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 0.4 mrem (less than 1 mrem) from radionuclides emitted to the atmosphere from all of the sources on the ORR in 2000; 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 (e.g., drinking water, eating fish, swimming, wading, and shoreline use) gives a maximum possible individual dose of about 1.3 mrem, which is a small percentage of the individual dose attributable to natural background radiation (~0.43%)

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 2000 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 0.02 mrem; and a person who ate an average turkey could have received a dose of 0.03 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 8 mrem for deer, 0.2 mrem for two geese, and 0.2 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 2000. Those releases are described, characterized, and quantified in previous chapters of this report. This chapter presents estimates of potential radiation doses to the public from the releases. These dose estimates are intended to demonstrate that no member of the public received a dose during 2000 in excess of those allowed by relevant regulatory authorities. The dose estimates are performed using monitored and estimated release data, environmental monitoring and surveillance data, estimated exposure conditions that tend to maximize the calculated dose equivalents, and environmental transport and dosimetry codes that also tend to overestimate the calculated dose equivalents. Thus, the presented dose estimates do not necessarily reflect doses received by typical people in the vicinity of the ORR; they likely are overestimates.

8.1.1 Terminology

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 G. 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 rem of effective dose equivalence, regardless of radiation type and method of delivery, has the same total radiological (in this case, also biological) risk effect. Because the doses being considered here are very small compared with the rem, EDEs are usually expressed in millirem (mrem), which is 1/1000 of a rem. (See Appendix G, Table G.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 2000 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 66 emission points, each of which includes one or more individual sources, on the ORR was modeled during 2000. This total includes 11 points at the Y-12 Complex, 45 points at ORNL, and 10 points at the ETTP. Table 8.1 is a list of the emission point parameter values and receptor locations used in the dose calculations.

Meteorological data used in the calculations for 2000 were in the form of joint frequency distributions of wind direction, wind speed class, and atmospheric stability category. (See Table 8.2 for a summary of tower locations used to model the various sources.)

During 2000, rainfall, as averaged over the four rain gauges located on the ORR, was 135.3 cm (53.3 in.). The average air temperature was 14.3°C (57.7°F), and the average mixing-layer height was 1000 m (3280 ft).

For occupants of residences, the dose calculations assume that the occupant remained at home (actually, 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 are produced in the local area (e.g., a home garden). The remaining portion of each food is assumed to be produced within 80 km (50 miles) of the ORR. The same assumptions are used for occupants of businesses, but the resulting doses are divided by 2 to compensate for the fact that businesses are occupied for less than one-half a year and that less than one-half of a worker’s food intake occurs at work. For collective EDE estimates, production of beef, milk, and crops within 80 km of the ORR was calculated using the state-specific production rates provided with CAP-88.

Results

Calculated EDEs from radionuclides emitted to the atmosphere from the ORR are listed in

