Appendix E
Dose Calculations

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Measurements

The interaction of radiation with matter results in energy being deposited in that matter. This is why your hand feels warm when it is exposed to a light source (e.g., sunlight, flame). Ionizing radiation energy deposited in a mass of material is called radiation absorbed dose. A special unit of measurement, called the rad, was introduced for this concept during the early 1950s. The rad is equal to 100 ergs of ionizing energy deposited in 1 gram of material. The International System of Units introduced the Gray and is defined as follows: 1 Gray = 1 Joule per kilogram and is numerically equivalent to 100 rad (American Society for Testing and Materials 1993).

One device to measure radiation absorbed dose is the thermoluminescent dosimeter (TLD). This device absorbs and stores the energy of ionizing radiation within its crystal lattice. By heating the dosimeter material under controlled laboratory conditions, the stored energy is released in the form of light, which is measured and related to the amount of ionizing radiation energy stored in the material. Thermoluminescence, or light output exhibited by dosimeters when heated, is proportional to the energy absorbed, which by convention is related to the amount of radiation exposure (X), which is measured in units of roentgen (R). The exposure is multiplied by a factor of 0.98 to convert to a dose (D), in rad, to soft tissue (Shleien 1992). This conversion factor relating R to rad is, however, assumed to be unity (1) throughout this report for consistency with past reports. This dose is further modified by a quality factor, Q = 1, for beta and gamma radiation and the product of all other modifying factors (N). N is assumed to be unity to obtain dose equivalence (H) measured in rem. The international unit, the sievert (Sv), is equivalent to 100 rem.

$$D\ (\text{rad}) = X\ (\text{R}) * 1.0$$

$$H\ (\text{rem}) = D * N * Q$$

Calculations

The radiological dose that the public could have received in 2003 from Hanford Site cleanup operations was calculated in terms of the "total effective dose equivalent." The total effective dose equivalent is the sum of the effective dose equivalent from external sources and the committed effective dose equivalent for internal exposure. Effective dose equivalent is a weighted sum of doses to organs and tissues that accounts for the sensitivity of the tissue and the nature of the radiation causing the dose. It is calculated in units rem, or more typically the sub-unit millirem (millisievert)[a] for individuals and in units of person-rem for the collective dose received by the total population within an 80-kilometer (50-mile) radius of the site operations areas. This appendix describes how the doses in this report were calculated.

The calculation of the effective dose equivalent takes into account the long-term (50 years) internal exposure from radionuclides taken into the body during the current year. The effective dose equivalent is the sum of individual committed (50 years) organ doses multiplied by weighting factors that represent the proportion of the total health effect risk that each organ would receive from uniform irradiation of the whole body. Internal organs may also be irradiated from external sources of radiation. The external exposure received during the current year is added to the

(a) 1 rem (0.01 Sv) = 1,000 mrem (10 mSv).

committed internal dose to obtain the total effective dose equivalent. In this report, the effective dose equivalent is expressed in millirem with the corresponding value in sievert (or millisievert) in parentheses. The transfer factors used for pathway and dose calculations are documented in PNL-6584 and in PNL-3777.

Releases of radionuclides from Hanford Site facilities are usually too small to be measured in offsite air, drinking water, and food crops. Therefore, the air dose calculations were based on measurements made at the point of release (stacks and vents). The water pathway dose calculations were based on measurements of releases to the Columbia River (from the 100 Areas) or the difference in detectable radionuclide concentrations measured upstream and downstream of the site. Environmental radionuclide concentrations were estimated from the effluent measurements by environmental transport models.

The transport of radionuclides in the environment to the point of exposure is predicted by empirically derived models of exposure pathways. These models calculate radionuclide levels in air, water, and foods. Radionuclides taken into the body by inhalation or ingestion may be distributed among different organs and retained for various times. In addition, long-lived radionuclides deposited on the ground become possible sources for long-term external exposure and uptake by agricultural products. Dietary and exposure parameters were applied to calculate radionuclide intakes and radiological doses to the public. Standardized computer programs were used to perform the calculations. These programs contain internally consistent mathematical models that use site-specific dispersion and uptake parameters. These programs are incorporated in a master code, *GENII - The Hanford Environmental Radiation Dosimetry Software System*, Version 1.485 (PNL-6584), which employs the dosimetry methodology described in International Commission on Radiological Protection reports (1979a, 1979b, 1980, 1981a, 1981b, 1982a, 1982b, 1988). The assumptions and data used in these calculations are described below.

