ORAU Team **NIOSH Dose Reconstruction Project** Technical Basis Document for the Hanford Site - Occupational Environmental Dose	Document Number: ORAUT-TKBS-0006-4 Effective Date: 10/15/2003 Revision No.: 00 Controlled Copy No.: ________ Page 1 of 33
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RECORD OF ISSUE/REVISIONS

ISSUE AUTHORIZATION DATE	EFFECTIVE DATE	REV. NO.	DESCRIPTION
Draft	09/15/2003	00-A	New document to establish Occupational Environmental Dose Section 4. Initiated by Edward D. Scalsky.
10/15/2003	10/15/2003	00	First approved issue. Initiated by Edward D. Scalsky.

ACRONYMS AND ABBREVIATIONS

Bq	Becquerel
Ci	Curie
PUREX	Plutonium Uranium Extraction
REDOX	Reduction Oxidation

4.1 OCCUPATIONAL ENVIRONMENTAL DOSE

The occupational environmental dose is the dose received by individuals while outside of operational facilities onsite such as process buildings, chemical separations plants, reactors or other structures at Hanford. Their internal dose from the inhalation of radioactive materials may be determined from radionuclide air concentrations. Their external dose to radioactive materials outside their bodies may be determined from immersion in a cloud of inert gases, from deposition of particles on the skin, or from adjacent operational facilities. This section of the Technical Basis Documents provides the rational and/or historic background information and data for the reconstruction of occupational environmental doses for unmonitored personnel at the Hanford Site.

The four chemical separations plants, T Pant, B Plant, REDOX Plant and the PUREX plant, along with the plutonium handling Z plant are shown in Figure 4.1.1 to be the most important release points at Hanford. Section 4.3.2 showed that ^{41}Ar from the reactors was also an important source of worker exposure. For individuals working outside process buildings and facilities at Hanford, pathways of concern are:

- the inhalation of radionuclides in the air,
- direct external radiation from plumes,
- physical contact with particulate radionuclides incident on the skin.

Construction workers, contractors, security guards, environmental monitoring personnel, and personnel involved with outdoor work duties would be the personnel likely to receive occupational environmental doses.

The Hanford Site atlas (http://www.bhierc.com/dm/hgis/hgis.htm) and Gerber (1992) show the location of the Hanford Camp, Columbia camp, and other locations where individuals worked and lived. For example up to 40,000 individuals, mainly construction workers, resided at Hanford Camp until it was closed in February 1945. Details on the buildings and facilities at the Hanford site are provided in Gerger (1993). Figure 4.1-1 shows many of these locations which were selected as locations where annual intakes of radionuclides in air were determined.

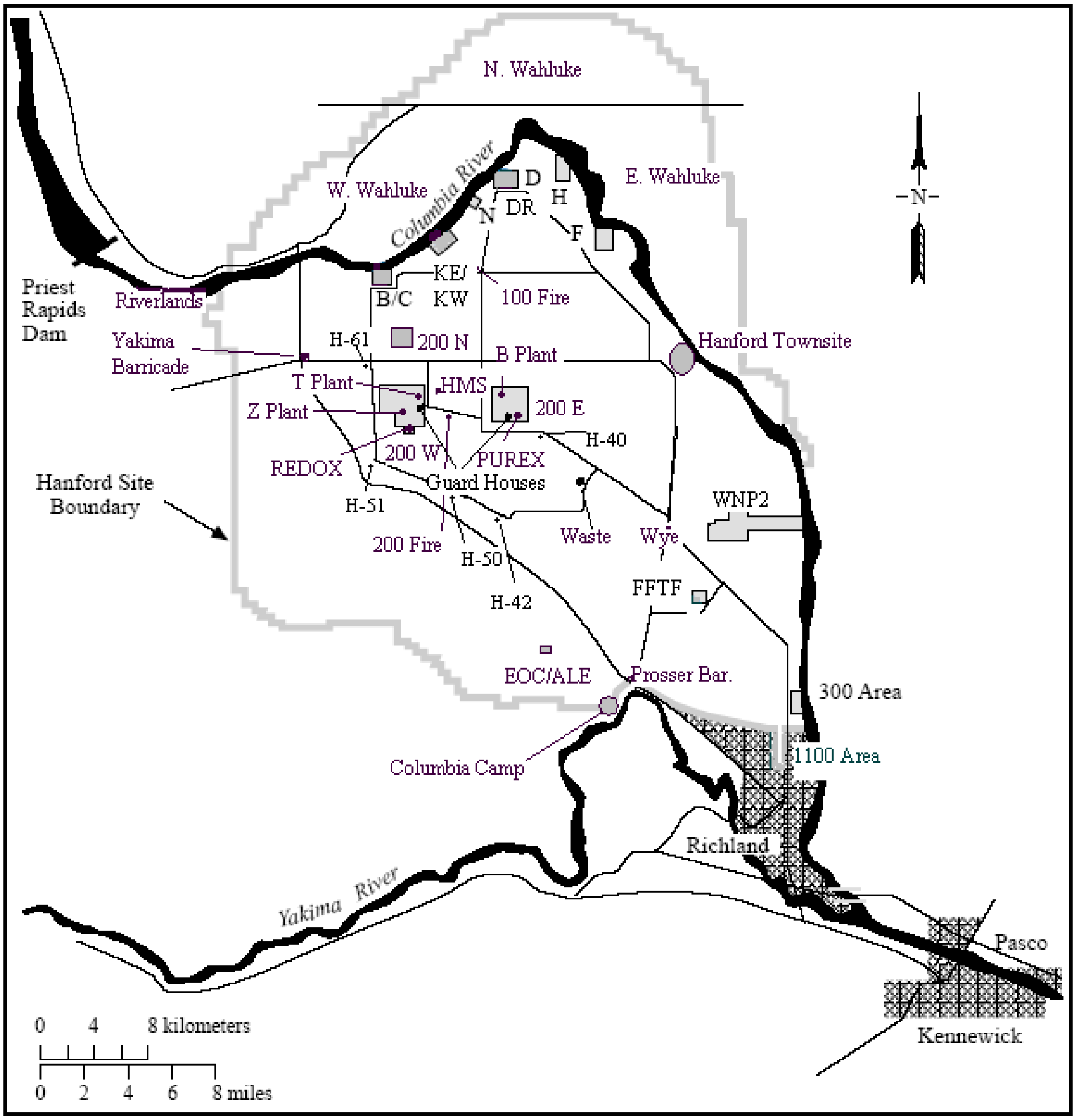

Figure 4.1-1. Locations of potential exposure for which intakes and exposures are provided.

4.2 DOSES FROM ONSITE ATMOSPHERIC RADIONUCLIDE CONCENTRATIONS

In 1943 the Hanford site was selected as the location to produce plutonium for the U.S. atomic weapons program (Groves 1962). A total of nine reactors, four chemical separations plants, and a plutonium handling plant became operational at the site in the following years (Ballinger and Hall 1991; Gydesen 1992; Till et al. 2002). The dates of operation of these facilities are presented in Table 4.2-1.

The plutonium produced in the reactor fuel elements was extracted from the irradiated fuel in the chemical separations plants (T, B, REDOX, and PUREX) and converted to metallic plutonium in the Z plant. Throughout operations of the reactor, the chemical separations plants, and the Z plant a portion of the radionuclides being processed was released into the atmosphere and transported primarily in the downwind direction towards the northeast (Farris et al. 1994).

Table 4.2-1. Facilities operation dates.

Reactor	Dates of Operation	Chemical Separations Plants	Dates of Operation
100-B	1944–1968	T	1944–1952
100-D	1944–1967	B	1945–1956
100-F	1945–1965	REDOX	1952–1966
100H	1949–1965	PUREX	1956–1992
100-DR	1950–1964		
100-C	1952–1969	**Pu Handling Plant**	
100-KE	1955–1971	**Pu Handling Plant**	
100-KW	1954–1970		
100-N	1963–1987	Z	1945–1976

4.2.1 On-Site Releases to Air

Figure 4.2.1-1 illustrates the “fuel element cooling time” which is the elapsed time between discharge of the fuel elements from the reactors and the start of fuel processing in the chemical plants. Between 1944 and 1945 the fuel element cooling time was approximately 40 days. By 1947 the cooling time was extended to approximately 90 days. The shorter cooling time resulted in the releases of larger quantities of volatile, short-lived radionuclides compared to later years. For example in 1945 up to 90,000 Curies of ^{131}I were released each month compared to 10,000 Curies per month after 1946. Since there was no filtration to limit release of the volatile radionuclides in the early days, the releases to the atmosphere in 1945 were the largest at any time at Hanford (Till et al. 2002).