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

Source name	Release height (m)	Stack diameter (m)	Effective exit gas velocity (m/s)	Exit gas temperature (°C)	Plant		ORR	
					Distance (m)	Direction	Distance (m)	Direction
ORNL								
X-2001	15.24	0.66	7.44	Ambient	3820	SSW	9650	NE
X-2026	22.9	1.05	10.36	Ambient	3900	SSW	9520	NE
X-2099	3.658	0.254	8.6	Ambient	3900	SSW	9520	NE
X-2523	7	0.3	4.53	Ambient	3640	SSW	9740	NE
X-3018 Graphite Reactor	61	4.11	0.23	Ambient	4090	SSW	9310	NE
X-3020	61	1.96	6.55	Ambient	4090	SSW	9310	NE
X-3039	76.2	5.68	2.59	Ambient	4010	SSW	9350	NE
X-3074 group	4	0.26	10.2	Ambient	4090	SSW	9310	NE
X-3505 grouped EW	6.09	0.51	13.78	Ambient	3700	SSW	9610	NE
X-3544	9.53	0.27	17.9	Ambient	3700	SSW	9610	NE
X-3608 air stripper	10.97	2.44	0.57	Ambient	3740	SSW	9550	NE
X-3608 filter press	8.99	0.36	13.91	Ambient	3740	SSW	9550	NE
X-5505 north/south ducts	11	0.91	21.68	Ambient	4360	SSW	8900	NNE
X-5505 main duct	11	0.29	3.88	Ambient	4360	SSW	8900	NNE
X-7025	4	0.3	13.47	Ambient	5700	SW	7560	NNE
X-7503	30.5	0.91	14.28	Ambient	3890	SW	9370	NNE
X-3003-A tank	1	0.36	0	Ambient	4090	SSW	9310	NE
X-7567	3.8	0.31	2	Ambient	3890	SW	9370	NNE
X-7569	4	0.15	2.6	Ambient	3890	SW	9370	NNE
X-7830	4.6	0.21	11.22	Ambient	2480	SW	10840	NNE
X-7852	2.13	0.2	2.2	Ambient	2480	SW	10840	NNE
X-7860	18.29	0.31	3.9	Ambient	2480	SW	10840	NNE
X-7877	13.9	0.51	8.61	Ambient	2480	SW	10840	NNE
X-7911	76.2	3.43	2.9	Ambient	3680	SW	9650	NNE
X-7966	6.096	0.2921	12.17	Ambient	3680	SW	9650	NNE
X-decommissioned hoods and facilities	15	NA	0	Ambient	4010	SSW	9350	NE
X-in-service lab hoods	15	NA	0	Ambient	4010	SSW	9350	NE
X-3618	1	0.36	0	Ambient	3740	SSW	9550	NE
X-7852 OHF tanks	1	0.36	0	Ambient	2480	SW	10840	NNE
X-STP sludge drier	7.6	0.203	11.16	Ambient	3550	SSW	9780	NE
X-South Tank Farm (W8/W9)	1.22	0.16	0	Ambient	3550	SSW	9780	NE
X-7856-CIP (MVST)	18.29	0.58	12.63	Ambient	2480	SW	10840	NNE
X-T-14 tank	1	0.36	0	Ambient	3550	SSW	9780	NE
X-W1 tank	1	0.36	0	Ambient	3550	SSW	9780	NE
X-W1A tank	1	0.36	0	Ambient	3550	SSW	9780	NE
X-WC-1 tank	1	0.36	0	Ambient	3550	SSW	9780	NE
X-WC-4 tank	1	0.36	0	Ambient	3550	SSW	9780	NE
X-WC-10 tank	1	0.36	0	Ambient	3550	SSW	9780	NE
X-WC-11 tank	1	0.36	0	Ambient	3550	SSW	9780	NE
X-WC-12 tank	1	0.36	0	Ambient	3550	SSW	9780	NE
X-WC-13 tank	1	0.36	0	Ambient	3550	SSW	9780	NE
X-WC-15 tank	1	0.36	0	Ambient	3550	SSW	9780	NE
X-WC-17 tank	1	0.36	0	Ambient	3550	SSW	9780	NE
X-W23T	4.6	0.3	0	Ambient	3550	SSW	9780	NE
X-TH-4	1.22	0.16	0	Ambient	3550	SSW	9780	NE

Table 8.1 (continued)

Source name	Release height (m)	Stack diameter (m)	Effective exit gas velocity (m/s)	Exit gas temperature (°C)	Plant		ORR	
					Distance (m)	Direction	Distance (m)	Direction
ETTP								
K-33 BNFL D&D workshop vents	22.86	1.37	0	Ambient	1320	SE	14840	ENE
K-1004-D lab hood	7.3	NA	0	Ambient	470	WNW	14040	ENE
K-1008-C respirator cleaning facility	4.52	0.51	10.46	Ambient	385	SW	13870	ENE
K-1066-E Yard UF_6 Cylinder Venting	1	NA	0	Ambient	930	E	14990	ENE
K-1407-U CNF air stripper	7.16	1.22	0.625	Ambient	2540	WSW	13500	ENE
K-1423 container processing facility	3.96	0.305	0	Ambient	660	S	13950	ENE
K-1423 TSCAI solid waste repack	7.62	0.71	10.02	Ambient	660	S	13950	ENE
K-1435 TSCAI	30.5	1.37	5.74	78.98	1020	SW	13240	ENE
K-1435 waste feed tanks	18.29	NA	0	Ambient	1020	SW	13240	ENE
K-1435-A lab hoods	3.96	NA	0	Ambient	1020	SW	13240	ENE
Y-12 Complex								
Y-monitored sources	20	NA	0	Ambient	1120	NNE	1120	NNE
Y-radcon-monitored room exhausts	20	NA	0	Ambient	1120	NNE	1120	NNE
Y-minor sources	20	NA	0	Ambient	1120	NNE	1120	NNE
Y-unmonitored lab hoods	20	NA	0	Ambient	1120	NNE	1120	NNE
Y-ASO Union Valley	4.27	0.762	13.44	Ambient	2350	WSW	2350	WSW
Y-WETF degasifier, Bldg. 9616-7	12.2	0.2	4.36	Ambient	2860	NE	2860	NE
Y-WETF lab hood, Bldg. 9616-7	12.2	NA	0.69	Ambient	2860	NE	2860	NE
Y-CPCF lab hood, Bldg. 9623	8.5	NA	0.64	Ambient	1340	NNE	1340	NNE
Y-9422-22 VOC air stripper	3.96	0.153	0	Ambient	2020	W	2020	W
Y-9204-3	20	NA	0	Ambient	740	NW	740	NW
Y-9224	10	NA	0	Ambient	740	NW	740	NW

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

Tower	Height (m)	Source
Y-12 Complex		
MT6	60[a]	All sources
ETTP		
MT1	60	TSCA Incinerator
MT7	10	All other sources
ORNL		
MT4	30	X-7503, X-7567, X-7569, X-7830, X-7852,X-7856, X-7860, X-7877, X-7911, X-7966
MT2	100	X-3018, X-3020, and X-3039
MT2	30	X-2001, X-2026, X-2099, X-2523, X-3003A, X-3074, X-3505, X-3544, X-3608, X-3618, X-5505, X-7025, X-EW-23, X-T14, X-TH-4, X-W8/W9, X-W-1, X-W-1A, X-WC-1, X-WC-4, X-WC-10, X-WC-11, X-WC-12, X-WC-13, X-WC-15, X-WC-17, decommissioned hoods, in-service hoods, and STP sludge drier

[a]Wind speeds adjusted to match conditions at a height of 20 m.

