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Estimated Radiological Doses to the Maximumly Exposed Individual and Downstream Populations from Releases of Tritium, Strontium-90, Ruthenium-106, and Cesium-137 from White Oak Dam

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HIGHLIGHTS

Concentrations of tritium, ^{90}Sr, ^{106}Ru, and ^{137}Cs in the Clinch River for 1978 were estimated by using the known 1978 releases of these nuclides from the White Oak Dam and diluting them by the integrated annual flow rate of the Clinch River. Estimates of 50-year dose commitment to a maximumly exposed individual were calculated for both aquatic and terrestrial pathways of exposure. The maximumly exposed individual was assumed to reside at the mouth of White Oak Creek where it enters the Clinch River and obtain all foodstuffs and drinking water at that location. The estimated total-body dose from all pathways to the maximumly exposed individual as a result of 1978 releases was less than 1% of the dose expected from natural background.

Using appropriate concentrations of the subject radionuclides diluted downstream, the doses to populations residing at Harriman, Kingston, Rockwood, Spring City, Soddy-Daisy, and Chattanooga were calculated for aquatic exposure pathways. The total-body dose estimated for aquatic pathways for the six cities was about 0.0002 times the expected dose from natural background.

For the pathways considered in this report, the nuclide which contributed the largest fraction of dose was ^{90}Sr. The largest dose delivered by ^{90}Sr was to the bone of the subject individual or community.

INTRODUCTION

Low-level waste management via land burial is a useful alternative to other methods because it is relatively convenient and inexpensive. However, some burial grounds have been closed because they did not adequately limit the spread of radionuclides which they were intended to contain. It is important that releases from burial grounds be minimal, if they occur at all.

The purposes of this study are (1) to estimate the maximum doses from releases at White Oak Dam to a hypothetical individual living near the confluence of the Clinch River and White Oak Creek, and (2) to estimate doses to populations living on or near the Clinch and Tennessee Rivers (Watt's Bar Lake) from the same releases. We assume, for the sake of conservatism with regard to health risks from waste management, that all releases from the White Oak Dam during any year are the result of leachate from the waste management burial grounds at ORNL.

DOSE TO THE MAXIMUMLY EXPOSED INDIVIDUAL

Releases from White Oak Dam

The annually integrated releases of ^{3}H (hereafter referred to as tritium in the text), ^{90}Sr, ^{106}Ru, and ^{137}Cs are estimated by staff members in the Industrial Safety and Applied Health Physics Division (ISAHP) of Oak Ridge National Laboratory (ORNL). Annual discharges for the years 1968–1977 were listed in Table 4.2.1 of ISAHP annual report for 1977. Radionuclide discharges for 1978 were obtained from Shank (1979) and are summarized in Table 1.

Table 1. Estimated annual average radionuclide concentrations in the Clinch and Tennessee Rivers as a result of releases at the White Oak Dam in 1978

Radionuclide	1978 release, Ci[a]	Concentration in water, μCi/ml		
		Clinch River[b]	Tennessee River above dam[c]	Tennessee River below dam[c]
^{3}H	6292	1.5E-6[d]	3.7E-7	3.1E-7
^{90}Sr	2.0	4.9E-10	1.2E-10	1.0E-10
^{106}Ru	0.21	5.1E-11	1.2E-11	1.0E-11
^{137}Cs	0.27	6.6E-11	1.6E-11	1.3E-11

[a]Shank, 1979.

[b]Dilution in Clinch River based on a mean annual flow rate of 4.1E+15 ml/year.

[c]Dilution from Clinch River to Tennessee River above and below Watt's Bar Dam based on flows listed in Table 14 of ORNL-3409 (Morton, 1963) and updates from Tennessee Valley Authority (Hill, 1979).

[d]Read as 1.5×10^{-6}.

It is assumed that, given the relatively short length of White Oak Creek, discharges at the White Oak Dam went directly into the Clinch River undiluted. Therefore, the annual average concentration of each radionuclide in the Clinch River is the annual discharge at the dam divided by the mean annual flow rate (4.1E+15 ml/year).

Aquatic Pathways

Assessment methodology

The maximumly exposed adult individual with respect to radiological doses from aquatic pathways is assumed to live on the banks of the Clinch River at the mouth of White Oak Creek. This individual (1) ingests all of his/her drinking water directly from the Clinch River at the rate of 1.2 liters/day, (2) eats fish from the Clinch River at the rate of 20 g/day, and (3) spends one percent of the time swimming in the river (87.6 hr/year).