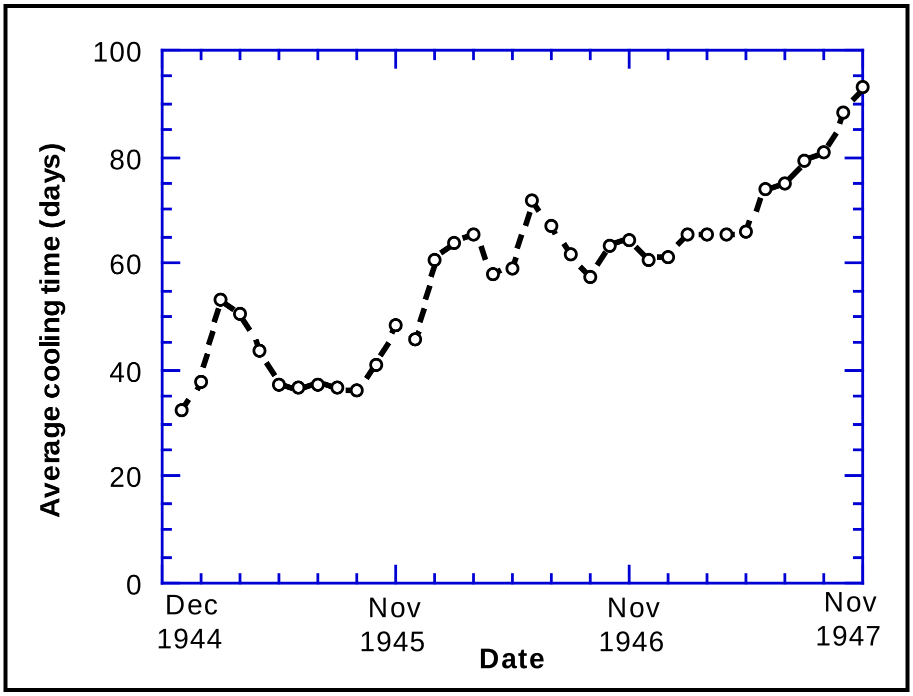

Figure 4.2.1-1. Average fuel cooling times prior to processing at Hanford.

Heeb (1994) published the releases of ^{41}Ar, ^{14}C, and ^{3}H from the reactors based on historical measurements. Screening studies eliminated from dose consideration ^{3}H and ^{14}C releases to the atmosphere from the reactors based on the product of the amount released and the dose conversion factors shown in Table 4.2.1-1. The estimated dose contribution of ^{41}Ar was 10,000 times greater than that of ^{3}H and 3000 times greater than that of ^{14}C. However due to the large ^{3}H release from the 108-B facility the dose from ^{3}H was assessed. (See the subsequent section on "Release of Tritium for 108-B." See also section 4.3.2 for additional information on ^{41}Ar.

Table 4.2.1-1. Estimated release rates from Hanford reactors and air pathway screening factors for ^{41}Ar, ^{3}H, and ^{14}C.

Radionuclide	**Estimated release from all reactors ($Bq\ d^{-1}$)[a]**	**Screening factor for inhalation and direct radiation exposure (Sv per $Bq\ m^{-3}$)[b]**
^{41}Ar	1.5×10^{13}	1.5×10^{-6}
^{3}H	5.2×10^{10}	1.4×10^{-7}
^{14}C	4.8×10^{9}	4.5×10^{-6}

a. Release estimates from Heeb (1994).
b. Screening factors from Appendix B of NCRP (1996).

Similar screening of the radionuclides released demonstrated that the dose from the following radionuclides should be considered (Till et al. 2002): The assumed absorption type is presented for each radionuclide.

Radionuclide	Absorption Type
^{41}Ar	na
^{3}H	water
	gas (HT or T_2) submersion
^{131}I	Class SR-1, Type F
^{144}Ce-^{144}Pr	M all compounds except oxides, hydroxides and fluorides
	S oxides
^{137}Cs	F all compounds
^{239}Pu	S
^{103}Ru-^{103}Rh	S
^{106}Ru-^{106}Rh	S
^{90}Sr-^{90}Y	F all compounds except
	S Strontium titanate ($SrTiO_3$)
^{95}Zr-^{95}Nb	F all compounds except
	M oxides, hydroxides, halides, and nitrates
	S carbides

S = Slow absorption
M = Moderate absorption
F = Fast absorption

Radionuclides listed in pairs are parents with associated short-lived progeny. These are assumed to be in equilibrium in the environment. Source terms are release rates of radioactive materials at specific locations. The source terms for the reactors, chemical separations plants and the plutonium handling plant are presented in Attachments A-1 through A-9.

Table 4.2.1-2. Physical, chemical, and radiological properties of radioactive particles released from Hanford, 1945–1956.

Interval		Source report	Location of sample	Physical characteristics	Chemical characteristics	Radiological characteristics
Beginning	Ending					
	May 7, 1945	HW-3-2894	Stack samples taken from the T Plant			0.6–0.8 MeV beta presumably from iodine; also 1.5–2.0 MeV beta
1945	1947	HW-10758	Vegetation, processing plant effluent air, and ambient air			Total beta 7 nCi per filter
	April 1947	HW-11082	Outside near T Plant fence	Presence of singular large particles not indicated		Mostly Ce and decay product, Pr
	April 1947	HW-55569	Outside in 200 Areas			Effective half-life of about 300 days. Principal contaminants were (in order): Ce, Y, Sr, Ru, Cs.
	Fall 1947	HW-7865	Outside ground near T, B Plants	Can be mechanically separated from dirt		Total beta activity ranging from 0.5 µCi to 1 µCi. Most of the beta activity was Ce; most alpha was Pu (range 0.07–1.7 nCi)
	Fall 1947	HW-9259	Outside ground near T, B Plants	Color reddish brown; carrier particles >100 µm, range 20 to 1500 µm linear dimensions; small particles, mists, and droplets emitted since operations began	Contain iron oxides; can be separated with magnets	Alpha activity mostly Pu, 1/20 as much U. Beta activity correlated with surface area of particle; mostly Ce (and daughter Pr-144), Y, Sr, Ru, and Cs
	April 1947	HW-7920	Outside ground near T, B Plants	Mass of 0.1 to 1 mg; brown color (different from soil)		0.1 µCi to 1 µCi. T Plant particles 60–90% Ce and up to 15%Y. B Plant 30–55% Ce, 7–20%, Sr and 30–45% Y
April 1947	April 1948	HW-8624	Outside ground near T, B Plants	Physical sizes of 153 large particles ranged from 40 µm to >1 mm. Median 300 µm. No reliable data on very small particles.	Essentially all particles contain enough iron to be separated magnetically	0.0001 to 3 µCi. 30–50% Ce; 10–50% Y; 10–20% Sr
	~March 1948	HW-9175	Processing plant effluent	Some are <1 µm		
	Spring 1948	HW-9864	Processing plant effluent	Mists mean size <5 µm; magnetic specks, density of iron		
	Spring 1948	HW-10261	Ground and roofs surrounding processing plants	Usually less than 500 µm; range 20–1500 µm	High in iron; low carbon and calcium	2.5 pCi to 3.2 µCi beta per particle. Max beta energy 3.0 MeV
	Spring 1948	HW-10261	Processing plant effluent			Beta mostly Ce; alpha mostly Pu
	~April 1948	Gregg 1948	Outside ground	10–1000 µm	Associated with rust	Max 3 µCi beta per particle
April 1948	April 1948	HW-12677	Particles collected by air samplers			1–10 pCi fission products per particle
April 1948	April 1948	HW-12677	Stacks of 314 Building, the Melt Plant, in 300 Area			Mostly uranium
?	1950	HW-15802	Ventilation air of the B Plant before sand filter			100% of alpha was Pu; most of beta was Ce, rare earths, Ru, Zr, Y, and Sr
	April 3, 1952	HW-33068	On survey meter inside car with window open			Particle read 40 rad h^{-1}

	April 29, 1952		Eastern and northern sections of the REDOX area			From 100 cpm at 1 in. to 800 mrad h^{-1} at surface; gross beta activity ranged up to 0.1 μCi per sample
April 1952	June 1952	HW-26493	Particles emitted from REDOX Plant (second, third, and fourth episodic releases on April 3, April 29, and June 24)	Ranged from microscopic translucent hydroscopic crystals adhering to the soil sand, to visible chalky particles varying in shape and size—a few with diameter ~ ½ in. Larger visible particles easily fractured, apparently a conglomerate of microscopic crystals.	Chemically, the composition of the inactive material was mainly ammonium nitrate with a small amount of occluded dust particles	90 to 98% of the total beta activity was Ru; ^{131}I in particulate contamination ranged from 1–5%. Beta particle activity varied in direct relationship with size.
	June 24, 1952	HW-32473	Outside: flakes from fourth episodic release from REDOX	1/64–1/32-in. thick and up to several inches in diameter. Large flaky radioactive particles found near the eastern REDOX exclusion area rapidly disappeared, though activity spots were detectable with survey instruments. Flakes fragile and hydroscopic.	Carrier crystal was predominately ammonium nitrate	Mostly ruthenium
	March 12, 1953	HW-28009	Ambient air near REDOX			36% of beta activity was Ru, 43% rare earths and Y
	Spring 1953	HW-28780	Base (inside) of the REDOX stack	Median particle size about 0.2 μm with GSD of 1.6 during one sample and 2.5 during another		Activity median particle size was 0.6 microns.
August 7, 1953	August 14, 1953	HW-29346 HW-32473	Outside ground southeasterly direction from the REDOX stack	Up to 5 in. (13 cm); average 0.5 in. (1.3 cm); up to 1/2 to ¾-in. thick	Carrier crystals were ammonium nitrate	Max 15 rep h^{-1}; average 300–500 mrep h^{-1} surface. 70% Ru, 25% rare earths and Y, and trace amounts of Sr, Ba, and Zr.
	December 1953	HW-32209	Air entering sand filter of REDOX	Two cascade impactor sample results geometric mean of 0.3 μm (GSD 2.8) and 0.5 μm (GSD 3.2); average particles per cubic meter was 5.3×10^8		
	December 1953	HW-32209	Air at 10-ft level inside REDOX stack	Four cascade impactor sample results ranged from geometric median size 0.3 μm (GSD 2.0) to 0.4 μm (GSD 3.8); average particles per cubic meter, 2.4×10^8		
August 9, 1954	May 18, 1954	HW-33896	Air entering REDOX Plant sand filter			92% of total beta activity was Ru in March; in May, 24% was Ru, 28% rare earths, 14% Zr, and 25% Nb
		HW-33068	General review: input side of process sand filter			Less Ru (80%) and more of the rare earths (10–15%) and Sr (1–2%), compared to particles emitted to the environment.

