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Offsite Radiation Doses Summarized from Hanford Environmental Monitoring Reports for the Years 1957-1984

J. K. Soldat
K. R. Price
W. D. McCormack

February 1986

Prepared for the U.S. Department of Energy
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Richland, Washington 99352

PREFACE

In 1957, Hanford became the first major U.S. nuclear facility to calculate and report potential radiation doses to people living nearby. The assessment of offsite doses began in 1957 when all of the information necessary to make such an assessment first became available. This document summarizes these radiation doses as reported each year from 1957 through 1984.

Plutonium facilities at Hanford began operating in late 1944, and together with the uranium program at Oak Ridge, Tennessee, began to produce materials to be used in the manufacture of nuclear weapons. With this historical change, a new phase developed in the philosophy of radiation protection. In 1946, the National Council on Radiation Protection (NCRP) and later the International Commission on Radiological Protection (ICRP) were reestablished and shifted their emphasis from X-rays and radium to include radiation protection for radiation workers and for members of the public living in the vicinity of nuclear-energy facilities. The development of sophisticated radiation detection equipment and the results from research and experience gained from working with radioactive materials made it possible in 1957 to estimate radiation doses to members of the public living near Hanford.

This document does not attempt to assess the potential doses to the offsite public resulting from Hanford operations before 1957. There are several reasons why an accurate assessment using the historical records would be extremely difficult to make.

- Data collected before 1957 were not directed toward dose assessment, and the measurements of radioactive materials in the environment were made with simple state-of-the-art instruments.
- The historical record is incomplete because of the scheduled routine destruction of some documents.
- Historical data related to effluent releases are inconsistent in many cases because different working groups at Hanford made estimates for different purposes.
- Accurate information on the dietary habits and population distribution of early local residents is not known.

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SUMMARY

One of the primary objectives of environmental monitoring at Hanford is the identification and evaluation of potential impacts resulting from onsite activities. Since 1957, evaluations of offsite impacts from each year of operation have been summarized in publicly available, annual environmental reports. These evaluations included estimates of potential radiation exposure to members of the public, either in terms of percentages of the then permissible limits or in terms of radiation dose. The evaluations of potential radiation dose provided in these annual reports have been reviewed and are discussed in this report. The estimated potential radiation doses to maximally exposed individuals from each year of Hanford operations, as given in the annual reports, are summarized in a series of tables and figures. The applicable standard for radiation dose to an individual for whom the maximum exposure was estimated is also shown on each table and figure. To the extent they were available, the methods and data used in developing the annual dose estimates are summarized in an annotated bibliography.

Although the estimates address potential radiation doses to the public from each year of operations at Hanford between 1957 and 1984, their sum will not produce an accurate estimate of doses accumulated over this time period. The estimates were the best evaluations available at the time to assess potential dose from the current year of operation as well as from any radionuclides still present in the environment from previous years of operation. There was a constant striving for improved evaluation of the potential radiation doses received by members of the public, and as a result the methods and assumptions used to estimate doses were periodically modified to add new pathways of exposure and to increase the accuracy of the dose calculations.

Three conclusions were reached from this review.

- Radiation doses reported for the years 1957 through 1984 for the maximum individual did not exceed the applicable dose standards.

- Radiation doses reported over the past 27 years are not additive because of the changing and inconsistent methods used. However, on the basis of the reported annual doses, the total whole-body dose received by a hypothetical maximum individual from Hanford operations would be less than 1000 mrem. This value can be compared to more than 3000 mrem received by residents of southeastern Washington from natural background and worldwide fallout during the same time period.
- Results from environmental monitoring and the associated dose calculations reported over the 27 years from 1957 through 1984 do not suggest a significant dose contribution from the buildup in the environment of radioactive materials associated with Hanford operations.

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GLOSSARY

absorbed dose - The amount of energy deposited by radiation in a given amount of material. The unit of absorbed dose is the "rad." One rad is equal to 100 erg of energy deposited per gram of absorbing material. (See dose equivalent).

activation product - A material made radioactive by exposure to neutrons in a nuclear reactor.

average Richland or Pasco resident - A hypothetical adult resident of the city of Richland or Pasco, Washington, whose diet is representative of the results of a survey taken in the early 1960s.

aquifer - An underground formation through which ground water percolates. A confined aquifer is bounded above and below by impermeable layers of rock. Ground water in the confined aquifer is under pressure. An unconfined aquifer contains ground water that is not confined by impermeable rocks. The pressure in the unconfined aquifer is equal to that of the atmosphere.

alpha particle - A positively charged particle with a mass equivalent to a helium nucleus that is emitted by certain radionuclides. Alpha particles can be stopped by a sheet of paper.

background radiation - Naturally occurring radioactivity in the environment; principally radiation from cosmogenic origin and radionuclides that occur naturally in the earth's crust.

criticality - State of being critical; refers to a self-sustaining nuclear chain reaction.

cumulative dose - The lifetime dose (50 or 70 years) that results from exposure to external sources of radiation and from any radionuclides taken in the body via ingestion and inhalation. It includes the dose from radionuclides that accumulate in the environment during the exposure period.

curie (Ci) - A unit of radioactivity equal to 3.7 x 10^{-10} nuclear transformations per second.

millicurie (mCi) = one thousandth of a curie (10^{-3} Ci)
microcurie (μCi) = 10^{-6} Ci
nanocurie (nCi) = 10^{-9} Ci
picocurie (pCi) = 10^{-12} Ci

beta particle - A negatively or positively charged particle with a mass equivalent to an electron that is emitted from the nucleus of an atom. A beta particle can be stopped by a thin sheet of aluminum.

body burden - The quantity of a specific radionuclide present in the human body at a given time.

concentration guide - The average concentration of a given radionuclide in air or water that could be inhaled or consumed continuously without exceeding the radiation protection standard.

detection level - The smallest amount of radioactivity that can be detected by a particular radioanalytical system.

dose assessment - The estimation of the dose received by individuals or populations from radionuclides or radiation sources.

dose commitment - The dose that occurs over a specified time period (e.g., 50 years, 70 years, lifetime) from radionuclides deposited in the body.

dose equivalent - Expresses doses from different types of radiation on a common biological effects basis. It is the product of the actual absorbed dose (rad) and certain modifying factors. The unit of dose equivalent is the "rem" (roentgen equivalent man). The "mrem" is one-thousandth of a rem (10^{-3} rem).

dose model - A mathematical method for systematically calculating the dose received by individuals; takes into account all the radionuclides present and possible environmental pathways that lead to man.

dosimeter - A device used to measure radiation exposure.

effluent - A liquid or gaseous stream that is discharged from a facility.

effluent monitoring - Sampling and measuring specific liquid or gaseous effluent streams for the presence of pollutants.

environmental transport - The movement of radionuclides through the environment. Environmental transport models are used to mathematically describe the behavior of radionuclides that lead to the exposure of people.

exposure - The measure of ionization produced in air by X- or gamma-radiation. Measured in units of roentgens, "R" (one R equals 2.58 x 10^{-4} coulomb per kilogram air). The "mR" is one-thousandth of an R (10^{-3} R).

external dose - The dose received by an individual from radiation sources outside the person's body.

fallout - Debris, including radioactive materials, that is formed during the detonation of a nuclear device and released into the earth's atmosphere. This debris is eventually deposited on the earth's surface.

"fence-post" dose - The dose calculated for a hypothetical person residing at the boundary of the Hanford Site.

fission - The splitting of a nucleus into two or more new nuclides. When uranium is split, large amounts of energy and one or more neutrons are released.

fission products - The nuclides formed by the fission of heavy nuclei. Most fission products are radioactive.

gamma rays - A penetrating form of electromagnetic radiation emitted from the nucleus. Heavy shielding such as lead or concrete may be required to reduce exposure from a gamma-emitting source.

GI tract - Gastrointestinal tract.

ground water - A subsurface body of water that saturates and flows through the soil.

half-life - The time required for a radionuclide to lose 50 percent of its activity by radioactive decay.

internal dose - The dose received by an individual from radionuclides deposited inside the person's body through ingestion or inhalation.

internal emitters - Radionuclides deposited inside the human body.

isotope - Different nuclei of the same chemical element that are distinguished by having different numbers of neutrons in the nucleus.

maximum fisherman - A hypothetical fisherman whose shoreline fishing time and annual fish consumption would result in the highest dose received by an individual in the general population from fishing.

maximum (or maximally exposed) individual - A hypothetical member of the public that resides at a location outside the boundary of a nuclear facility where the individual's dose resulting from the release of radioactive gaseous and liquid effluents would be the greatest.

maximum pathway - An environmental transport pathway that produces the highest possible projected dose to a hypothetical individual in the general population.

maximum permissible concentration (MPC) - The average concentration of a given radionuclide in air or water that an individual can inhale or consume without exceeding an established radiation dose limit.

maximum permissible rate of intake (MPRI) - The rate of intake of a given radionuclide by an individual that could be continued for 50 years without exceeding an established radiation dose limit standard.

mR - See exposure.

mrem - See dose equivalent.

offsite - Any place outside the Hanford Site boundary.

population dose - An estimation of the collective dose to a given group of people. It is the sum of individual doses (rem) for the defined population group. Expressed in units of man-rem or person-rem.

radioactive decay - See radioactivity.

radiation dose limit - See radiation dose standards.

radiation dose standard - Maximum allowable dose a worker or the general population can receive, as established by a regulatory organization.

radiation protection standard - See radiation dose standard.

radioactivity - A property of certain nuclides that spontaneously emit charged particles or photons.

radioisotope - A radioactive isotope of a specified element. (Carbon-14 is a radioisotope of carbon.)

radionuclide - A radioactive nuclide.

representative diet - A diet of milk and produce identified to contain on a year-round basis the levels of radionuclides that were measured during the growing season. Used only in the 1958 annual report.

source term - The types and quantity of radionuclides released from a facility.

tolerance level - The maximum concentration of radionuclides on edible vegetation that if consumed by farm animals or people would not result in doses that exceed applicable radiation dose standards.

total-body dose - The radiation dose to the entire human body. It includes the dose from external sources and internally deposited radionuclides. It is the same as whole-body dose.

typical Richland or Pasco resident - A hypothetical adult resident of the city of Richland or Pasco, Washington, who is assumed to consume quantities of locally grown food and drinking water at rates determined from the scientific literature.

whole-body counter - A radiation detection instrument that measures the quantity of gamma rays emitted from a human body to determine the quantity of certain radionuclides present in the individual's body.

whole-body dose - See total-body dose.

X-rays - A form of electromagnetic radiation that is emitted from the orbital electron shells of an atom. X-rays are basically the same type of radiation as gamma rays.

HISTORICAL PERSPECTIVE

This document summarizes estimated radiation doses to members of the public as reported in annual reports on environmental monitoring at Hanford. The summary includes an annotated bibliography of the dose estimates published in the annual environmental monitoring reports from 1957 to 1984. The following background information provides perspective for the radiation doses estimated and reported for the past 27 years.

INTRODUCTION

Environmental monitoring has been conducted at Hanford since the startup of operations in 1944; however, estimates of radiation doses to individuals in the vicinity of the plant were not calculated until 1957 when the methods for such estimates were developed. Environmental monitoring reports published from 1946 to 1957 were originally classified and not generally available to the public until 1986 when they were released by the Department of Energy. These early reports contained information on radioactive effluents from operating facilities and the results from environmental samples and radiation measurements. Annual reports published from 1957 to 1984 were originally released as publicly available documents and contained estimates of potential radiation exposure to the public as well as the results from sample analyses and field measurements.

HANFORD FACILITIES AND OPERATIONS

The first two nuclear production reactors constructed at Hanford were located at 100-B and 100-D Areas and began operations in late 1944 (see Figure 1). They were followed by the startup of two plutonium separations (fuel reprocessing) plants known as B Plant and T Plant located in the 200-East and 200-West Areas, respectively, and soon a third production reactor at 100-F Area. During the next 11 years, five additional production reactors (H, DR, C, KW and KE) were added to the 100 Areas, and two new fuel reprocessing plants called REDOX (in 200-West) and PUREX (in 200-East) replaced B Plant and T Plant. All eight production reactors and the two newer reprocessing

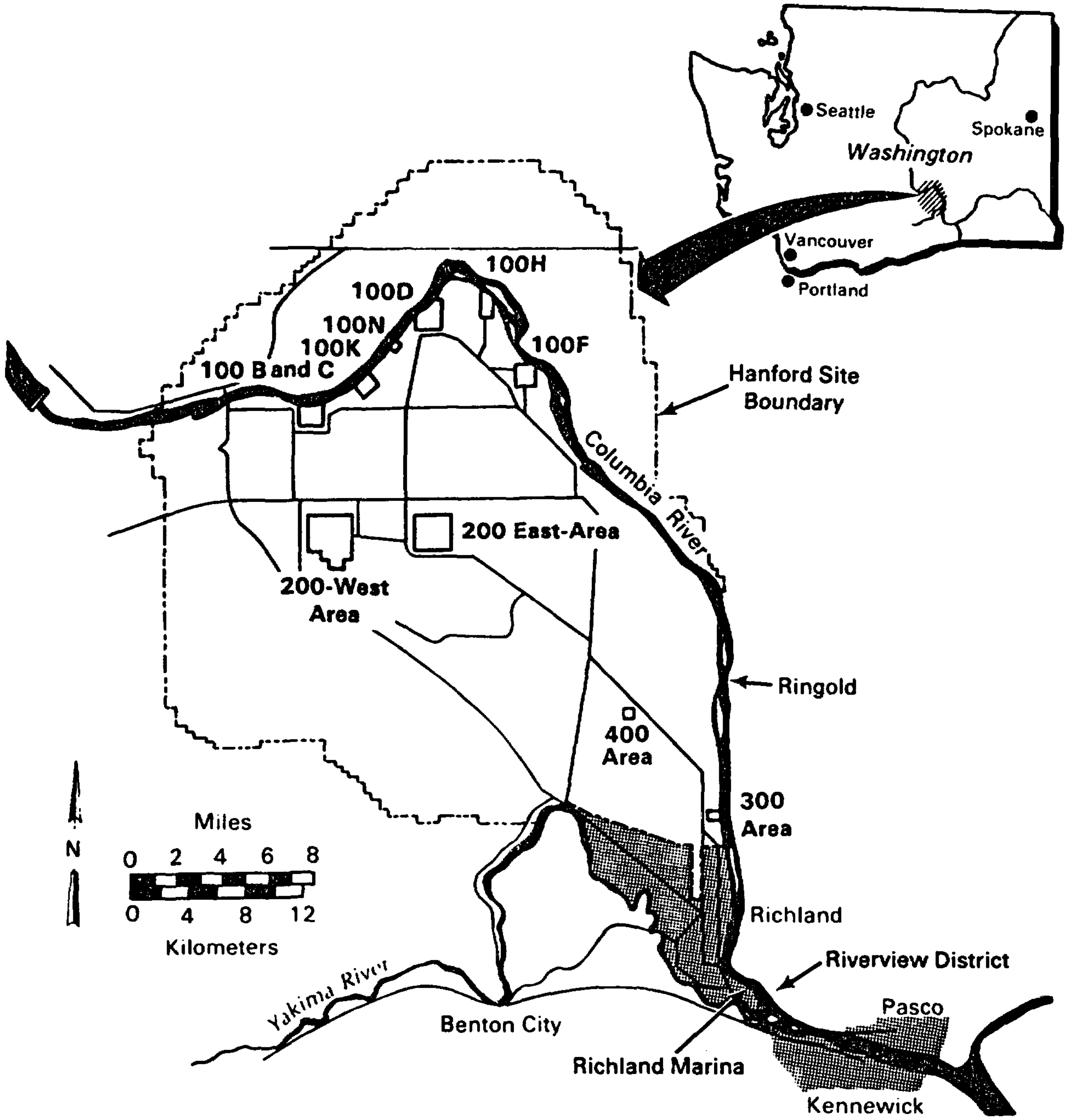

FIGURE 1. Hanford Site and Environs

plants operated from 1956 to 1963 when a new production and steam-producing reactor was started at 100-N Area. Other production facilities operating in the 200 Areas included 231-Z Plant (plutonium purification, 1945 to 1949), 234-5 Z Plant (plutonium purification and scrap recovery operations, 1949 to present), U Plant (recovery of uranium from liquid wastes, 1952 to 1958), and the UO_3 Plant (uranium calcining, 1952 to 1972; restarted in 1983). The 300 Area contained fuel fabrication facilities and research laboratories (1943 to present). In 1964, the older facilities began to be shut down. The REDOX fuel processing plant and about one production reactor per year were shut down from 1964 to 1971. PUREX, the newest fuel reprocessing plant, was placed in standby condition in 1972 and restarted in 1983. The dual-purpose N-Reactor has been in operation (excluding routine shutdown for maintenance and refueling) since its startup in 1963 and has been the only production reactor in operation since 1971. The FFTF test reactor in the 400 Area has operated intermittently since 1981 for the testing of new fuels and materials.

RADIATION DOSE ESTIMATES

Estimates of radiation doses to members of the public were made for the first time in 1957. Measured concentrations of radionuclides in air, water, and locally available foodstuffs were combined with standard intake values and the results of local dietary surveys to estimate intake rates of radioactive materials and subsequent radiation doses. A key factor at the time was the development of new analytical methods that enhanced the identification and measurement of individual radionuclides in environmental samples. The application of new data and technology has continually refined the process of estimating radiation doses since 1957.

The evaluation of the significance of radionuclides present in the environment, due to Hanford operations from 1945 to 1956, consisted of an extensive program to measure radiation, collect and analyze various kinds of samples, and compare the results with "Tolerance Levels" and "Maximum Permissible Concentrations" (MPCs). The tolerance levels and MPCs were based on the then current external radiation dose limits and estimates of acceptable organ doses. A tolerance level for iodine-131 in edible plants was established by the Hanford Medical Department in early 1946 to protect people and farm animals from accumulating excessive amounts of iodine-131 in their thyroid glands. The MPCs for many radionuclides in air and water were first published by the National Council on Radiation Protection (NCRP) in 1953 and soon adopted for use at Hanford (NCRP 1953). The MPCs were calculated from the maximum permissible amounts of radionuclides in the human body which in turn were derived from internationally acceptable radiation protection standards. The establishment of these maximum permissible body burdens was fundamental to the development of methods suitable for calculating the total radiation dose to the public from Hanford operations each year.