The RESRAD-BIOTA computer code was used to screen the 2003 radionuclide concentrations in environmental media (water and sediment) for exceeding established biota concentration guides (e.g., soil, sediment, or water concentrations that result in a dose rate of 1 rad per day for aquatic biota or 0.1 rad per day for terrestrial organisms). Both internal and external doses to aquatic, riparian, and terrestrial animals as well as to terrestrial plants are included in the screening process. For analyses with multiple media and multiple radionuclides, a sum of fractions is calculated to account for the contribution to dose from each radionuclide relative to its corresponding biota concentration guide. In the initial screening assessment, one compares maximum measured concentrations to the biota concentration guide. If the sum of fraction does not exceed one, no further analysis is required. However, if the sum of fractions does exceed one, a second analysis is performed using average concentrations. The screening process is further described in *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota* (DOE-STD-1153-2002).

The computer program, CAP88-PC, was used to calculate an air pathway dose to a maximally exposed individual as required by the U.S. Environmental Protection Agency (EPA) through Title 40, Code of Federal Regulations, Part 61 (40 CFR 61), Subpart H from airborne radionuclide effluent (other than radon) released at U.S. Department of Energy (DOE) facilities. Technical details of the CAP88-PC calculations are provided in the 2003 air emissions report (DOE/RL-2004-09).

Types of Dose Calculations Performed

Calculations of radiological doses to the public from radionuclides released into the environment are performed to demonstrate compliance with applicable standards and regulations.

DOE Order 5400.5 requires the following:

- Effective dose equivalent to be used in estimating public doses.
- Biokinetic models and metabolic parameters given by the International Commission on Radiological Protection to be used when estimating doses.
- Doses to the public to be calculated using facility effluent data when environmental concentrations are too low to measure accurately.

The following types of radiological doses were estimated.

Boundary Dose Rate (mrem/h and mrem/yr). The external radiological dose rates during the year in areas accessible by the general public were determined from measurements obtained near Hanford Site facilities.

Maximally Exposed Individual Dose (mrem). The maximally exposed individual is a hypothetical member of the public who lives at a location and has a lifestyle that makes it unlikely that other members of the public would receive higher doses. All potentially significant exposure pathways to this hypothetical individual were considered, including the following:

- Inhalation of airborne radionuclides.
- Submersion in airborne radionuclides.
- Ingestion of foodstuffs contaminated by radionuclides deposited on vegetation and the ground by both airborne deposition and irrigation water drawn from the Columbia River downstream of N Reactor.
- Exposure to ground contaminated by both airborne deposition and irrigation water.
- Ingestion of fish taken from the Columbia River.
- Recreation along the Columbia River, including boating, swimming, and shoreline activities.

Determination of the Location of Maximally Exposed Individual. The location of the hypothetical maximally exposed individual can vary from year to year, depending on the relative contributions of the several sources of radioactive effluent released to the air and to the Columbia River from Hanford facilities. Based on experience since 1990, three separate locations (Figure 5.0.1) have been used to assess the dose to the maximally exposed individual: (1) the Ringold area, along the east shoreline of the Columbia River 26 kilometers (16 miles) east of separations facilities in the 200 Areas; (2) the Sagemoor area, across the Columbia River from the 300 Area; and (3) the Riverview area across the river from Richland. Although the Ringold area is closer than Riverview to Hanford facilities that historically released airborne effluent, at Riverview the maximally exposed individual receives a higher dose rate from radionuclides in the Columbia River than a Ringold resident. The applicable exposure pathways for Ringold and Sagemoor are described in the following paragraphs. In 1990, the maximally exposed individual was located at Ringold. In 1991, 1992, 2000, and again in 2002, the maximally exposed individual resided in the Riverview area. However, from 1993 through 1999, 2001, and again in 2003, the hypothetical, maximally exposed individual was located across the Columbia River from the 300 Area at Sagemoor (Figure 5.0.1).

