could have been about 4.5 mrem (0.045 mSv).

It is possible that one person could have eaten more than one goose that spent time on the ORR. If one person consumed nine average geese, that person could have received an EDE of about 18 mrem (0.18 mSv). This is a conservative assumption because most hunters harvest on average one to two geese per hunting season (USFWS 1995).

Goose harvest data for the 1997–1998 hunt season were not available from the state at the time of this report. Using average (1983 to 1996) goose harvest data for regions that include Anderson, Knox, Loudon, and Roane counties and weighting this data based on 1996 goose harvest per county, approximately 817 geese could have been harvested in the four counties (TWRA, 1997). Of the total number of geese harvested in the four counties, it is possible that 302 of these geese could have spent time on the ORR. The collective EDE from consuming 302 average geese could have been about 0.60 person-rem (0.0060 person-Sv).

Eastern Wild Turkey

Two wild turkey hunts were held on the ORR during 1997. A total of 90 birds were harvested; 1 was retained. The average weight of the turkeys was 8.5 kg (19 lb), and their average ^{137}Cs concentration was 0.1 pCi/g (0.004 Bq/g). A person who ate an average turkey could have received an EDE of about 0.021 mrem (0.00021 mSv). The maximum weight of a released turkey was 10.7 kg (23.5 lbs), and the maximum ^{137}Cs concentration in a turkey (not the heaviest turkey) was 0.62 pCi/g (0.023 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 0.17 mrem (0.0017 mSv).

In addition to the turkey hunt, a turkey roundup was conducted during January and February 1997 to provide baseline data prior to conducting the wild turkey hunt. Approximately 31 turkeys were whole-body gamma scanned, and tissue samples from 6 sacrificed turkeys were analyzed. The maximum concentrations of ^{137}Cs and ^{90}Sr measured in tissue samples were 0.12 pCi/g (0.044 Bq/g) and 0.22 pCi/g (0.0081 Bq/g), respectively. The heaviest roundup turkey weighed 9.9 kg (22 lb). A person who ate a hypothetical turkey (a combination of the heaviest turkey and the highest ^{137}Cs and ^{90}Sr concentrations) could have received an EDE of about 0.03 mrem (0.0003 mSv).

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 1997 was about 5.4 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 1997.

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.

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 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 6.6): 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). At ORNL, the highest dose rates, which were associated with maximum concentrations of radionuclides in water, occurred at First Creek: 9E–3 rad/day (9E–5 Gy/day) to fish, 6E–3 rad/day (6E–5 Gy/day) to crustacea, and 4E–2 rad/day (4E–4 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 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). Maximum calculated dose rates to fish and muskrats were 7E–04 rad/day (7E–06 Gy/day) and 1E–1 rad/day (1E–3 Gy/day), respectively, at SWHISS 9422-1. The dominant radionuclide contributor to the muskrat dose was ^{228}Ra, a decay product of ^{232}Th, a naturally occurring radionuclide. The maximum calculated dose rate to crustacea was 4E–3 rad/day (4E–5 Gy/day) at BCK 4.55.

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 (upstream of the ETTP), Clinch River at K-901-A, East Fork Poplar Creek (kilometers 0.1 and 5.4), and at Bear Creek (BCK 0.6). At East Fork Poplar Creek (kilometer 5.4), the maximum dose rates to fish and muskrats were 1E–4 rad/day (1E–6 Gy/day) and 2E–2 rad/day (2E–4 rad/day), respectively. At Mitchell Branch (K-1700) the maximum dose rate to crustacea was estimated to be 4E–4 rad/day (4E–6 Gy/day). 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.

6.1.4 Current-Year Summary

A summary of the maximum EDEs to individuals by pathway of exposure is given in Table 6.7 It is very unlikely (if not impossible) that any real person could have been irradiated by all of these sources and pathways for the duration of 1997; however, if someone was, that person could have received a total EDE of about 2.8 mrem (0.028 mSv): 0.41 mrem (0.0041 mSv) from

Table 6.6. 1997 total dose rate for aquatic organisms (rad/day)[a,b]