During the peak period of Hanford operations (1956 to 1964), elevated concentrations of several Hanford-related radionuclides were easily detected in the environment, especially the Columbia River. Evaluations of radiological impacts on the public were based on measured concentrations of radionuclides in environmental media and estimates of radiation dose from exposure to these materials. However, as effluent treatment systems at Hanford were improved and the number of operating facilities was reduced, the presence of Hanford-related radionuclides in the environment became increasingly difficult to detect and distinguish from worldwide fallout from nuclear weapons tests. By the early 1970s, it was no longer possible to estimate offsite radiation doses from Hanford operations solely on the basis of samples and measurements in the environment. Beginning in 1974, environmental transport and radiation dose models and their associated computer codes were used routinely to calculate potential radiation doses using data on effluents released into the atmosphere and the Columbia River. These models, developed in large part at Hanford, used as a basis much of the environmental data collected during earlier years when radionuclides were present in measurable quantities and when their movement in the environment could be traced. Empirical information and research data from other locations and other countries were also used in the models.

REPORTING AND EVALUATION CRITERIA

Reporting practices and the criteria used to evaluate potential offsite radiation doses underwent significant development and change during the period of 1957 through 1982, and each annual report described changes effective for that year. For 1957 and 1958, the potential individual doses from various pathways were evaluated in terms of the percentage of permissible dose limits. The evaluation of potential offsite radiation doses during 1959 and 1960 addressed a loosely defined "maximum individual," and results were expressed in a mixture of dose units and percentages of dose limits. Beginning in 1961 and 1962, radiation doses were evaluated for individuals residing in Richland, Kennewick, and Pasco. Reports for 1963 through 1966 included the evaluation of potential radiation doses for a hypothetical maximum individual and a Richland resident variously called "average" or "typical." For the 1967 and 1968 reports, doses were evaluated for a maximum individual and also separately for both an average Richland resident and a typical Richland resident. Potential doses for 1969 through 1973 were evaluated only for a maximum individual and an average Richland resident. In addition, the report for calendar year 1972 included the potential whole-body dose to the total population within 50 miles (80 km) of the Hanford Site. Since 1974, the evaluation of radiation doses has included an assessment of the maximum external dose rate at a location accessible to the general public where persons could be exposed, the doses to a hypothetical maximally exposed individual, and the doses to the population within 80 km of the Site.

For the years 1974 through 1981, the maximally exposed individual and population doses were calculated in terms of the doses received during that current operating year (first-year dose) and the doses that could have been received during the next 50 years from radionuclides that were internally deposited as a result of inhalation or ingestion during the first year (50-year dose). In both cases, the calculations were based on potential exposure and intake during, but not beyond, the calendar year of operation. The annual report for 1982 was the first to report potential doses for the maximum individual and the population in terms of the 50-year cumulative dose.

The cumulative dose calculation considered exposure to and intake of radionuclides during the current year of release as well as potential continued external and internal exposures to long-lived radionuclides that would remain in the environment for the next 50 years. Thus, the cumulative dose considered the possible long-term residency of potentially exposed persons. In 1983, the new cumulative doses were calculated for the 6-year period of 1977 through 1982 and compared with the dose commitments previously calculated for the same years.

The maximum permissible radiation dose to the whole body for an individual member of the public has been 500 mrem/yr throughout the period reviewed here. Maximum permissible doses to most organs have been set at 1500 mrem/yr since 1944. Two exceptions were the limits for bone and thyroid, which were reconsidered and raised to 3000 mrem/yr in 1959 by the International Commission on Radiological Protection. In 1960 these two limits were lowered to 1500 mrem/yr by the Federal Radiation Council. In the meantime, however, MPC limits for bone and thyroid derived from the 1959 limit of 3000 mrem/yr had been incorporated into various agencies' orders and regulations. The higher MPC values in these regulations were used at Hanford as the basis for evaluating thyroid doses until the early 1960s and bone doses until the late 1960s.

ENVIRONMENTAL MONITORING REPORTS FOR THE YEARS 1957-1984

Information on the offsite doses reported in the annual environmental monitoring reports published from 1957 through 1984 is presented in the Annotated Bibliography section of this document. Each annual report contains more information than is summarized here and should be consulted for details where needed. As a means of providing perspective to the data reported over the 27-year period, doses estimated for the whole body and several organs are summarized further and presented graphically in the following section. Conclusions are also stated.

SUMMARY OF REPORTED OFFSITE RADIATION DOSES

This document summarizes the information provided in annual Hanford environmental reports published for the years 1957 through 1984. Figures 2 through 5 and Tables 1 through 5 summarize the reported doses. Several conclusions can be made based on the information reviewed.

- Figures 2 through 4 and Tables 1 through 5 show that applicable radiation dose standards were not exceeded during the period 1957 through 1984. The figures also show that during that time period the years of highest radiation doses occurred from about 1960 through 1965. However, as recorded in the environmental reports for those years, the doses were strongly influenced by worldwide fallout from atmospheric testing of nuclear weapons.

- The values of the doses reported over the years depended on the calculational methods used, which were subject to change and improvement. Thus, the total dose potentially received by a long-term resident of the area cannot be accurately determined by simply summing the published estimates. Based on the information shown in Figure 2, a rough estimate of the maximum whole-body dose received by any one person living in the area since the late 1950s would be less than 1000 mrem. This dose can be compared to the more than 3000 mrem the same person would have received at the time from naturally occurring background sources and worldwide fallout.

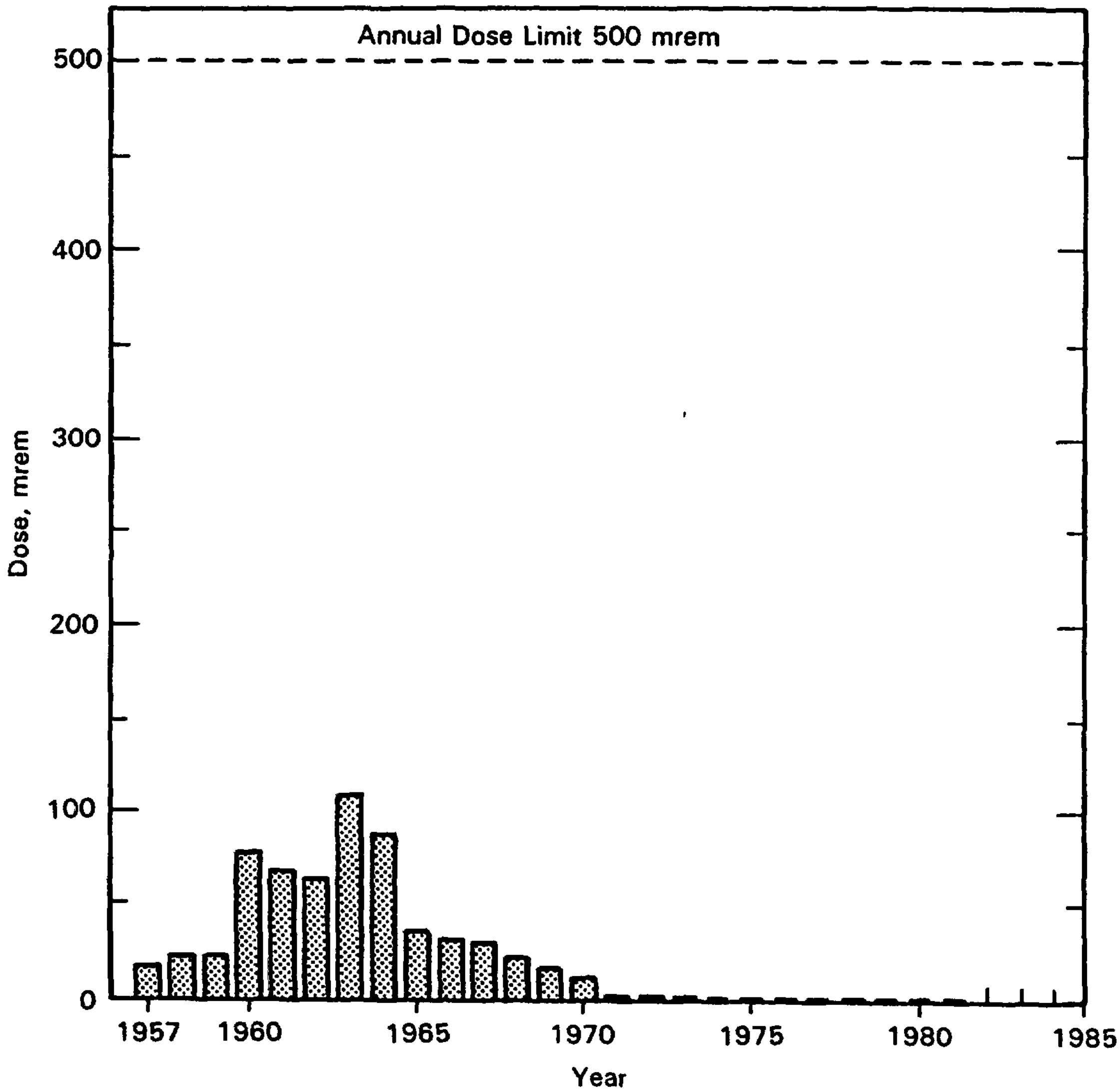

FIGURE 2. Estimated Doses to the Whole Body of the Maximum Individual

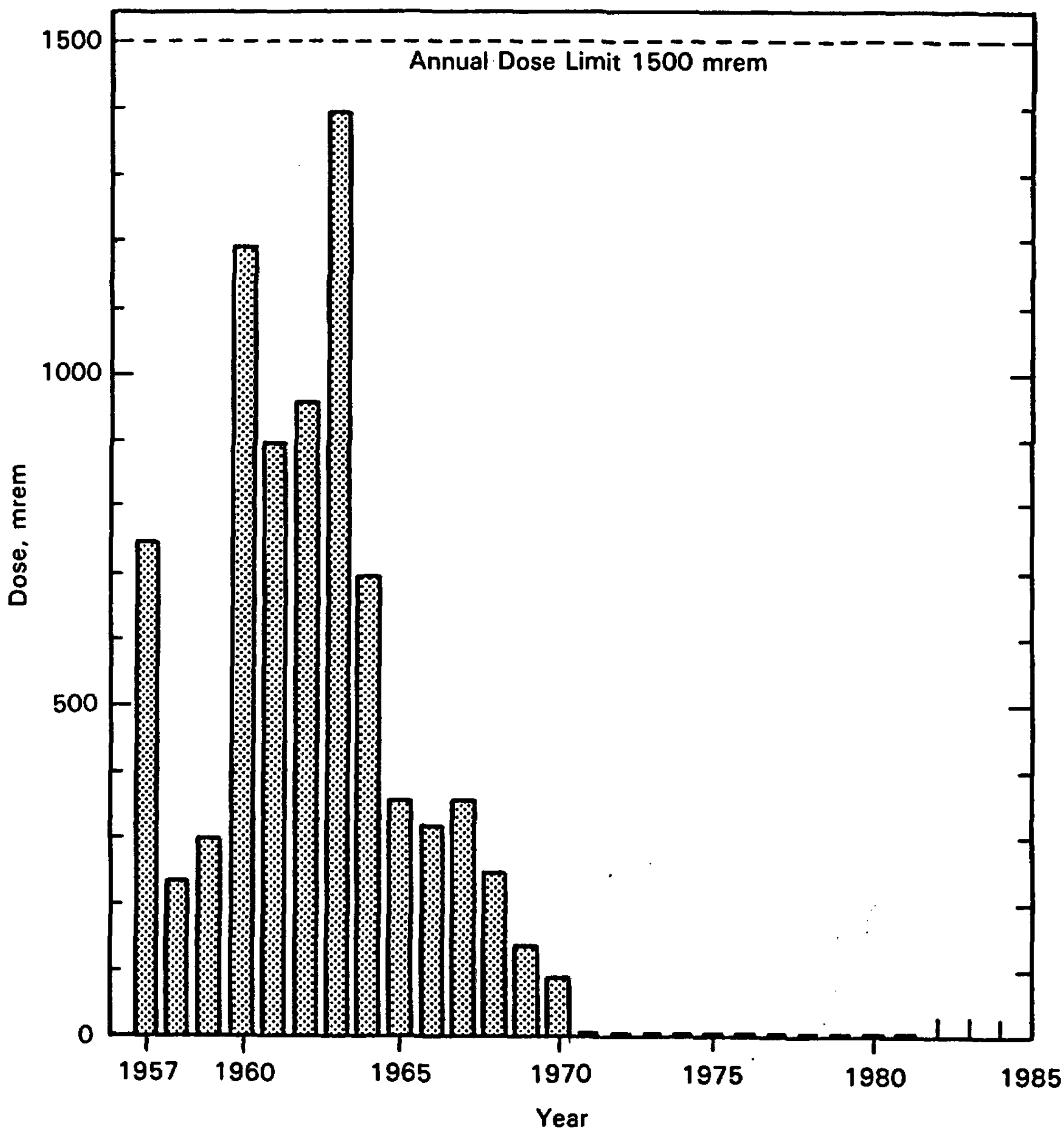

FIGURE 3. Estimated Doses to the Bone of the Maximum Individual

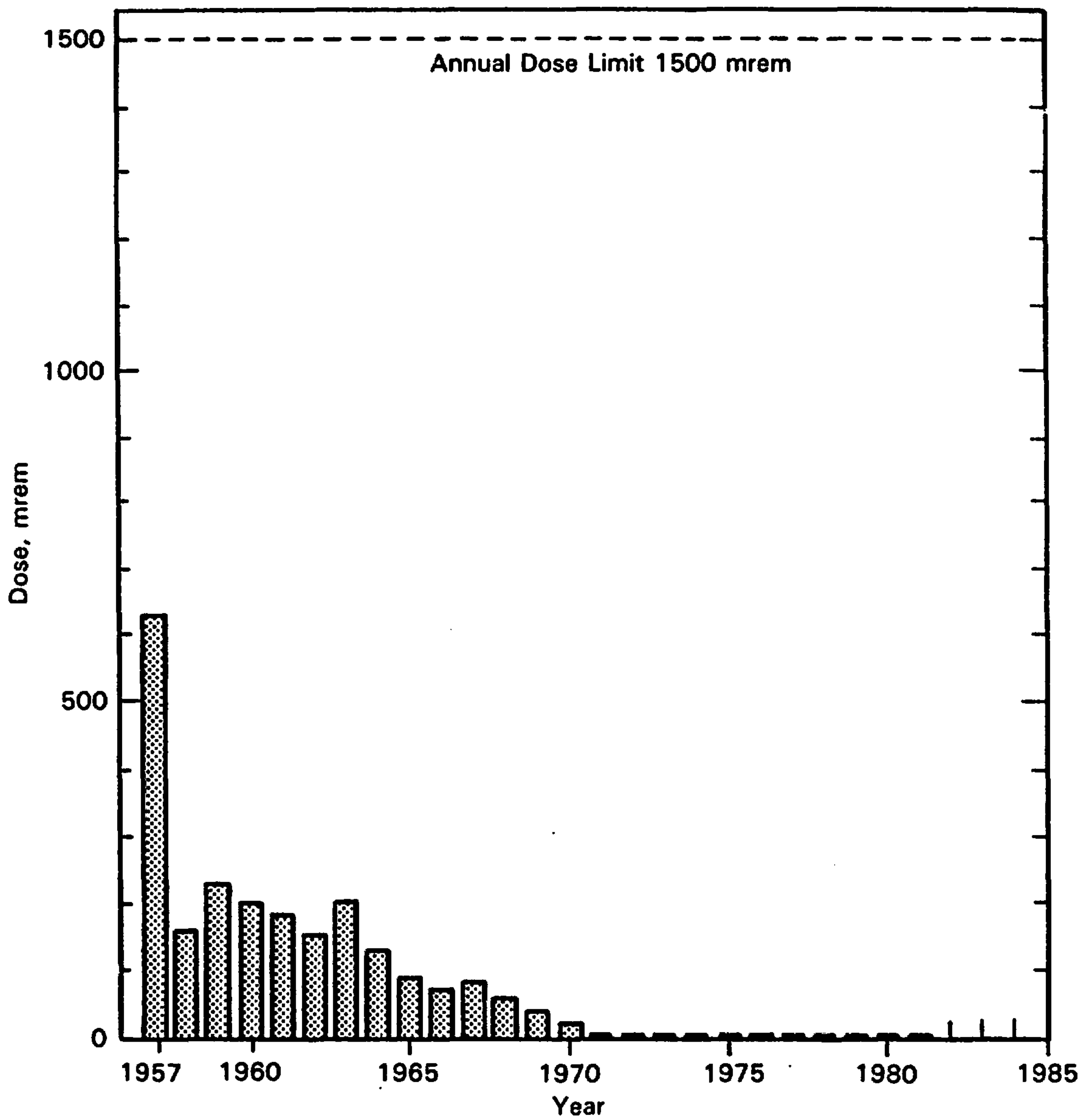

FIGURE 4. Estimated Doses to the GI Tract of the Maximum Individual

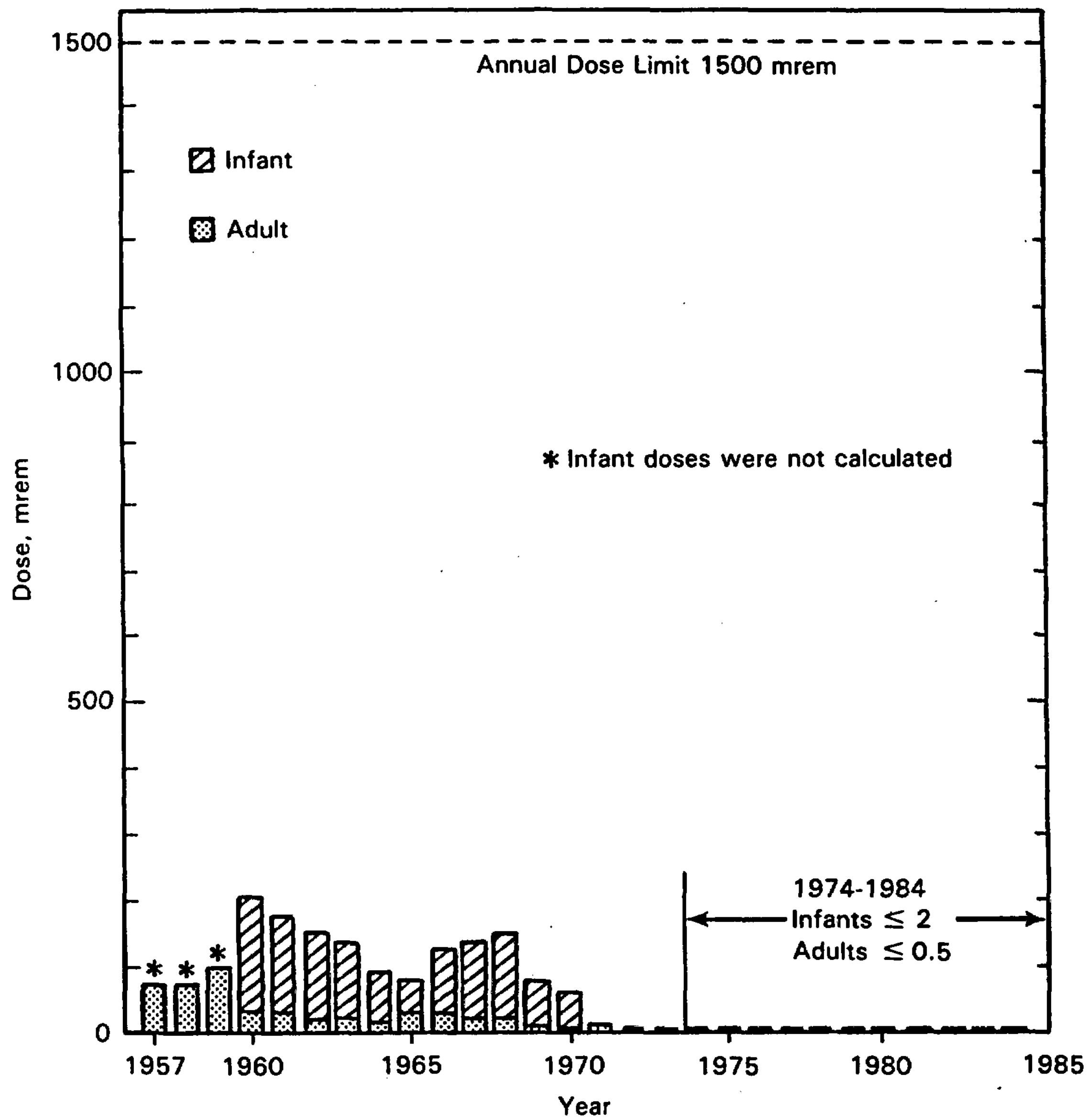

FIGURE 5. Estimated Doses to the Thyroid of the Maximum Individual

TABLE 1. Estimated Doses to the Whole Body of the Hypothetical Maximum Individual in the Vicinity of Hanford, 1957-1984 (mrem)[a]