1952	1954	HW-33068	General review: REDOX releases to environment	Primary particles about 2 μm; large secondary particles typically 100 μm.	Carrier base is aggregate of ammonium nitrate, sometimes sand. Inhalable particles were between 40–80% soluble after 36 h in simulated lung fluid. Large particles were 3– 70% soluble after 48 h in simulated gastric juice.	Primary particles up to 5 nCi per particle, dose rate of 0.5 mrad h^{-1}; secondary particles dose rates up to 20 rad h^{-1} and 200 μCi per particle. Ru and Rh activity 98% of the total, with Sr-89 and Sr-90 <0.3%; rare earths plus Y <1.0%; and Zr-95 <0.5%.
	June 1954	HW-32473	Outside ground in 200 Areas	No well-defined relationship between particle size and dose rate. Particles of several thousand square μm were observed. Easily fractured.	Ammonium nitrate present	90% of beta activity was Ru; activity ratio 103:106 was 0.6 to 1.4; one particle with dose rate of 1.2 rad h^{-1} contained 6.3 μCi; another reading 120 mrad h^{-1} had 0.49 μCi; average dose rate per μCi was about 200 mrad h^{-1}
	November 7, 1954	HW-36505	Five particles emitted from REDOX stack	Four of the particles were agglomerates of smaller white crystals with yellow discoloration on some surfaces. One particle was bright yellow without the crystalline appearance.	Ammonium nitrate and iron were found in four particles. The bright yellow particle was mostly calcium and iron.	95% of the beta activity was from Ru/Rh isotopes with the ratio of activity of ^{103}Ru to ^{106}Ru being less than 0.05. Also Sr, rare earths, Zr, Pu.
October 1954	December 1954	HW-36504	Ground surfaces around REDOX	Maximum dimensions ranging from a few μm to ~1000 μm		Nearly all beta was Ru/Rh; Ru-103:Ru-106 ratio less than 1
	December 1954	HW-35542	Ground surfaces around REDOX	Relative to a unit length, the average width was 0.75 +/– 0.14 and the depth was 0.39 +/– 0.18. The density is believed to be about 1.5		
May 29, 1956	June 4, 1956	HW-44215	Outside of U Plant in 200-West Area	Large paint flakes up to 8 in. long, peeled off duct work between sand filter and U Plant stack	Associated with painted stack liner	Alpha and beta

Routine Releases from T and B Plants

Stack releases to the environment under normal operating conditions at the chemical separations plants were proportional to the rates at which the material entered the plant as irradiated fuel from the reactors. The most likely source of these releases was iron oxide particulates from corroding ductwork in the ventilation systems of the T and B plants. Analysis of the particles indicated that the radionuclides were deposited on the blowers and other iron surfaces and were released into the ventilation air stream as the iron parts corroded. Figure 4.2.1-2 presents the estimated distributions of physical, aerodynamic, and radiological properties of the released particles. Other physical characteristics of the particles and their distributions are reported in HW-7865, HW8624, HW-9175, and HW-10261. (See also Table 4.2.1-2)

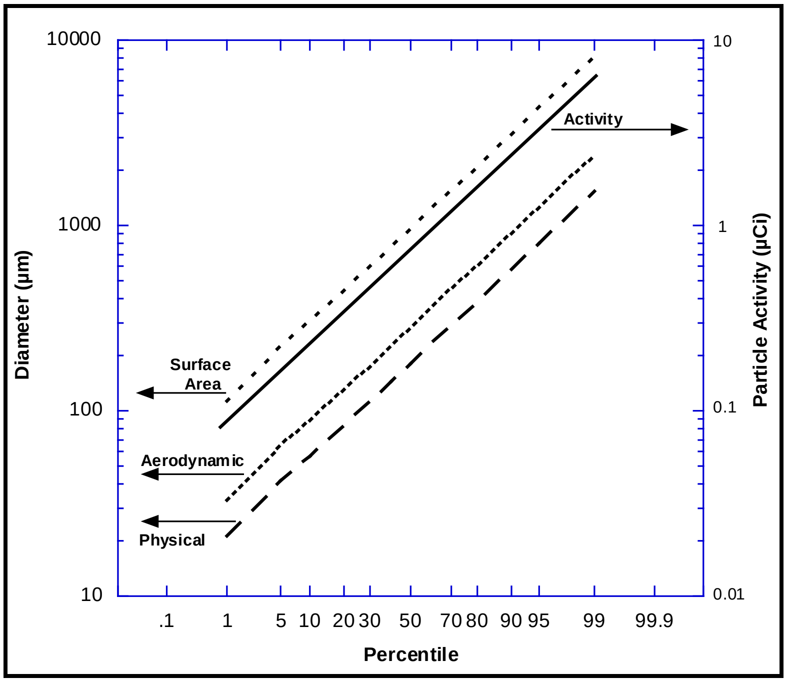

Figure 4.2.1-2. Estimated distributions of physical and aerodynamic diameters for large “active particles” together with estimated distributions for particle surface area and activity. (Till et al. 2002).

For routine releases from T and B plants the estimated monthly release is the product of the following factors:

- The monthly processing rates for each radionuclide compiled by Heeb (1994) which are the rates at which the radionuclide enter the separation plants as irradiated fuel from the reactors. The processing rates were estimated by Heeb (1994) for ^{90}Sr, ^{103}Ru, ^{106}Ru, ^{131}I, ^{144}Ce, and ^{239}Pu and by Till et al. (2002) for ^{137}Cs.

- The release fraction which is the ratio of the rate that the radionuclide was released to the processing rate of that radionuclide.

- The effluent treatment modifier which accounted for increased release rates in the early years of operation of T and B plant when there were no scrubbers or filters on the effluents.

- Uncertainty factors related to processing rates and the amount of radioactive decay that occurred between fuel irradiation and fuel processing.

Figures 4.2.1-3 and 4.2.1-4 illustrate the releases of ^{144}Ce and ^{131}I from T plant.

Effluents from B plant were similar to those from T plant but were higher due to difficulties encountered with the effluent filtration and scrubber system.

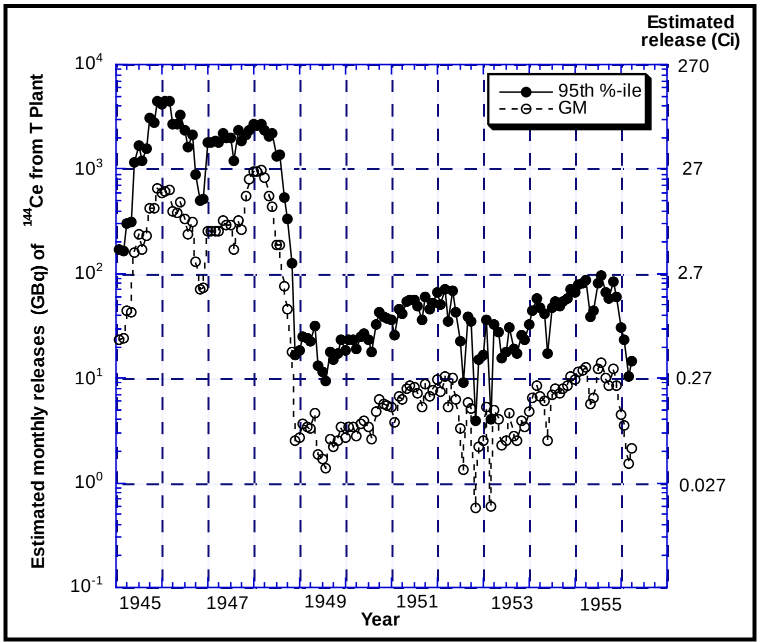

Figure 4.2.1-3. Estimated releases of ^{144}Ce from T Plant. (Till et al. 2002).

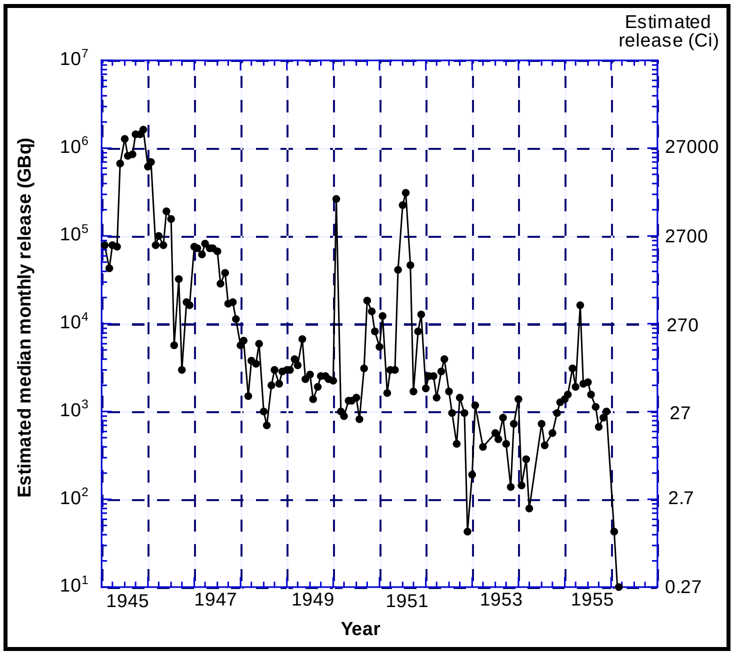

Figure 4.2.1-4. Estimated releases of ^{131}I from T Plant. Heeb (1994) and Napier (2002) provided estimates. (Till et al. 2002).