Table 8.3 (maximum individual) and Table 8.4 (collective). The hypothetical maximally exposed individual (MEI) for the ORR was located about 1120 m (0.69 miles) north-northeast of the main Y-12 National Security Complex release point, about 9650 m (5.9 miles) north-northeast of the X-7911 stack at ORNL, and about 13,240 m (8.2 miles) east-northeast of the K-1435 (TSCA Incinerator) stack at the ETTP. This individual could have received an EDE of about 0.39 mrem (0.0039 mSv), which is well below the NESHAP standard of 10 mrem (0.10 mSv) and is about 0.13% of the 300 mrem (3 mSv) that the average individual receives from natural sources of radiation. The calculated collective EDE to the entire population within 80 km (50 miles) of the ORR (about 879,546 persons) was about 13 person-rem (0.13 person-Sv), which is approximately 0.0049% of the 264,000 person-rem that this population received from natural sources of radiation.

Table 8.3. Calculated radiation doses to maximally exposed off-site individuals from airborne releases during 2000

Plant	Total effective dose equivalents [mrem (mSv)]	
	Plant max	ORR max
ORNL	0.2 (0.002)[a]	0.03 (0.0003)
ETTP	0.2 (0.002)[b]	0.04 (0.0004)
Y-12	0.3 (0.003)[c]	0.3 (0.003)
Entire ORR	*d*	0.4 (0.004)[e]

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

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

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

[d]Not applicable.

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

Table 8.4. Calculated collective EDEs from airborne releases during 2000

Plant	Effective dose equivalents[a]	
	(Person-rem)	(Person-Sv)
ORNL	3	0.03
ETTP	7	0.07
Y-12	3	0.03
Entire ORR	13	0.13

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

The MEI for the Y-12 National Security Complex was located about 1120 m (0.7 miles) north-northeast of the main Y-12 National Security Complex release point. This individual could have received an EDE of about 0.32 mrem (0.0032 mSv) from Y-12 National Security Complex emissions. Inhalation and ingestion of uranium radioisotopes (i.e., ^{234}U, ^{235}U, ^{236}U, and ^{238}U) accounted for more than 99% of the dose. The contribution of Y-12 Complex emissions to the 50-year committed collective EDE to the population residing within 80 km of the ORR was calculated to be about 3.0 person-rem (0.030 person-Sv), which is approximately 23% of the collective EDE for the ORR.

The MEI for ORNL was located about 4010 m (2.5 miles) south-southwest of the X-3039 stack and 3680 m (2.3 miles) southwest of the X-7911 stack. This individual could have received an EDE of about 0.22 mrem (0.0022 mSv) from ORNL emissions. Radionuclides contributing 1% or more to the dose include ^{41}Ar (39%), ^{138}Cs (38%), ^{244}Cm (4.9%), ^{212}Pb (3.7%), ^{90}Sr (2.6%), ^{191}Os (1.7%), ^{131}I (1.4%), ^{3}H (1.2%), ^{138}Xe (1.2%), and ^{239}Pu (1.0%). The contribution of ORNL emissions to the collective EDE to the population residing within 80 km of the ORR was calculated to be about 3.1 person-rem (0.031 person-Sv), which is approximately 24% of the collective EDE for the ORR.

The MEI for the ETTP was located at a business about 1020 m (0.6 miles) southwest of the TSCAI stack, K-1435. The EDE received by this individual was calculated to be about 0.19 mrem (0.0019 mSv). About 92.5% of this dose is from ingestion and inhalation of uranium radioisotopes, about 5.6% is from thorium radioisotopes, and about 1.0% is from ^{3}H. The contribution of ETTP emissions to the collective EDE to the population residing within 80 km of the ORR was calculated to be about 7.0 person-rem

(0.070 person-Sv), which is approximately 54% 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. 7.4) and the remote air monitoring station (RAM). Hypothetical individuals assumed to reside at the PAMs could have received EDEs between 0.07 and 0.15 mrem/year (0.0007 and 0.0015 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 0.11 mrem/year (0.0011 mSv/year).