Year	Annual Dose	50-yr Dose Commitment	50-yr Cumulative Dose	Comments
(Current Annual Limit 500 mrem)				
1957[b,c]	10-20	--[d]	--	Calculated from environ-
1958[b,c]	25	--	--	mental measurements
1959[e]	25	--	--	
1960[e]	80	--	--	
1961[e]	70	--	--	
1962[e]	67	--	--	
1963[e]	110	--	--	
1964[c,f]	90	--	--	
1965[g]	38	--	--	
1966[g]	33	--	--	
1967[g]	32	--	--	
1968[g]	24	--	--	
1969[g]	18	--	--	
1970[g]	12	--	--	
1971[g]	3	--	--	
1972[g]	2	--	--	
1973[g]	2	--	--	
1974[h]	0.03	0.05	--	Calculated from effluent
1975[h]	0.007	0.02	--	data using computer codes
1976[h]	0.03	0.1	--	
1977[h]	0.03	0.2	0.8	
1978[h]	0.08	0.1	0.5	
1979[h]	0.02	0.1	0.7	
1980[h]	0.01	0.1	0.6	
1981[h]	0.03	0.4	0.5	
1982[h]	--	0.1	0.7	
1983[h]	--	--	1	
1984[h]	--	--	2	

(a) Methods of calculation and exposure assumptions evolved rapidly in the early years. See discussion under each year's annual report.
(b) External gamma only.
(c) Doses for 1957, 1958, and 1964 include contributions from all fallout nuclides except strontium-90.
(d) Dash indicates dose not calculated.
(e) Doses for 1959-1963 include contributions from all fallout nuclides including strontium-90.
(f) Originally reported as 100 mrem including 10 mrem from fallout strontium-90.
(g) Doses from 1965-1973 exclude contribution from all fallout nuclides except iodine-131.
(h) Doses for 1974-1984 exclude contributions from all fallout nuclides.

TABLE 2. Estimated Doses to the Bone of the Hypothetical Maximum Individual in the Vicinity of Hanford, 1957-1984 (mrem)[(a)]

Year	Annual Dose	50-yr Dose Commitment	50-yr Cumulative Dose	Comments
(Current Annual Limit 1500 mrem)				
1957[(b)]	750	--[(c)]	--	Calculated from environmental measurements
1958[(b)]	240	--	--	↓
1959[(d)]	300	--	--	
1960[(d)]	1200	--	--	
1961[(d)]	900	--	--	
1962[(d)]	960	--	--	
1963[(d)]	1400	--	--	
1964[(b)]	700	--	--	
1965[(e)]	360	--	--	
1966[(e)]	320	--	--	
1967[(e)]	360	--	--	
1968[(e)]	250	--	--	
1969[(e)]	140	--	--	
1970[(e)]	94	--	--	
1971[(e)]	3	--	--	
1972[(e)]	3	--	--	
1973[(e)]	3	--	--	
1974[(f)]	0.03	0.10	--	Calculated from effluent data using computer codes
1975[(f)]	0.009	0.04	--	↓
1976[(f)]	0.09	0.3	--	
1977[(f)]	0.05	0.9	3	
1978[(f)]	<0.04	0.2	2	
1979[(f)]	0.04	0.9	3	
1980[(f)]	0.04	0.4	2	
1981[(f)]	0.1	1.3	2	
1982[(f)]	--	0.4	2	
1983[(f)]	--	--	4	
1984[(f)]	--	--	8	

(a) Methods of calculation and exposure assumptions evolved rapidly in the early years. See discussion under each year's annual report.
(b) Doses for 1957, 1958, and 1964 include contributions from all fallout nuclides except strontium-90.
(c) Dash indicates dose not calculated.
(d) Doses for 1959-1963 include contributions from all fallout nuclides including strontium-90.
(e) Doses for 1965-1973 exclude contribution from all fallout nuclides except iodine-131.
(f) Doses for 1974-1984 exclude contributions from all fallout nuclides.

TABLE 3. Estimated Doses to the GI Tract of the Hypothetical Maximum Individual in the Vicinity of Hanford, 1957-1984 (mrem)[(a)]

Year	Annual Dose	50-yr Dose Commitment	50-yr Cumulative Dose	Comments
(Current Annual Limit 1500 mrem)				
1957[(b)]	550	--[(c)]	--	Calculated from environmental measurements
1958[(d)]	160	--	--	↓
1959[(e)]	230	--	--	
1960[(e)]	200	--	--	
1961[(e)]	180	--	--	
1962[(e)]	150	--	--	
1963[(e)]	200	--	--	
1964[(d)]	130	--	--	
1965[(f)]	86	--	--	
1966[(f)]	70	--	--	
1967[(f)]	82	--	--	
1968[(f)]	62	--	--	
1969[(f)]	40	--	--	
1970[(f)]	27	--	--	
1971[(f)]	3	--	--	
1972[(f)]	2	--	--	
1973[(f)]	2	--	--	
1974[(g)]	0.05	0.05	--	Calculated from effluent data using computer codes
1975[(g)]	0.03	0.04	--	↓
1976[(g)]	0.05	0.05	--	
1977[(g)]	0.1	0.1	0.2	
1978[(g)]	<0.04	<0.01	0.1	
1979[(g)]	0.02	0.02	0.2	
1980[(g)]	0.02	0.02	0.1	
1981[(g)]	0.05	0.05	0.06	
1982[(g)]	--	0.02	0.07	
1983[(g)]	--	--	0.2	
1984[(g)]	--	--	0.3	

(a) Methods of calculation and exposure assumptions evolved rapidly in the early years. See discussion under each year's annual report.
(b) Originally given as 74% MPRI (based on an annual limit of 1500 mrem) with approximately 40% from fallout radionuclides in vegetation.
(c) Dash indicates dose not calculated.
(d) Doses for 1958 and 1964 include contributions from all fallout nuclides except strontium-90.
(e) Doses for 1959-1963 include contributions from all fallout nuclides including strontium-90.
(f) Doses for 1965-1973 exclude contributions from all fallout nuclides except iodine-131.
(g) Doses for 1974-1984 exclude contributions from all fallout nuclides.

TABLE 4. Estimated Doses to the Thyroid of the Hypothetical Maximum Individual in the Vicinity of Hanford, 1957-1984 (mrem)[a]

Year	Infant Annual Dose	Adults Annual Dose	Adults 50-yr Dose Commitment	Adults 50-yr Cumulative Dose	Comments
(Current Annual Limit 1500 mrem)					
1957[b]	--	75	--[c]	--	Calculated from environmental measurements
1958[b]	--	75	--	--	
1959[d]	--	<150	--	--	
1960[d]	70-280	10-40	--	--	
1961[d]	~150	7-40	--	--	
1962[d]	140	15	--	--	
1963[d]	115	19	--	--	
1964[b]	75	16	--	--	
1965[e]	58	30	--	--	
1966[e]	86	27	--	--	
1967[e]	97	21	--	--	
1968[e]	110	~20	--	--	
1969[e]	60	~10	--	--	
1970[e]	<30	<5	--	--	
1971[e]	<15	~3	--	--	
1972[e,f]	1.4	~2	--	--	
1973[e]	<15	~2	--	--	
1974[g]	0.5	0.2	0.5	--	Calculated from effluent data using computer codes
1975[g]	0.9	0.2	0.9	--	
1976[g]	--	0.2	0.2	--	
1977[g]	--	0.4	0.4	0.4	
1978[g]	--	0.4	0.5	1	
1979[g]	--	0.4	0.4	0.8	
1980[g]	0.7	0.2	0.2	0.2	
1981[g]	0.6	0.1	0.1	0.2	
1982[g]	0.5	--	0.2	0.2	
1983[g]	0.3	--	--	0.2	
1984[g]	0.3	--	--	0.8	

(a) Methods of calculation and exposure assumptions evolved rapidly in the early years. See discussion under each year's annual report.
(b) Doses for 1957, 1958, and 1964 include contributions from all fallout nuclides except strontium-90.
(c) Dash indicates dose not calculated.
(d) Doses for 1959-1963 include contributions from all fallout nuclides including strontium-90.
(e) Doses for 1965-1973 exclude contributions from all fallout nuclides except iodine-131.
(f) From ERDA-1538 (ERDA 1975).
(g) Doses for 1974-1984 exclude contributions from all fallout nuclides.

TABLE 5. Estimated Doses to the Lung of the Hypothetical Maximum Individual in the Vicinity of Hanford, 1957-1984 (mrem)[a]

Year	Annual Dose	50-yr Dose Commitment	50-yr Cumulative Dose	Comments
(Current Annual Limit 1500 mrem)				
1957[b]	1.5	--[c]	--	Calculated from environmental measurements
1958[b]	90	--	--	↓
1959	--	--	--	
1960	--	--	--	
1961	--	--	--	
1962	--	--	--	
1963	--	--	--	
1964	--	--	--	
1965	--	--	--	
1966	--	--	--	
1967	--	--	--	
1968	--	--	--	
1969	--	--	--	
1970	--	--	--	
1971	--	--	--	
1972[d]	0.002	0.01	--	
1973	--	--	--	
1974	--	--	--	Calculated from effluent data using computer codes
1975	--	--	--	↓
1976[e]	0.01	0.01	--	
1977[e]	0.03	0.03	0.03	
1978[e]	<0.04	<0.01	0.02	
1979[e]	0.1	0.6	0.4	
1980[e]	<0.01	0.01	<0.01	
1981[e]	0.01	0.02	0.01	
1982[e]	--	0.02	0.02	
1983[e]	--	--	0.01	
1984[e]	--	--	0.02	

(a) Methods of calculation and exposure assumptions evolved rapidly in the early years. See discussion under each year's annual report.
(b) Doses for 1957 and 1958 include contributions from all fallout nuclides except strontium-90.
(c) Dash indicates dose not calculated.
(d) For plutonium inhalation only. Calculated from 200 Areas gaseous effluent data, assuming that all gross alpha radioactivity was plutonium. See ERDA-1538 (ERDA 1975) for details.
(e) Doses for 1976-1984 exclude contributions from all fallout nuclides.

- Results from environmental monitoring reported over the 27 years from 1957 through 1984 and the associated dose calculations do not suggest a significant dose contribution from the buildup in the environment of radioactive materials associated with Hanford operations. Over the years, small quantities of long-lived radioactive materials were released from operating facilities, and some of these materials are still present in the environment. However, the radionuclide concentrations measured in environmental samples collected during recent years were so low as to be either unmeasurable or of little significance in terms of radiation doses to the public.

ANNOTATED BIBLIOGRAPHY

The following annotated bibliography describes the dose assessments published in annual environmental monitoring reports for the period 1957 through 1984. The methods used to estimate radiation doses resulting from the operation of a major nuclear production facility were first developed at Hanford and presented in 1958 at the "Second International Conference on Peaceful Uses of Atomic Energy" for the 1957 operating year. Each annotated entry contains one or more tables that summarize the dose estimates given in the original annual report, and, whenever possible, the tables and footnotes are copies of original information. In most cases numerical values are rounded to one significant digit, and, occasionally, word changes are used to clarify the information. Various types of tables, graphs, and numerical data were used over the years to communicate dose estimates. Thus, for the sake of an accurate reproduction, some editorial inconsistencies are apparent among the tables presented here.

For the purpose of clarity, we describe in the past tense the work and conclusions taken from annual reports on Hanford environmental monitoring. Any assumptions or conclusions occasionally contributed by the authors of this document are written in the present tense or otherwise specifically identified.

References

Energy Research and Development Administration (ERDA). 1975. Final Environmental Statement Waste Management Operations, Hanford Reservation, Richland, Washington. ERDA-1538, Richland Operations, Richland, Washington.

National Committee on Radiation Protection (NCRP). 1953. Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air an Water. NBS Handbook 52, National Bureau of Standards, Washington, D.C.

1957

Healy, J. W., B. V. Andersen, H. V. Clukey and J. K. Soldat. 1958. "Radiation Exposure to People in the Environs of a Major Production Atomic Energy Plant." In Proceedings of the Second United Nations International Conference on the Peaceful Uses of Atomic Energy. 18:309-318, United Nations Publishers, Pergamon Press, London.

This paper by Healy et al. reported the results of the first comprehensive study of environmental radiation exposure pathways leading to public radiation doses as a result of production plants run by the U.S. Atomic Energy Commission (AEC). Maximizing assumptions were used to assure that radiation doses were not underestimated. The study 1) identified major environmental pathways of public exposure, 2) quantified, as best possible, the radiation doses received through each pathway, and 3) compared those doses with public radiation dose standards and guides.

No attempt was made to construct a plausible maximally exposed individual or to estimate total dose to the surrounding population. Doses were calculated for a "standard man" by using maximum permissible concentrations of radionuclides in air and water as given by the National Committee on Radiation Protection (NCRP)[a] in their National Bureau of Standards (NBS) Handbook 52 (1953). Calculations represented doses from one year of exposure to radionuclides measured in the environs. Doses were estimated for bone, thyroid, GI tract, lungs, and gonads using dietary information compiled mainly by Bustad and Terry (1956). Some data on the radionuclide composition in gaseous and liquid effluents were also reported. Whole-body dose from internally deposited radionuclides was not estimated, but an estimate was made of external gamma exposure of the whole body. Dose limits in effect were 500 mrem/yr to the whole body and gonads, and 1500 mrem/yr to other tissues (ICRP 1955; NCRP 1957, 1958). Table 6 summarizes these results in terms of percent of maximum permissible limits.

Measurements of the external whole-body radiation exposure received primarily from natural background ranged from 100 to 150 mR/yr in residential

(a) The current name of this organization is the National Council on Radiation Protection and Measurements.

TABLE 6. Total Exposures from Internal Emitters at the Hanford Plant Perimeter for 1957

	Percent of Maximum Permissible Limits			
	Bone	Thyroid	GI	Lung
Drinking Water	3	2	20	---
Air	---	0.03	---	0.1
Vegetation	2[a]	3	40[a]	---
Fish	20[b]	---	6[b]	---
Waterfowl	25[b]	---	8[b]	---

(a) Primarily from radionuclides associated with fallout from nuclear detonations.
(b) Only a very small portion of the population received these calculated maximum doses.

areas at the perimeter of the Hanford plant. Healy et al. were not able to identify any Hanford contribution to this exposure rate, but they presumed this contribution was less than 10-20 mR/yr, which represented less than 2-4% of the limit for the general population.

The majority of the Hanford exposure occurred from the release of reactor cooling water to the Columbia River. The actual exposures received by the majority of the people from drinking water were stated to be 25-50% lower than those listed in Table 6 because of the influence of the water treatment plants, which lowered the concentration of many of the radionuclides present in the water. Fish and waterfowl consumed by some individuals could have been their highest single source of internal emitters, but relatively few individuals would have been affected. It was predicted that the radiation received by even the most highly exposed individuals did not approach 20-50% of the permissible limit for bone.

The report concluded:

> "The overall summation of results from an environmental survey program of this nature is complicated by the large number of possible sources of exposure and, recently, by the general prevalence of fallout isotopes. The best estimates of the actual exposures to

people are still uncertain because of the wide variations possible in diet, occupancy and other factors. At the present levels the estimates are adequate to indicate low exposures to people, but refinements of the technique are constantly being made so that improved values will be available. Throughout the history of the Hanford project, radiation exposures in the environs due to plant contributions are believed to have been well within the maximum permissible limits."

References

Bustad, L. K., and J. L. Terry. 1956. Basic Anatomical, Dietary and Physiological Data for Radiological Calculations. HW-41638, Hanford Atomic Products Operation, Richland, Washington.

International Commission on Radiological Protection (ICRP). 1955. "Recommendations of the International Commission on Radiological Protection (Revised December 1, 1954)." British Journal of Radiology, Supplement No. 6. 1955.

National Committee on Radiation Protection (NCRP). 1953. Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water. NBS Handbook 52, National Bureau of Standards, Washington, D.C.

National Committee on Radiological Protection and Measurements (NCRP). 1957. "Maximum Permissible Radiation Exposures to Man. A Preliminary Statement of the National Committee on Radiation and Measurement." (January 8, 1957). Am. Ind. Hyg. Assoc. Quart. 18:73 (March 1957)

National Committee on Radiation Protection and Measurements (NCRP). 1958. Maximum Permissible Radiation Exposures to Man. An Addendum to the National Bureau of Standards Handbook 59 "Permissible Dose from External Sources of Ionizing Radiation" (Extends and Replaces Insert of January 8, 1957). National Bureau of Standards, Washington, D.C.

1958

Andersen, B. V. 1959. Hanford Environmental Monitoring Annual Report - 1958. HW-61676, Hanford Atomic Products Operation, Richland, Washington.

The author identified a "representative diet" for milk and produce that was assumed to contain consistently (year-round) the radionuclide concentrations measured during the growing season. The representative diet did not include local fish and waterfowl. However, it was possible that a limited number of persons may have ingested relatively large quantities of fish and waterfowl. The statement was also made that the actual doses received were probably less than those given in the report because conservative assumptions were used when the doses were estimated. The report stated "...nuclear weapons fallout is strongly indicated as the source of the isotopic concentration [sic] in these produce samples."