The equations used to calculate the estimated radiological dose to the maximumly exposed individual for each of i radionuclides and for each organ are as follows:

$$R_{DWi} = K_{DW} \, C_i \, I_w \, D_{Ii} \, , \qquad (1)$$

where

R_{DWi} is the 50-year dose commitment for the ith nuclide per year of intake of drinking water (millirem),

K_{DW} is a unit conversion constant [3.65×10^8 (ml•millirem•day)/(liter•rem•year)],

C_i is the annual average concentration of the ith nuclide in water (μCi/ml),

I_w is the drinking rate of water (1.2 liters/day),

D_{Ii} is the 50-year dose commitment factor for ingestion of the ith nuclide (rem/μCi);

$$R_{Fi} = K_F \, C_i \, B_F \, I_F \, D_{Ii} \ , \qquad (2)$$

where

R_{Fi} is the 50-year dose commitment for the ith nuclide per year of fish intake (millirem),

K_F is a unit conversion constant [3.65 x 10^5 (day·millirem)/(year·rem)],

B_F is the bioaccumulation factor for the ith nuclide in freshwater fish (μCi/g per μCi/ml),

I_F is the ingestion rate of fish (20 g/day),

D_{Ii} is the 50-year dose commitment factor for ingestion of the ith nuclide (rem/μCi);

$$R_{Si} = K_S \, F_S \, C_i \, D_{xi} \ , \qquad (3)$$

where

R_{Si} is the dose from the ith nuclide per year from swimming (millirem),

F_s is the fraction of the year spent swimming (unitless),

C_i is the annual average concentration of ith nuclide in water (μCi/ml),

D_{xi} is the dose conversion factor for external exposure to the ith nuclide (millirem/year per μCi/ml).

These equations are essentially the same as those used in ORNL-4992 (Killough and McKay, 1976) and the U.S. Nuclear Regulatory Commission

(USNRC) Regulatory Guide 1.109 (USNRC, 1977). The actual calculations were made using an interactive computer code, AQUAMAN, which provides necessary nuclide-dependent and some nuclide-independent data (Shaeffer and Etnier, 1979). The user of AQUAMAN supplies pertinent radionuclide concentrations in water. The user may also vary the water and fish intake rates, I_w or I_F, the swimming fraction, F_s, and the value of the bioaccumulation factor, B_F. For this assessment, none of these values were altered. The primary input parameter, concentration of each nuclide in river water, was calculated as described earlier based on 1978 releases.

Estimated doses

Estimated 50-year dose commitments to the maximumly exposed individual from the three aquatic pathways are listed in Tables 2–4. The largest organ dose calculated was 1.8 millirems to bone from ^{90}Sr via drinking water (Table 2).

The total-body dose commitment was larger for the drinking water pathway (7.7E-2 millirem) than for the consumption of fish (1.2E-2 millirem). Swimming accounted for only 7.2E-8 millirem annually, with negligible contributions from tritium and ^{90}Sr. The sum of the total-body doses from one year's exposure through all pathways (Tables 2–4) equalled 8.9E-2 millirem.

Terrestrial Pathways

Assessment methodology

The maximumly exposed adult individual with respect to terrestrial pathways lives on the banks of the Clinch River at the mouth of White Oak

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Table 2. Estimated total-body and organ dose commitments to the maximumly exposed individual (millirem) from ingestion of one year's drinking water

Radionuclide	Total body	GI	Bone	Thyroid	Lungs	Liver	Kidneys	Testes
^{3}H	4.0E-2[a]	4.0E-2	4.0E-2	4.0E-2	4.0E-2	4.0E-2	4.0E-2	4.0E-2
^{90}Sr	3.6E-2	1.0E-2	1.8E+0	3.6E-2	3.6E-2	3.6E-2	3.6E-2	3.6E-2
^{106}Ru	7.1E-6	4.3E-3	5.5E-5	7.1E-6	7.1E-6	7.1E-6	1.1E-4	7.1E-6
^{137}Cs	1.2E-3	1.4E-3	2.3E-3	1.2E-3	3.6E-4	3.2E-3	1.1E-3	1.2E-3
TOTAL	7.7E-2	5.6E-2	1.8E+0	7.7E-2	7.7E-2	7.9E-2	7.7E-2	7.7E-2

[a] Read as 4.0×10^{-2}.

Table 3. Estimated total-body and organ dose commitments to the maximumly exposed individual (millirem) from ingestion of one year's fish consumption

Radionuclide	Total body	GI	Bone	Thyroid	Lungs	Liver	Kidneys	Testes
^{3}H	6.7E-4[a]	6.7E-4	6.7E-4	6.7E-4	6.7E-4	6.7E-4	6.7E-4	6.7E-4
^{90}Sr	3.0E-3	8.7E-4	1.5E-1	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3
^{106}Ru	1.2E-6	7.2E-4	9.1E-6	1.2E-6	1.2E-6	1.2E-6	1.8E-5	1.2E-6
^{137}Cs	8.3E-3	9.3E-3	1.6E-2	8.3E-3	2.4E-3	2.1E-2	7.3E-3	8.3E-3
TOTAL	1.2E-2	1.2E-2	1.7E-1	1.2E-2	6.1E-3	2.5E-2	1.1E-2	1.2E-2

[a] Read as 6.7×10^{-4}.