Measurement location	Fish		Crustacea		Muskrat	
	Av	Max	Av	Max	Av	Max
ORNL						
Melton Branch (K 0.2)	1E–3	2E–3	3E–4	6E–4	3E–3	6E–3
White Oak Creek (K 1.0)	8E–4	2E–3	3E–4	5E–4	2E–3	3E–3
White Oak Creek (K 2.6)	4E–4	7E–4	1E–4	2E–4	1E–3	2E–3
White Oak Creek (K 6.8)	7E–8	1E–7	7E–8	1E–7	1E–7	2E–7
First Creek	7E–3	9E–3	6E–3	6E–3	3E–2	4E–2
Fifth Creek	6E–5	8E–5	1E–5	1E–5	2E–4	3E–4
Northwest Tributary	2E–4	4E–4	6E–5	1E–4	7E–4	1E–3
Raccoon Creek	9E–5	2E–4	2E–5	3E–5	3E–4	6E–4
Ish Creek	2E–5	3E–5	4E–5	6E–5	5E–6	8E–6
Y-12 Plant						
East Fork Poplar Creek (SWHISS 9422-1)	1E–4	7E–4	5E–4	3E–3	1E–2	1E–1
Bear Creek (BCK 4.55)[c]	2E–4	6E–4	9E–4	4E–3	3E–2	9E–2
Rogers Quarry (Outfall S19)[d]	4E–5	3E–4	2E–4	1E–3	4E–3	8E–2
ETTP						
Mitchell Branch (K-1700)	2E–5	5E–5	1E–4	4E–4	1E–4	2E–4
Poplar Creek (K-1007B)	2E–6	4E–6	3E–5	1E–4	6E–6	1E–5
Poplar Creek (K-1710) upstream of the ETTP	3E–6	9E–6	5E–6	8E–5	1E–5	4E–5
Clinch River (K-901-A)	5E–6	1E–5	8E–5	2E–4	1E–5	3E–5
East Fork Poplar Creek (K0.1)	3E–5	4E–5	7E–5	7E–5	6E–3	6E–3
East Fork Poplar Creek (K5.4)	1E–4	1E–4	2E–4	2E–4	2E–2	2E–2
Bear Creek (BCK 0.6)	3E–5	4E–5	5E–5	6E–5	9E–5	1E–4

[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.

Table 6.7. Summary of maximum potential radiation dose equivalents to an adult during 1997 and locations of the maximum exposures

Pathway	Location	Effective dose equivalent (mrem)[a]
Gaseous effluents:	Maximally exposed resident to	
Inhalation,	Y-12 Plant	
immersion, direct	ORNL	0.33
radiation from	ETTP	0.38
ground, and food	ORR	0.059
chains		0.41
Liquid effluents		
Drinking water	Kingston Water Plant	0.40
Eating fish	Clinch River, CRK 23	0.96
	Clinch River, CRK 58	
Other activities		0.015
Eating deer		3.0[b]
Eating geese		4.5[c]
Eating turkey		0.2[d]
Direct radiation	Clinch River shoreline	0.25
	Poplar Creek (ETTP)	1.0

[a]1 mrem = 0.01 mSv.

[b]Hypothetical deer = the heaviest deer containing highest measured concentrations of ^{137}Cs and ^{90}Sr.

[c]Hypothetical goose = the heaviest goose containing highest measured concentration of ^{137}Cs and ^{90}Sr.

[d]Hypothetical turkey = the heaviest turkey containing highest measured concentration of ^{137}Cs.

airborne emissions, 0.40 mrem (0.0040 mSv) from drinking water from the Kingston plant, 0.96 mrem (0.0096 mSv) from eating fish from Upper Clinch River, 1 mrem (0.01 mSv) from fishing on Poplar Creek inside the ETTP, and 0.015 mrem (0.00015 mSv) from other water uses on Melton Hill Lake. This dose is about 0.93% of the annual dose [300 mrem (3 mSv)] from background radiation. If this person also was the person who received the highest EDEs from eating wildlife harvested on the ORR, that person could not have received an additional committed EDE greater than about 7.7 mrem (0.077 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 1997 maximum EDE could not have exceeded about 10.5 mrem (0.105 mSv), or about 10.5% 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.

The total collective EDE to the population living within a 50-mile (80-km) radius of the ORR was estimated to be about 17 person-rem (0.17 person-Sv). This dose is about 0.0064% of the 264,000 person-rem (2640 person-Sv) that this population received from natural sources during 1997.