Of particular interest is a comparison of doses calculated using measured air concentrations at PAMs located near the MEIs for each plant and doses calculated to those individuals using CAP-88 and measured emissions. PAM 46 is located near the MEI for the Y-12 Complex; the EDE calculated using measured air concentrations was 0.11 mrem/year (0.0011 mSv/year), which is about 37% of the 0.30 mrem/year (0.0030 mSv/ year) calculated using CAP-88. PAM 39 is located at about the same distance as, but in an adjacent wind direction from, the MEI for ORNL; the EDE calculated using measured air concentrations was 0.11 mrem/year (0.0011 mSv/year), which is about 50% of the 0.22 mrem/year (0.0022 mSv/ year) calculated using CAP-88. PAM 35 is located in the general area of the MEI for the ETTP; the EDE calculated using measured air concentrations at PAM 35 was 0.15 mrem/year (0.0015 mSv/ year), which is about 79% of the 0.19 mrem/year (0.0091 mSv/ year) modeled value to the MEI.

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

8.1.2.2 Waterborne Radionuclides

Radionuclides discharged to surface waters from the ORR enter the Tennessee River system by way of the Clinch River and various feeder streams (see Sect. 1.4 for the surface water setting of the ORR). Discharges from the Y-12 Complex enter the Clinch River via Bear Creek and 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). Discharges from the ETTP enter the Clinch River either directly or via Poplar Creek. This section discusses the potential radiological impacts of these discharges to persons who drink water; eat fish; and swim, boat, and use the shoreline at various locations along the Clinch and Tennessee rivers.

Two methods are used to estimate potential radiation doses to the public. The first method uses radionuclide concentrations in the medium of interest (i.e., in water and fish) that were determined by laboratory analyses of actual water and fish samples (see Sects. 7.4 and 7.9). The second method uses radionuclide concentrations in water and fish that were calculated from measured radionuclide discharges and known or estimated stream flows. The advantage of the first method is the use of measured concentrations of radionuclides in water and fish; disadvantages are the inclusion of naturally occurring radionuclides in total alpha- and beta-activity measurements, the possibility that some radionuclides of ORR origin might be present in quantities too low to be measured, and the possibility that the presence of some radionuclides might be overstated. (If the analytical laboratory looks for the presence of a given nuclide, a quantity will be reported for that nuclide even if the nuclide is not really present or is present at a quantity below the detection limit.) The advantages of the second method are that most radionuclides discharged from the ORR will be quantified and naturally occurring radionuclides will not be considered or will be accounted for separately; the disadvantage is the use of models to estimate the concentrations of the radionuclides in water and fish. 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 2000; 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 the Environmental Monitoring Plan (EMP) water sampling location CRK 58. A highly exposed individual could have received an EDE of about 0.035 mrem (0.00035 mSv) from drinking this water. The collective dose to the estimated 37,510 persons who drink this water could have been about 0.67 person-rem (0.0067 person-Sv). Based on known radionuclide discharges to Melton Hill Lake, the highly exposed individual could have received an EDE of about 0.00024 mrem (0.0000024 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. For assessment purposes, we assume that workers obtain half their annual water (370 L) intake at work. No in-plant water sampling data are available. Based on water samples taken from the Clinch River (CRK 23), the worker could have received an EDE of about 0.32 mrem (0.0032 mSv), and the collective EDE could have been about 0.32 person-rem (0.0032 person-Sv). Using radionuclide discharge data, the maximum individual EDE was estimated to be 0.14 mrem (0.0014 mSv); the collective EDE was 0.14 person-rem (0.0014 person-Sv).

The Kingston municipal water plant draws water from the Tennessee River, just above its confluence with the Clinch River. The in-plant sampling program has been discontinued, and 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 0.026 mrem (0.00026 mSv); the collective EDE to the estimated 7438 water users could have been about 0.26 person-rem (0.0026 person-Sv).

Several water treatment plants are located on tributaries of Watts Bar Lake and Chickamauga Lake. Based on discharge data, persons drinking water from these plants could not have received EDEs greater than the 0.026 mrem (0.00026 mSv) calculated for Kingston water. The estimated collective EDE, using discharge data, was about 2.3 person-rem (0.023 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 2000; the average person, to have consumed 6.9 kg of fish. EDEs were calculated using measured radionuclide contents in fish (see Sect. 7.9) and by using measured concentrations of radionuclides in water and the calculated concentrations from discharges as input to the LADTAP XL code (Hamby 1991).

Fish samples were collected from Melton Hill Lake above all ORR inputs (CRK 70), from the upper part of the Clinch River (CRK 32), and from the Clinch River below all ORR inputs (CRK 16). Based on these samples, avid eaters could have received, from statistically significant detected radionuclides that could have been discharged from the ORR, an EDE between 0.003 and 0.008 mrem (0.00003 and 0.00008 mSv) from eating CRK 70 fish, between 0.03 and 0.1 mrem (0.0003 and 0.001 mSv) from eating CRK 32 fish, and between 0.005 and 0.04 mrem (0.00005 and 0.0004 mSv) from eating CRK 16 fish.