Table 4. Estimated total-body and organ dose commitments to the maximumly exposed individual (millirem) from swimming during one year

Radionuclide	Total body	GI	Bone	Thyroid	Lungs	Liver	Kidneys	Testes	Ovaries
^{3}H	*a*								
^{90}Sr									
^{106}Ru	1.5E-8[b]	1.1E-8	1.8E-8	1.5E-8	1.4E-8	1.2E-8	1.3E-8	1.6E-8	5.7E-9
^{137}Cs	5.7E-8	4.4E-8	6.9E-8	6.0E-8	5.4E-8	4.7E-8	5.0E-8	6.3E-8	2.1E-8
TOTAL	7.2E-8	5.5E-8	8.7E-8	7.5E-8	6.8E-8	5.9E-8	6.3E-8	7.9E-8	2.7E-8

[a]Negligible.
[b]Read as 1.5×10^{-8}.

Creek and produces all of his/her foodstuffs, including meat, milk, produce, and leafy vegetables at his home location. It is also assumed that all crops, are irrigated with the equivalent of 15 in. of Clinch River water annually (Morton, 1965). Any dilution from rainfall was not considered.

The doses from the terrestrial pathways were calculated using an existing computer program known as INGDOS (Pleasant, 1979). The code is an interactive implementation of the models suggested by USNRC (1977) for use in calculating doses to various organs from ingestion of foods contaminated by airborne radionuclides. The USNRC Regulatory Guide 1.109 equations as used in INGDOS are also applicable to ingestion of foods irrigated with contaminated water.

As stated by Pleasant (1979), the equation used to calculate concentrations on vegetation for all radionuclides except tritium and ^{14}C is as follows:

$$C_i^v(r, \theta) = d_i(r, \theta) \quad \frac{R[1 - \exp(-\lambda_{Ei} t_e)]}{Y_v \lambda_{Ei}} + \frac{B_{iv}[1 - \exp(-\lambda_i t_b)]}{P \lambda_i} \exp(-\lambda_i t_h), \quad (4)$$

where

$C_i^v(r, \theta)$ is measured in pCi/kg;

$d_i(r, \theta)$ is the deposition rate of radionuclide i onto ground at location (r, θ), in pCi/m²·hr;

R is the fraction of deposited activity retained on crops, dimensionless;

λ_i is the radioactive decay constant for nuclide i, in hr^{-1};

λ_{Ei} is the effective removal rate constant for radionuclide i from crops, in hr^{-1}, where $\lambda_{Ei} = \lambda_i + \lambda_w$, λ_i is the radioactive decay constant, and λ_w is the removal rate constant for physical loss by weathering;

t_e is the time period that crops are exposed to contamination during the growing season, in hr;

Y_v is the agricultural productivity (yield), in kg(wet weight)/m^2;

B_{iv} is the concentration factor for uptake of radionuclide i from soil by edible parts of crops, in pCi/kg (wet weight) per pCi/kg dry soil;

t_b is the period of long-term buildup for activity in sediment or soil, in hr;

P is the effective "surface density" for soil, in kg(dry soil)/m^2;

t_h is a holdup time that represents the time interval between harvest and consumption of the food, in hr.

When the vegetation is used as animal feed, Eq. (4) becomes:

$$C_i^v(r, \theta) = f_p f_s C_i^p(r, \theta) + (1 - f_p f_s)\ C_i^s(r, \theta) \ , \qquad (5)$$

where

$C_i^v(r, \theta)$ is the concentration of radionuclide i in the animal's feed, in pCi/kg;

$C_i^p(r, \theta)$ is the concentration of radionuclide i on pasture grass in pCi/kg;

$C_i^s(r, \theta)$ is the concentration of radionuclide i in stored feeds in pCi/kg;

f_p is the fraction of the year that animals graze on pasture;

f_s is the fraction of daily feed that is pasture grass when the animals graze on pasture.

Using the value of $C_i^v(r, \theta)$ calculated by use of this equation, the concentration of radionuclide i in milk is estimated as:

$$C_i^m(r, \theta) = F_m C_i^v(r, \theta) Q_F \exp(-\lambda_i t_f) , \tag{6}$$

where

$C_i^m(r, \theta)$ is the concentration in milk of nuclide i, in pCi/liter;

$C_i^v(r, \theta)$ is the concentration of radionuclide i in the animal's feed, in pCi/kg;

F_m is the average fraction of the animal's daily intake of radionuclide i which appears in each liter of milk, in days/liter;

Q_F is the amount of feed consumed by the animal per day, in kg/day;

t_f is the average transport time of the activity from the feed into the milk and to the receptor;

λ_i is the radiological decay constant of nuclide i, in days^{-1}.