Routine Releases of Plutonium from Z Plant

Z plant was not one of the chemical separations plants but was located in the 200-W area of Hanford. Z plant produced and fabricated metallic plutonium from plutonium nitrate that came from the chemical separations plants. ^{239}Pu was released as small particles usually less than 1 µm. Figure 4.2.1-5 presents the estimated annual releases of ^{239}Pu from Z plant as median estimates and the 95th percentiles of the distribution.

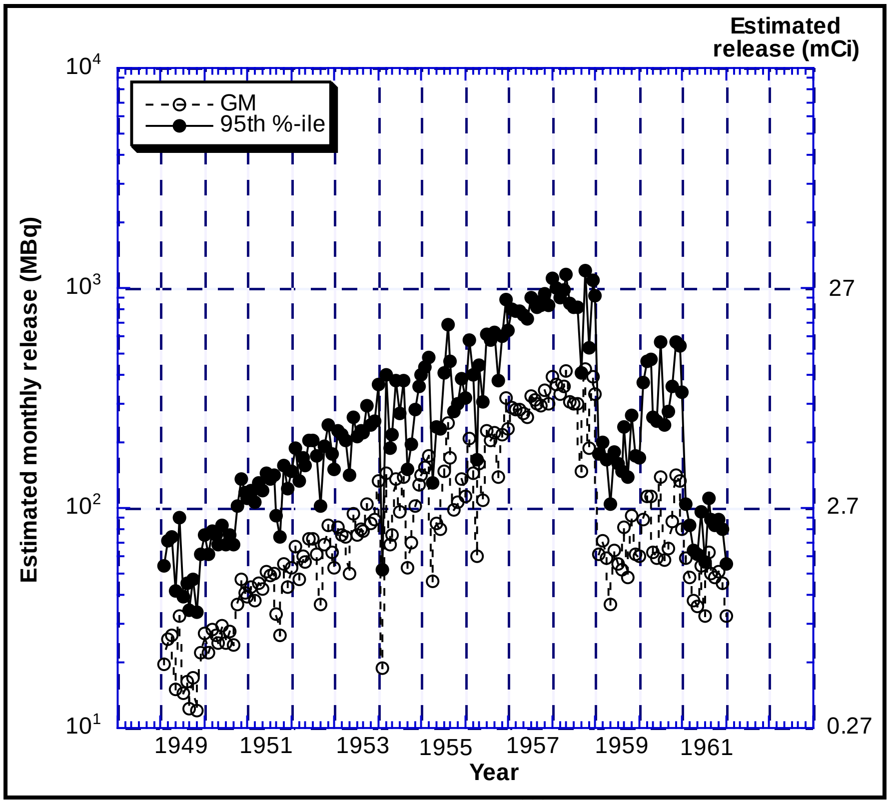

Figure 4.2.1-5. Estimated releases of ^{239}Pu from Z Plant. (Till et al. 2002).

Routine Releases of Iodine from the Chemical Separations Plants

^{131}I was released from the four chemical separations plants, T, B, REDOX, and PUREX from 1946 until 1962. Screening calculations indicate that ^{131}I was the most important radionuclide conveying dose to people on site (Till et al., 2002). Heeb 1994, Warren 1961, Junkins et al. 1960 and Foster and Nelson 1961 reported estimates of the ^{131}I releases. The estimates were complicated by different reported fuel element cooling times for the same fuel elements, unusual releases not included in the release estimates such as a boil-over and a fire in a dissolver, the presence of organic halides that were not included in the estimates, and unaccounted for plateout of elemental iodine in the sampling systems. The estimates of ^{131}I releases for T plant are presented in Figure 4.2.1-4. The estimates were compiled by Till et al. (2002) based on the amount of iodine in the fuel elements sent to the dissolvers of the chemical separations plants (Heeb, 1994) and the stack monitoring data and environmental measurements (Napier 2002). The absorption types for all compounds of iodine is F and is assumed to be a class SR-1 vapor for internal dose calculations.

Non-routine Releases from the REDOX Plant

Ammonium nitrate flakes formed on the inside of the exhaust stack of the REDOX plant and were released in 1952 through 1954. The largest release occurred in 1954. The flakes formed from the mixture of ammonia and nitrous oxides in the ventilation air. Volatile ruthenium oxide, RuO4, formed in an oxidation step in the plant, combined with the ammonium nitrate to form the flakes containing ^{103}Ru and ^{106}Ru. Some of the flakes were up to 10 cm diameter, contained up to 200 µCi (7.4E6 Bq) of ruthenium, and produced surface contact dose rates up to 20 rad/hour. (1 Ci = 3.7 x 1010 Bq). Physical characteristics of the particles are reported in HW-28780, and HW-33061. Contact dose rates for 65.5% of the particles were in the 5-50 mrad/hr range. The maximum deposition density occurred within about 400 m of the stacks and was 2-5 particles per 100 m2 (Parker 1956, HW-33068). These releases exposed military and other personnel onsite (Johnson 1954).

Table 4.2.1-2 is a summary of the physical, chemical, and radiological properties of radioactive particles released from Hanford 1945-1956 and includes releases from T, B, and REDOX plants; Figure 4.2.1-6 presents the monthly ^{106}Ru releases from the REDOX plant (Till et al. 2002).

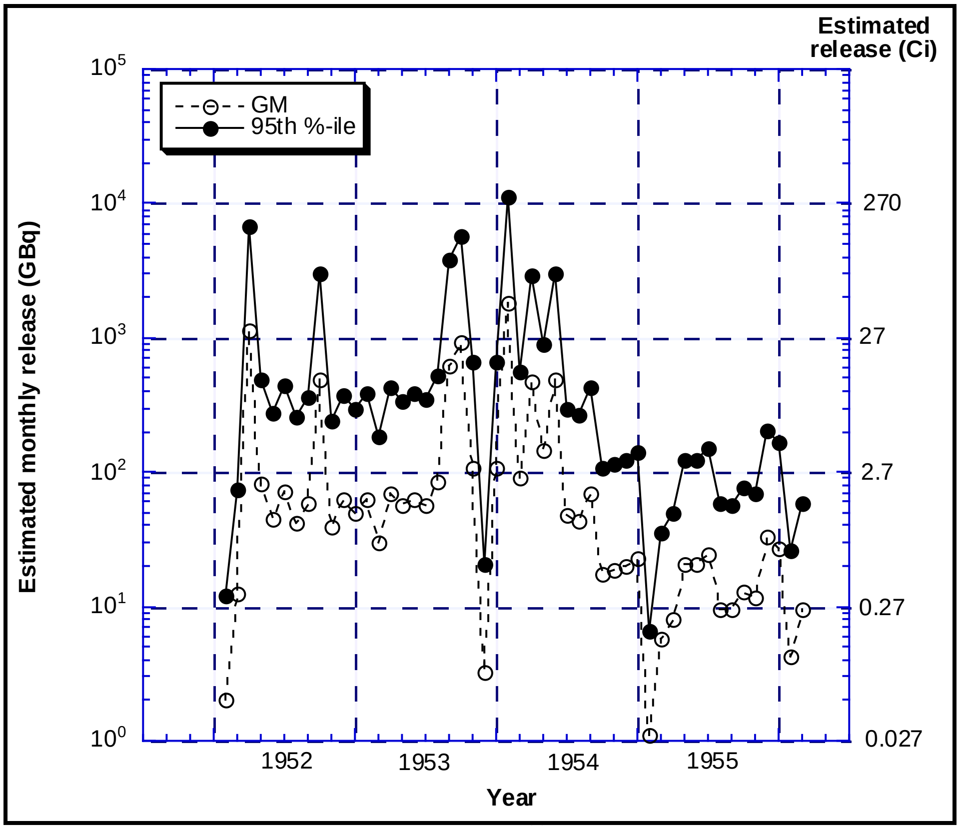

Figure 4.2.1-6. Estimated releases of ^{106}Ru from REDOX Plant. (Till et al. 2002).

Releases of Tritium from 108-B

Between 1949 and 1954, the Hanford Site produced tritium for the early weapons development period; the tritium was extracted in the 108-B facility from targets irradiated in the Hanford reactors. The product tritium was collected in flasks and sent to Los Alamos in gaseous diatomic form (T_2). The facility initially had a roof vent about 75 feet off the ground, and eventually all building and hood air was exhausted to a 300-foot stack. Releases from both routine operations and process upsets were estimated by Heeb and Gydesen (1994). Heeb and Gydesen described the uncertainty in the releases using a uniform distribution ranging from 0.222 to 1.778 times the central estimate. For the purposes of propagating the uncertainty in this dose reconstruction, that has been approximated as a standard deviation of 40% of the central estimate. Total annual releases and standard deviations are presented in Table 4.2.1-3.

Table 4.2.1-3. Annual amount of tritium released from 108-B

Year	Tritium Released (Ci)	Standard Deviation (Ci)
1949	683	273
1950	6134	2455
1951	27060	10824
1952	39737	15895
1953	3911	1564
1954	122728	49091

The releases were primarily elemental tritium. Elemental tritium slowly oxidizes to tritiated water (HTO and T_2O) in the atmosphere. If dose reconstruction inhalation estimates are made with dose conversion factors for tritiated water, the level of conservatism will range from factors between 1 and 1000.