Water samples were collected from Melton Hill Lake (CRK 70, 66, and 58); from the Clinch River below Melton Hill Dam (CRK 32, 23, and 16); from East Fork Poplar Creek, just before it joins Poplar Creek (EFK 0.1) and downstream of its floodplain (EFK 5.4); and from Poplar Creek, after it is formed by East Fork Poplar Creek and prior to its joining the Clinch River. Based on analyses of these samples (see Sect. 7.4), avid fish eaters could have received, from radionuclides that could have been discharged from the ORR, EDEs between 0.01 and 0.3 mrem (0.0001 and 0.003 mSv) from fish taken from Melton Hill

Lake; between 0.8 and 1 mrem (0.008 and 0.01 mSv) from fish taken from the Clinch River; no less than between 0.04 and 0.2 mrem (0.0004 and 0.002 mSv) from fish taken from Poplar Creek and between 0.1 and 0.8 mrem (0.001 and 0.008 mSv) from fish taken from East Fork Poplar Creek. It should be noted that catching and consuming fish from East Fork Poplar Creek is discouraged.

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 0.0003 mrem (0.000003 mSv), 0.8 mrem (0.008 mSv), and 2.2 mrem (0.022 mSv), respectively. The collective EDE from eating fish from the above locations and from the Tennessee River system down to Chattanooga could have been 2.2 person-rem (0.022 person-Sv).

Other Uses

Other uses include swimming or wading, boating, and use of the shoreline. A highly exposed other user was assumed to swim or wade for 27 h/year, boat for 63 h/year, and use the shoreline for 67 h/year. Measured and calculated concentrations of radionuclides in water and the LADTAP XL code were used to estimate potential EDEs from these activities. When compared with EDEs from eating fish from the same waters, the EDEs from these other uses are relatively insignificant.

Based on the above-noted water samples, highly exposed other users could have received EDEs between 0.0000004 and 0.0008 mrem (0.000000004 and 0.000008 mSv) from using Melton Hill Lake; between 0.008 and 0.01 mrem (0.00008 and 0.0001 mSv) from using the Clinch River; between 0.00005 and 0.0008 mrem (0.0000005 and 0.000008 mSv) from using Poplar Creek; and between 0.00006 and 0.02 mrem (0.0000006 and 0.0002 mSv) from using East Fork Poplar Creek.

Based on radionuclide discharges to the Clinch River–Poplar Creek system, a user could have received an EDE between 0.000002 and 0.008 mrem (0.00000002 and 0.00008 mSv); the collective EDE could have been 0.008 person-rem (0.00008 person-Sv).

Summary

Table 8.5 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 1.3 mrem (0.013 mSv). The collective EDE to the 50-mile population was estimated to be about 4.9 person-rem (0.049 person-Sv). These are small percentages of individual and collective doses attributable to natural background radiation, about 0.4% and 0.002%, respectively.

8.1.2.3 Radionuclides in Other Environmental Media

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

Milk

Milk collected at four locations near the ORR and at a remote location was found to contain small quantities of radio-strontium, ^{3}H, ^{7}Be, and ^{40}K. 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 (see Sect. 7.8).

These hypothetical persons could have received an EDE between 0.05 and 0.08 mrem (0.0005 and 0.0008 mSv) from radionuclides that could have been emitted from the ORR; the average EDE could have been 0.06 mrem (0.0006 mSv). The average EDE associated with just total strontium and ^{131}I in milk in EPA Region 4 is about 0.09 mrem (0.0009 mSv) (EPA 1993).

Table 8.5. Summary of annual maximum individual EDEs from waterborne radionuclides (mrem)[a]

Type of sample	Drinking water	Eating fish	Other uses	Total of highest
Melton Hill Lake, CRK 70, CRK 66, CRK 58				
Fish[b]		0.008		
Water[c]	0.04	0.3	0.0008	0.3
Discharge[d]	0.0002	0.0003	0.000002	0.0005
Upper Clinch River, CRK 23, Gallaher Water Plant, CRK 32				
Fish[b]		0.1		
Water[c]	0.3	1	0.008	1.3
Discharge[d]	0.1	0.8	0.0006	0.9
Lower Clinch River, CRK 16				
Fish[b]		0.04		
Water[c]	NA	0.8	0.01	0.8
Discharge[d]	NA	0.7	0.0006	0.7
Upper Watts Bar Lake, Kingston Municipal Water Plant				
Discharge[d]	0.03	0.1	0.0001	0.1
Lower System (Lower Watts Bar Lake and Chickamauga Lake)				
Discharge[d]	0.03	0.1	0.0001	0.1
Poplar Creek				
Water[c]	NA	0.2	0.0008	0.2
Discharge[d]	NA	2	0.008	2
East Fork Poplar Creek				
Water[c]	NA	0.8	0.02	0.8
Discharge[d]	NA	3	0.0007	3

[a]1 mrem = 0.01 mSv.
[b]Doses based on measured radionuclide concentrations in fish tissue.
[c]Doses based on measured radionuclide concentrations in water.
[d]Doses based on releases of radionuclides to water.

For perspective, the doses resulting from the naturally occurring ^{7}Be and ^{40}K in the sampled milk could be between 7 and 9 mrem (0.07 and 0.09 mSv).