Ringold Maximally Exposed Individual. Because of its location, an individual in the Ringold area has the potential to receive the maximum exposure to airborne emissions from the 200 Areas, including direct exposure to a contaminated plume, inhalation, external exposure to radionuclides that deposit on the ground, and ingestion of contaminated locally grown food products. In addition, it is assumed that individuals in the Ringold area irrigate their crops with water taken from the Columbia River downstream of where groundwater enters the river from the 100 and 200-East Areas. This results in additional exposure from ingestion of irrigated food products and external irradiation from radionuclides deposited on the ground by irrigation. Recreational use of the Columbia River also is considered for this individual, resulting in direct exposure from water and radionuclides deposited on the shoreline and doses from ingestion of locally caught fish.

Riverview Maximally Exposed Individual. Because of its location, an individual in the Riverview area has the potential to receive the maximum exposure to waterborne emissions from effluent from Hanford facilities. For the calculation, it was assumed that the Riverview maximally exposed individual obtained domestic water from a local water treatment system that pumped from the Columbia River just downstream of the Hanford Site. In addition, it was assumed that individuals in the Riverview area irrigate their crops with water taken from the Columbia River. This results in additional exposure from ingestion of irrigated food products and external irradiation from radionuclides deposited on the ground by irrigation. Recreational use of the Columbia River was also considered, resulting in direct exposure from water and radionuclides deposited on the shoreline and doses from ingestion of locally caught fish. This individual also receives exposure via the air pathways, including direct exposure to a contaminated plume, inhalation, external exposure to radionuclides that deposit on the ground, and ingestion of locally grown food products contaminated by air deposition.

Sagemoor Maximally Exposed Individual. Because of the shift in site operations from nuclear weapons production to the current mission of managing waste products, cleaning up the site, and researching new ideas and technologies for waste disposal and cleanup, the significance of air emissions from production facilities in the 200 Areas has decreased compared to emissions from research facilities in the 300 Area.

An individual at Sagemoor, located approximately 1.4 kilometers (0.87 mile) directly across the Columbia River from the 300 Area, receives the maximum exposure to airborne emissions from the 300 Area. However, domestic water at this location comes from wells rather than from the river, and wells in this region are not directly contaminated by radionuclides of Hanford origin (EPS-87-367A). Because the farms located across from the 300 Area obtain irrigation water from the Columbia River upstream of the Hanford Site, the conservative assumption was made that the diet of an individual from the Sagemoor location consisted totally of foods purchased from the Riverview area, which could contain radionuclides present in both the liquid effluent and air emissions pathways. The added contribution of radionuclides in the Riverview irrigation water maximizes the calculated dose from the air and water pathways combined.

80-kilometer (50-mile) Collective Population Doses (person-rem). Regulatory limits have not been established for population doses. However, evaluation of the collective population doses to all residents within an 80-kilometer (50-mile) radius of Hanford Site operations is required by DOE Order 5400.5. The radiological dose to the collective population within 80 kilometers (50 miles) of the site operations areas was calculated to confirm adherence to DOE environmental protection policies, and provide information to the public. The 80-kilometer (50-mile) collective dose is the sum of doses to all individual members of the public within 80 kilometers (50 miles) of the site operations areas.

Pathways similar to those used for the maximally exposed individual were used to calculate doses to the offsite population. In calculating the effective dose, an estimate was made of the fraction of the offsite population expected to be affected by each pathway. The exposure pathways for the population are as follows:

- **Drinking water** – The cities of Richland and Pasco obtain their municipal water directly and Kennewick indirectly from the Columbia River downstream from the Hanford Site. Approximately 130,000 people in the three cities are assumed to obtain all their drinking water directly from the Columbia River or from wells adjacent to the river.
- **Irrigated food** – Columbia River water is withdrawn for irrigation of small vegetable gardens and farms in the Riverview district of Pasco in Franklin County. Enough food is grown in this district to feed an estimated 2,000 people. Commercial crops are also irrigated by Columbia River water in the Horn Rapids area of Benton County. These crops are widely distributed.
- **River recreation** – These activities include swimming, boating, and shoreline recreation. Specific pathways include external exposure from radionuclides in the water or on the shoreline and ingestion of river water while swimming. An estimated 125,000 people who reside within 80 kilometers (50 miles) of the Hanford Site operations areas are assumed to be affected by these pathways.
- **Fish consumption** – Population doses from the consumption of fish obtained locally from the Columbia River were calculated from an estimated total annual catch of 15,000 kilograms (33,075 pounds) per year without reference to a specified human group of consumers.