Likewise, the radionuclide concentration in meat is calculated by Pleasant (1979) using the following:

$$C_i^F(r, \theta) = F_f C_i^v(r, \theta) Q_F \exp(-\lambda_i t_s) \ , \qquad (7)$$

where

$C_i^F(r, \theta)$ is the concentration of nuclide i in animal flesh, in pCi/kg;

F_f is the fraction of the animal's daily intake of nuclide i which appears in each kilogram of flesh, in days/kg;

$C_i^v(r, \theta)$ is the concentration of radionuclide i in the animal's feed, in pCi/kg;

Q_F is the amount of feed consumed by the animal per day, in kg/day;

λ_i is the radiological decay constant of nuclide i, in days^{-1}; and

t_s is the average time (days) from slaughter to consumption.

Values of default (generic) factors were used as suggested by Pleasant (1979). The fact that the contamination was applied by irrigation does not change these calculations if it is assumed that the irrigation occurred during 100% of the year (see USNRC, 1977, p. 1.109-3) and if the total deposition is known (15 in./year at known concentration).

Once concentrations in foodstuffs were calculated, doses were estimated using INGDOS by multiplying by the appropriate dose conversion and intake factors (Killough and McKay, 1976; Pleasant, 1979). Default values were used whenever necessary.

For tritium doses from irrigation, USNRC Regulatory Guide 1.109 is used (USNRC, 1977, p. 1.109-3). The guide conservatively assumes that the concentration of tritium in vegetation is equivalent to the concentration in the irrigation water, allowing for no loss due to radioactive decay, evaporation, or dilution by rainfall (USNRC, 1977, 1.109-15). In this assessment, the water concentration, and, therefore, the concentration in vegetation is 1.5E-6 μCi/ml (Table 1).

Intake or consumption rates of vegetation and animal products are found in Pleasant (1979). Ingestion dose conversion factors for tritium are taken from Killough et al. (1978). Other pertinent parameter values were used as recommended by USNRC (1977, Tables E-1 and E-3).

Estimated doses

Estimated 50-year dose commitments for each terrestrial pathway are given in Tables 5–8 for the four nuclides. The largest organ dose (0.5 millirems) is to the bone from the ingestion of ^{90}Sr contaminated produce (Table 6). The sum of the total-body doses from all nuclides and all terrestrial pathways is about 0.24 millirem.

The total 50-year dose commitment to the maximumly exposed individual from both aquatic (8.9E-2 millirem) and terrestrial (2.4E-1 millirem) pathways is about 3.3E-1 millirem to the total body. This is 0.003 times the natural background dose (∿100 millirems) (Oakley, 1972).

Table 5. Estimated dose commitments to the maximumly exposed individual (millirem) from ingestion of tritium (^{3}H) in foodstuffs

	Milk	Meat	Produce	Leafy vegetables	Total
Total body	1.9E-2[a]	8.2E-3	6.5E-2	8.0E-3	1.0E-1
Bone	8.6E-3	3.7E-3	2.9E-2	3.6E-3	3.6E-2
GI	3.3E-2	1.4E-2	1.1E-1	1.4E-2	1.7E-1
Kidney	2.0E-2	8.5E-3	6.7E-2	8.2E-3	1.0E-1
Liver	1.9E-2	8.2E-3	6.5E-2	7.9E-3	1.0E-1
Lung	1.9E-2	8.3E-3	6.5E-2	8.0E-3	1.0E-1
Thyroid	1.9E-2	8.2E-3	6.5E-2	7.9E-3	1.0E-1

[a] Read as 1.9×10^{-2}.

Table 6. Estimated dose commitments to the maximumly exposed individual (millirem) from ingestion of ^{90}Sr in foodstuffs

	Milk	Meat	Produce	Leafy vegetables	Total
Total body	3.9E-3[a]	1.0E-3	1.2E-1	2.0E-2	1.4E-1
Bone	1.6E-2	4.2E-3	5.0E-1	8.1E-2	6.0E-1
GI	4.4E-4	1.2E-4	1.4E-2	2.3E-3	1.7E-2
Kidney	*b*				
Liver					
Lung					
Thyroid					

[a]Read as 3.9×10^{-3}.

[b]Negligible.

Table 7. Estimated dose commitments to the maximumly exposed individual (millirem) from ingestion of ^{106}Ru in foodstuffs

	Milk	Meat	Produce	Leafy vegetables	Total
Total body	3.1E-11[a]	3.9E-6	7.2E-7	1.3E-7	4.8E-6
Bone	2.3E-10	3.1E-5	5.8E-6	1.0E-6	3.8E-5
GI	1.5E-8	2.1E-3	3.6E-4	6.7E-5	2.5E-3
Kidney	4.4E-10	6.1E-5	1.1E-5	2.0E-6	7.4E-5
Liver	*b*				
Lung					
Thyroid					

[a]Read as 3.1×10^{-11}.

[b]Negligible.