6.1.5 Five-Year Trends

Dose equivalents associated with selected exposure pathways for the years from 1993 to

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

Pathway	Effective dose equivalent (mrem)[a]				
	1993	1994	1995	1996	1997
All air	1.4	1.7	0.5	0.45	0.41
Fish consumption	0.2	1.6	0.9	1.2	0.96
Drinking water (Kingston)	0.07	0.04	0.15	0.32	0.40
Direct radiation (Clinch River)	1[b]	1[b,c]	1[b,c]	1[b,c]	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.

1997 are given in Table 6.8. The variations in values over this 5-year period likely are not statistically significant. The dose estimates for direct irradiation along the Clinch River have been corrected for background.

6.1.6 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 Illinois Avenue, 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 NESHAPs regulations. These reports indicate that no individual located in the vicinity of the ORR should have received in EDE in excess of 0.20 mrem (0.0020 mSv) because of airborne emissions from these facilities. When combined with doses that could have been caused by emissions from the 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.

6.1.7 Findings

The maximally exposed off-site individual could have received a 50-year committed EDE of about 0.41 mrem (0.0041 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. No individual EDE was calculated that even approaches the 100-mrem/year (1.0-mSv/year) limit prescribed by the DOE. The estimated collective committed EDE to the about 880,000 persons living within 50 miles (80 km) of the ORR was about 10 person-rem (0.10 person-Sv) for 1997 airborne emissions. This represents about 0.004% of the 264,000 person-rem (2640 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 Primary 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

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. (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 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.

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
Aldrin	1.7E+01	SF
Aluminum	5.7E–03	SMCL
Antimony	4.0E–04	RfD
Aroclor-1016	7.0E–05	RfD
Aroclor-1221	1.25E–08	TN WQC
Aroclor-1232	1.25E–08	TN WQC
Aroclor-1242	1.25E–08	TN WQC
Aroclor-1248	1.25E–08	TN WQC
Aroclor-1254	2.0E–05	RfD
Aroclor-1260	1.25E–08	TN WQC
Arsenic	3.0E–04	RfD
Barium	7.0E–02	RfD
Beta-BHC	4.0E–06	TN WQC
Beryllium	2.0E–03	RfD
Boron	9.0E–02	RfD
2-Butanone	6.0E–01	RfD
Cadmium	5.0E–04	RfD
Carbon disulfide	1.0E–01	RfD
Chlordane (alpha, gamma)	5.0E–04	RfD
Chloride	7.1E+00	SMCL
Chromium (VI)	5.0E–03	RfD
Copper	3.7E–02	MCL
4,4′-DDD	2.4E–01	SF
4,4′-DDE	3.4E–01	SF
4,4′-DDT	5.0E–04	RfD
Dieldrin	1.6E+01	SF
Endosulfan I, II	6.0E–03	RfD
Endosulfan sulfate	3.1E–03	TN WQC
Endrin	3.0E–04	RfD
Endrin aldehyde	2.2E–05	TN WQC
Fluoride	6.0E–02	RfD
Heptachlor	5.0E–04	RfD
Heptachlor epoxide	1.3E–05	RfD
Iron	8.6E–03	SMCL
Lead	4.0E–04	MCL

Table 6.9 (continued)

Chemical	Reference dose or slope factor[a]	Reference[b]
Manganese	4.7E–02	RfD
Mercury	5.7E–05	MCL
Methoxychlor	5.0E–03	RfD
Nickel (soluble salts)	2.0E–02	RfD
Nitrate	1.6E+00	RfD
PCBs (mixed)	2.0E+00	SF
Selenium	5.0E–03	RfD
Silver	5.0E–03	RfD
Strontium	6.0E–01	RfD
Sulfate	1.4E+01	MCL
Thallium	8.0E–05	RfD
Toluene	2.0E–01	RfD
Toxaphene	1.1E+01	SF
Uranium (soluble salts)	3.0E–03	RfD
Vanadium	7.0E–03	RfD
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 an RfD (mg kg^{-1} day^{-1}), the concentration was multiplied by the consumption rate (2 L/day) and divided by the mass of a reference man, 70 kg.

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 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 for upstream and downstream of the ORR discharge points. Upstream of all DOE discharge point 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, antimony, iron, lead, thallium, and vanadium surface water concentrations resulted in HQ values greater than 1 (HQs less than 1 are desirable). HQs greater than 1 for aluminum, iron, lead, and vanadium were observed in both upstream and downstream locations. 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. Tildes associated with HQs shown in Table 6.10 indicate that estimated values and/or detection limits were used in the calculation of these surface water chemical concentrations.