Data

The data that are needed to perform dose calculations are based on either measured upstream/downstream differences or measured effluent releases and include information on initial transport through the atmosphere or river, transfer or accumulation in terrestrial and aquatic pathways, and public exposure. By comparison, radiological dose calculations based on measured activities of radionuclides in food require data describing only dietary and recreational activities and exposure times. These data are discussed below.

Population Distribution and Atmospheric Dispersion

Geographic distributions of the population residing within an 80-kilometer (50-mile) radius of the Hanford Site operating areas are shown in PNNL-14687, APP. 1. These distributions are based on 2000 Bureau of the Census data (PNNL-14428). These data influence the population dose by providing estimates of the number of people exposed to radioactive effluent and their proximity to the points of release.

Atmospheric dispersion data are also shown in PNNL-14687, APP. 1. These data describe the transport and dilution of airborne radioactive material, which influence the amounts of radionuclides being transported through the air to specific locations.

Terrestrial and Aquatic Pathways

Important parameters affecting the movement of radionuclides within exposure pathways such as irrigation rates, growing periods, and holdup periods are listed in Table E.1. Certain parameters are specific to the lifestyles of either maximally exposed individuals or individuals for whom average parameter values were used.

Public Exposure

The offsite radiological dose is related to the extent of external exposure to or intake of radionuclides released from Hanford Site operations. Tables E.2 through E.4 give the parameters describing the diet, residency, and river recreation parameters assumed for maximally exposed and average individuals.

Dose Calculation Documentation

DOE established the Hanford Dose Overview Panel to promote consistency and defensibility of environmental dose calculations at Hanford. The panel is responsible for defining standard, documented computer codes and input parameters used for radiological dose calculations for the public in the vicinity of the Hanford Site. Only those procedures, models, and parameters previously defined by the panel were used to calculate the radiological doses (PNL-3777). The calculations were then reviewed by the panel. Summaries of dose calculation technical details for this report are shown in Tables E.5 through E.9 and in PNNL-14687, APP. 1.

400 Area Drinking Water

Drinking water at the Fast Flux Test Facility contained slightly elevated levels of tritium. The potential doses to 400 Area workers consuming this water in 2003 are given in Table E.10.

Table E.1. Food Pathway Parameters Used in Hanford Site Dose Calculations, 2003

	Holdup, d[a]						
Medium	Maximally Exposed Individual	Average Individual	Growing Period, d	Yield, kg/m^2	(lb/yd^2)	Irrigation Rate, L/m^2/mo	(gal/yd^2/mo)
Leafy vegetables	1	14	90	1.5	(3.3)	150	(40)
Other vegetables	5	14	90	4	(8.2)	170	(45)
Fruit	5	14	90	2	(4.41)	150	(40)
Cereal	180	180	90	0.8	(1.76)	0	
Eggs	1	18	90	0.8	(1.76)	0	
Milk	1	4	--	--		--	
Hay	(100)[b]	(100)	45	2	(4.41)	200	(53)
Pasture	(0)	(0)	30	1.5	(3.3)	200	(53)
Red meat	15	34	--	--		--	
Hay	(100)	(100)	45	2	(4.41)	200	(53)
Grain	(180)	(180)	90	0.8	(1.76)	0	
Poultry	1	34	90	0.8	(1.76)	0	
Fish	1	1	--	--		--	
Drinking water	1	1	--	--		--	

(a) Holdup is the time between harvest and consumption.
(b) Values in ( ) are the holdup in days between harvest and consumption by farm animals.

Table E.2. Dietary Parameters Used in Hanford Site Dose Calculations, 2003

Medium	Consumption: Maximally Exposed Individual		Consumption: Average Individual	
Leafy vegetables	30 kg/yr	(66 lb/yr)	15 kg/yr	(33 lb/yr)
Other vegetables	220 kg/yr	(485 lb/yr)	140 kg/yr	(310 lb/yr)
Fruit	330 kg/yr	(728 lb/yr)	64 kg/yr	(140 lb/yr)
Grain	80 kg/yr	(180 lb/yr)	72 kg/yr	(160 lb/yr)
Eggs	30 kg/yr	(66 lb/yr)	20 kg/yr	(44 lb/yr)
Milk	270 L/yr	(71 gal/yr)	230 L/yr	(61 gal/yr)
Red meat	80 kg/yr	(180 lb/yr)	70 kg/yr	(150 lb/yr)
Poultry	18 kg/yr	(40 lb/yr)	8.5 kg/yr	(19 lb/yr)
Fish	40 kg/yr	(88 lb/yr)	--(a)	
Drinking water	730 L/yr	(193 gal/yr)	440 L/yr	(116 gal/yr)

(a) Average individual consumption not identified; radiation doses were calculated based on estimated total annual catch of 15,000 kg (33,075 lb).