4.2.2 Environmental Air Monitoring

Beginning in 1946 beta activity was monitored on air filters to measure ^{131}I concentrations in air (HW-9871) and in 1951 alpha monitoring began (HW-44215). The reported values are of limited utility because the atmospheric releases from weapons testing in the 1950s contributed to activity on the environmental filters that was not associated with operations at the Hanford site. However the measured activities are useful as a check on the atmospheric dispersion calculations used to calculate occupational environmental doses.

4.2.3 Intake of Airborne Radionuclides

The computer program RATCHET and an Excel® spreadsheet were used to calculated claimant-favorable but realistic intakes from airborne radionuclides as opposed to the computer program Hcalc (Till et al. 2002) because Hcalc calculates “worst case” or maximum hypothetical dose as opposed to a realistic dose. Examples of the conservative overbiasing in the Hcalc program include:

- The program neglects plume rise at the point of release of radionuclides to the atmosphere. Without plume rise the program overestimates air concentrations and deposition on vegetation and soil near the point of release.

- The program neglects plume depletion caused by wet and dry deposition. Without plume depletion this program overestimates air concentrations and deposition on vegetation and soil.

- The program overestimates the radionuclides concentrations in the shallow surface soil and the external gamma dose because the program neglects leaching.

- The program assumes a 12-year, as opposed to the NCRP (1996) default value of 30-year, buildup of radionuclides in the root zone of soil. The smaller buildup maximizes root uptake for

- the food ingestion pathway. The work scope of the Hanford Technical Basis Document specifically excludes the food pathway.

The computer file *scrlist.dat* (Till et al. 2002) provided the initial source terms in the spreadsheet. That file was based on the extensive research performed by Heeb (1994). The files from Till et al. (2002) provide monthly release estimates for the period from Hanford Site startup in 1944 through 1961. These files were extended to Hanford facility shutdown dates using the data from Heeb (1994), augmented with the revisions to the ^{131}I releases by Napier (2002). Minor releases in the 1980s were also added as reported in the Hanford Site annual reports for those years. The ^{41}Ar source terms for the reactors from Till et al. (2002) were also extended through the date when each reactor was shut down using the approach used in that report. The ^{239}Pu releases from the Z Plant were also extended using the two-month-lag-time approximation of Till et all (2002). Because of differences in estimating atmospheric transport described below, emissions were tabulated as particulate, iodine, and noble gases. The following radionuclides were evaluated:

- ^{41}Ar
- ^{144}Ce-^{144}Pr
- ^{137}Cs-^{137}Ba
- ^{3}H
- ^{131}I-^{131m}Xe
- ^{239}Pu
- ^{103}Ru-^{103m}Rh
- ^{106}Ru-^{106}Rh
- ^{90}Sr-^{90}Y
- ^{95}Zr-^{95}Nb

Annual emissions were evaluated for the following sources:

- T Plant particles
- B Plant particles
- REDOX particles
- PUREX particles
- Z Plant particles
- T Plant iodine
- B Plant iodine
- REDOX iodine
- PUREX iodine
- B & C reactor noble gas
- KE & KW reactors noble gas
- N reactor noble gas
- D & DR reactors noble gas
- H reactor noble gas
- F reactor noble gas
- 108-B elemental Tritium

Uncertainties in the source term were described using the “uncertainty factor estimates” of Heeb (1994). The list of source terms is presented in Attachments A-1 through A-9 along with the uncertainties expressed as a standard deviation. Some uncertainties in the decade of the 1980s were approximated as the standard deviation equal to 10 % of the measured values. Uncertainties are presented as standard deviations in Table A-10, atmospheric dispersion factors. The estimated intakes are assumed to be lognormally distributed and are presented in GSD which can be expressed as (Till, et al. 2003)

$$\mathrm{GSD} = \left(\frac{95^{th}\ \text{percentile}}{50^{th}\ \text{percentile}}\right)^{\left(\frac{1}{1.65585}\right)}$$

See also section 4.4 for additional information on uncertainties.

The computer program RATCHET (Ramsdell et al. 1994) was used to calculate annual average atmospheric dispersion coefficients. The RATCHET code was run for unit releases of 1 μm particles, noble gases, and iodine speciated as a combination of elemental iodine, particle-bound iodine, and organic iodine as described in Farris, et al. (1994). Hourly observations of wind speed, direction, stability, and precipitation from the extensive Hanford network of meteorological monitoring stations were used as input to the code. Results were calculated for monthly intervals from 1993 through 2002. A dense calculation output grid of 41X53 nodes on 1-km centers was used for all release points. Output was integrated to give total integrated exposure, in units of Bq-sec/m^3 per Bq released. These normalized values were then averaged over the 10-year observation period to provide monthly averages and standard deviations, which were then further rolled up into annual averages and standard deviations and are presented in Attachment A-10. The dose reconstructionist can calculate intakes for different source terms than those presented in Attachments A-1 through A-9 by multiplying the atmospheric dispersion coefficient in Attachment A-10 by the source term in Bq.

A total of 38 potential receptor locations were selected to represent exposure locations on the Hanford Site. These locations are listed in Table 4.2.3-1, along with the east-west and north-south node identifiers from the computational grid and the longitude and latitude of each point. The locations are illustrated in Figure 4.1-1.

The atmospheric dispersion factors for each location were multiplied by the emission rates from each source by radionuclide for each year from 1944 through 2001 even though the emissions from the reactors or the chemical separations plants after 1988 were minimal. The resulting annual air concentrations were then multiplied by 2400 m^3 per year which is the recommended breathing rate by reference man doing light work of 1.2 m^3/hour times a use factor of 2,000 hours per year (SR-TBD 2003). A standard deviation of 0.4 m^3/hour was assigned to this breathing rate. The final intake results presented in Attachments A-13 through A-21 provide the annual intake in Bq/yr for each receptor location by year by radionuclide. Maximum intake values by radionuclide are presented below.

Radionuclide	Maximum Intake in Bq
^{144}Ce	6.64E1
^{137}Cs	2.35E0
^{3}H	1.15E5
^{131}I	1.04E5
^{239}Pu	1.47E-2
^{103}Ru	1.93E2
^{106}Ru	5.84E2
^{90}Sr	2.67E0
^{95}Zr	7.92E1

In a similar fashion, the annual exposures for air submersion in ^{41}Ar were adjusted for 2000 hour/year occupancy. Those exposure values in Bq-sec/m^3 were multiplied by the dose factor 6.15 x 10^{-14} Sv per Bq-sec/m^3 (FGR 13) to give a submersion dose in sieverts that are presented in Attachment A-11. (1 Sv = 100 rem). Similarly the annual exposures from ^{41}Ar were multiplied by the dose factor 1.01 x 10^{-13} Sv per Bq-sec/m^3 (FGR 13)to give the skin beta-gamma dose in sieverts in Attachment A-12. . The maximum ^{41}Ar submersion dose was 3.47 x 10^{-5} Sv and the maximum ^{41}Ar beta skin dose was 5.7 x 10^{-5}.

The dose reconstructionist would then be able to select the years of exposure of a worker and the radionuclides related to the worker's cancer and determine the occupational environmental exposure.

As an example:

Worker exposed at the Wye Barricade guard shack from 1947-1949.

Worker developed thyroid cancer. Using Attachment A-17 the intake was:

Date	^{131}I Bq
1947	1.89×10^3
1948	1.08×10^2
1949	4.69×10^2
Total	2.47 x 10^3

The reconstructionist can calculate the dose from an intake of 2,470 Bq and enter the dose into the computer program NIOSH_IREP to calculate the probability of causation of the cancer.

Table 4.2.3-1. Selected receptor locations with identifying computational nodes.

Receptor location	E-W Node	N-S Node
T Plant	12	30
B Plant	20	29
REDOX	11	28
PUREX	20	29
Z Plant	11	29
B & C Reactors	9	37
KW & KE Reactors	13	39
N Reactor	16	43
D & DR Reactors	18	45
H Reactor	22	46
F Reactor	25	41
200 N	12	34
Midway (Riverland)	3	38
West Waluke	11	46
North Waluke	21	49
East Waluke	27	46
Yakima Barricade	4	32
Prosser Barricade	28	11
Wye Barricade	29	21
200 Firestation	15	29
100 Firestation	17	38
HMS Tower (622)	14	30
Columbia Camp	26	10
North Richland	38	6
300 Area	38	9
1100 Area	37	3
EOC/ALE Hq	19	10
Hanford Townsite	31	32
Waste Disposal Site	26	21
WNP2 Region	34	21
FFTF Region	31	14
Army H-61	8	32
Army H-51	8	26
Army H-42	18	22
Army H-40	20	28
Army H-50	8	28
200E Guard House	19	28
200W Guard House	12	30

4.3 EXTERNAL DOSE

4.3.1 Ambient Radiation

The chemical separations plants began operations in April, 1945. Quarterly environmental monitoring reports published from 1945 to 1955 and annual environmental reports published since 1956 present gamma exposure levels at various locations throughout the Hanford site. Up through 1953 radiation exposure measurements were reported in milliroentgen (mR), milliroentgen-equivalent-physical (mrep), and subsequently in millirad (mrad). Hanf and Thiede (1994) stated that the difference in deposited energy in tissue between units is so small that the units can be considered nearly identical.

The data in HW-9871 summarized measured natural background radiation levels between 1946 and 1948 as 0.3 to 0.5 mrad per day. For the purpose of the Hanford Technical Basis Document the natural gamma background radiation level attributed to cosmic radiation and naturally occurring radioactive materials in the environment is assumed to be 0.4 mrad per day or 146 mrad/yr. The work scope from NIOSH for the Hanford Technical Basis Document precludes subtraction of background from ambient readings.