Food Crops

Samples of tomatoes, lettuce, turnip greens, and turnips were collected from five local and one remote gardens in 2000 (see Sect. 7.7). These vegetable types are representative of fruit-bearing, leafy, and root vegetables. All radionuclides found in the food crops are found in the natural environment and in commercial fertilizers, and all but ^{7}Be and ^{40}K also are emitted from the ORR. The sampling results were used to calculate potential EDE to a person who ate 32 kg (71 lb) of homegrown tomatoes, 10 kg (22 lb) of homegrown leafy vegetables, and 37 kg (82 lb) of homegrown turnips during the year.

This person could have received an EDE between 0.04 and 0.1 mrem (0.0004 and 0.001 mSv). Of this EDE, between 0.006 and 0.02 mrem (0.00006 and 0.0002 mSv) was from eating tomatoes; between 0.01 and 0.07 mrem (0.0001 and 0.0007 mSv) was from eating leafy vegetables, and between 0.02 and 0.03 mrem (0.0002 and 0.0003 mSv) was from eating turnips.

If the doses from the naturally occurring ^{7}Be and ^{40}K are included, the maximum potential dose could have increased by about 4 mrem (0.04 mSv).

Hay

As shown in Sect. 7.6.2, the average and maximum EDE to a person eating beef and drinking milk from cattle that eat hay gathered from the ORR was about 0.7 mrem (0.007 mSv) and 1.3 mrem (0.013 mSv), respectively, from radionuclides that could have been emitted from the ORR. If doses due to naturally occurring ^{40}K and ^{7}Be are added, the average EDE from drinking milk and eating beef was estimated to be about 13 mrem (0.13 mSv).

White-Tailed Deer

As shown in Sect. 7.10.2, the average EDE associated with eating deer harvested from the ORR was estimated to be 0.15 mrem (0.0015 mSv) assuming an average Cs-137 concentration of 0.14 pCi/g (0.005 Bq/g). The maximum EDE from consumption of venison was estimated to be about 7.8 mrem (0.078 mSv), based solely on the maximum ^{137}Cs and ^{90}Sr concentrations measured in tissue.

In 1998 a special study was conducted to quantify isotopes that are not analyzed for in routine screening of geese and deer. To follow up on the special study conducted in 1998, two muscle samples from deer harvested in Jackson County and one muscle sample from a deer harvested near the Park City/Tower Shielding area were analyzed for a number radionuclides. Statistically significant concentrations of ^{3}H, ^{90}Sr, ^{239}Pu, ^{230}Th, ^{234}U, and ^{238}U were measured in all the deer samples collected in Jackson County (considered to be a background location) and collected in the Park City/Tower Shielding Area. The estimated EDEs due to consumption of venison from the two deer harvested in Jackson County were 0.2 mrem (0.002 mSv) and 0.7 mrem (0.007 mSv), respectively. The estimated EDEs due to consumption of venison from the deer harvested in the Tower Shielding Area was 0.6 mrem (0.006 mSv), within the estimated EDE range for deer collected at the background location.

Canada Geese

As shown in Sect. 7.11.1, the average and maximum EDE associated with eating a goose harvested from the ORR was estimated to be 0.02 mrem (0.0002 mSv) and 0.09 mrem (0.0009 mSv), respectively, based on measured ^{137}Cs concentrations in tissue.

To follow up on the special study conducted in 1998, muscle samples from three geese collected from ETTP, ORNL, and the Oak Ridge Marina were analyzed for a number of radionuclides. Statistically significant concentrations of ^{60}Co, ^{137}Cs, ^{3}H, ^{90}Sr, ^{234}U, and ^{238}U were measured in all three goose muscle samples. Using the statistically significant concentrations and the average weight of geese collected during the roundup , the estimated EDEs ranged from about 0.05 mrem to 0.1 mrem (0.0005 mSv and 0.001 mSv). The goose collected at ORNL resulted in the higher EDE; this was due primarily to ^{137}Cs and ^{241}Am.

Eastern Wild Turkey

As shown in Sect. 7.11.2, the average and maximum EDE associated with eating turkey harvested from the ORR was estimated to be 0.03 mrem (0.0003 mSv) and 0.2 mrem (0.002 mSv), respectively, based on field-measured ^{137}Cs concentrations in tissue. The muscle sample from one turkey killed at the intersection of I-95 and Bethel Valley Road was analyzed for a number of radionuclides. Statistically significant concentrations of ^{3}H, ^{234}U, and ^{238}U were measured in the turkey muscle sample. Using the statistically significant concentrations and the average weight of turkey collected during the hunt, the estimated EDE was about 0.013 mrem (0.00013 mSv).