Table 8. Estimated dose commitments to the maximumly exposed individual (millirem) from ingestion of ^{137}Cs in foodstuffs

	Milk	Meat	Produce	Leafy vegetables	Total
Total body	1.8E-4[a]	2.1E-5	3.6E-4	6.1E-5	6.2E-4
Bone	2.0E-4	2.3E-5	4.2E-4	6.7E-5	7.0E-4
GI	5.3E-6	6.1E-7	1.1E-5	1.8E-6	1.9E-5
Kidney	9.2E-5	1.1E-5	1.9E-4	3.1E-5	3.3E-4
Liver	2.7E-4	3.1E-5	5.8E-4	9.2E-5	9.7E-4
Lung	3.1E-5	3.6E-6	6.4E-5	1.1E-5	1.1E-4
Thyroid	[b]				

[a]Read as 1.8×10^{-4}.

[b]Negligible.

DOSES TO DOWNSTREAM POPULATIONS VIA AQUATIC PATHWAYS

Dilution in Downstream Rivers

The annual discharge of each radionuclide from White Oak Dam was diluted by the flow of the Clinch River to estimate dose to the population of Harriman, Tennessee. Harriman's drinking water intake is actually located on the Emory River, but may at times extract Clinch River water due to periods of stratified flow when the Clinch River may flow up the Emory River as far as Harriman (Morton, 1961). For these reasons, the fraction of Clinch River water taken from the Emory River at Harriman is not known; therefore, the concentrations in Clinch River water were used to calculate doses to persons in Harriman.

Radionuclide concentrations in the Tennessee River above Watt's Bar Dam (for populations in Kingston, Rockwood, and Spring City) were diluted by a factor of 4.1 from the Clinch River (Table 1). This factor is based on annual average flows published by Morton (1963) and updated by more recent data from TVA (Hill, 1979). Similarly, the radionuclide concentrations in the Tennessee River below Watt's Bar Dam (used for Soddy-Daisy and Chattanooga populations) were diluted by a factor of 4.9 from the Clinch River (Table 1).

Assessment Methodology

The populations within 100 miles downstream of White Oak Dam that obtain some drinking water from either the Clinch or the Tennessee River include Harriman, Kingston, Rockwood, Spring City, Soddy-Daisy, and Chattanooga. It was assumed that each city used river water for 100% of its drinking water, and that water purification did not decrease radioactivity concentrations. Populations are assumed to be composed entirely of adults.

As with the maximumly exposed individual dose calculations, each member of the population of each city considered was assumed to (1) drink 1.2 liters of water each day, (2) eat 20 g of fish from the river each day, and (3) swim in the river 1% of the year.

To estimate population dose for each community, radionuclide, and organ, the estimated individual dose (Eqs. 1, 2, or 3) was multiplied by the population of the community. The computer implementation AQUAMAN (Shaeffer and Etnier, 1979) was again used to make the calculations.

Estimated Population Doses

Population doses from drinking water to the various organs for each city are listed in Tables 9–12 for tritium, ^{90}Sr, ^{106}Ru, and ^{137}Cs, respectively. The nuclide that contributes the largest doses is ^{90}Sr with bone receiving the largest organ dose.

Tables 13–16 list organ population doses from ingestion of fish, by community, for the four radionuclides of concern. For this pathway, ^{90}Sr again contributes the majority of the population dose commitment (e.g., 1.8 person-rems to bone to persons in Harriman — Table 14). Population dose commitments from ^{106}Ru and ^{137}Cs are larger for the fish ingestion pathway than from the drinking water pathway.

Tables 17 and 18 detail the population doses from swimming 1% of the year (87.6 hr) in water contaminated with ^{106}Ru and ^{137}Cs, respectively. Doses from beta-emitters tritium and ^{90}Sr via swimming are negligible. The doses delivered via the swimming pathway are several orders of magnitude smaller than those from the same nuclides via the drinking water and fish ingestion.

Table 9. Estimated total-body and organ population dose commitments (person-rem) from ingestion of tritium (^{3}H) in one year's drinking water

Community	Population	Total body	GI	Bone	Thyroid	Lungs	Liver	Kidneys	Testes[a]	Ovaries[a]
Harriman	12,000	4.8E-1[b]	4.8E-1	4.8E-1	4.8E-1	4.8E-1	4.8E-1	4.8E-1	2.4E-1	2.4E-1
Kingston	6,500	6.5E-2	6.5E-2	6.5E-2	6.5E-2	6.5E-2	6.5E-2	6.5E-2	3.3E-2	3.3E-2
Rockwood	7,000	7.0E-2	7.0E-2	7.0E-2	7.0E-2	7.0E-2	7.0E-2	7.0E-2	3.5E-2	3.5E-2
Spring City	2,000	2.0E-2	2.0E-2	2.0E-2	2.0E-2	2.0E-2	2.0E-2	2.0E-2	1.0E-2	1.0E-2
Soddy-Daisy	8,000	6.7E-2	6.7E-2	6.7E-2	6.7E-2	6.7E-2	6.7E-2	6.7E-2	3.4E-2	3.4E-2
Chattanooga	230,000	1.9E0	1.9E0	1.9E0	1.9E0	1.9E0	1.9E0	1.9E0	9.7E-1	9.7E-1

[a]Assumes population evenly divided into male and female.

[b]Read as 4.8×10^{-1}.