Figure 4.3.1-1 illustrates that external gamma radiation attributed to site operations in the chemical separations area (200-East) averages 0.4 mrad/day above background levels and reached maximum exposures in 1945 and 1946. The external gamma exposure levels measured near the reactors were near natural background levels (HW-9871). Figure 4.3.1-2 illustrates the exposure rates measured near the REDOX Plant and the closest residence location to REDOX which were military sites H-50, H-51, and H-61 (HW-34882).

The relationship between ^{131}I and ^{106}Ru releases per year, and the net radiation exposures levels measured between at the REDOX plant perimeter and between the 200 areas is illustrated in Figure 4.3.1-3. The net gamma exposure rates are mainly due to the ^{131}I and ^{106}Ru release. The principal gamma ray from ^{131}I is 0.364 MeV emitted 82% of the time. The principal gamma rays from^{106}Ru are from its progeny ^{106}Rh and are 0.512 MeV emitted 21% of the time and 0.622 MeV emitted 11% of the time.

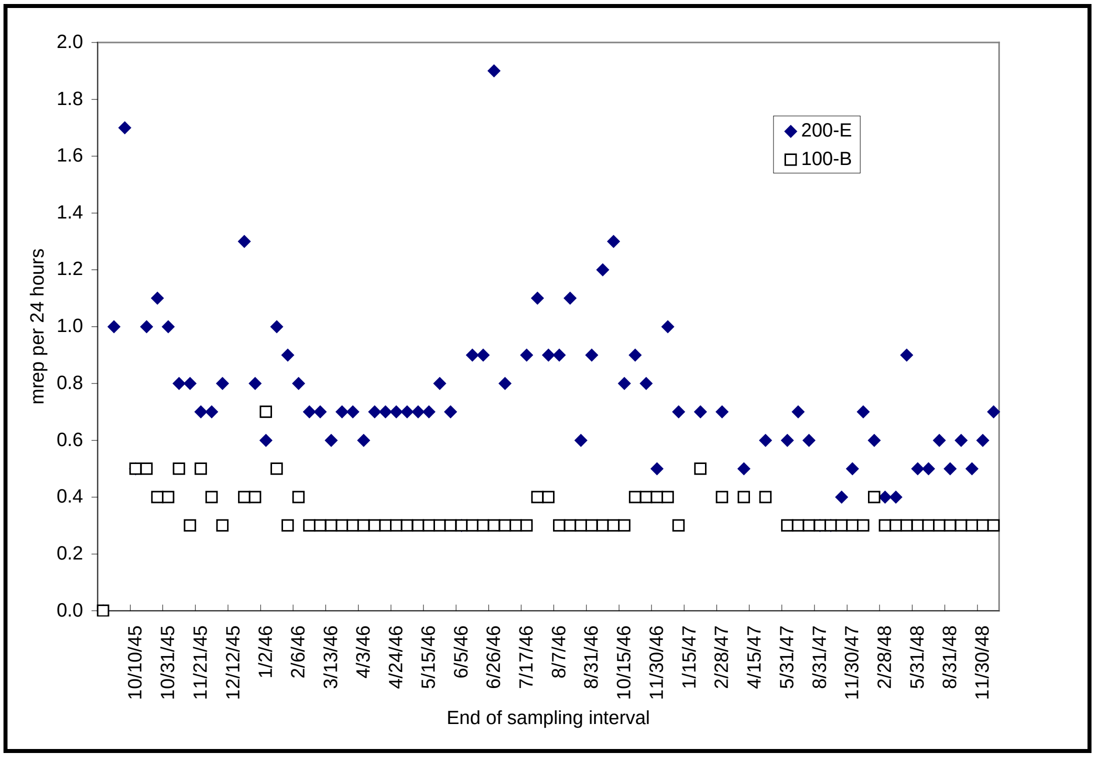

Figure 4.3.1-1. Radiation levels measured by detachable C chambers at two locations on the Hanford Site, 1945–1948. Levels at 200-East (separations area) averaged roughly twice those at 100-B (a reactor area). The average level at 100-B was 0.35 mrep per 24 hours, which is within the stated background range of the instrument (0.3–0.5 mrep per 24 hours), and the average level at 200-East was 0.75 mrep per 24 hours (data from HW-9871) (Till et al. 2002).

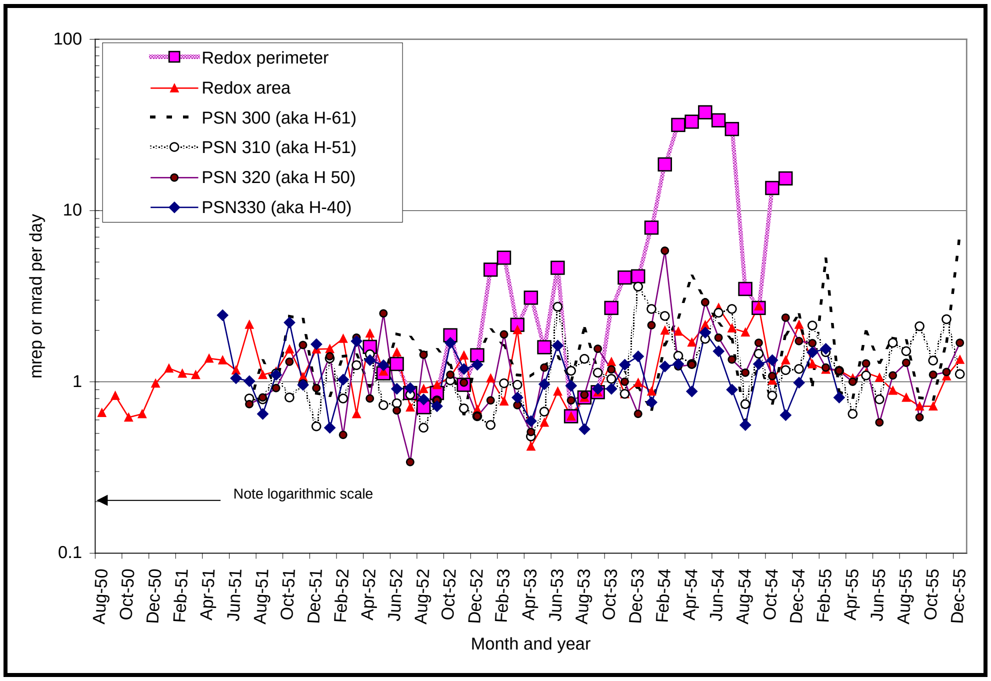

Figure 4.3.1-2. Exposure rates measured near the REDOX Plant and at four military installations. Measured exposure rates at the REDOX perimeter are the highest of all environmental stations monitored between 1945 and 1955. Monitoring at the perimeter was discontinued in December 1954, although monitoring continued in the REDOX area (Till et al. 2002)

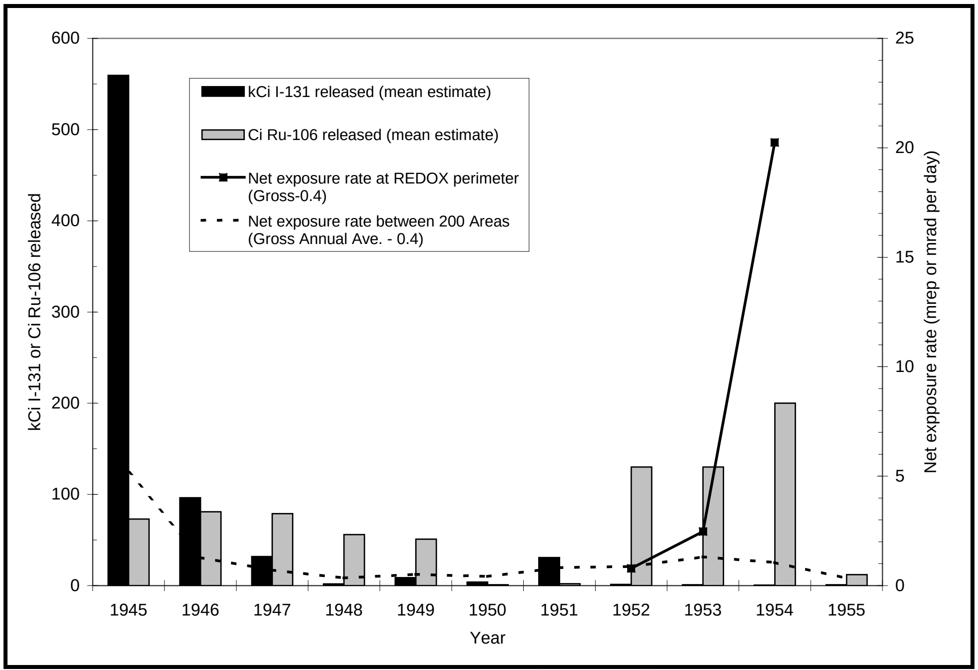

Figure 4.3.1-3. Time trends in annual ^{131}I and ^{106}Ru releases to air and net exposure rates between the 200 Areas (Building 622) and at the REDOX plant perimeter. A measured background exposure rate of 0.4 mrep per day was subtracted from the onsite exposure rate measurements to obtain net exposure rate (Till et al. 2002).

Table 4.3.1-1 presents the external gamma measurements at Hanford from 1944 through 2001 including fallout and background. The values are average values in mrem per year for exposures of 2000 hours per year. Blank values in the table indicate that measurements were not available for those years.