Table E.3. Residency Parameters Used in Hanford Site Dose Calculations, 2003

Parameter	Exposure, h/yr: Maximally Exposed Individual	Exposure, h/yr: Average Individual
Ground contamination	4,383	2,920
Air submersion	8,766	8,766
Inhalation(a)	8,766	8,766

(a) Inhalation rates: adult 270 cm^3/s (16.5 $in.^3/s$).

Table E.4. Recreational Parameters Used in Hanford Site Dose Calculations, 2003

Parameter	Exposure, h/yr(a): Maximally Exposed Individual	Exposure, h/yr(a): Average Individual
Shoreline	500	17
Boating	100	5
Swimming	100	10

(a) Assumed river-water travel times from 100-N Area to the point of aquatic recreation were 8 hours for the maximally exposed individual and 13 hours for the average individual. Correspondingly lesser times were used for other locations.

Air Surveillance Inhalation Doses

Radionuclide concentrations measured in ambient air at locations on or near the Hanford Site were used to calculate radiological doses from breathing contaminated air. Inhalation rates were taken from International Commission on Radiological Protection (1994). Occupancy times ranged from 100% at offsite locations to 33% for onsite locations.

Table E.5. Technical Details of Airborne Release Dose Calculations for the 100 Areas of the Hanford Site, 2003

Facility name	100-K Area
Releases (Ci [Bq])	^{90}Sr (9.0 x 10^{-6} [3.33 x 10^{5}]), ^{106}Ru (1.1 x 10^{-6} [4.07 x 10^{4}]), ^{137}Cs (7.5 x 10^{-6} [2.77 x 10^{5}]), ^{238}Pu (3.4 x 10^{-7} [1.26 x 10^{4}]), ^{239}Pu (2.5 x 10^{-6} [9.25 x 10^{4}]), ^{241}Pu (2.3 x 10^{-5} [8.51 x 10^{5}]), ^{241}Am (1.7 x 10^{-6} [6.29 x 10^{4}])
Meteorological conditions	2003 annual average, calculated from data collected at the 100-K Area and the Hanford Meteorology Station from January through December 2003, using the computer code HANCHI
$\overline{X}$/Q'	Maximally exposed individual, 1.8 x 10^{-8} s/m^3 at 53 km (33 mi) SSE; 80-km (50-mi) population, 4.6 x 10^{-3} s/m^3 person-s/m^3
Release height	10-m (33-ft) effective stack height
Population distribution	~482,000 (PNNL-14687, APP. 1, Table D-1)
Computer code	GENII, Version 1.485, December 3, 1990 (PNL-6584)
Doses calculated	Chronic, 1-yr exposure, 50-yr committed internal dose equivalent, and annual effective dose equivalent to individual and population
Pathways considered	External exposure to plume and ground deposits Inhalation Ingestion of foods produced locally at Riverview
Files addressed	Radionuclide Library, Rev. 7-1-92 Food Transfer Library, Rev. 8-29-88 External Dose Factor Library, Rev. 5-9-88 Internal Dose Factor Library, Rev. 12-3-90

Table E.6. Technical Details of Liquid Release Dose Calculations for the 100-N Area of the Hanford Site, 2003

Facility name	100-N Area
Releases (Ci [Bq])	^{3}H (1.5 x 10^{-2} [5.55 x 10^{8}]), ^{90}Sr (9.4 x 10^{-2} [3.48 x 10^{9}]), ^{238}Pu (3.8 x 10^{-7} [1.4 x 10^{4}]), ^{239}Pu (7.1 x 10^{-6} [2.63 x 10^{5}])
Mean river flow	2,856 m^3/s (100,835 ft^3/s)
Shore-width factor	0.2
Population distribution	70,000 for drinking water pathway 125,000 for aquatic recreation 2,000 for consumption of irrigated foodstuffs 15,000 kg/yr (33,075 lb/yr) total harvest of Columbia River fish
Computer code	GENII, Version 1.485, December 3, 1990 (PNL-6584)
Doses calculated	Chronic, 1-yr exposure, 50-yr committed internal dose equivalent, and annual effective dose equivalent to individual and population
Pathways considered	External exposure to irrigated soil, to river water, and to shoreline sediments Ingestion of aquatic foods and irrigated farm products
Files addressed	Radionuclide Library, Rev. 7-1-92 Food Transfer Library, Rev. 8-29-88 External Dose Factor Library, Rev. 5-9-88 Internal Dose Factor Library, Rev. 12-3-90