Table 10. Estimated total-body and organ population dose commitments (person-rem) from ingestion of ^{90}Sr in one year's drinking water

Community	Population	Total body	GI	Bone	Thyroid	Lungs	Liver	Kidneys	Testes[a]	Ovaries[a]
Harriman	12,000	4.3E-1[b]	1.2E-1	2.2E+1	4.3E-1	4.3E-1	4.3E-1	4.3E-1	2.2E-1	2.2E-1
Kingston	6,500	5.7E-2	1.6E-2	2.9E0	5.7E-2	5.7E-2	5.7E-2	5.7E-2	2.8E-2	2.8E-2
Rockwood	7,000	6.1E-2	1.8E-2	3.1E0	6.1E-2	6.1E-1	6.1E-2	6.1E-2	3.0E-2	3.0E-2
Spring City	2,000	1.7E-2	5.0E-3	8.8E-1	1.7E-2	1.7E-2	1.7E-2	1.7E-2	8.7E-3	8.7E-2
Soddy-Daisy	8,000	5.8E-2	1.7E-2	2.9E0	5.8E-2	5.8E-2	5.8E-2	5.8E-2	2.9E-2	2.9E-2
Chattanooga	230,000	1.7E0	4.8E-1	8.3E+1	1.7E0	1.7E0	1.7E0	1.7E0	8.4E-1	8.4E-1

[a]Assumes population evenly divided into male and female.

[b]Read as 4.3×10^{-1}.

Table 11. Estimated total-body and organ population dose commitments (person-rem) from ingestion of ^{106}Ru in one year's drinking water

Community	Population	Total body	GI	Bone	Thyroid	Lungs	Liver	Kidneys	Testes[a]	Ovaries[a]
Harriman	12,000	8.5E-5[b]	5.2E-2	6.6E-4	8.5E-5	8.5E-5	8.5E-5	1.3E-3	4.3E-5	4.3E-5
Kingston	6,500	1.1E-5	6.8E-3	8.5E-5	1.1E-5	1.1E-5	1.1E-5	1.6E-4	5.5E-6	5.5E-6
Rockwood	7,000	1.2E-5	7.3E-3	9.1E-5	1.2E-5	1.2E-5	1.2E-5	1.8E-4	6.0E-6	6.0E-6
Spring City	2,000	3.4E-6	2.1E-3	2.6E-5	3.4E-6	3.4E-6	3.4E-6	5.2E-5	1.7E-6	1.7E-6
Soddy-Daisy	8,000	1.1E-5	7.0E-3	8.8E-5	1.1E-5	1.1E-5	1.1E-5	1.7E-4	1.1E-5	1.1E-5
Chattanooga	230,000	3.2E-4	2.0E-1	2.5E-3	3.2E-4	3.2E-4	3.2E-4	5.0E-3	1.6E-4	1.6E-4

[a] Assumes population evenly divided into male and female.

[b] Read as 8.5×10^{-5}.

Table 12. Estimated total-body and organ population dose commitments (person-rem) from ingestion of ^{137}Cs in one year's drinking water

Community	*Population*	Total body	GI	*Bone*	*Thyroid*	*Lungs*	Liver	Kidneys	Testes[a]	Ovaries[a]
Harriman	12,000	1.4E-2[b]	1.7E-2	2.8E-2	1.4E-4	4.3E-3	3.8E-2	1.3E-2	7.2E-3	7.2E-3
Kingston	6,500	2.0E-3	2.2E-3	3.7E-3	2.0E-3	5.7E-4	5.0E-3	1.8E-3	1.0E-3	1.0E-3
Rockwood	7,000	2.1E-3	2.4E-3	4.0E-3	2.1E-3	6.1E-4	5.4E-3	1.9E-3	1.1E-3	1.1E-3
Spring City	2,000	6.0E-4	6.8E-4	1.1E-3	6.0E-4	1.7E-4	1.5E-3	5.4E-4	3.0E-4	3.0E-4
Soddy-Daisy	8,000	2.0E-3	2.2E-3	3.7E-3	2.0E-3	5.7E-4	5.0E-3	1.8E-3	1.0E-3	1.0E-3
Chattanooga	230,000	5.8E-2	6.4E-2	1.1E-1	5.8E-2	1.6E-2	1.4E-1	5.1E-2	2.9E-2	2.9E-2

[a]Assumes population evenly divided into male and female.

[b]Read as 1.4×10^{-2}.