Table 4.3.1-1. External gamma radiation at Hanford (mrem/yr).

	300 Area	**400 Area/ FFTF**	**Hanford Townsite**	**Columbia Camp**	**Prosser Barricade**	**ALE**	**Wahluke**	**WNP2 Region**	**Wye Barricade**	**Yakima Barricade**	**Army Loop**
1945	170		149								
1946	69		41								
1947	121		88								
1948	76		115								
1949	60		158								
1950	49		32								
1951	49		32								
1952	96		15								
1953	35		23								
1954	24		31								
1955	84		76								
1956	160		126								
1957	269										
1958											
1959											
1960 [1,3]	80	30	30	30	30	30	30	30	30	30	30
1961 [1,3]	80	30	30	30	30	30	30	30	30	30	30
1962 [1,3]	80	39	39	39	39	39	39	39	39	39	39
1963 [1,4]	46	39	39	39	39	39	39	39	39	39	39
1964 [1,4]	46	34	34	34	34	34	34	34	34	34	34
1965 [1,5]	46	27	27	27	27	27	27	27	27	27	27
1966	39	30	44	30	30	30	30	30	30	30	30
1967	40		49								
1968	39		35								
1969	80										
1970	31		13								
1971	17	16	13			15	16		13	16	
1972	21	19	17			18	20		16	22	
1973	18	16	16		17	17	17		16	17	
1974	17	16	15		17	17	17		16	18	
1975	17	16	15		16	17	17		16	17	
1976	16	16	15		16	17	16		16	17	
1977	16	16	15		16	16	17		15	17	
1978	15	16	15		16	16	16		16	17	
1979	16	16	16		17	18	18		17	18	
1980	19	16	16		17	17	17		16	18	
1981	29	16	16		18	18	17		17	18	
1982	121	16	17		17	18	18		17	18	
1983	98	17	16	16	16	18	18		17	18	17
1984	21	17	16	15	16	17	18		17	18	16
1985	19	14	13	14	15	16	16	16	15	16	15
1986	21	16	12	16	17	17	16	15	14	17	16
1987	21	18	17	18	19	20	19	18	18	21	19
1988	19	19	18	20	20	21	20	19	18	21	20
1989	20	20	19	19	20	21	20	23	18	23	21
1990	19	19	19	18	17	20	20	20	19	20	19
1991	22	21						21	21		
1992	22	22						22	21		

1993	21	23						20	22		
1994	24	24						24	24		
1995	19	19						20	19		
1996	18	19						20			
1997	18	19						19			
1998	19	19			20		21	19	19	21	19
1999	19	19	20		20	22	21	21	20	22	20
2000	19	19	17		20	20	20	20	19	22	19
2001	19	19	18		21	22	21	20	20	22	20

[1] Based on the annual average dose rate for entire Hanford Site as reported in annual reports, except for 100, 200, and 300 areas.

Table 4.3.1-1. External gamma radiation at Hanford (mrem/yr) (cont'd)

	100 Area Fire Station	**100 B**	**100 D**	**100 F**	**100 K**	**100 N**	**100 H**	**1100 Area**	**200 East**	**200 West**	**200 N**
1945		127	135	123					194	185	
1946		47	33	38					122	50	
1947		42	60	85					115	57	
1948		24	52	76					67	30	
1949		31	17	38			25		16	20	
1950		55	44	40			37		37	45	
1951		55	44	40			37		37	45	
1952		35	31	19			33		13	37	
1953		48	33	34			38		49	63	
1954		88	119	71			133		71	217	
1955		38	95	253	87		35		178	265	
1956		347	216	258			37		242	230	
1957[2]									146		
1958[2]									319		
1959[2]									173		
1960[3]		111	99	127	87		55		98	143	
1961[3]		111	99	127	87		55		98	143	
1962[3]		111	99	127	87		55		98	143	
1963[4]	30	53	45	52	118	76	46	30	64	45	30
1964[4]	30	53	45	52	118	76	46	30	64	45	30
1965[4]	30	53	45	52	118	76	46		64	45	30
1966	30	53	48	44	108	56	39	30	66	56	30
1967		60	47	75	125	69	53		69	41	
1968		63	47	49	157	95	46		42	41	
1969		62	55	69	125	83			103	57	
1970		29	29	24	74				39	31	
1971			17	16	17	31			30	17	
1972			17	19	24	34			30	21	
1973	16		18	18	17	37			37	21	
1974	16		17	18	17	22			33	22	
1975	18		17	17	17	22			31	21	
1976	16		17	15	15	19			27	18	
1977	15		16	15	14	20			27	19	
1978	16		17		15	21		15	22	20	
1979	16		18		16	21		14	22	21	
1980	16		17		15	20		14	22	18	
1981	17		17		15	20		14	21	18	
1982	16		17		17	21		14	21	17	
1983	17		17		15	21		15	17		18
1984	16		18		17	21			15		17
1985	13		15		13	18		14	14		16

1986	15		16		13	20		14	16		16
1987	18		19		17	20		17	19		19
1988	18		20		17	21		18	19		20
1989	19		19		18	21		20	20	20	20
1990	19		19		18	21		17	17	20	19
1991			27		19	23		19	20	21	21
1992			21		20	24		20	22	22	23
1993			23		19	23		19	22	23	23
1994			25		22	28		22	24	25	26
1995			20		16			17	19	19	20
1996			20		16			17	19	19	20
1997			20		16			16	19	18	20
1998			20		17			17	19	19	21
1999			20	20	16			17	20	20	22
2000			19	19	17			17	19	19	21
2001			20	20	18			19	20	19	21

[2] Based on Monthly reports where dose rate ranges (max and min) were reported for “Separations Area” and “Residential Area” only. Maximum dose rate reported here.
[3] Based on an average of 1952-1956 gamma levels at the 100, 200, and 300 areas.
[4] Based on an average of 1966-1970 gamma levels at the 100, 200, and 300 areas.

4.3.2 Releases of Noble Gases

Xenon

The relative dose contribution of ^{133}Xe to ^{131}I can be estimated by comparing the products of the release rates and the dose conversion factors. At its peak in 1946 the ^{133}Xe release rate was 42,000 Ci per month. The increase in fuel element cooling time that began in 1946 resulted in more than a 10-fold reduction in ^{133}Xe releases to the atmosphere and continued in subsequent years. The ^{131}I release rate at the peak Xe release rate was 89,000 Ci per month. The dose conversion factor for ^{133}Xe is 4.3×10^{-8} and for ^{131}I is 2.4×10^{-4} Sv per Bqm^{-3}. Comparing the products of the release rate and the dose conversion factor for each radionuclide, the ^{131}I contribution to the dose was more than 10,000 times larger than that from ^{133}Xe (Till et al. 2002). Thus ^{131}I is listed as a major contributor to the occupational environmental dose and ^{133}Xe is not.

Argon releases from the Production Reactors

^{41}Ar was released from the Hanford reactors as a neutron activation product of stable argon in air and not from the chemical separations facilities. Effluent concentrations were measured for only brief periods over the years and the reactors did not operate all the time. Despite those problems Till et al. (2002) created percentiles from the distributions of monthly releases of ^{41}Ar which are presented in Table 4.3.2-1. The ^{41}Ar concentrations in the reactor stacks and the stack flow rates are presented in Table 4.3.2-2.

Table 4.3.2-1. Distributions of monthly release estimates for 41Ar from reactors and areas. (Till et al., 2002).

Reactor	Percentiles of distributions of release estimates ($Ci\ mo^{-1}$) for individual reactors and areas with two reactors				
	5th	25th	50th	75th	95th
B, D, or F	320	1200	2200	3300	4100
C	4000	5600	7000	8700	11000
B and C[a]	5600	7600	9300	11000	14000
DR	5900	6600	7600	8500	9400
D and DR[b]	7100	8600	9800	11000	13000
H	5700	7000	8600	10000	12000
KE	4200	5900	7400	9100	12000
KW	4100	5600	7000	8700	11000
KE and KW[c]	10000	13000	15000	17000	20000

a. Both reactors operated in the same area after November 1952.
b. Both reactors operated in the same area after October 1950.
c. Both reactors operated in the same area after April 1955.

Table 4.3.2-2. Argon-41 concentrations measured in and effluent flow rates for production reactor stacks. (Till et al. 2002)

Reactor	N[b]	Measured concentration ($\mu Ci\ m^{-3}$) of ^{41}Ar[a]		Stack effluent flow rate ($m^3\ s^{-1}$)[c]
		Average	Maximum	
B	0	20	39	47
D	4	23	39	47
F	0	17	27	47
DR	11	80	110	40
C	3	<4	<4	64
H	8	48	66	76
KE	d	d	d	67
KW	d	d	d	64

a. ^{41}Ar concentration data from Paas (1953a).
b. Number of samples collected (Paas 1953a,b,).
c. Based on flow rates given in Heeb (1994).
d. The reactor was not operating at the time of the measurements.