Table E.7. Technical Details of Airborne Release Dose Calculations for the 200 Areas of the Hanford Site, 2003

Facility name	200 Areas
Releases (Ci [Bq])	200-East Area ^{60}Co (3.9 x 10^{-8} [1.44 x 10^{3}]), ^{90}Sr (1.2 x 10^{-4} [4.44 x 10^{6}]), ^{129}I (1.4 x 10^{-3} [5.18 x 10^{7}]), ^{137}Cs (6.3 x 10^{-5} [2.33 x 10^{6}]), ^{238}Pu (3.8 x 10^{-8} [1.41 x 10^{3}]), $^{239/240}$Pu (1.7 x 10^{-6} [6.29 x 10^{4}]), ^{241}Am (2.0 x 10^{-6} [7.4 x 10^{4}]) 200-West Area ^{90}Sr (3.0 x 10^{-5} [1.11 x 10^{6}]), ^{137}Cs (1.5 x 10^{-5} [5.55 x 10^{5}]), ^{238}Pu (1.3 x 10^{-6} [4.81 x 10^{4}]), $^{239/240}$Pu (8.3 x 10^{-5} [3.07 x 10^{6}]), ^{241}Pu (7.2 x 10^{-5} [2.66 x 10^{6}]), ^{241}Am (1.4 x 10^{-5} [5.18 x 10^{5}])
Meteorological conditions	2003 annual average, calculated from data collected at the Hanford Meteorology Station from January through December 2003, using the computer code HANCHI
$\overline{X}/Q'$	Maximally exposed individual, 7.6 x 10^{-9} s/m^3 at 32 km (20 mi) SE; 80-km (50-mi) population, 1.1 x 10^{-3} person-s/m^3
Release height	89-m (292-ft) effective stack height
Population distribution	~486,000 (PNNL-14687, APP. 1, Table D-2)
Computer code	GENII, Version 1.485, December 3, 1990 (PNL-6584)
Doses calculated	Chronic, 1-yr exposure, 50-yr committed internal dose equivalent, and annual effective dose equivalent to individual and population
Pathways considered	External exposure to plume and ground deposits Inhalation Ingestion of foods produced locally at Riverview
Files addressed	Radionuclide Library, Rev. 7-1-92 Food Transfer Library, Rev. 8-29-88 External Dose Factor Library, Rev. 5-9-88 Internal Dose Factor Library, Rev. 12-3-90

Table E.8. Technical Details of Airborne Release Dose Calculations for the 300 Area of the Hanford Site, 2003

Facility name	300 Area
Releases (Ci)	^{3}H (as HT)[(a)] (7.8 x 10^{0} [2.89 x 10^{11}]), ^{3}H (as HTO)[(a)] (3.5 x 10^{1} [1.29 x 10^{10}]), ^{90}Sr (1.3 x 10^{-6} [4.81 x 10^{4}]), ^{137}Cs (2.1 x 10^{-5} [7.77 x 10^{5}]), ^{220}Rn (2.3 x 10^{2} [8.51 x 10^{8}]), ^{234}U (6.3 x 10^{-11} [2.33 x 10^{0}]), ^{235}U (4.6 x 10^{-11} [1.7 x 10^{0}]), ^{238}Pu (4.9 x 10^{-9} [1.81 x 10^{2}]), ^{238}U (3.5 x 10^{-11} [1.3 x 10^{0}]), ^{239}Pu (1.1 x 10^{-7} [4.07 x 10^{3}]), ^{241}Am (1.3 x 10^{-8} [4.81 x 10^{2}])
Meteorological conditions	2003 annual average, calculated from data collected at the 300 Area and the Hanford Meteorology Station from January through December 2003, using the computer code HANCHI
$\overline{X}/Q'$	Maximally exposed individual at residence, 9.0 x 10^{-7} s/m^{3} at 1.4 km (0.87 mi) E; 80-km (50-mi) population, 1.1 x 10^{-2} person-s/m^{3}
Release height	10 m (33 ft)
Population distribution	~349,000 (PNNL-14687, APP. 1, Table D-3)
Computer code	GENII, Version 1.485, December 3, 1990 (PNL-6584)
Doses calculated	Chronic, 1-yr exposure, 50-yr committed internal dose equivalent, and annual effective dose equivalent to individual and population
Pathways considered	External exposure to plume and ground deposits Inhalation Ingestion of foods produced locally at Riverview
Files addressed	Radionuclide Library, Rev 7-1-92 Food Transfer Library, Rev. 8-29-88 External Dose Factor Library, Rev. 5-9-88 Internal Dose Factor Library, Rev. 12-3-90