Table 13. Estimated total-body and organ population dose commitments (person-rem) from ingestion of tritium (^3H) in one year's fish consumption

Community	Population	Total body	GI	Bone	Thyroid	Lungs	Liver	Kidneys	Testes[a]	Ovaries[a]
Harriman	12,000	8.0E-3[b]	8.0E-3	8.0E-3	8.0E-3	8.0E-3	8.0E-3	8.0E-3	4.0E-3	4.0E-3
Kingston	6,500	1.1E-3	1.1E-3	1.1E-3	1.1E-3	1.1E-3	1.1E-3	1.1E-3	5.5E-4	5.5E-4
Rockwood	7,000	1.2E-3	1.2E-3	1.2E-3	1.2E-3	1.2E-3	1.2E-3	1.2E-3	6.0E-4	6.0E-4
Spring City	2,000	3.4E-4	3.4E-4	3.4E-4	3.4E-4	3.4E-4	3.4E-4	3.4E-4	1.7E-4	1.7E-4
Soddy-Daisy	8,000	1.1E-3	1.1E-3	1.1E-3	1.1E-3	1.1E-3	1.1E-3	1.1E-3	5.6E-4	5.6E-4
Chattanooga	230,000	3.2E-2	3.2E-2	3.2E-2	3.2E-2	3.2E-2	3.2E-2	3.2E-2	1.6E-2	1.6E-2

[a]Assumes population evenly divided into male and female.

[b]Read as 8.0×10^{-3}.

Table 14. Estimated total-body and organ population dose commitments (person-rem) from *ingestion of ^{90}Sr in one year's fish consumption*

Community	Population	Total body	GI	Bone	Thyroid	Lungs	Liver	Kidneys	Testes[a]	Ovaries[a]
Harriman	12,000	3.6E-2[b]	1.0E-2	1.8E0	3.6E-2	3.6E-2	3.6E-2	3.6E-2	1.8E-2	1.8E-2
Kingston	6,500	4.8E-3	1.4E-3	2.4E-1	4.8E-3	4.8E-3	4.8E-3	4.8E-3	2.4E-3	2.4E-3
Rockwood	7,000	5.1E-3	1.5E-3	2.6E-1	5.1E-3	5.1E-3	5.1E-3	5.1E-3	2.6E-3	2.6E-3
Spring City	2,000	1.5E-3	4.2E-4	7.3E-2	1.5E-3	1.5E-3	1.5E-3	1.5E-3	7.3E-4	7.3E-4
Soddy-Daisy	8,000	4.9E-3	1.4E-3	2.4E-1	4.9E-3	4.9E-3	4.9E-3	4.9E-3	2.4E-3	2.4E-3
Chattanooga	230,000	1.4E-1	4.1E-2	6.9E0	1.4E-1	1.4E-1	1.4E-1	1.4E-1	7.0E-2	7.0E-2

[a]Assumes population evenly divided into male and female.

[b]Read as 3.6×10^{-2}.

Table 15. Estimated total-body and organ population dose commitments (person-rem) from ingestion of ^{106}Ru in one year's fish consumption

Community	Population	Total body	GI	Bone	Thyroid	Lungs	Liver	Kidneys	Testes[a]	Ovaries[a]
Harriman	12,000	1.4E-5[b]	8.6E-3	1.1E-4	1.4E-5	1.4E-5	1.4E-5	2.2E-4	7.0E-6	7.0E-6
Kingston	6,500	1.8E-6	1.1E-3	1.4E-5	1.8E-6	1.8E-6	1.8E-6	2.9E-5	9.0E-7	9.0E-7
Rockwood	7,000	2.0E-6	1.2E-3	1.5E-5	2.0E-6	2.0E-6	2.0E-6	3.1E-5	1.0E-6	1.0E-6
Spring City	2,000	5.6E-7	3.4E-4	4.4E-6	5.6E-7	5.6E-7	5.6E-7	8.8E-6	2.8E-7	2.8E-7
Soddy-Daisy	8,000	2.0E-6	2.0E-3	E-5	2.0E-6	2.0E-6	2.0E-6	2.9E-5	9.8E-7	9.8E-7
Chattanooga	230,000	5.6E-5	3.4E-2	4.3E-4	5.6E-5	5.6E-5	5.6E-5	8.4E-4	2.8E-5	2.8E-5

[a]Assumes population evenly divided into male and female.

[b]Read as 1.4×10^{-5}.

Table 16. Estimated total-body and organ population dose commitments (person-rem) from ingestion of ^{137}Cs in one year's fish consumption

Community	Population	Total body	GI	Bone	Thyroid	Lungs	Liver	Kidneys	Testes[a]	Ovaries[a]
Harriman	12,000	1.0E-1[b]	1.1E-1	1.9E-1	1.0E-1	2.9E-2	2.5E-1	8.8E-2	5.0E-2	5.0E-2
Kingston	6,500	1.3E-2	1.5E-2	2.5E-2	1.3E-2	3.8E-3	3.3E-2	1.2E-2	6.5E-3	6.5E-3
Rockwood	7,000	1.4E-2	1.6E-2	2.7E-2	1.4E-2	4.1E-3	3.6E-2	1.3E-2	7.0E-3	7.0E-3
Spring City	2,000	4.0E-3	4.6E-3	7.8E-3	4.0E-3	1.2E-3	1.0E-2	3.6E-3	2.0E-3	2.0E-3
Soddy-Daisy	8,000	1.3E-2	1.4E-2	2.5E-2	1.3E-2	3.8E-3	3.4E-2	1.1E-2	6.4E-3	6.4E-3
Chattanooga	230,000	3.9E-1	4.4E-1	7.5E-1	3.9E-1	1.1E-1	9.9E-1	3.4E-1	1.9E-1	1.9E-1

[a]Assumes population evenly divided into male and female.