Direct Radiation

External exposure rates from background sources in the state of Tennessee average about 6.4 μR/h and range from 2.9 to 11 μR/h. These exposure rates translate into annual EDE rates that average 42 mrem/year (0.42 mSv/year) and range between 19 and 72 mrem/year, or 0.19 and 0.72 mSv/year (Myrick et al. 1981). External radiation exposure rates are measured at a number of locations on and off the ORR. The average exposure rate at PAMs around the ORR during 2000 was about 5.3 μR/h. This rate corresponds to an EDE rate of about 35 mrem/year (0.35 mSv/year). Except for three locations, all measured exposure rates at or near the ORR boundaries are near background levels. The exceptions are a stretch of bank along the Clinch River, a section of Poplar Creek that flows through the ETTP, and a parking lot adjacent to the K-1066-E cylinder yards.

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/h and ranged between 6.9 and 9.3 μR/h. This corresponds to an average exposure rate of about 2 μR/h (0.0015 mrem/h) above background.

A potential MEI would be a hypothetical fisherman who was assumed to have spent 5 h/week (250 h/year) near the point of average exposure. This hypothetical MEI could have received an EDE of about 0.38 mrem (0.0038 mSv) during 2000.

As described in Sect. 4.12, potential annual doses to maximally exposed individuals were 0.25 mrem along Poplar Creek near the K-1066-J cylinder yard, 1.25 mrem along Poplar Creek near the K-1066-E cylinder yard, and 1.25 mrem in the parking lot near the K-1066-K cylinder yard.

8.1.3 Doses to Aquatic Biota

DOE Order 5400.5, Chapter II, sets an absorbed dose rate limit of 1 rad/day (0.01 Gy/day) to native aquatic organisms from exposure to radiation or radioactive material releases into the aquatic environment (see Appendix G for definitions of absorbed dose and the rad). To demonstrate compliance with this limit, absorbed dose rates to aquatic organisms were calculated using the radionuclide biota concentration guide (RAD-BCG) calculator, a companion electronic calculational tool to the proposed DOE Technical Standard ENVR-0011 entitled, "Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota."

The intent of the graded approach is to protect populations of aquatic organisms from the effects of exposure to anthropogenic ionizing radiation. Certain organisms are more sensitive to ionizing radiation than others. Based on this observation, it is generally assumed that protecting the more sensitive organisms will adequately protect other, less sensitive organisms. Dependant on the radionuclide, either aquatic organisms (e.g., crustaceans or mollusks) or riparian organisms (e.g., raccoons) are often considered to be the more sensitive and are the limiting organisms for the general screening phase of the graded approach for aquatic organisms. The graded approach for evaluating radiation doses to aquatic biota consists of a three-step process that includes (1) data assembly, (2) general screening of media-specific radionuclide concentrations to media-specific biota concentration guides (BCGs), and (3) site-specific screening and analysis. In the general screening phase, surface water radionuclide concentrations and sediment radionuclide concentrations can be compared to the media-specific BCGs using default parameters. If sediment concentrations, are not available, the RAD-BCG calculator will estimate sediment BCGs from the surface water concentrations. Surface water sampling data were used for this aquatic dose assessment.

At ORNL, doses to aquatic organisms are based on surface water concentrations at nine different sampling locations: Melton Branch (kilometer 0.2); WOC (kilometers 0.1, 2.6, and 6.8); First Creek; Fifth Creek; Raccoon Creek; Ish Creek; and Northwest Tributary. All of these locations, with the exception of Melton Branch (MEK 0.2) and White Oak Creek (WOC 2.6), passed the initial general screening (using default parameters for BCGs). At Melton Branch (MEK 0.2) and White Oak Creek (WCK 2.6), the default bioaccumulation factors for ^{137}Cs and ^{90}Sr in fish were adjusted to reflect on-site bioaccumulation of these radionuclides in fish. Riparian organisms are the limiting receptor for ^{137}Cs and ^{90}Sr in surface water; however, the best available bioaccumulation data for Melton Branch and White Oak Creek are for fish. Because fish are consumed by riparian organisms (e.g., raccoons), adjustment of the fish bioaccumulation factor modified the bioaccumulation of ^{137}Cs and ^{90}Sr in riparian organisms. This resulted in the absorbed dose rates to aquatic organisms at all locations to be below the DOE aquatic dose limit of 1 rad/day.

At the Y-12 Complex, doses to aquatic organisms were estimated from surface concentrations of radionuclides in water obtained from East Fork Poplar Creek at 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). None of the sites passed the initial screening due to ^{226}Ra and ^{228}Ra concentrations in surface water. The riparian organism was the limiting receptor for both ^{226}Ra and ^{228}Ra. Radium-226, a decay product of ^{238}U, and ^{228}Ra, a decay product of ^{232}Th, are naturally occurring radionuclides; therefore, it was necessary to determine background ^{226}Ra and ^{228}Ra concentrations. Using surface water and shallow groundwater data upgradient from known contamination areas/plumes, the difference between the sum of fraction results from these on-site locations to the sum of fraction results from the background locations was less than one; therefore the aquatic absorbed doses from anthropogenic sources were less than 1 rad/day.

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 K-1407-J, and East Fork Poplar Creek (kilometers 0.1 and 5.4). Even when the maximum radionuclide concentrations from these locations were used, the absorbed doses were less than 1 rad/day (0.01 Gy/day).