4.3.3 Skin Deposition of Airborne Particulate Emissions

Particulate emissions occurred from 1945 through 1955 from T and B plants and from 1952 through 1955 from the REDOX plant. Notable were the large ammonium sulfate flakes containing ^{103}Ru and ^{106}Ru that were emitted in March 1952. The median estimate for the total release activity was 145 Ci (5.37 TBq). An estimated 290 million particles were released. Based on binomial and Poisson distribution theory the probability that an individual would encounter one or more released particles on their skin is almost one (Till et al. 2002)

Till et al. (2002) calculated the number of radioactive particles from the REDOX Plant that would fall on a person at different locations during the 1950s. The values ranged from 100 particles for a person in Richland to 830 particles at military location H-50. Since the numbers are maximum values for 24-hour occupancy 7 days a week, the numbers should be multiplied by the use factor of 0.1 to provide a realistic, claimant favorable number of particles. The use factor was developed as follows. If one assumes that an individual works 8 work hours per day, 5 days a week the use factor would be 40 work hours divided by 168 hours per week or 0.24. If the workers hands, forearms, and head are uncovered 0.16 of his surface area is available for deposition on the skin as opposed to deposition on a worker's clothing. If the worker wears shorts and a short-sleeved shirt 0.33 of his skin is available for deposition (Till et al. 2002). Multiplying the work hour factor by the exposed skin factor gives a range of use factors of 0.04 to 0.08. Thus a use factor of 0.1 is a claimant favorable use factor. Using the 0.1 use factor the greatest number of particle encounters at any of the military camps is 83 particles from March 1952 through June 1954 at military location H-50. Table 4.3.3-1 presents the number of particles that would be expected to fall on a person by location assuming a use factor of 0.1.

Table 4.3.3-1. Expected Number of Particle Encounters for REDOX Plant Emissions during the Early 1950s assuming a use factor of 0.1. (original data from Till et al. 2002).

	Location							
Month/yr	H-61	H-51	H-42	H-40	H-50	200-E Tower	200-W Tower	Hanford Townsite
Mar-52	1.1E+01	9.2E+00	2.3E+01	5.9E+00	2.6E+01	7.1E+00	2.1E+01	2.5E+00
Apr-52	7.5E-01	6.5E-01	1.6E+00	4.2E-01	1.9E+00	5.0E-01	1.5E+00	1.8E-01
Jun-52	6.7E-03	5.7E-03	1.5E-02	3.8E-03	1.6E-02	4.5E-03	1.3E-02	1.8E-03
Sep-53	3.9E-02	3.3E-02	8.5E-02	2.2E-02	9.2E-02	2.6E-02	7.3E-02	1.0E-02
Aug-53	5.3E-02	4.4E-02	1.1E-01	3.0E-02	1.2E-01	3.5E-02	9.8E-02	1.4E-02
Sep-53	7.4E+00	6.2E+00	1.6E+01	4.2E+00	1.7E+01	5.0E+00	1.4E+01	1.9E+00
Jan-54	1.5E+01	1.3E+01	3.2E+01	8.3E+00	3.7E+01	1.0E+01	3.0E+01	3.5E+00
Apr-54	1.1E-02	9.6E-03	2.5E-02	6.5E-03	2.7E-02	7.7E-03	2.1E-02	3.0E-03
May-54	2.7E-02	2.3E-02	6.0E-02	1.6E-02	6.6E-02	1.9E-02	5.2E-02	7.2E-03
Jun-54	4.3E-03	3.7E-03	9.5E-03	2.5E-03	1.0E-02	3.0E-03	8.3E-03	1.1E-03
Total	3.4E+01	2.9E+01	7.3E+01	1.9E+01	8.2E+01	2.3E+01	6.7E+01	8.1E+00

Table 4.3.3-2 presents the dose coefficients for different radionuclides attached to or contained in the particles released to the air. Based on 5 µCi (1.85 E5 Bq) particles released as iron particles in the 1940 and a use factor of 0.1, the estimated skin dose rate was 1.2-3.6 rads per hour assuming a mean residence time on the skin of 1.4-4.3 hours (Whicker and Schultz 1982). Likewise for the ruthenium particles containing 300 µCi (1.11E7 Bq) ^{106}Ru and 170 µCi (6.29E6 Bq). ^{103}Ru released in the 1950s the estimated skin dose rate was 130-240 rads per hour.

Table 4.3.3-2. Dose coefficients for radionuclides contained in Hanford active particles. (Till et al. 2002).

Primary radionuclide and (decay product)	Fraction of beta activity for T and B Plant particles	Dose coefficient (nGy h^{-1} per Bq cm^{-2})[a]	
		Skin depth of 0.07 mm	Skin depth of 0.4 mm
^{103}Ru	0.13	568	28
^{141}Ce	0.14	1538	169
^{95}Zr (^{95}Nb)	0.06	1288	86
^{89}Sr	0.14	1667	887
^{91}Y	0.23	1669	897
^{106}Ru (^{106}Rh)	0.03	1845	1165
^{144}Ce (^{144}Pr)	0.26	2630	634
^{90}Sr (^{90}Y)	0.05	3133	1384
^{137}Cs	0.05	1432	384

a. Dose coefficients for distances along the axis of a circular source with area of 1 cm^2 or a point source averaged over that area from Cross et al. (1992). Tabled values include contributions of radioactive decay products. For short exposure times, doses attributed to ^{95}Zr and ^{90}Sr would be overestimated because the half-lives of ^{95}Nb and ^{90}Y are 35.1 d and 64.1 h, respectively.

4.4 UNCERTAINTIES

The calculation of the occupational radiation dose to an individual is specific to the past activities of the individual. The dose reconstructionist needs to know the dates that the individual was present at Hanford, where he worked, the type of work performed, the amount of time he spent outside facilities such as process buildings, chemical separations plants, product handling plants, reactors or other structures where his radiation exposure was monitored. The NIOSH work scope for the Hanford Technical Basis Document specifically excluded the radiation dose from foods, including milk, and resuspension as not a result of occupational exposures at Hanford.

Occupational environmental doses at Hanford include but are not limited to:

- Internal Dose from Airborne Concentrations
- External Doses from Plumes
- External Doses from Skin Deposition

The total occupational environmental dose is the sum of the environmental doses applicable to an individual submitting a claim under the Energy Employees Occupational Illness Compensation Program Act of 2000. The work of others has provided estimates of the upper and lower bounds of the occupational environmental dose at Hanford.

The lower bound is provided by Farris et al. 1994. They calculated the off-site environmental doses. The lowest environmental dose at the boundary of the Hanford Site is presented below and is the lower bound on the occupational environmental dose received on site:

> Cumulative ^{131}I dose to the thyroid of an adult from all air exposure 1944-1951 with milk cows on fresh pasture is 1-3 rad. Since the work scope for the Hanford TBD specifically excludes food pathways and the external and inhalation doses account for 36% of the total dose, the lower bound without doses from the food pathway would be (1-3 rad)(0.36) = 0.36-1.07 rad over 7 years or 0.051–0.154 rad/yr.
>
> Cumulative effective dose to an adult at Richland, 1945-1972 is 0.42 rem or 0.016 rem/yr.

The upper bound is provided by Till et al. 2002. They calculated the "worst case" on-site environmental dose as follows:

> For a hypothetical person on site 24 hours a day from1945 through 1961 without any ingestion pathways the absorbed dose to the thyroid was estimated to be 120 rad and an cumulative effective whole-body dose to be 6.5 rem. NOTE: That calculation is of marginal value since no one could have lived 24 hours a day for 17 years on site.
>
> For a worker that spent 2000 hours a year from 1945 through 1961 on the Hanford site the absorbed dose to the thyroid was estimated at 27 rem or 1.688 rem/yr. His cumulative effective whole-body dose from the inhalation of airborne particulates and from gaseous releases was an estimated 2.6 rem or 0.08 rem/yr.

Note: The upper and lower bounds were derived from exposures that began in the mid 1940s and lasted 7-27 years. Since exposures were greatest in the early years, the dose reconstructionist should apply the derived upper and lower bounds only to similar time periods.

Uncertainties in the estimation of the occupational environmental dose to individuals present on the Hanford Site begin with the determination of when the person was on site, where he worked on site, what type of work was done outside the facilities such as process buildings, the chemical separations plant, the material handling buildings, the reactors, or other facilities. Additional uncertainties are the determination of the quantity, concentration, date, and duration of effluents from records that were often incomplete especially in the early days at Hanford. Uncertainties were present in the air dispersion modeling of radionuclides at receptor locations such as uncertainties in the meteorological data used in the modeling. Other uncertainties associated with the fate of the dispersed particles and gases include estimates of the breathing rates of the workers, the amount of skin covered by work clothes, and the retention time of the deposited particulates on the skin.

The range of uncertainties for the final dose estimates produced by the dose reconstructionist for work that began in 1945 and extended until approximately 1972 may be calculated by multiplying the dose rates presented above by the years worked, viz.

> The range of doses to the thyroid of an adult is 1 - 45 rem.
>
> The range of cumulative effective whole-body dose due to environmental occupational exposures to an adult worker is 0.44 - 2.5 rem.

The intakes calculated and presented in Attachments A-13 through A-21 can be used by the dose reconstructionist to calculate doses. The following example indicates that those doses should approximate the ranges presented above:

> The maximum intake presented in Attachment A-17 for ^{131}I is 1.04×10^5 Bq/yr. Using a dose factor of 7.39×10^{-7} rem/Bq for a 27 year exposure, the cumulative effective whole-body dose is $(1.04 \times 10^5 \text{ Bq/yr})(7.39 \times 10^{-7})(27) = 2.1$ rem. That value falls in the range of 0.44 – 2.5 rem presented above.

Considering that one is attempting to reconstruct events that occurred a half century ago the uncertainties are large compared to today's events where record keeping and dosimetry systems are much more precise. With large uncertainties the use of realistic data favorable to the claimant is justified. The creation and use of worst-case scenarios, such as working 24 hours on site for 17 years, only increases the uncertainty of the final estimated dose.

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GLOSSARY

None