The concept of "percent MPRI"[(a)] was defined as the ratio of the radionuclide intake from produce consumption to the product of the recommended maximum permissible concentration (MPC) in water and the water intake rate of the standard man. Because MPC values were derived on the basis of 50 years of continuous exposure, any doses that might be back-calculated from percent MPRI values would more closely approximate 50-year dose commitments rather than one-year doses. As in 1957, the MPC values were taken from NBS Handbook 52 (NCRP 1953).[(b)] The dose limits in effect were 500 mrem/yr to the whole body and gonads, and 1500 mrem/yr to other tissues (ICRP 1955; NCRP 1958).

Table 7 summarizes the percent of MPRI and percent of external exposure limits estimated for the representative person.

(a) The maximum permissible rate of intake.
(b) Because the limits for dose to a member of the public were 10% of those for the worker, the MPRI was based on 10% of the MPC values given in NBS Handbook 52 (NCRP 1953).

TABLE 7. Estimated Environmental Exposures from Hanford Sources for 1958

Source	Percent of Nonoccupational Exposure Limits					
	Body	GI	Bone	Thyroid	Kidney	Lung
Drinking Water	---	4.0	0.7	0.9	0.15	---
Milk and Produce	---	<0.01	<0.01	<1.5	<0.01	<0.01
Air	---	---	---	0.04	---	<1.2
Fish and Wildfowl	---	2.0	10[a]	---	---	---
External - Swimming and Boating	~5	<5	<5	~2.5	~5	~5
Max. Probable Totals	5	11	16	5	5	6

(a) It was conceivable that a few individuals ate enough fish to raise their average body burden of phosphorus-32 above 10%, but it was highly unlikely that anyone routinely ate an amount large enough to raise their body burden to a nonoccupational limit.

References

International Commission on Radiological Protection (ICRP). 1955. "Recommendations of the International Commission on Radiological Protection (Revised December 1, 1954)." British Journal of Radiology, Supplement No. 6. 1955.

National Committee on Radiation Protection (NCRP). 1953. Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water. NBS Handbook 52, National Bureau of Standards, Washington, D.C.

National Committee on Radiation Protection and Measurements (NCRP). 1958. Maximum Permissible Radiation Exposures to Man. An Addendum to the National Bureau of Standards Handbook 59 "Permissible Dose from External Sources of Ionizing Radiation" (Extends and Replaces Insert of January 8, 1957). National Bureau of Standards, Washington, D.C.

1959

Junkins, R. L., E. C. Watson, I. C. Nelson and R. C. Henle. 1960. Evaluation of Radiological Conditions in the Vicinity of Hanford for 1959. HW-64371, Hanford Atomic Products Operation, Richland, Washington.

The representative diet used in 1958 was expanded to include cereal grains, Pacific coast oysters, increased quantities of fruit, and small amounts of local fish and waterfowl. The dose limits and MPC values used in 1959 were taken from a report published that year by the National Council on Radiation Protection and Measurements (NCRP 1959).

A notable difference in this report is an increase in the dose limits from 1500 mrem/yr to 3000 mrem/yr for the thyroid and bone.[a] Because dose estimates for most organs were reported in terms of percent MPRI for 1959, it is important to note this change in the relationship between the reported values and the radiation dose.

Air filter samples collected throughout the Pacific Northwest revealed the presence of fallout from nuclear tests. Boise, Idaho, probably because of its elevation and climate, seemed to have slightly elevated air concentrations of fallout debris compared to other Northwest locations including the Tri-Cities (Richland, Kennewick and Pasco).

Analytical results of vegetation samples collected along the highways between Hanford and Portland, Spokane, Lewiston, Walla Walla and Union Gap revealed generally similar levels of contamination in all directions from Hanford, which was undoubtedly the result of fallout from the testing of nuclear weapons. The concentration of iodine-131 in vegetation within 15 miles of the exhaust stacks at the separations areas during November and December was somewhat higher than at more distant locations.

Table 8 summarizes estimated doses and fractional MPRI values discussed by Junkins et al.

(a) The MPC values for bone for occupational exposure were actually derived on the basis of biological effects equivalent to those of a bone burden of 0.1 µg of radium-226. Such a burden was calculated to deliver a dose equivalent of approximately 30 rem/yr to bone. Therefore, one-tenth of those MPC values, when used for nonoccupational exposure, implied a dose of 3 rem/yr to bone.

TABLE 8. Estimated Radiation Exposure to Persons in the Vicinity of Hanford for 1959[a]

Pathway	Total Body (% MPRI)	Bone (% MPRI)	Thyroid (mrem/yr)	GI Tract (mrem/yr)
Drinking Water	<0.5	<1.		75
Milk	0.5	1.5		35
Produce	1.5	2	<150	55
Fish or Fowl	<3	5		45
Oysters	<0.5	<0.5		10
External - Swimming and Boating	1 (6 mR/yr)	<1	<1	6
Total - as % MPRI	5	10	<5	15
- as mrem/yr	25	300	<150	230

(a) Including strontium-90 from fallout.

Junkins et al. stated that the estimated doses were within the range of 3 to 15% of the limits. The corresponding maxima for exceptional cases, where unusual amounts of local fish and leafy vegetables were eaten, fell within the range of about 40 to 60% of the limits.

Reference

National Council on Radiation Protection and Measurements (NCRP). 1959. Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water. NBS Handbook 69, U.S. Department of Commerce, Washington, D.C.

1960

Nelson, I. C., ed. 1961. Evaluation of Radiological Conditions in the Vicinity of Hanford for 1960. HW-68435, Hanford Atomic Products Operation, Richland, Washington.

This report contained the first recorded use of the "hypothetical individual" whose exposure was based on combining "plausible assumptions on sources, diets, etc." Three hypothetical persons were discussed:

- a Riverview resident who caught and ate unusual quantities of fish from the Columbia River
- a typical Pasco resident
- a typical Richland resident

Although the word "maximum" was not used in the report, the first resident listed above probably represents the beginning of what is currently defined as the "hypothetical maximum individual."

Table 9 summarizes the doses estimated for these three types of persons and the assumed diets used to calculate those doses.

TABLE 9. Estimated Radiation Exposure to Persons in the Vicinity of Hanford for 1960 (mrem/yr)

Person	Total Body	GI Tract	Bone
Maximum Individual[a]	80	200	1200 (40)[b]
Typical Resident			
Pasco[c]	10	80	150 (5)[b]
Richland[d]	5	5[e]	90 (3)[b]

(a) Diet: 10 lb/yr fresh, Columbia River whitefish; Riverview produce; Pasco sanitary water; and external exposure from swimming and boating in the Columbia River for 240 h/yr. The word "maximum" is not used in the report.
(b) These exposures were originally reported as percent MPRI as shown in parentheses, based on a limit of 3000 mrem/yr. The values of dose are obtained from the percent MPRI values and the dose limit.
(c) Diet: Pasco sanitary water; food from local stores.
(d) Diet: No Columbia River water or products derived therefrom.
(e) The majority of this dose is from worldwide fallout resulting from nuclear weapons tests.

Results of most analyses for iodine-131 in locally produced milk were below the detection limit of 50 pCi/L. Four of 24 samples collected at Ringold had detectable concentrations of iodine-131; the highest was 100 pCi/L. The annual average concentration of iodine-131 in milk from the Ringold area was between 15 and 55 pCi/L, "depending on whether results below the detection limit are considered to contain no iodine-131, or the amount of the detection limit" (50 pCi/L). The dose to the thyroid of a standard man who consumed such milk would have been between 10 and 40 mrem/yr. No estimate was given in the report for the dose to the thyroid of an infant who had consumed milk from the Ringold area. Were there such an individual their dose could have been between 70 and 280 mrem/yr. Estimates of iodine-131 concentrations in milk can be made from concentrations in air, based on historical ratios observed in the Hanford environs. When this is done, concentrations in milk at Pasco are estimated to have been about 15 pCi/L. Corresponding thyroid doses from consuming such milk are about 10 mrem/yr for an adult and about 75 mrem/yr for an infant. Estimated iodine-131 concentrations in milk and corresponding thyroid doses would be about twice as high for Benton City as for Pasco. Thyroid doses from additional pathways such as consumption of sanitary water derived from the Columbia River, consumption of local produce, inhalation and external exposure were not estimated in the report.

Because of the moratorium on nuclear weapons testing, it was probable that very little iodine-131 from fallout was present in the environment. However, because of tests in previous years, the long-lived radionuclides strontium-90 and cesium-137 were present. Exposures received from fallout radionuclides during 1960 were estimated to be 5 mrem to the GI tract and 9 mrem to bone.

Radiation exposure limits for individuals in the public were 500 mrem/yr to the whole body, 3000 mrem/yr to the thyroid, 3000 mrem/yr bone,[a] and 1500 mrem/yr to other organs.

(a) The MPC values for bone for occupational exposure were actually derived on the basis of biological effects equivalent to those of a bone burden of 0.1 μg of radium-226. Such a burden was calculated to deliver a dose equivalent of approximately 30 rem/yr to bone. Therefore, one-tenth of those MPC values, when used for nonoccupational exposure, implied a dose rate of 3 rem/yr to bone.

1961

Nelson, I. C., ed. 1962. Evaluation of Radiological Conditions in the the Vicinity of Hanford for 1961. HW-71999, Hanford Atomic Products Operation, Richland, Washington.

There were three notable items in the 1961 report. First, the local operational release guide for iodine-131 was lowered from 10 Ci/wk to 2 Ci/wk. This change was made in response to the desire of the AEC and the General Electric Company to control releases of iodine-131 at Hanford so that iodine-131 concentrations in the environment normally did not exceed the lowest range of iodine-131 intake (0-10 pCi/d) specified by the Federal Radiation Council Guidelines (FRC 1961). Second, the analytical detection limit for iodine-131 in milk was lowered from 50 pCi/L to 1 pCi/L to ensure detection at the lower concentrations expected as a result of lowering the release guide. Third, the moratorium on nuclear weapons testing ended in September 1961 when the U.S.S.R. and then the United States resumed testing. Air concentrations of radioactive particulate material increased by a factor of 100 within one month. The fallout was also responsible for higher concentrations of iodine-131 in the environs. The peak concentration of iodine-131 in milk was 1500 pCi/L in November.

The report stated:

"An evaluation of results...for 1961 indicates that most of the environmental radiation exposure for the majority of persons in the neighborhood of the Hanford project was due to natural sources and worldwide fallout rather than to Hanford operations."

"The composite annual exposure, exclusive of those contributed by recent fallout, were similar to those reported for 1960, but trends in several Hanford sources were downward late in the year."

Table 10 summarizes the estimated radiation exposure to persons in the vicinity of Hanford during 1961. The assumptions for diet and exposure were similar to those used in the 1960 annual report.

TABLE 10. Estimated Radiation Doses to Persons in the Vicinity of Hanford for 1961 (mrem/yr)

Person	Total Body	Thyroid	GI Tract	Bone	
Maximum Individual	70	7-40[a]	180	900	(30)[b]
Typical Resident					
- Pasco	10	16[c]	80	90	(3)[b]
- Richland	5	11[c]	5	<30	(<1)[b]

(a) Based on results obtained during the first 8 months of 1961 before nuclear tests were resumed and when most analyses for iodine-131 in milk were below detection limits.
(b) These exposures were originally reported as percent MPRI, as shown in parentheses, based on a limit of 3000 mrem/yr. The values of dose are obtained from the percent MPRI values and the dose limit.
(c) Not reported in 1961; iodine-131 concentrations in foods, and resulting dose calculated in 1985 using annual average concentrations of iodine-131 in air including fallout.

In addition to estimating the individual sources of exposure, an attempt was made to estimate the number of persons possibly exposed to each source. A series of complex histograms was developed to illustrate the diversity of the population in the vicinity of the Site and of the exposure received. The text listed the total dose from the combined pathways for the maximum individual and for residents of Richland and Pasco. The values in Table 10 are derived from both the text and the histograms.

Reference

FRC. 1961. Background Material for the Development of Radiation Protection Standards. Staff Report No. 2, Federal Radiation Council, Washington, D.C.

1962

Wilson, R. H., ed. 1963. Evaluation of Radiological Conditions in the Vicinity of Hanford for 1962. HW-76526, Hanford Atomic Products Operation, Richland, Washington.

The complex histograms developed for the 1961 report were repeated in 1962 to illustrate the diversity of exposures received by the local population. The text, however, listed the doses to the hypothetical maximum individual from a combination of maximum pathways.

The estimated consumption of fresh Columbia River whitefish by the maximum individual was raised from 10 lb/yr, as used in previous years, to 25 lb/yr. The new value represented one meal per week and was based on the preliminary results of a creel census that began in 1961. However, the census also indicated that those persons who caught the largest numbers of whitefish ate none of them fresh. The fish were frozen and/or smoked and stored. Such storage provided for a decrease in the concentration of short-lived phosphorus-32, which, in turn, lowered the estimated bone doses to levels below those previously reported. In addition, the census revealed that most panfish were eaten fresh, and that perhaps the maximum individual diet should have included the consumption of panfish rather than whitefish.

On April 7, 1962, a criticality occurred in a plutonium solution vessel in the 234-5 Building in the 200-West Area. Filter samples were collected from gaseous effluents released from the facility during and after the incident. Analytical results obtained from these samples plus meteorological data were combined to predict the concentrations of particulate and gaseous fission products released and the potential maximum possible exposure that could have occurred on and off the Hanford Site from such releases. The maximum offsite exposure from this event was calculated to be less than 0.001 mR at a point along the Columbia River shoreline 5 miles north of the 300 Area.

Table 11 summarizes the estimated doses to three categories of persons in the Hanford environs. As in previous years, bone-dose estimates based on percent MPRI values more appropriately represent 50-year dose commitments rather than 1-year doses.

TABLE 11. Estimated Radiation Doses to Persons in the Vicinity of Hanford for 1962[a] (mrem/yr)

Person	Total Body	Thyroid	GI Tract	Bone
Maximum Individual[b]	67	15 (adult) 140 (infant)[d]	150	960 (32)[c]
Typical Resident				
- Pasco	14	80 (infant)	50	210 (7)[c]
- Richland	12	80 (infant)	25	210 (7)[c]

(a) Including contributions from radionuclides present as a result of fallout from nuclear tests.
(b) An external dose of 14 mrem/yr was included only in the total-body dose of the hypothetical maximum individual.
(c) These exposures were originally reported as percent MPRI, as shown in parentheses, based on a limit of 3000 mrem/yr. The values of dose are obtained from the percent MPRI values and the dose limit.
(d) Calculated (1985) from annual average concentrations of iodine-131 including fallout in Riverview milk and assuming consumption of 1 liter of milk per day.

In addition to the doses tabulated in Table 11, an annual thyroid dose of 470 mrem was estimated for an infant (small child) who consumed 1 L/d of milk containing the average concentration of iodine-131 measured in milk produced at Ringold in 1962. This dose included the contribution from iodine-131 in fallout.

1963

Wilson, R. H., ed. 1964. Evaluation of Radiological Conditions in the Vicinity of Hanford for 1963. HW-80991, Hanford Atomic Products Operation, Richland, Washington.

During August of 1963, a new Richland city water plant using Columbia River water came into full operation, replacing the Yakima River as the main source of municipal water. During the last 4 months of 1963, consumption of sanitary water from this new source water contributed some radionuclides of Hanford origin to the dose received by Richland residents.

The diet of the hypothetical maximum individual was assumed to include 1 qt/d of milk, 1/2 lb/d of beef, and 1/2 lb/d of fresh leafy vegetables, all produced on irrigated farms in the Riverview district; 200 meals per year of Columbia River panfish; and 2 qt/d of water from the Pasco system.

The report stated:

> "During the past 2 years, over 600 fishermen have been questioned by employees of the State of Washington Department of Game on their consumption of fish. The greatest consumption reported was about 200 meals per year, consisting dominantly of crappie, perch, bass, catfish caught near Burbank....Whether the individual actually ate that much fish is not confirmed. Some other persons reporting unusually high consumption of local fish have been counted in the Whole Body Counter and contained far less Zn^{65} than predicted on the basis of their estimates of the quantities of fish eaten."

The amount of iodine-131 in the Hanford environs was substantially less than in the previous 2 years when extensive testing of nuclear weapons was in progress. Nevertheless, worldwide fallout continued to be the dominant source of the iodine-131 found locally, except in May when an unusual release of fission products from a reactor to the river occurred and in September when abnormal releases occurred at the PUREX plant.

On May 12, 1963, the failure of an experimental fuel element at the KE reactor resulted in the "largest single release of fission products to the river yet experienced at Hanford" (Hall 1963). About one pound of uranium was missing when the fuel element was examined. The transport of fission products by the river measured at the 300 Area and Pasco supported that estimate. However, samples of sanitary water from the Pasco system did not reveal the same elevated concentrations of radionuclides as the samples from the Columbia River near Pasco. At this time of the year, the Pasco water plant was routinely shut down during the night because of low water demands. The arrival of radioactive materials from the failed fuel coincided with this shutdown period. Nonetheless, dose estimates were based on the assumed consumption of untreated river water. On that basis, the estimated incremental thyroid dose was about 8 mrem for the 2-gram thyroid of an infant and 1 mrem for an adult. Estimated doses to the whole body, GI tract and bone of an adult who consumed 2 liters of raw river water were all less than 1 mrem.

The Whole-Body Counter was used to obtain thyroid counts on project employees who drank water at their work locations and on several Pasco residents who drank the water during the time the added contamination was in the system. About one-half of the thyroid measurements were at or below the detection level of 28 pCi. The maximum thyroid burden measured in a Pasco resident was 80 pCi. If a person had consumed 2 liters of raw Columbia River water containing 310 pCi/L of iodine-131, their initial thyroid burden could have been about 190 pCi.

An incident at the PUREX plant in September released about 60 Ci of iodine-131 to the atmosphere. The maximum radiation dose to the thyroid of a 2-year-old child was calculated as 35 mrem (Soldat 1965). This dose was less than the annual thyroid dose of 115 mrem that was calculated for the hypothetical maximum child. This latter dose was calculated on the basis of a daily intake of 50 grams of fresh vegetables and 1 liter of milk from the Riverview district, and 0.8 liter of water from the Pasco system, which included any iodine-131 that was present from both the May and September incidents.

The 1963 annual report referred to contamination in ground water and stated, "In all probability some tritium and ruthenium-106 originating at the chemical processing areas is now entering the Columbia River. However, the contribution of these nuclides is too small to be detectable in the river water and any exposure from them is negligible."

Table 12 summarizes the radiation doses estimated for the maximum and average individuals in the vicinity of Hanford for 1963.