Table 6.10. 1997 chemical hazard quotients for drinking water[a]

Chemical	Hazard quotient		
	CRK 70[b]	CRK 23[c]	CRK 16[d]
Metals			
Aluminum	~1.3	~1.4	~2.1
Antimony		~3.2	
Barium	~3E–2	~3E–2	4E–2
Boron	6E–3	7E–3	7E–3
Chromium	~5E–2	~5E–2	~5E–2
Copper	~4E–3	~7E–3	
Iron	~1.2	~1	1.6
Lead	~3E+1	~3	
Manganese	~4E–2	3E–2	4E–2
Stronium	4E–3	4E–3	4E–3
Thallium	~2E+1		
Uranium	~4E–3	~4E–3	~4E–3
Vanadium	~1.3	~1.3	
Zinc	~3E–3	~2E–3	~2E–3
Volatile organics			
Acetone	~2E–3	~2E–3	~2E–3
2-Butanone	~4E–4	~4E–4	~4E–4
Toluene	~6E–4		
Xylene	~6E–5		

[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.

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 6.11 is a summary of the HQs and I/CDI ratios derived from average concentrations of chemicals detected in fish samples taken both upstream and downstream from the ORR.

Antimony, arsenic, and lead concentrations in catfish tissue resulted in HQs greater than 1. HQs greater than 1 for these metals were found in catfish collected both upstream and downstream of the ORR. An HQ greater than 1 was found for mercury in sunfish collected at CRK 16, which is downstream from the ORR. HQs greater than 1 were estimated for benzene hexachloride (BHC) and Aroclors (-1221, -1232, -1242, -1248, -1254, and -1260) in sunfish samples collected at CRK 16. HQs greater than 1 for Aroclor-1260 were also

Table 6.11. 1997 chemical hazard quotients (HQs) for metals 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						
Antimony				<3E+0	<3E+0	<3E+0
Arsenic				<4E+0	<4E+0	<4E+0
Beryllium				<4E–3	<4E–3	<4E–3
Cadium				<1E–1	<2E–1	<1E–1
Chromium	~4E–2		~7E–2	<5E–2	<5E–2	<5E–2
Copper	7E–3	8E–3	5E–3			
Lead				<3E+0	<3E+0	<3E+0
Mercury	~6E–1	6E–1	2E+0			
Nickel			~8E–3	<1E–2	<1E–2	<1E–2
Selenium		~2E–1		<2E–1	<3E–1	<2E–1
Silver				<3E–2	<3E–2	<3E–2
Zinc	4E–2	4E–2	5E–2			
HQs for pesticides and Aroclors						
Chlordane			1E–1			
Benzine hexachloride (alpha, beta)			~1E+0			
Gamma BHC			~6E–1			
4,4′-DDT			~2E–2			
Endosulfan I			~7E–4			
Endosulfan II			~1E–3			
Endosulfan sulfate			~3E–3			
Endrin			~3E–2			
Endrin aldehyde			~4E–1			
Heptachlor			~8E–3			
Heptachlor epoxide			~3E–1			
Methoxychlor			~8E–3			
Aroclor-1016			~7E–1			
Aroclor-1221			~4E+3			
Aroclor-1232			~4E+3			
Aroclor-1242			~4E+3			
Aroclor-1248			~4E+3			
Aroclor-1254			~3E+0			
Aroclor-1260	~2E+3	~1E+3	~2E+3			
I/CDIs for carcinogens						
Aldrin			~7E+0			
4,4′-DDD			~2E–1			
4,4′-DDE			~3E–1			
Dieldrin			~1E+1			
Toxaphene			~7E+0			

[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 Oak Ridge city input.
[c]Clinch River, downstream of ORNL.
[d]Clinch River, downstream of all DOE inputs.

determined in sunfish collected upstream of the ORR. None of these chemicals were detected in catfish samples. However, more sunfish samples were collected than catfish samples. In many cases, the hazard quotients, especially for pesticides and Aroclors, 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 1 indicate a risk greater than 10^{-5}. In sunfish collected downstream of ORR, I/CDIs greater than 1 were estimated for aldrin, dieldrin, and toxaphene (Table 6.11). Because of analytical detection limitations, the actual fish tissue concentrations are unknown.