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 2000; however, if someone were, that person could have received a total EDE of about 3.1 mrem (0.031 mSv): 0.4 mrem (0.004 mSv) from airborne emissions, 0.3 mrem (0.003 mSv) from drinkingCRK 23 water, 1.1 mrem (0.011 mSv) from eating fish from CRK 32, 1.3 mrem (0.013 mSv) from fishing on Poplar Creek inside

Table 8.6. Summary of maximum potential radiation dose equivalents to an adult during 2000 and locations of the maximum exposures

Pathway	Location	Effective dose equivalent (mrem)[a]
Gaseous effluents:	Maximally exposed resident to	
inhalation,	Y-12 Complex	0.3
immersion, direct	ORNL	0.2
radiation from	ETTP	0.2
ground, and food	ORR	0.4
chains		
Liquid effluents:		
drinking water	ETTP, CRK 23	0.3
eating fish	Clinch River, CRK 32	1.1
other activities	CRK 32	0.01
Eating deer		6.4[b]
Eating geese		0.6[c]
Eating turkey		0.06[d]
Direct radiation	Clinch River shoreline	0.4
	Poplar Creek (ETTP)	1.3

[a]1 mrem = 0.01 mSv.

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

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

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

the ETTP, and 0.01 mrem (0.0001 mSv) from other water uses on Melton Hill Lake. This dose is about 1.0% of the annual dose [300 mrem (3 mSv)] from background radiation. If this person also was the person who received the highest EDEs from eating wildlife harvested on the ORR, that person could not have received an additional committed EDE greater than about 7 mrem (0.07 mSv).

DOE Order 5400.5 limits to no more than 100 mrem (1 mSv) the EDE that an individual may receive from all exposure pathways from all radionuclides released from the ORR during 1 year. As described in the preceding paragraph, the 2000 maximum EDE could not conceivably have exceeded about 13 mrem (0.13 mSv), or about 13% of the limit given in DOE Order 5400.5. For further information, see Table G.2 in Appendix G, which provides a summary of dose levels associated with a wide range of activities.

The total collective EDE to the population living within a 50-mile (80-km) radius of the ORR was estimated to be less than 20 person-rem (0.20 person-Sv). This dose is about 0.008% of the 264,000 person-rem (2640 person-Sv) that this population received from natural sources during 2000.

8.1.5 Five-Year Trends

Dose equivalents associated with selected exposure pathways for the years from 1995 to 2000 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

Seven privately operated facilities could have contributed to radiation doses received by members of the public around the ORR. These facilities are located on Bear Creek Road, Kerr Hollow Road, Flint Road, Gallaher Road, and the ETTP. Based on emissions and NESHAP reports provided by these facilities, no individual located in the vicinity of the ORR should have received an EDE in excess of 5 mrem (0.05 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 the DOE annual limit of 100 mrem (1 mSv). No information was provided 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 0.4 mrem (0.004 mSv) from airborne effluents from the ORR. This dose is below

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

Pathway	Effective dose equivalent (mrem)[a]				
	1996	1997	1998	1999	2000
All air	0.45	0.41	0.73	0.7	0.4
Fish consumption	1.2	0.96	2.3	4	1
Drinking water (Kingston)	0.32	0.40	0.19	0.16	No data
Direct radiation (Clinch River)	1[b,c]	0.4[b]	0.4[b]	0.4[b]	0.4[b]
Direct radiation (Poplar Creek)	1[b]	1[b]	1[b]	2[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.

10 mrem (0.10 mSv) per year, the limit specified in the Clean Air Act for DOE facilities. No individual EDE could have exceeded the 100-mrem/year (1.0-mSv/year) limit prescribed by DOE. The estimated collective committed EDE to the approximately 880,000 persons living within 50 miles (80 km) of the ORR was about 13 person-rem (0.13 person-Sv) for 2000 airborne emissions. This represents about 0.005% 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 Drinking Water Consumption

As described in Sect. 7.4.2.2 (see Table 7.7), no surface water concentrations resulted in hazard quotient (HQ) values equal to or greater than 1 (HQs less than 1 are desirable). Refer to Appendix H for a detailed description of the chemical dose methodology.

8.2.2 Fish Consumption

No HQ values equal to or greater than 1 were calculated for consumption of sunfish collected at all three locations. For consumption of catfish, HQ values greater than one were calculated for Aroclor-1254 and Aroclor-1260 at all three locations (see Table 7.11).

For carcinogens, I/I(10^{-5}) ratios greater than 1 indicate a cancer risk greater than 10^{-5}. I/I(10^{-5}) ratios greater than 1 were calculated for the intake of dieldrin found in sunfish and catfish collected at CRK 32. I/I(10^{-5}) ratios greater than 1 were calculated for mixed PCBs (Aroclor-1254 and Aroclor-1260) in catfish collected at all locations, including upstream and downstream of ORR. 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 1999).