TABLE 12. Estimated Radiation Doses to Persons in the Vicinity of Hanford for 1963[a] (mrem/yr)

Person	Total Body	Thyroid[b]	GI Tract	Bone[d]
Maximum Individual[c]	110	19 (adult) 115 (child)	200	1380 (46)
Average Richland Resident	1	8 (adult) 66 (child)	25	4 (6.4)

(a) Including contributions from fallout radionuclides.
(b) Thyroid doses for the child include consumption of leafy vegetables. Previous estimates for infant included only milk and water consumption.
(c) An external dose of 50 mrem (received while fishing from the river bank) is included only in the whole-body dose of the maximum individual.
(d) These exposures were originally reported as percent MPRI as shown in parentheses. The values of dose are obtained from the percent MPRI values and the applicable limit (3000 mrem/yr for the maximum individual and 1000 mrem/yr for the average resident).

References

Hall, R. B. 1963. Environmental Effects of a Fuel Element Failure. HW-79073, Hanford Laboratories, Richland, Washington.

Soldat, J. K. 1965. "Environmental Evaluation of an Acute Release of ^{131}I to the Atmosphere." Health Phys. 11:1009-1015.

1964

Wilson, R. H., ed. 1965. Evaluation of Radiological Conditions in the Vicinity of Hanford for 1964. BNWL-90, Pacific Northwest Laboratory, Richland, Washington.

The report stated:

> "There were no unusual releases of radionuclides from the Hanford plants during 1964 that warranted special assessment of the radiation dose to persons in the environs. The deposition of Sr^{90} from worldwide fallout was significantly less in 1964 than in 1962 or 1963, and consequently, this nuclide contributed less exposure."

It was estimated that persons in the vicinity of Hanford ingested about 6000 pCi of strontium-90 from fallout during 1964. The corresponding (50-year committed) radiation doses were 59 mrem to bone and 9 mrem to the whole body.

The report further stated:

> "I^{131} in the Hanford environs remained at very low concentrations in 1964. The Chinese nuclear test on October 16 caused a brief increase in I^{131}, but concentrations soon returned to the low levels experienced during most of 1964. The postulated "maximum" exposure from I^{131} to the thyroid of a small child amounted to only about 5% of the Radiation Protection Guide recommended for individuals by the Federal Radiation Council."

Table 13 summarizes the radiation doses estimated for the maximum and average individuals in the vicinity of Hanford for 1964. The contribution of strontium-90, which originated from fallout, was subtracted from the reported doses before they were listed in Table 13. The contributions of iodine-131 that originated from fallout could not be clearly separated from iodine-131 originating from Hanford plant sources. Therefore, the reported doses included contributions of iodine-131 from both sources.

The new dual-purpose (plutonium and electric power) production reactor located in 100-N Area was started up in December 1963 (see Figure 1). It was operated on a power-ascension program during 1964.

TABLE 13. Estimated Radiation Doses to Persons in the Vicinity of Hanford for 1964[a] (mrem/yr)

Person	Total Body	Thyroid	GI Tract	Bone[c]
Maximum Individual[b]	90	16 (adult) 75 (child)	130	700 (23)
Average Richland Resident	3	13 (adult) 40 (child)	50	10 (1.0)

(a) Excluding strontium-90, which was present from fallout, but including all iodine-131, which was present from both fallout and Hanford plant sources.
(b) An external dose of 50 mrem was included only in the estimated whole-body dose of the maximum individual.
(c) These exposures were originally reported as percent MPRI as shown in parentheses. The values of dose are obtained from the percent MPRI values and the applicable limit (3000 mrem/yr for the maximum individual and 1000 mrem/yr for the average resident).

The report also stated:

> "In contrast with the old production reactors that circulate water once through as a coolant before it is returned to the river, the new reactor uses recirculating demineralized water as a primary coolant. Only a very small amount of radionuclides generated in auxiliary systems, such as the control rod cooling water, are released to the river. At the old reactors, stable elements present in the cooling water are transformed into radionuclides during passage through the reactors. In addition, radioactive materials formed on the surfaces of fuel elements and channels are eventually carried away by the cooling water to the river."

1965

Soldat, J. K., and T. H. Essig, eds. 1966. Evaluation of Radiological Conditions in the Vicinity of Hanford for 1965. BNWL-316, Pacific Northwest Laboratory, Richland, Washington.

Methods for estimating the radiation doses were revised in 1965 to better reflect actual conditions at that time.

- The location used for measuring the external exposure from the river bank for the maximum fisherman was changed from Ringold to the Richland Marina.
- An external dose for average exposure from recreational use of the Columbia River was added to the typical dose received by a Richland resident.
- External gamma radiation exposure was added to all organs except bone for the maximum individual.
- An empirical ratio of the iodine-131 concentration in milk to the iodine-131 concentration in vegetation was used occasionally to replace analytical results that were less than the detection limit.
- Contributions of the fallout radionuclides tritium, strontium-90 and cesium-137 (but not iodine-131) were excluded from the reported doses.

The report stated in the summary:

> "The evaluation of results obtained from Hanford environmental surveillance program for 1965 indicates that most of the environmental radiation dose received by the majority of persons living in the neighborhood of the Hanford project was due to natural sources and worldwide fallout rather than to Hanford operations."

> "Iodine-131 in the Hanford environs remained at very low concentrations in 1965. The Chinese nuclear test on May 14 caused a brief increase in I^{131}, but concentrations soon returned to the low levels experienced during most of 1965. The postulated "maximum" annual dose from I^{131} to the thyroid of a small child amounted to only about 4% of the Radiation Protection Guide recommended for individuals by the Federal Radiation Council."

The shutdown of three plutonium-production reactors reduced the radiation doses to the maximum individual from river-water pathways. The dates for the three reactor shutdowns were DR on December 30, 1964; H on April 21, 1965; and F on June 25, 1965.

Table 14 summarizes the radiation doses estimated for the maximum and average individuals in the vicinity of Hanford for 1965.

TABLE 14. Estimated Radiation Doses to Persons in the Vicinity of Hanford for 1965[a] (mrem/yr)

Person	Whole Body	Thyroid	GI Tract	Bone[c]
Maximum Individual[b]	38	30 (adult) 58 (child)	86	360 (12)
Typical Richland[d] Resident	5	10 (adult) 30 (child)	37	9 (0.9)

(a) Excluding the fallout nuclides tritium, strontium-90 and cesium-137, but including iodine-131, which was present from both fallout and Hanford plant sources.
(b) An external dose of 15 mrem received while fishing from the Columbia River shoreline was included in doses to all organs except the bone.
(c) These exposures were originally reported as percent MPRI as shown in parentheses. The values of dose are obtained from the percent MPRI values and the applicable limit (3000 mrem/yr for the maximum individual and 1000 mrem/yr for the average resident).
(d) An external dose of 2 mrem received from swimming and boating in the Columbia River was included in doses to all organs except the bone.

1966

Essig, T. H., and J. K. Soldat, ed. 1967. Evaluation of Radiological Conditions in the Vicinity of Hanford for 1966. BNWL-439, Pacific Northwest Laboratory, Richland, Washington.

The 1966 annual report stated:

> "Two events occurred during 1966 which significantly influenced radiation levels in the Hanford environs. The first of these was an abnormal release of radioiodines from a production reactor to the Columbia River on February 11, 1966. . . ."

> "The effect of the release was to increase the thyroid dose received by the Typical Richland Child from 6% of the limit (1965) to 9% of the limit for 1966, and to have the maximum annual thyroid dose (86 mrem) occur in Richland rather than in the Riverview district. . . ."

> "The second event resulted in a significant reduction of radiation levels in the Hanford environs during a two-month period. A strike was called against Hanford contractors on July 8, 1966. Within a few days, all reactors were shut down and remained out of operation until late August. The overall effect of the extended reactor shutdown was to reduce the estimated annual doses to the GI tract, whole body, and bone by as much as two percent of the appropriate limits from the 1965 values. . . ."

> "Except for the unusual release of radioiodines to the river during February, ^{131}I concentrations in the Hanford environs were at very low levels during 1966. The Chinese weapons test on May 9 and the Chinese and Russian nuclear tests on October 27, 1966 caused brief increases in ^{131}I concentrations in the environment, but concentrations soon returned to the low levels experienced during most of 1966."

Table 15 summarizes the radiation doses estimated for the maximum and average individuals in the vicinity of Hanford for 1966.

In addition to the doses listed in Table 15, some exposure was received from the fallout radionuclides tritium, strontium-90, iodine-131, and cesium-137. The principal radionuclide of interest in fallout exposure is strontium-90, which contributed a dose of 60 mrem to the bone and 5 mrem to the whole body of the maximum individual.

TABLE 15. Estimated Radiation Doses to Persons in the Vicinity of Hanford for 1966[(a)] (mrem/yr)

Person	Whole Body	Thyroid	GI Tract	Bone	
Maximum Individual	33	27 (adult) 86 (child)[(c)]	70	300	(10)[(b)]
Typical Richland Resident	4	12 (adult) 44 (child)[(c)]	33	8	(0.8)

(a) Excluding contributions from fallout.
(b) These exposures were originally reported as percent MPRI as shown in parentheses. The values of dose are obtained from the percent MPRI values and the applicable limit (3000 mrem/yr for the maximum individual and 1,000 mrem/yr for the average resident).
(c) Both of these thyroid doses were for a small child residing in Richland. About one-half of these doses were the result of an unusual release of iodine-131 to the Columbia River from an operating reactor on 2/11/66.

1967

Wooldridge, C. B., ed. 1969. Evaluation of Radiological Conditions in the Vicinity of Hanford for 1967. BNWL-983, Pacific Northwest Laboratory, Richland, Washington.

The report stated:

> "Noteworthy events during 1967 included the June shutdown of D reactor, the fourth Hanford production reactor to be retired since 1964. The Redox separations plant was also retired from routine operation. Abrupt but temporary increases in ^{131}I concentrations in environmental media in January were attributed to an announced foreign weapons test."

The "average" Richland resident was added to the list of persons for whom doses were calculated for the 1967 calendar year. Such calculations were made possible by analyzing drinking-water samples collected from taps in homes in various parts of the city. Concentrations of radionuclides at the homes and at the Richland water plant during different seasons of the year were compared to assess the travel time of the water through the city system. These travel times were used to generate decay corrections applied to the results of treated water samples collected at the water plant. However, for continuity, doses were also calculated for the "typical Richland resident" for another two years, using the same assumptions used in previous years.

Another innovation introduced for the 1967 annual report was the calculation of doses based on the results from 4500 individual diet questionnaires accumulated since 1962. Data from the questionnaires were used to construct the diet of an average Richland resident. The three different diets used in the 1967 report are summarized in Table 16, and the radiation doses calculated from these diets are listed in Table 17.

During 1967, Tri-City residents also received some radiation exposure from fallout radionuclides, principally strontium-90. The bone and whole-body 50-year committed doses from fallout for the maximum individual (Riverview district) were 33 and 5 mrem, respectively. Corresponding doses for the typical Richland resident were 31 and 3 mrem, respectively, and for the average Richland resident, they were 18 and 2 mrem, respectively.

TABLE 16. Dietary Assumptions

Foodstuffs	Maximum Individual	Typical Adult Richland Resident	Average Adult Richland Resident
Water, L/yr	730	440	680[a]
Milk, L/yr	380	310	130[a]
Meat, kg/yr	80	80	74[a]
Chicken, kg/yr	8	5.4	5.4
Eggs, kg/yr	30	15	15
Seafood, kg/yr	0	5.5[b]	1.4[a,b]
Col. Riv. Fish, kg/yr	40	0	0.48[a]
Game Birds, kg/yr	0	0	1.2[a]
Leafy Veg., kg/yr	73[c]	36.5	36.5
Other Veg. and Fruits, kg/yr	530[c]	200[c]	200[c]

Foodstuffs	Maximum Infant	Typical Richland Infant	Average Richland Infant
Water, L/d	0.8	0.4	0.4
Milk, L/d	1.0	0.6	0.6
Leafy Veg., g/d	50	25	25

(a) Based on responses to dietary questionnaires supplied by Richland residents employed at Hanford.
(b) One-tenth of the total was assumed to be Willapa Bay oysters, the remainder free of radionuclides of Hanford origin.
(c) The 1967 report contained lower values for these four intake rates. The correct values as listed here were actually used in the dose calculations for 1967. The 1968 annual report (Wilson 1970) pointed out these errata.

TABLE 17. Estimated Radiation Doses to Persons in the Vicinity of Hanford for 1967[(a)]

Organ	Annual Dose, mrem	Standard, mrem	% of Standard	% MPRI for Bone
Maximum Individual				
GI Tract	82	1500	5	
Whole Body	32	500	6	
Bone	360[(b)]	1500	24	12
Thyroid (infant)	97	1500	6	
Typical Richland Resident				
GI Tract	24	500	5	
Whole Body	4	170	3	
Bone	6[(b)]	500	1.2	0.6
Thyroid (infant)	50	500	10	
Average Richland Resident				
GI Tract	30	500	6	
Whole Body	4	170	3	
Bone	20[(b)]	500	4	2
Thyroid (infant)	38	500	8	

(a) Doses from fallout and natural background were not included.
(b) Calculated (1985) from the % MPRI given in the report and corresponding dose limits.
(c) Percent of MPRI derived from MPC values based on the ICRP standards of 3000 mrem/yr for the maximum individual and 1000 mrem/yr for the average member of the public.

Reference

Wilson, C. B., ed. 1970. Evaluation of Radiological Conditions in the Vicinity of Hanford for 1968. BNWL-1341, Pacific Northwest Laboratory, Richland, Washington.

1968

Wilson, C. B., ed. 1970. Evaluation of Radiological Conditions in the Vicinity of Hanford for 1968. BNWL-1341, Pacific Northwest Laboratory, Richland, Washington.

The report stated:

> "Doses were estimated for the whole body, gastrointestinal-tract, and thyroid as in previous years and, for the first time, the annual intake of bone-seeking radionuclides was also expressed in terms of dose to skeletal bone."

> "The population considered included the Maximum Individual, the Average Richland Resident, and the Typical Richland Resident. Population dose estimates were less than one-tenth of the appropriate standards except for the skeletal bone of the Maximum Individual (17% of the 1500 mrem/year standard) and for the thyroid of the infant Typical Richland Resident (11% of the 500 mrem/year standard). A single radionuclide, ^{32}P, contributed 96% of the estimated skeletal bone dose received by the Maximum Individual with Columbia River fish the major source of intake."

The dietary assumptions used for the 1968 calculations were the same as those used for the 1967 report. The diet data that was reported in the 1967 report for consumption of "other vegetables and fruit," however, was in error. The correct consumption data were reported in the 1968 report and are footnoted in Table 16, which is presented under the year 1967.

The phasing out of older production reactors continued with the shutdown of the B reactor on February 12, 1968.

Table 18 summarizes the radiation doses estimated for persons in the vicinity of Hanford for 1968.

An announced foreign weapons test caused increased iodine-131 concentrations in the environment in January 1968 and higher concentrations of total beta activity associated with airborne particulates during the first half of

TABLE 18. Estimated Radiation Doses to Persons in the Vicinity of Hanford for 1968[a]

Organ	Annual Dose, mrem	Standard, mrem	% of Standard
Maximum Individual			
Bone[b]	250	1500	17
Whole Body	24	500	5
GI Tract	62	1500	4
Thyroid (infant)	110	1500	7
Typical Richland Resident			
Bone(b)	8	500	2
Whole Body	3	170	2
GI Tract	24	500	5
Thyroid (infant)	55	500	11
Average Richland Resident			
Bone(b)	13	500	3
Whole Body	3	170	2
GI Tract	25	500	5
Thyroid (infant)	39	500	8

(a) Doses from fallout and natural background were not included.
(b) The external exposure received from fishing and aquatic recreation in the Columbia River was included in the bone dose. (External exposure had been added to the whole-body doses since 1957 and was added to organs other than bone beginning in 1965.)

the year. A nuclear test, Schooner, conducted December 8, 1968, at the Nevada Test Site caused an abrupt but temporary increase in atmospheric beta activity in December. Table 19 summarizes the additional radiation doses potentially received by persons in the Hanford environs from the fallout radionuclides tritium, strontium-90, and cesium-137.

TABLE 19. Estimated Radiation Doses to Persons in the Vicinity of Hanford from Fallout Radionuclides for 1968 (mrem/yr)

Person	Whole Body	GI Tract	Bone
Maximum Individual	5	<1	40
Typical Richland Resident	4	<1	36
Average Richland Resident	3	<1	19

1969

Wilson, C. B., and T. H. Essig. 1970. Evaluation of Radiological Conditions in the Vicinity of Hanford for 1969. BNWL-1505, Pacific Northwest Laboratory, Richland, Washington.

The C reactor was shut down on April 25, 1969. During 1969, dose estimates for a typical Richland resident were discontinued in favor of the more appropriate average Richland resident. Both types of calculations had been performed for 1967 and 1968.

The "dose factor" for calculating whole-body dose from cesium-137 ingestion was changed from 31 mrem/μCi to 60 mrem/μCi because of a change in the recommended effective half-time for retaining cesium in the body. This new dose factor coincided with recommendations made by the Federal Radiation Council (FRC 1965) and the International Commission on Radiological Protection (ICRP 1968). This change did not impact the doses previously calculated for Hanford sources, since nearly all of the cesium-137 present in the Hanford environs was the result of fallout from weapons tests. One exception was the presence of cesium-137 in waterfowl sampled directly from onsite waste disposal swamps. Such waterfowl were not representative of those available to the public. The 1969 annual report detailed the results of the on- and offsite waterfowl sampling program.

The report also discussed the results of a survey of recreation and dietary habits of Richland teenagers that indicated this age group spent an average of 115 h/yr on or along the Columbia River. Based on these data, the annual external exposure to teenagers from aquatic recreation was estimated to be 6 mR during 1969.

Estimates were made of doses received by residents of the Hanford environs from the fallout radionuclides tritium, strontium-90 and cesium-137.

The report stated:

> "Unlike previous years, no increases of ^{131}I concentrations in milk attributable to fallout from weapons testing were observed during 1969, even though foreign weapons tests were conducted in late December 1968. . . . and September 1969. . . ."

Table 20 summarizes the annual dose commitments from fallout radionuclides in the Hanford environs, and Table 21 summarizes the radiation doses estimated for residents of the Hanford Environs for 1969, excluding contributions from fallout.

TABLE 20. Estimated Radiation Dose Commitments to Persons in the Vicinity of Hanford from Fallout Radionuclides for 1969 (mrem)

Person	Whole Body[(a)]	GI Tract	Bone
Maximum Individual	5	<1	39
Average Richland Resident	2	<1	13

(a) The dose conversion factor of 60 mrem/µCi specified by the Federal Radiation Council was used for the whole-body dose commitment from ingestion of cesium-137 by an adult. A factor of 31 mrem/µCi, based on older ICRP values, was used for previous reports in this series.