(a) HT = Elemental tritium; HTO = Tritiated water vapor.

Table E.9. Technical Details of Airborne Release Dose Calculations for the 400 Area of the Hanford Site, 2003

Facility name	400 Area
Releases (Ci [Bq])	^{3}H (as HTO)[(a)] (6.6 x 10^{-1} [2.44 x 10^{7}]), ^{137}Cs (4.9 x 10^{-6} [1.81 x 10^{5}]), $^{239/240}Pu$ (1.4 x 10^{-7} [5.18 x 10^{3}])
Meteorological conditions	2003 annual average, calculated from data collected at the 400 Area and the Hanford Meteorology Station from January through December 2003, using the computer code HANCHI
$\overline{X}/Q'$	Maximally exposed individual at residence, 9.0 x 10^{-8} s/m^{3} at 11 km (7 mi) SE; 80-km (50-mi) population, 6.7 x 10^{-3} person-s/m^{3}
Release height	10 m (33 ft)
Population distribution	~354,000 (PNNL-14687, APP. 1, Table D-4)
Computer code	GENII, Version 1.485, December 3, 1990 (PNL-6584)
Doses calculated	Chronic, 1-yr exposure, 50-yr committed internal dose equivalent, and annual effective dose equivalent to individual and population
Pathways considered	External exposure to plume and ground deposits Inhalation Ingestion of foods produced locally at Riverview
Files addressed	Radionuclide Library, Rev. 7-1-92 Food Transfer Library, Rev. 8-29-88 External Dose Factor Library, Rev. 5-9-88 Internal Dose Factor Library, Rev. 12-3-90

(a) HTO = Tritiated water vapor.

Table E.10. Annual Dose to Workers in the 400 Area of the Hanford Site from Ingestion of Drinking Water Obtained from Groundwater Wells, 2003

Radionuclide	Average Drinking Water Activity, pCi/L (mBq/L)[(a)]	Intake, pCi/yr (Bq)[(b)]	Ingestion Dose Factor, rem/pCi[(c)]	Ingestion Dose, rem/yr (Sv/yr)
Gross beta[(d)]	7.0 ± 0.3 (259 ± 11.1)	1,680 (62.2)	5.00 x 10^{-8} (500 pSv/pCi)	8.4 x 10^{-5} (8.4 x 10^{-7})
Tritium	3,350 ± 135 (123,950 ± 4,995)	804,000 (22, 748)	6.40 x 10^{-11} (0.6 pSv/pCi)	5.1 x 10^{-5} (5.1 x 10^{-7})
^{226}Ra	0.04 ± 0.03 (1.48 ± 1.11)	9.6 (0.35)	1.3 x 10^{-6} (0.013 µSv/pCi)	1.3 x 10^{-5} 1.3 x 10^{-7}
Total				1.5 x 10^{-4} (1.5 x 10^{-6})

(a) Drinking water concentrations are annual averages obtained from quarterly samples taken during 2003.
(b) Intake is based on the assumption that a worker ingests 1 L/d (0.264 gal/d) of groundwater during the entire working year (taken to be 240 days for the analysis).
(c) Ingestion effective dose conversion factors are taken from EPA/520/1-88-020 and converted from International System of Units (SI). Where the document lists dose factors for more than one chemical form of a radionuclide, the most soluble chemical form was assumed.
(d) Gross beta concentrations were assumed to be ^{137}Cs for the purposes of this analysis.

References

40 CFR 61, Subpart H. U.S. Environmental Protection Agency. "National Emission Standards for Hazardous Air Pollutants." *U.S. Code of Federal Regulations*.

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