[b]Read as 1.0×10^{-1}.

Table 17. Estimated total-body and organ population dose commitments (person-rem) from submersion 1% of the time in water contaminated with ^{106}Ru

Community	Population	Total body	GI	Bone	Thyroid	Lungs	Liver	Kidneys	Testes[a]	Ovaries[a]
Harriman	12,000	1.8E-7[b]	1.3E-7	2.2E-7	1.8E-7	1.7E-7	1.4E-7	1.6E-7	9.6E-8	3.4E-8
Kingston	6,500	2.3E-8	1.8E-8	2.9E-8	2.3E-8	2.1E-8	1.8E-8	2.0E-8	1.2E-8	4.5E-9
Rockwood	7,000	2.5E-8	1.9E-8	3.1E-8	2.5E-8	2.4E-8	2.0E-8	2.1E-8	1.4E-8	4.9E-9
Spring City	2,000	7.2E-9	5.4E-9	8.8E-9	7.2E-9	6.8E-9	5.9E-9	6.3E-9	3.9E-9	1.4E-9
Soddy-Daisy	8,000	2.4E-8	1.8E-8	2.8E-8	2.4E-8	2.2E-8	1.9E-8	2.0E-8	1.2E-8	4.7E-9
Chattanooga	230,000	6.9E-7	5.1E-7	8.4E-7	6.9E-7	6.6E-7	5.5E-7	6.0E-7	3.7E-7	1.3E-7

[a]Assumes population evenly divided into male and female.

[b]Read as 1.8×10^{-7}.

Table 18. Estimated total-body and organ population dose commitments (person-rem) from submersion 1% of the time in water contaminated with ^{137}Cs

Community	Population	Total body	GI	Bone	Thyroid	Lungs	Liver	Kidneys	Testes[a]	Ovaries[a]
Harriman	12,000	6.8E-7[b]	5.3E-7	8.3E-7	7.2E-7	6.5E-7	5.6E-7	6.0E-7	3.8E-7	1.3E-7
Kingston	6,500	9.1E-8	7.0E-8	1.1E-7	9.5E-8	8.5E-8	7.5E-8	7.8E-8	4.9E-8	1.6E-8
Rockwood	7,000	9.8E-8	7.5E-8	1.2E-7	1.0E-7	9.1E-8	8.0E-8	8.4E-8	5.3E-8	1.8E-8
Spring City	2,000	2.8E-8	2.2E-8	3.4E-8	2.8E-8	2.6E-8	2.3E-8	2.4E-8	1.5E-8	5.0E-9
Soddy-Daisy	8,000	9.3E-8	7.2E-8	1.1E-7	9.8E-8	8.8E-8	7.7E-8	8.2E-8	5.0E-8	1.6E-8
Chattanooga	230,000	2.6E-6	2.0E-6	3.2E-6	2.8E-6	2.5E-6	2.1E-6	2.3E-6	1.4E-6	4.8E-7

[a]Assumes population evenly divided into male and female.

[b]Read as 6.8×10^{-7}.

Assuming 100 millirems per year per person, the population dose from natural background to the six exposed communities would be approximately 26,000 person-rems annually to the total body. The sum of the total-body doses in Tables 9–18 equals about 5,6 person-rems, or about 0.0002 times the natural background dose.

SUMMARY AND CONCLUSION

Concentrations of tritium, ^{90}Sr, ^{106}Ru, and ^{137}Cs in the Clinch River for 1978 were estimated by using the known 1978 releases of these nuclides from the White Oak Dam and diluting them by the integrated annual flow rate of the Clinch River. Estimates of 50-year dose commitment to a maximumly exposed individual were calculated for both aquatic and terrestrial pathways of exposure. The maximumly exposed individual was assumed to reside at the mouth of White Oak Creek where it enters the Clinch River and obtain all foodstuffs and drinking water at that location. The estimated total-body doses from all pathways to the maximumly exposed individual as a result of 1978 releases was about 0.003 times the dose expected from natural background.

Using appropriate concentrations of the subject radionuclides diluted downstream, the doses to populations residing at Harriman, Kingston, Rockwood, Spring City, Soddy-Daisy, and Chattanooga were calculated for the aquatic pathways. The total-body dose estimates for aquatic pathways for the six cities was about 0.0002 times the expected doses from natural background.

For the pathways considered in this report, the nuclide which contributes the greatest percent of the dose was ^{90}Sr. The maximum dose delivered by ^{90}Sr was to the bone of the subject individual or community. While doses from the radionuclides released were very low, any approach designed to attain "as low as reasonably achievable" population doses from ORNL waste management activities, should primarily consider methods for further limiting the release of ^{90}Sr.

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