TABLE 21. Estimated Radiation Doses to Persons in the Vicinity of Hanford for 1969[a]

Organ	Annual Dose, mrem	Standard, mrem	% of Standard
Maximum Individual			
Bone	140	1500	9
Whole Body	18(b)	500	4
GI Tract	40	1500	3
Thyroid (Infant)	60	1500	4
Average Richland Resident			
Bone	15	500	3
Whole Body	4	170	2
GI Tract	19	500	4
Thyroid (Infant)	23	500	5

(a) Doses from fallout and natural background radiation were not included.
(b) About one-half of this dose was from external exposure received while fishing from the Columbia River shoreline for 500 h/yr.

References

Federal Radiation Council (FRC). 1965. Background Material for the Development of Radiation Protection Standards--Protective Action Guides for Sr-89, Sr-90, and Cs-137. FRC Report No. 7, U.S. Government Printing Office, Washington, D.C.

International Commission on Radiological Protection (ICRP). 1968. Report of Committee IV on Evaluation of Radiation Doses to Body Tissues from Internal Contamination Due to Occupational Exposure. ICRP Publication 10, Pergamon Press, New York.

1970

Corley, J. P. 1973. Environmental Surveillance at Hanford for CY-1970. BNWL-1669, Pacific Northwest Laboratory, Richland, Washington.

Dietary assumptions for the 1970 dose assessment were the same as those used since 1967; however, a change was made in the calculation of dose to the GI tract from the consumption of sanitary water. Data from previous years was used to determine a ratio between gross beta counting rates on water samples and the GI-tract dose rates calculated from specific isotopic analyses. This ratio was then applied to the gross beta counting rates obtained for sanitary water samples collected in 1970.

The new method was necessary because of the continued decrease in radionuclide concentrations in the Columbia River. The KW reactor was retired in February of 1970, and "...from February to April and again in September, no reactors were operating."

The report further stated:

> "A marked reduction from 1969 occurred in releases of radioiodine from the chemical processing facilities. Effects of a reported atmospheric nuclear weapons test were detected temporarily in air and milk in December."

> "In late December, 1969, two ducks collected during routine surveillance from the K Reactor area trench were found to contain greater amounts of radioactivity, primarily ^{32}P, than birds taken from the river. The trench received single-pass reactor coolant, and the ducks had apparently consumed algae from this site. Initial followup in January, 1970, involved collection of waterfowl from all open ponds and trenches at the Hanford site. One duck was found at the K trench and one more with unusually high ^{32}P concentrations was found residing on the N Reactor trench. Corrective action was taken to prevent further access by gamebirds. As in past years, none of the many gamebirds collected along the river and close to public hunting areas showed any similar concentrations of radionuclides."

The maximum phosphorus-32 concentration (0.14 μCi/g) was found in a duck collected from the 100-N Area reactor trench. The maximum found in ducks along the river was 0.00017 μCi/g. Immediate (with no time for radioactive decay of the phosphorus-32) consumption of one-half pound of duck flesh with the highest concentration "...would have resulted in a calculated skeletal-bone dose to an adult of about 6 rem, four times the applicable annual dose standard. The associated whole-body dose, including a contribution from zinc-65, would have been about 250 mrem, or about 15% (sic)[a] of the applicable annual dose standard."

> "...any delays in consumption of more than four weeks would have reduced the skeletal bone dose to less than 1500 mrem (the annual standard). . . ."
>
> "The consumption of such a bird by any member of the public, however, is considered highly improbable in view of the facts that: (a) very few birds (out of some 200,000 in the area at that time) would have been likely to spend sufficient time on the trenches near the reactor areas to accumulate such large amounts of radioactive materials, and (b) concentrations of this magnitude have never been found in hundreds of birds sampled along the river for over 20 years. In our judgment, ducks collected on swamps, trenches, or ponds are not representative of those available to the general population, and dose estimates derived therefrom are not pertinent for inclusion in comparisons with the established dose standards."

Table 22 summarizes the radiation doses received by residents of the Hanford environs from the fallout radionuclides tritium, strontium-90 and cesium-137. Essentially all of the doses listed were from strontium-90. Table 23 summarizes the radiation doses estimated for persons in the Hanford environs as reported for 1970.

(a) Actually 50% of the limit of 500 mrem/yr for the whole body of the maximum individual.

TABLE 22. Estimated Radiation Dose Commitments to Persons in the Vicinity of Hanford from Fallout Radionuclides for 1970 (mrem)

Person	Whole Body	GI Tract	Bone
Maximum Individual	5	<1	51
Average Richland Resident	1	<1	12

TABLE 23. Estimated Radiation Doses to Persons in the Vicinity of Hanford for 1970[a]

Organ	Annual Dose, mrem	Standard, mrem	% of Standard
Maximum Individual			
Bone	94	1500	6
Whole Body	12	500	2
GI Tract	27	1500	2
Thyroid (Infant)	30	1500	2
Average Richland Resident			
Bone	9	500	2
Whole Body	2	170	1
GI Tract	12	500	2
Thyroid (Infant)	8	500	2

(a) Doses from fallout and natural background radiation were not included.

1971

Bramson, P. E., and J. P. Corley. 1972. Environmental Surveillance at Hanford for CY-1971. BNWL-1683, Pacific Northwest Laboratory, Richland, Washington.

The report stated:

> "In January, 1971, the last production reactor with once-through cooling by river water, KE, was shut down. As a result, the amount of radioactivity released to the Hanford environment, other than to soil within the plant reservation, decreased to relative insignificance. N Reactor has a closed primary cooling loop and releases only minor quantities of radioactivity to the river. . . ."
>
> "Radiation dose estimates for population groups in the plant environs for 1971 were all less than 1% of applicable standards for plant operations. Offsite measurements of other air and water quality parameters were also well within applicable criteria and showed no significant evidence of plant operations."

A total of 18 nuclear weapons tests were recorded during the last half of 1971 (Carter and Moghissi 1977). Six of these tests were atmospheric tests conducted by France and China. The others were underground tests. During 1971 several measurements above the analytical detection levels for strontium-90 and cesium-137 were obtained on locally available milk samples. Most of these measurements were in the last half of 1971. However, the annual average concentrations of iodine-131 in the milk from nearly all farms were at or below the analytical limit of 2 pCi/L. The maximum value of 25 pCi/L was recorded in the composite sample collected on December 2, 1985, from the West Richland-Benton City area.

Table 24 summarizes the 50-yr committed radiation doses from the fallout radionuclides strontium-90 and cesium-137 that were estimated for residents of the Hanford environs. Table 25 summarizes the radiation doses estimated for residents of the Hanford environs as reported for 1971.

TABLE 24. Estimated Radiation Dose Commitments to Persons in the Vicinity of Hanford from Fallout Radionuclides for 1971 (mrem)

Person	Whole Body	GI Tract	Bone
Maximum Individual	3	<1	31
Average Richland Resident	2	<1	15

TABLE 25. Estimated Radiation Doses to Persons in the Vicinity of Hanford for 1971[(a)]

Organ	Annual Dose, mrem	Standard, mrem	% of Standard
Maximum Individual			
Bone	3	1500	<1
Whole Body	3	500	<1
GI Tract	3	1500	<1
Thyroid (Infant)	(b)	1500	<1
Average Richland Resident			
Bone	<1	500	<1
Whole Body	<1	170	<1
GI Tract	<1	500	<1
Thyroid (Infant)	(b)	500	<1

(a) Doses from fallout and natural background radiation were not included.
(b) Annual average concentrations of iodine-131 were below the respective analytical limits for samples of air, water, milk and food from the Hanford environs.

Reference

Carter, M. W., and A. A. Moghissi. 1977. "Three Decades of Nuclear Testing." Health Physics. 33(1):55-71.

1972

Bramson, P. E., and J. P. Corley. 1973. Environmental Surveillance at Hanford for CY-1972. BNWL-1727, Pacific Northwest Laboratory, Richland, Washington.

The report stated:

"In 1972 the average river radionuclide concentrations were less than 1% of the Concentration Guides for all identified radionuclides. Unidentified alpha emitters were 2.2% of which about 0.4% was due to Hanford operations."

"Airborne radioactivity concentrations at the Hanford boundary were, on the average, the same as the more distant sampling locations, indicating that Hanford operations did not contribute detectably to off-site airborne radioactivity."

"Soil and vegetation samples were analyzed for plutonium, uranium, Sr-90 and gamma emitters. Individual results showed no particular geographical pattern and the concentrations are believed to be the result of natural occurrence and regional fallout. Local plutonium concentrations are typical of arid western states."

"Estimated 1972 dose to the average Richland resident from Hanford sources was less than 1 mrem (0.6% of the standard), about the same as for 1971."

Table 26 summarizes the radiation doses estimated for residents of the Hanford environs as reported for 1972.

Table 26 also lists annual doses calculated from effluent measurements as reported by Hanford contractors for 1972. These doses were calculated using computer codes developed at Hanford. A description of these codes, their

TABLE 26. Estimated Radiation Doses to Persons in the Vicinity of Hanford for 1972[a]

Organ	Calculated from Effluent Measurements[b]	Estimated from Environmental Measurements[c]	Standard mrem	% of Standard
Maximum Individual (mrem/yr)				
Bone	2.1	3	1500	<1
Whole Body	0.6	2	500	<1
GI Tract	1.4	2	1500	<1
Thyroid - Infant	1.4	(d)	1500	<1
Thyroid - Adult	1.1	(d)	1500	<1
Average Resident (mrem/yr)				
Bone	(e)	<1	500	<1
Whole Body	---	<1	170	<1
GI Tract	---	<1	500	<1
Thyroid - Infant	---	(d)	500	<1
Thyroid - Adult	---	(d)	500	<1
Population (man-rem/yr)				
Bone	---	---	NA[f]	
Whole Body	2.5[g]	---	NA	
GI Tract	3.4[h]	---	NA	
Thyroid - Adult	12[g]	---	NA	

(a) Doses from fallout and natural background radiation were not included.
(b) Calculated from effluent measurements using computer codes as described in ERDA-1538 (ERDA 1975).
(c) Estimated from measurements of air, water, foods and external exposure in the Hanford environs.
(d) Annual average concentrations of iodine-131 were below the respective analytical limits for samples of air, water, milk and foods from the Hanford environs.
(e) A dash (---) indicates that the dose was not reported.
(f) No applicable standards.
(g) Total dose to 250,000 persons residing within 50 miles of the Hanford fuel reprocessing facilities, as reported in ERDA-1538 (ERDA 1975).
(h) Estimated from data in ERDA-1538 (ERDA 1975).

application and the results obtained were discussed in the Hanford Waste Management Environmental Impact Statement (ERDA 1975). Doses were listed in that report for the maximum individual and the population within 50 miles of the Site. The population doses were based on a total population of 250,000 persons.

There was close agreement between the two sets of doses for the maximum individual considering that the doses estimated from environmental measurements were based on sample results that were in many instances at or below the analytical limits. Another complicating factor was the need to use annual average meteorological data and annual average river flow for calculating the dilution of effluents which were not always released at a continuous, uniform rate.

A further comparison was made between the two sets of dose results by dividing the population doses by 250,000 to obtain a "per capita" dose. These doses were then compared with doses for the average Richland resident of less than 1 mrem/yr. The per capita doses for the whole body and the GI tract were 0.01 mrem/yr, while that for the adult thyroid was 0.05 mrem/yr. Although the "per capita" diets were somewhat smaller than those of the average Richland resident, there was no disagreement between these "per capita" doses and the values of less than 1 mrem/yr for the average Richland resident listed in Table 26.

In addition to the doses from Hanford sources, residents of the Hanford environs received additional exposure from fallout radionuclides, principally strontium-90. Table 27 summarizes the 50-year committed radiation doses from fallout radionuclides estimated for residents of the Hanford environs in 1972.

TABLE 27. Estimated Radiation Dose Commitments to Persons in the Vicinity of Hanford from Fallout Radionuclides for 1972 (mrem)

Person	Whole Body	GI Tract	Bone
Maximum Individual	3	<1	27
Average Richland Resident	1	<1	10

Reference

Energy Research and Development Administration (ERDA). 1975. Final Environmental Statement Waste Management Operations, Hanford Reservation, Richland, Washington. ERDA-1538, Richland Operations, Richland, Washington.

1973

Nees, W. L., and J. P. Corley. 1974. Environmental Surveillance at Hanford for CY-1973. BNWL-1811, Pacific Northwest Laboratory, Richland, Washington.

During 1973, the principal Hanford sources of radiation exposure to residents in the Hanford environs were liquid effluents from the 100-N reactor. The largest sources of exposure to the hypothetical maximum individual were consumption of 40 kg/yr of freshly caught Columbia River panfish (0.8 mrem/yr to the bone) and external gamma radiation received from the river shoreline while fishing (2.0 mrem/yr to all organs). The PUREX reprocessing plant was shut down in September 1972, and concentrations of iodine-131 in environmental samples were generally below the respective analytical limits (Nees and Corley 1974). All but two of 210 milk samples collected from the Hanford environs and local grocery stores were found to have concentrations of iodine-131 at or below the detection limit of 2 pCi/L. These two were both at 5 pCi/L and were both collected on July 12, 1973, at widely separated farms. These two results were possibly the result of a large Chinese weapons test conducted in the atmosphere on June 26, 1973 (Carter and Moghissi 1977).

Table 28 summarizes the radiation doses estimated for residents of the Hanford environs as reported for 1973. The new methodology described in the annual report for 1972 was first put into routine use for the 1974 report, and the 1973 radiation doses for residents of the Hanford environs were not yet calculated from effluent measurements using computer codes.

Table 29 summarizes the 50-year committed radiation doses estimated for residents of the Hanford environs from fallout radionuclides, principally strontium-90.

TABLE 28. Estimated Radiation Doses to Persons in the Vicinity of Hanford for 1973[(a)]

Organ	Annual Dose, mrem	Standard, mrem	% of Standard
Maximum Individual			
Bone	3	1500	<1
Whole Body	2	500	<1
GI Tract	2	1500	<1
Thyroid (Infant)	(b)	1500	<1
Average Richland Resident			
Bone	<1	500	<1
Whole Body	<1	170	<1
GI Tract	<1	500	<1
Thyroid (Infant)	(b)	500	<1

(a) Doses from fallout and natural background radiation were not included.
(b) Annual average concentrations of iodine-131 were at or below the respective analytical limits for samples of air, water, milk, and food from the Hanford environs.

TABLE 29. Estimated Radiation Dose Commitments to Persons in the Vicinity of Hanford from Fallout Radionuclides for 1973 (mrem)

Person	Whole Body	GI Tract	Bone
Maximum Individual	1	<1	13
Average Richland Resident	<1	<1	8

References

Carter, M. W., and A. A. Moghissi. 1977. "Three Decades of Nuclear Testing." Health Physics. 33(1):55-71.

Nees, W. L., and J. P. Corley. 1974. Environmental Surveillance at Hanford for CY-1973, BWNL-1811 ADD, Pacific Northwest Laboratory, Richland, Washington.

1974

Fix, J. J. 1975. Environmental Surveillance at Hanford for CY-1974. BNWL-1910, Pacific Northwest Laboratory, Richland, Washington.

The 1974 report initiated routine evaluations of potential radiation doses from Hanford operations using environmental pathway models and computer codes. Doses calculated in this manner included the first-year dose and the 50-year committed dose for the maximum individual (MI) and the population within 50 miles of Hanford operating areas.

The report stated:

> "The contribution from Hanford operations during 1974 to the radiation levels measured in all environmental media (atmosphere, water, foodstuffs, wildlife, soil, and vegetation) were indistinguishable from pre-existing radiation levels. Some of the radioactivity that was measured in occasional samples from Columbia River islands, and oysters from Willapa Bay was due to past once-through cooling production reactor operation. The last of these reactors, KE, was deactivated during January 1971. The radioactivity in the river sediments and biota due to this cause is gradually becoming undetectable through dilution and radioactive decay."

During 1974, the radiation levels in fish and game birds were only occasionally above analytical detection limits. Levels of zinc-65 in Willapa Bay oysters continued to decrease and were about 1% of the levels found during the early part of 1970.

Calculated from 1974 effluent, the maximum "fence-post" exposure rate was 0.18 mR/yr (0.00002 mR/hr) along the uninhabited northwest boundary of the Hanford Reservation. The highest external exposure rate measured on Columbia River islands was 0.014 mR/hr, in addition to approximately 0.01 mR/hr from natural background radiation. Any contribution to the total population dose was insignificant because of the remoteness of the islands and the small number of people potentially affected.

The report also stated:

"Because of the difficulty in measuring the contribution (of Hanford effluents) to the existing radiation levels due to the fall-out and natural radioactivity, the radiological impact from Hanford operations during 1974 was estimated from theoretical models relating releases of radioactivity from Hanford operations with subsequent radiation dose to the population. The models have been used previously to determine the radiological impact from Hanford facilities (Waste Management Operations - Hanford Reservation - WASH-1538)."[a]

"All significant environmental exposure pathways were evaluated including submersion in the plume, drinking water, foodstuffs irrigated with Columbia River water, atmospheric iodine-pasture-cow-milk pathway, etc. The methods employed are expected to provide a best estimate of the doses due to the different exposure pathways. The calculated doses are conservative since (effluents reported as) less-than numbers were... assumed to be positive measurements for the purposes of dose calculation."

"Past studies, combined with results of the environmental surveillance program, have facilitated the construction of a hypothetical person whose dietary and recreational habits maximize the dose he might receive from Hanford operations. Such a hypothetical person is called the maximum individual. The habits and diet of the maximum individual include the maximum reported for each exposure mode in spite of the fact that the maximum values are not, in actuality, attributable to the same person. The maximum individual is a person assumed to have the following characteristics:

- resides continuously directly across the river from the Hanford 300 Area
- obtains drinking water from the Columbia River
- drinks 275 liters of milk during a 9-month period from a cow eating pasture grass near his residence

(a) The report number was later revised to ERDA-1538 (ERDA 1975).

- eats 710 kg of produce grown near his residence and irrigated with Columbia River water
- eats 40 kg of fish per year caught from the Columbia River
- spends as much as 500 hours per year on the shoreline of the Columbia River, 100 hours per year swimming in the river, and 100 hours per year boating."

The results of the calculations for the first-year dose and the 50-year dose commitment for the maximum individual are shown in Tables 30 and 31, respectively. The first-year dose to the GI-LLI of the MI from irrigated foods was erroneously reported as 0.075 mrem in the 1974 annual report. The value of 0.0075 shown in Table 30 is compatible with the other doses from irrigated foods and with the total GI-LLI dose of 0.032 mrem that were given in the 1974 annual report. Population doses are summarized in Tables 32 and 33.

TABLE 30. Calculated Doses to the Maximum Individual During 1974 from Effluents Released from Hanford Facilities During 1974 (mrem)

Pathway	Annual Exposure	Total Body	GI-LLI[a]	Bone	Thyroid
Gaseous Effluents					
Air Submersion and Tritium Inhalation and Transpiration	8766 hr	0.02	0.02	0.02	0.02
Radioiodine-Inhalation	7300 m^3	---	---	---	0.002
Milk	274 L[b]	---	---	---	0.006
Leafy Vegetables	30 kg[c]	---	---	---	0.01
Total Air Pathways		0.02	0.02	0.02	0.09
Liquid Effluents					
Drinking Water	730 L	0.0002	0.0005	0.0004	0.017
Fish Consumption	40 kg	0.0057	0.021	0.0062	0.018
Irrigated Foods	710 kg[d]	0.0048	0.0075[e]	0.0025	0.063
Shoreline	500 hr	0.0030	0.0030	0.0030	0.0030
Swimming	100 hr	$2X10^{-6}$[f]	$2X10^{-6}$	$2X10^{-6}$	$2X10^{-6}$
Boating	100 hr	$8X10^{-6}$[g]	$8X10^{-6}$	$8X10^{-6}$	$8X10^{-6}$
Total Water Pathways		0.014	0.032	0.012	0.10
TOTAL ADULT DOSES		0.03	0.05	0.03	0.19
		Infant Thyroid Dose			
Airborne Tritium and Air Submersion	8766 hr				0.02
Inhalation	2045 m^3				0.006
Milk	274 L				0.4
Drinking Water	292 L				0.05
TOTAL INFANT THYROID DOSE					0.5

(a) Gastrointestinal tract, lower large intestine.
(b) One liter per day for a 9-month grazing season.
(c) 200 g/d for a 5-month growing season.
(d) Only the potentially irrigated produce was included.
(e) Erroneously given as 0.075 in the original report.
(f) $2X10^{-6}$ = 0.000002.
(g) $8X10^{-6}$ = 0.000008.

TABLE 31. Calculated 50-Year Dose Commitments to the Maximum Individual from Effluents Released from Hanford Facilities During 1974 (mrem)

Pathways	Total Body	GI-LLI[(a)]	Bone	Thyroid Adult	Thyroid Infant
Gaseous Effluents	0.02	0.02	0.02	0.09	0.43
Liquid Effluents	0.03	0.03	0.08	0.10	0.05
Total	0.05	0.05	0.10	0.19	0.5

(a) Gastrointestinal tract, lower large intestine.

TABLE 32. Calculated Population Doses During 1974 from Effluents Released from Hanford Facilities During 1974 (man-rem)

Pathways	Total Body	GI-LLI	Bone	Lung	Thyroid
Gaseous Effluents	1.1	1.1	1.1	1.4	3.6
Liquid Effluents	0.03	0.04	0.02	---	0.6
Total	1.1	1.1	1.1	1.4	4.2

TABLE 33. Calculated 50-Year Dose Commitments to the Population from Effluents Released from Hanford Facilities During 1974 (man-rem)

Pathways	Total Body	GI-LLI	Bone	Lung	Thyroid
Gaseous Effluents	1.5	1.1	4.2	2.4	3.6
Liquid Effluents	0.057	0.043	0.15	---	0.58
Total	1.6	1.1	4.4	2.4	4.2

Reference

Energy Research and Development Administration (ERDA). 1975. Final Environmental Statement Waste Management Operations, Hanford Reservation, Richland, Washington. ERDA-1538, Richland Operations, Richland Washington.

1975

Speer, D. R., J. J. Fix and P. J. Blumer. 1976. Environmental Surveillance at Hanford for CY-1975. BNWL-1979 (REV), Pacific Northwest Laboratory, Richland, Washington.

The contribution from Hanford operations during 1975 to the radiation levels measured in all environmental media (atmosphere, water, foodstuffs, wildlife, soil and vegetation) was indistinguishable from preexisting levels. Some residual radionuclides were still present in the Columbia River because of the past operation of once-through-cooled reactors. These radionuclides were measured in occasional samples of wildlife, suspended sediment in river water, soil samples from Columbia River islands, and oysters from Willapa Bay.

As in 1974, there was only a small contribution by Hanford facilities to the existing radiation levels from fallout and natural background radionuclides. The radiological impact was again calculated from theoretical models relating releases of radionuclides from Hanford to subsequent radiation doses to members of the general public. The methods employed were designed to provide a best estimate of the calculated doses resulting from Hanford operations during 1975. The radiological impacts from radionuclides present in wildlife, island soil samples, river sediments, and oysters were addressed separately in the report.

The same hypothetical maximum individual postulated for 1974 was used for the 1975 calculations. The results of these calculations for the first-year dose and the 50-year dose commitment are summarized in Tables 34 and 35, respectively. Corresponding doses for the population residing within 50 miles of the Hanford facilities are summarized in Table 36.

TABLE 34. Calculated Doses to the Maximum Individual During 1975 from Effluents Released from Hanford Facilities During 1975 (mrem)

	Annual Exposure	Total Body	GI-LLI	Bone	Thyroid
Gaseous Effluents					
Air Submersion and Tritium Inhalation and Transpiration	8766 hr	0.003	0.003	0.003	0.003
Radioiodine - Inhalation	7300 m^3	---	---	---	0.004
Milk	274 L	---	---	---	0.1
Leafy Vegetables	30 kg				0.022
Total Air Pathways		0.003	0.003	0.003	0.13
Liquid Effluents					
Drinking Water	730 L	0.0002	0.001	0.0003	0.025
Fish Consumption	40 kg	0.003	0.028	0.004	0.025
Irrigated Foods	710 kg	0.0002	0.001	0.006	0.008
Shoreline	500 hr	0.0006	0.0006	0.0006	0.0006
Swimming	100 hr	$3x10^{-5}$[a]	$3x10^{-5}$	$3x10^{-5}$	$3x10^{-5}$[a]
Boating	100 hr	$2x10^{-5}$[b]	$2x10^{-5}$	$2x10^{-5}$	$2x10^{-5}$[b]
Total Water Pathways		$4.5x10^{-3}$	$3.1x10^{-2}$	$5.9x10^{-3}$	$5.8x10^{-2}$
TOTAL ADULT DOSES		0.007	0.03	0.009	0.2
		Infant Thyroid Dose			
Airborne Tritium and Air Submersion	8766 hr				0.003
Inhalation	2045 m				0.008
Milk	274 L				0.74
Drinking Water	292 L				0.095
TOTAL INFANT THYROID DOSE					0.9

(a) $3x10^{-5}$ is 0.00003.
(b) $2x10^{-5}$ is 0.00002.

TABLE 35. Calculated 50-Year Dose Commitments to the Maximum Individual from Effluents Released from Hanford Facilities During 1975 (mrem)

Pathways	Total Body	GI-LLI	Bone	Thyroid
Gaseous Effluents	0.003	0.003	0.003	0.13
Liquid Effluents	0.031	0.10	0.44	0.11
TOTAL - Adult	0.03	0.10	0.44	0.24

TABLE 36. Calculated First-Year Doses and 50-Year Dose Commitments to the Population from Effluents Released from Hanford Facilities During 1975 (man-rem)

	Total Body	GI-LLI	Bone	Lung	Thyroid
First-Year Dose	0.9	0.9	1.1	2.1	2.8
50-Year Dose Commitment	1.5	0.9	4.5	6.4	2.8

1976

Fix, J. J., P. J. Blumer, G. R. Hoenes and P. E. Bramson. 1977. Environmental Surveillance at Hanford for CY-1976. BNWL-2142, Pacific Northwest Laboratory, Richland, Washington.

With two exceptions, contributions by Hanford operations to radiation levels were not distinguishable from preexisting levels resulting from fallout and natural radioactivity. The exceptions were 1) residual levels of long-lived radionuclides, primarily cobalt-60, associated with sediments along the Columbia River islands and shoreline near the Hanford Site; and 2) very low concentrations of radionuclides in Columbia River water, resulting from ongoing N-Reactor operations. As in 1974 and 1975, empirical dose models and computer codes were used to calculate the radiation doses resulting from Hanford effluents.

In previous years, radionuclides released to the Columbia River were the dominant mode of exposure, whereas other pathways became more important in later years. Calculations for 1976 included estimates of the dose received from 1) airborne contaminants at a location 1 mile east of the 300 Area, 2) drinking water at Richland, 3) irrigated foodstuffs at Riverview, and 4) aquatic recreation along the Hanford reach of the Columbia River.

Radiation doses were calculated using environmental transport and dosimetry models and associated computer codes. The results of these calculations for the first-year dose and the 50-year dose commitment are shown in Tables 37 and 38, respectively. The doses shown in these tables are not strictly additive, because the location of the maximum dose received from any one pathway was separated by many miles from the location of the dose from any other pathway. For purposes of this report, however, they are added together to yield a conservative upper bound to the potential doses from effluents released in 1976. Calculated population doses for 1976 are given in Table 39.

TABLE 37. Calculated Annual Doses to the Maximum Individual from Effluents Released from Hanford Facilities During 1976[a] (mrem)

Environmental Pathway	Skin	Total Body	GI-LLI	Bone	Lung	Thyroid
Airborne[b]	0.01	0.01	0.01	0.01	0.01	0.07
Drinking Water	--	0.01	0.01	0.01	--	0.02
Irrigated Foodstuff	0.01	0.01	0.01	0.06	--	0.05
Aquatic Recreation[c]	0.01	0.01	0.03	0.03	--	0.02
TOTAL	0.01	0.03	0.05	0.09	0.01	0.16

(a) The doses shown are not strictly additive. The dose received depends on the location and assumed living habits of the hypothetical maximum individual. The pathways shown are separated by many miles.
(b) Including dose contribution from inhalation, submersion, ingestion of foodstuffs contaminated by airborne deposition, and exposure to ground contamination.
(c) Including consumption of fish from the Columbia River.

TABLE 38. Calculated 50-Year Dose Commitments to the Maximum Individual from Effluents Released from Hanford Facilities During 1976 (mrem)

Pathways	Skin	Total Body	GI-LLI	Bone	Lung	Thyroid
Gaseous Effluents	0.01	0.02	0.01	0.12	0.01	0.07
Liquid Effluents	0.01	0.04	0.04	0.21	---	0.09
TOTAL - Adult	0.01	0.06	0.05	0.33	0.01	0.16

TABLE 39. Calculated First-Year Doses and 50-Year Dose Commitments to the Population from Effluents Released from Hanford Facilities During 1976 (man-rem)

	Total Body	GI-LLI	Bone	Lung	Thyroid
First-Year Dose	0.7	1.0	4.3	0.5	1.3
50-Year Dose Commitment	0.8	1.0	5.9	0.6	1.3

1977

Houston, J. R., and P. J. Blumer. 1978. Environmental Surveillance at Hanford for CY-1977. PNL-2614, Pacific Northwest Laboratory, Richland, Washington.

In general, offsite levels of radionuclides attributed to Hanford operations during 1977 were indistinguishable from background levels. However, external dosimeter measurements along the Columbia River islands and the shoreline near the Hanford Site showed elevated doses attributed to the continued presence of a few long-lived radionuclides, notably cobalt-60, from the past operation of once-through-cooled reactors.

Concentrations of a few of the radionuclides released to the Columbia River from N Reactor during 1976 were observed at the downstream sampling location at concentrations of less than 1% of the applicable guidelines given in ERDA Manual Chapter 0524 (ERDA 1973).

Environmental transport and dose models and computer codes were used to calculate radiation doses to members of the public from Hanford operations during 1977. Differences in the calculated doses have occurred from year to year because of the varying quantities and types of effluents and the flow rate of the Columbia River. During 1977, for instance, the river flow was considerably below normal; hence, calculated doses for exposure via river pathways were higher than in recent years.

Dose calculations for the maximum individual for 1977 included estimates of the dose received from 1) exposure to airborne contaminants at a location 1 mile east of the 300 Area, 2) drinking water at Richland, 3) irrigated foodstuffs at Riverview, and 4) aquatic recreation along the Hanford reach of the Columbia River. The results of these calculations for the first-year dose and the 50-year dose commitment are shown in Tables 40 and 41, respectively. The doses shown in these tables are not additive, because the location of the maximum dose received from any one pathway were separated by many miles from the location of the dose from any other pathway. However, they are added together for purposes of this report.

In 1983, calculations of the new cumulative dose were made for the six-year period of 1977 through 1982 for comparison with the dose commitments previously calculated for the same years (McCormack et al. 1983). The new cumulative dose included the additional contributions from residual (after the first year) environmental contamination to both external exposure and internal dose from future ingestion of foods raised on contaminated soil. The results for 1977 are summarized in Table 42.

The first-year doses and 50-year dose commitments for the population for 1977 are summarized in Table 43. Also included in Table 43 are the 50-year cumulative population doses from McCormack et al. (1983).

TABLE 40. Calculated Annual Doses to the Maximum Individual from Effluents Released from Hanford Facilities During 1977[a] (mrem)

Environmental Pathway	Skin	Total Body	GI-LLI	Bone	Lung	Thyroid
Airborne[b]	0.03	0.03	0.03	0.02	0.03	0.06
Drinking Water	---	<0.01	<0.01	<0.01	---	0.06
Irrigated Foodstuff	<0.01	<0.01	0.02	0.02	---	0.20
Aquatic Recreation[c]	<0.01	<0.01	0.06	0.01	---	0.06
TOTAL	0.03	0.03	0.1	0.05	0.03	0.4

(a) The doses shown are not strictly additive. The dose received depends on the location and assumed living habits of the hypothetical maximum individual. The pathways shown were separated by many miles.
(b) Including dose contributions from inhalation, submersion, ingestion of foodstuffs contaminated by airborne deposition, and exposure to ground contamination.
(c) Including consumption of fish from the Columbia River.

TABLE 41. Calculated 50-Year Dose Commitments to the Maximum Individual from Effluents Released from Hanford Facilities During 1977 (mrem)

Pathway	Skin	Total Body	GI-LLI	Bone	Lung	Thyroid
Gaseous Effluents	0.03	0.03	0.03	0.07	0.03	0.06
Liquid Effluents	<0.01	0.20	0.08	0.78	---	0.32
TOTAL	0.03	0.2	0.1	0.9	0.03	0.4

TABLE 42. Calculated 50-Year Cumulative Doses to the Maximum Individual from Effluents Released from Hanford Facilities During 1977[a] (mrem)

Pathway	Total Body	GI-LLI	Bone	Lung	Thyroid
Gaseous Effluents	0.01	0.01	0.02	0.02	0.01
Liquid Effluents	0.74	0.15	3.1	0.01	0.43
TOTAL	0.8	0.2	3	0.03	0.4

(a) From PNL-4713 (McCormack et al. 1983).

TABLE 43. Calculated Doses to the Population from Effluents Released from Hanford Facilities During 1977 (man-rem)

	Total Body	GI-LLI	Bone	Lung	Thyroid
First-Year Dose	2	2	2	2	6
50-Year Dose Commitment	3	2	6	2	6
50-Year Cumulative Dose[a]	7	4	20	6	13

(a) From PNL-4713 (McCormack et al. 1983).

Comments

The CY 1977 report mentioned that environmental doses estimated by the empirical models were sensitive to the input data and assumptions. To improve the consistency and accuracy of Hanford-related environmental dose calculations, DOE-RL directed Pacific Northwest Laboratory (PNL), in late 1977, to implement the Hanford Dose Overview Program to coordinate and review all dose calculations for the Hanford Site. The Overview Program also established a standard set of models, data, and assumptions to be used for all Hanford dose calculations.

The environmental doses calculated for CY 1977 and subsequent years were reviewed and approved by the Dose Overview Program. Calculations used standard models and data as described in the appendix to each report.

References

McCormack, W. D., J. M. V. Carlile, R. A. Peloquin and B. A. Napier. 1983. A Comparison of Environmental Radiation Doses Estimated for Hanford Operations, 1977 through 1982. PNL-4713, Pacific Northwest Laboratory, Richland, Washington.

U.S. Energy Research and Development Administration (ERDA). 1973. Standards for Radiation Protection, with Appendix. Manual Chapter 0524. Washington, D.C.

1978

Houston, J. R., and P. J. Blumer. 1979. Environmental Surveillance at Hanford For CY-1978. PNL-2932, Pacific Northwest Laboratory, Richland, Washington.

Hanford operations during 1978 caused no distinguishable impact on the concentrations of airborne radionuclides or external radiation doses measured near to and far from the Hanford Site. Radionuclides observed in foodstuffs, wildlife and soil samples were all attributed to either worldwide fallout or natural sources. Once again, contributions from Hanford operations were distinguishable from other sources in only two areas: 1) residual levels of long-lived radionuclides, primarily cobalt-60, associated with sediments along the Columbia River islands and shoreline near the Hanford Site, and 2) the very low concentrations of radionuclides in Columbia River water as a result of current N-Reactor operations. Because of the continued low levels of radionuclides in Willapa Bay oysters, they were not sampled after 1977.

Environmental transport and dosimetry models and computer codes, in use since 1974, were used to calculate radiation doses for 1978 to the hypothetical maximum individual (MI) and to the population in the vicinity of Hanford. Dose calculations for the MI were based on the same assumptions of living habits and diet as used in 1976 and 1977 and are not strictly additive. The calculated first-year doses to the MI are listed in Table 44, and the 50-year dose commitments and the 50-year cumulative doses to the MI are summarized in Table 45. The first-year and 50-year doses to the population are listed in Table 46.

TABLE 44. Calculated Annual Doses to the Maximum Individual from Effluents Released from Hanford Facilities During 1978[a] (mrem)

Environmental Pathway	Skin	Whole Body	GI-LLI	Bone	Lung	Thyroid
Airborne[b]	0.1	0.08	0.01	0.01	0.01	0.15
Drinking Water	---	0.01	0.01	0.01	---	0.05
Irrigated Foodstuff	0.01	0.01	0.01	0.01	---	0.16
Aquatic Recreation[c]	0.01	0.01	0.01	0.01	---	0.05
TOTAL	0.1	0.09	0.01	0.02	0.01	0.4

(a) The doses shown are not strictly additive. The dose received depends on the location and assumed living habits of the hypothetical maximum individual. The location of the maximum individual was different for each pathway shown; in some cases these locations were separated by many miles.
(b) Including any dose contributions from inhalation, submersion, and ingestion of foodstuffs contaminated by airborne deposition, and exposure to ground contamination.
(c) Including consumption of fish from the Columbia River.

TABLE 45. Calculated 50-Year Doses to the Maximum Individual from Effluents Released from Hanford Facilities During 1978 (mrem)

	Skin	Whole Body	GI-LLI	Bone	Lung	Thyroid
50-year Dose Commitment	0.1	0.1	0.01	0.2	0.01	0.5
50-year Cumulative Dose[a]	---	0.5	0.1	2	0.02	1

(a) From McCormack et al. (1983).

TABLE 46. Calculated Doses to the Population from Effluents Released from Hanford Facilities During 1978 (man-rem)

	Whole Body	GI-LLI	Bone	Lung	Thyroid
First-Year Dose	2	2	2	2	5
50-Year Dose Commitment	2	2	2	2	5
50-Year Cumulative Dose[a]	7	3	20	5	12

(a) From McCormack et al. (1983).

Reference

McCormack, W. D., J. M. V. Carlile, R. A. Peloquin and B. A. Napier. 1983. A Comparison of Environmental Radiation Doses Estimated for Hanford Operations, 1977 through 1982. PNL-4713, Pacific Northwest Laboratory, Richland, Washington.

1979

Houston, J. R., and P. J. Blumer. 1980. Environmental Surveillance at Hanford for CY-1979. PNL-3283, Pacific Northwest Laboratory, Richland, Washington.

Hanford operations during 1979 caused no distinguishable impact on concentrations of airborne radionuclides or on external radiation doses measured near to and far from the Hanford Site. The only distinguishable impact to wildlife from Hanford operations was to ducks at onsite waste-water ponds. Radionuclides observed in foodstuffs and soil samples were attributed to either worldwide fallout or natural sources.

Environmental dosimeter measurements on the islands and shoreline along the Hanford reach of the Columbia River showed elevated doses attributed to the presence of a few long-lived radionuclides, principally cobalt-60, cesium-137, and europium-154. These radionuclides were present because of the past operation of the once-through-cooled reactors. An extensive radiation survey of the shoreline and islands conducted during 1979 revealed areas where dose rates were higher than previously predicted. The incremental increase in radiation exposure to recreational users of the river was still considered to be insignificant.

The doses to the hypothetical maximum individual (MI) and to the population in the vicinity of Hanford for 1979 were calculated using the same PNL dose codes and standard assumptions as employed in previous years. The results are tabulated in Tables 47 and 48. The MI pathway doses given in the report were not strictly additive but are summed here as an estimate of the upper bound to the potential doses from effluents released in 1979.

TABLE 47. Calculated Doses to the Maximum Individual from Effluents Released from Hanford Facilities During 1979 (mrem)

	Skin	Whole Body	GI-LLI	Bone	Lung	Thyroid
First-Year Dose	0.2	0.02	0.02	0.04	0.1	0.4
50-Year Dose Commitment	0.2	0.1	0.02	0.9	0.6	0.4
50-Year Cumulative Dose[a]	---	0.6	0.1	3.0	0.5	0.4

(a) From McCormack et al. (1983).

TABLE 48. Calculated Doses to the Population from Effluents Released from Hanford Facilities During 1979 (man-rem)

	Whole Body	GI-LLI	Bone	Lung	Thyroid
First-Year Dose	1	1	1	2	5
50-Year Dose Commitment	2	1	3	2	5
50-Year Cumulative Dose[a]	4	3	10	5	12

(a) From McCormack et al. (1983).

Comments

The report indicated that individual pathway doses were not additive because not all pathways were available at a single location. That situation resulted from the standard practice of ensuring the conservatism of these calculations by maximizing individual pathways rather than the maximum individual (MI) location. However, DOE Order 5480.1, required that the assessment of MI dose be as realistic as possible without overlooking potential sources of exposure (USDOE 1980).

As a result of the DOE Order, the annual reports for 1980 and subsequent years would postulate an MI that resides in a single location where the sum of exposures from all pathways credibly available at that location would provide an estimate of the maximum offsite exposure resulting from Hanford operations.

References

McCormack, W. D., J. M. V. Carlile, R. A. Peloquin and B. A. Napier. 1983. A Comparison of Environmental Radiation Doses Estimated for Hanford Operations, 1977 through 1982. PNL-4713, Pacific Northwest Laboratory, Richland, Washington.

U.S. Department of Energy (USDOE). 1980. Environmental Protection, Safety, and Health Protection Program for DOE Operations. DOE 5480.1, Washington, D.C.

1980

Sula, M. J., and P. J. Blumer. 1981. Environmental Surveillance at Hanford for CY-1980. PNL-3728, Pacific Northwest Laboratories, Richland, Washington.

No distinguishable differences were detected between the airborne radionuclide concentrations in samples collected near the Hanford Site and those collected at more remote locations.

An apparent increase in iodine-129 concentrations in Columbia River water downstream of the Hanford Site was observed. However, the observed concentrations were negligible in comparison to radionuclide concentration guides.

Low levels of radionuclides attributed to past operations at Hanford were observed in several samples of whitefish that were collected from the Columbia River and in duck samples collected from onsite waste-water ponds. In addition, the thyroids of Hanford deer contained small amounts of iodine-129 attributed to onsite operations. Calculated doses resulting from assumed consumption of edible portions of the animals were very small and far below dose standards.

Environmental dosimeter measurements on the islands and shoreline along the Hanford reach of the Columbia River showed elevated doses attributed to the presence of a few long-lived radionuclides, principally cobalt-60 and europium-154, which were present because of past operations of the Hanford production reactors. The incremental increase in radiation dose to recreational users of the river from these radionuclides was very low and well below the applicable dose standards.

Quantities of radionuclides in liquid and gaseous effluents discharged from Hanford facilities during 1981 were so small that when dispersed in the environment they could not be discerned from radionuclides already present as a result of natural processes, worldwide fallout, and previous (primarily pre-1971) Hanford operations. Therefore, except for "fence-post" dose rate measurements, the assessment of the radiological impact of Hanford operations during 1980 did not use results from the direct analysis of environmental samples.

To assess the radiological impact from 1980 operations, radiation doses were calculated using environmental transport and dose models and associated computer codes. The released quantities of radionuclides used as source terms for the dose calculations included all radionuclides reported to have been discharged to the environment during 1980 from Hanford facilities.

The following exposure pathways were considered in evaluating the maximum individual (MI) dose: inhalation and submersion in the airborne release plumes, consumption of foodstuffs contaminated by deposition of airborne material, use of drinking water obtained from the Columbia River, ingestion of foodstuffs irrigated with Columbia River water, consumption of fish taken from the Columbia River, and direct exposure to radionuclides in the river water during recreational activities on the river. Thyroid doses were calculated for both an adult and an infant (1 year old). Other organ doses were calculated for adults only. The definition of the MI was changed in 1980, which permitted the summation of pathway doses for annual and 50-year committed doses.

The hypothetical maximum-exposed individual during 1980 was a person who

- resided in the southeastern part of the Riverview district in Pasco, approximately 13 km (8 miles) south-southeast of the 300 Area
- consumed foodstuffs grown in the northwestern part of the Riverview district using Columbia River water for irrigation
- consumed Pasco city drinking water obtained from the Columbia River
- used the Columbia River extensively for recreational activities including boating, swimming, and fishing (including consumption of fish).

The calculated radiation doses to the MI and the population in the vicinity of Hanford are summarized in Tables 49 and 50, respectively.

TABLE 49. Calculated Doses to the Maximum Individual from Effluents Released from Hanford Facilities During 1980 (mrem)

	Whole Body	GI-LLI	Bone	Lung	Thyroid	
					Adult	Infant
First-Year Dose	0.01	0.02	0.04	0.01	0.2	0.7
50-Year Dose Commitment	0.1	0.02	0.4	0.01	0.2	0.7
50-Year Cumulative Dose[a]	0.6	0.1	0.2	0.01	0.2	---

(a) From McCormack et al. (1983).

TABLE 50. Calculated Doses to the Population from Effluents Released from Hanford Facilities During 1980 (man-rem)

	Whole Body	GI-LLI	Bone	Lung	Thyroid
50-Year Dose Commitment	0.6	0.5	1	0.4	2
50-Year Cumulative Dose[a]	2	1	5	1	4

(a) From McCormack et al. (1983).

Reference

McCormack, W. D., J. M. V. Carlile, R. A. Peloquin and B. A. Napier. 1983. A Comparison of Environmental Radiation Doses Estimated for Hanford Operations, 1977 through 1982. PNL-4713, Pacific Northwest Laboratory, Richland, Washington.

1981

Sula, M. J., W. D. McCormack, R. L. Dirkes, K. R. Price and P. A. Eddy. 1982. Environmental Surveillance at Hanford for CY-1981. PNL-4211, Pacific Northwest Laboratory, Richland, Washington.

Low concentrations of radionuclides attributed to operations at Hanford were observed in several samples of wildlife collected onsite near operating areas. However, it was calculated that if an individual were to consume all edible portions of the specific game animal at the maximum observed concentration, the resulting radiation dose would be well below the applicable dose standard.

Low concentrations of fallout radionuclides from worldwide atmospheric nuclear testing were observed in samples of foodstuffs, soil and vegetation. There was no indication of any contribution from Hanford sources to radionuclide levels in these media.

A difference was observed between iodine-129 concentrations in Columbia River water samples collected downstream of the Hanford Site and samples collected upstream of the Site. The net increase at the downstream location was 4×10^{-5} pCi/L. A slight difference in strontium-90 concentrations was also observed in 1981 as a result of relocating the upstream sample point. Strontium-90 concentrations observed downstream of the site were similar to past years while concentrations observed in the upstream samples were lower. In addition, during 1981, cobalt-60 and iodine-131 were observed occasionally in river water samples, but at concentrations too low to determine quantitative differences between upstream and downstream samples. In all of the above cases, the downstream concentrations were small in comparison to those listed in DOE radionuclide Concentration Guides (USDOE 1981).

The radiological impacts from operations at the Hanford Site were measured directly or were calculated based on measured environmental radionuclide concentrations or contractor supplied environmental release source terms. Doses were calculated using environmental dose pathway models and source terms based on measurements of radioactive materials that were released to the environment at Hanford in 1981. Standard dietary parameters and exposure data provided by the Hanford Dose Overview Program were used to calculate potential doses via these pathways (McCormack 1982).

Thyroid doses were calculated for both an adult and a 1-year-old infant. Other organ doses were calculated for adults only. With the exception of strontium-90 in the Columbia River, doses were calculated using the source terms reported by the Hanford contractors. Doses for strontium-90 were calculated from a net contribution of 0.09 pCi/L to Columbia River water during 1981. Water-treatment plant cleanup factors were used to calculate the radionuclide concentrations of drinking water. These factors were inadvertently omitted from the CY 1980 calculations.

The doses calculated for the maximum individual are summarized in Table 51. The population doses are summarized in Table 52. The values for the 50-year cumulative dose in both tables are taken from PNL-4713 (McCormack et al. 1983).

TABLE 51. Calculated Doses to the Maximum Individual from Effluents Released from Hanford Facilities During 1981 (mrem)

	Whole Body	GI-LLI	Bone	Lung	Thyroid	
					Adult	Infant
First-Year Dose	0.03	0.05	0.1	0.01	0.1	0.6
50-Year Dose Commitment	0.4	0.05	1	0.02	0.1	0.6
50-Year Cumulative Dose[a]	0.5	0.06	2	0.01	0.2	---

(a) From McCormack et al. (1983).

TABLE 52. Calculated Doses to the Population from Effluents Released from Hanford Facilities During 1981 (man-rem)

	Whole Body	GI-LLI	Bone	Lung	Thyroid
50-Year Dose Commitment	4	3	6	3	4
50-Year Cumulative Dose[a]	3	3	5	3	5

(a) From McCormack et al. (1983).

References

McCormack, W. D. 1982. Hanford Dose Overview Program: Standardized Methods and Data for Hanford Environmental Dose Calculations. PNL-3777, Pacific Northwest Laboratory, Richland, Washington.

McCormack, W. D., J. M. V. Carlile, R. A. Peloquin and B. A. Napier. 1983. A Comparison of Environmental Radiation Doses Estimated for Hanford Operations, 1977 through 1982. PNL-4713, Pacific Northwest Laboratory, Richland, Washington.

U.S. Department of Energy (USDOE). 1981. Environmental Protection, Safety, and Health Protection Program for DOE Operations. DOE 5480.1A, Washington, D.C.

1982

Sula, M. J., J. M. V. Carlile, K. R. Price and W. D. McCormack. 1983. Environmental Surveillance at Hanford for CY-1982. PNL-4657, Pacific Northwest Laboratory, Richland, Washington.

In 1982 there were no distinguishable differences between radionuclide concentrations in air samples collected near the site perimeter and those collected some distance from the Site. Radionuclide concentrations in airborne particulates at all sampling locations were lower than those from 1981 as a result of declining fallout levels associated with a foreign atmospheric nuclear test conducted during late 1980.

A difference was observed between iodine-129 concentrations in Columbia River water collected downstream of the Hanford Site and those collected upstream of the Site. The difference, attributed to seepage from the unconfined Hanford aquifer, was similar to differences observed since sampling for iodine-129 in the river began in 1977. The iodine-129 concentrations downstream of the Hanford Site were only one-millionth of the applicable DOE Concentration Guides (USDOE 1981).

Tritium and strontium-90 were observed in all upstream and downstream river water samples, but no difference attributable to Hanford sources could be quantified.

Low levels of radionuclides, attributed to weapons test fallout, were observed in most foodstuff samples. There was no indication of the presence of radioactivity associated with Hanford in any of the samples.

Low concentrations of radionuclides attributed to operations at Hanford were observed in several samples of ducks, game birds and deer that were collected near operating areas. Concentrations were low enough that any radiation dose resulting from consumption of an animal containing even the highest observed concentration would have been well below the applicable DOE radiation protection standard.

Once dispersed in the offsite environment, the quantities of radionuclide released from Hanford operations in 1982 were too small to be measured. As a result, the potential offsite doses were once again calculated using environmental computer models and computer codes that predicted the concentrations of radioactive materials in the environment and subsequent radiation doses from the reported quantities of radionuclides released to the environment. The doses estimated by these models were quite small and well below the sensitivity of direct measurement. Although the uncertainty associated with these calculations was not specified, it was relatively large. As a result, these doses were viewed as conservative best estimates of the potential doses from Hanford operations in 1982.

Because the effluents included small quantities of long-lived radionuclides that could have persisted in the environment, the maximum individual (MI) was appropriately assumed to be a long-term resident. Thyroid doses were calculated for a 1-year-old infant in addition to an adult because the potential thyroid dose to an infant from radioiodine releases is generally slightly higher than for an adult. Other organ doses were calculated only for adults.

The report for 1982 was the first to present calculated cumulative doses. Because cumulative doses were, in some instances, higher than the previously calculated 50-year commitments, cumulative doses from operations during the previous 5 years were calculated (McCormack et al. 1983) to provide a comparison with the previously calculated 50-year dose commitments. In the process of recalculating the potential doses, several corrections were made to the previously used input data. These corrections included using the more recent 1980 census results for population distributions, and a more current breakdown of radionuclides contributing to gross beta measurements. These corrections were detailed in PNL-4713 (McCormack et al. 1983).

Because the 1982 report was the first to present cumulative doses, calculated 50-year dose commitments for the MI and population were also provided in an appendix. These calculated 50-year doses for the MI and for the population in the vicinity of Hanford are summarized in Tables 53 and 54, respectively.

TABLE 53. Calculated 50-Year Doses to the Maximum Individual from Effluents Released from Hanford Facilities During 1982 (mrem)

	Whole Body	GI-LLI	Bone	Lung	Thyroid Adult	Thyroid Infant
50-Year Dose Commitment	0.1	0.02	0.4	0.02	0.2	0.5
50-Year Cumulative Dose	0.7	0.07	2	0.02	0.2	0.5

TABLE 54. Calculated 50-Year Doses to the Population from Effluents Released from Hanford Facilities During 1982 (man-rem)

	Whole Body	GI-LLI	Bone	Lung	Thyroid
50-Year Dose Commitment	3	3	4	4	7
50-Year Cumulative Dose	4	3	7	4	7

References

McCormack, W. D., J. M. V. Carlile, R. A. Peloquin and B. A. Napier. 1983. A Comparison of Environmental Radiation Doses Estimated for Hanford Operations, 1977 through 1982. PNL-4713, Pacific Northwest Laboratory, Richland, Washington.

U.S. Department of Energy (USDOE). 1981. Environmental Protection, Safety, and Health Protection Program for DOE Operations. DOE 5480.IA, USDOE, Washington, D.C.

1983

Price, K. R., J. M. V. Carlile, R. L. Dirkes and M. S. Trevathan. 1984. Environmental Surveillance at the Hanford Site for CY-1983. PNL-5038, Pacific Northwest Laboratory, Richland, Washington.

There were no distinguishable differences in radionuclide concentrations between air samples collected near the Site perimeter and controls collected some distance from the Site. Gross beta radioactivity concentrations in airborne particulates at all sampling locations were lower than during 1982 as a result of declining levels of worldwide fallout.

Water samples collected from the Columbia River downstream of the Hanford Site contained slightly higher concentrations of tritium, strontium-90, iodine-129, and uranium than those collected upstream. Downstream concentrations were considerably below applicable DOE Concentration Guides. The major source of radionuclides added to the river was assumed to be ground water flowing from beneath the Site into the river through natural springs along the shoreline. Cesium-137 and plutonium were observed in upstream and downstream samples at approximately the same concentrations. Other radionuclides found included cobalt-60, strontium-89 and iodine-131.

Low levels of radionuclides, attributed to worldwide fallout and naturally occurring materials, were observed in most samples of soil, vegetation and foodstuffs. There was no indication in any of the samples that radionuclides specifically contributed by Hanford operations were present.

Low concentrations of radionuclides attributed to operations at Hanford were observed in several samples of fish and ducks collected from the Columbia River and game birds and deer collected near operating areas. Concentrations were low enough that any resulting radiation dose from consuming the edible portion of an animal containing even the highest observed concentration would have been well below the applicable radiation protection standards.

Because the quantities of radionuclide releases associated with 1983 Hanford operations were too small to be measured in the environment, the potential offsite doses were calculated using environmental models and computer codes. The results of these calculations are summarized in Tables 55 and 56.

TABLE 55. Calculated 50-Year Cumulative Doses to the Maximum Individual from Effluents Released from Hanford Facilities During 1983 (mrem)

	Whole Body	GI-LLI	Bone	Lung	Thyroid	
					Adult	Infant
50-Year Cumulative Dose	1	0.2	4	0.1	0.2[a]	0.3

(a) Originally reported as 0.09; later corrected to 0.2 (Price et al. 1985).

TABLE 56. Calculated 50-Year Cumulative Dose to the Population from Effluents Released from Hanford Facilities During 1983 (man-rem)

	Whole Body	GI-LLI	Bone	Lung	Thyroid
50-Year Cumulative Dose	4	3	7	3	17[a]

(a) Originally reported as 7; later corrected to 17 (Price et al. 1985).

The radiation doses listed in the tables are quite small and well below the sensitivity of direct measurements. All potential MI doses resulting from effluents discharged to the environment during operations at Hanford in 1983 were well below the applicable Radiation Protection Standards in DOE Order 5480.1 (USDOE 1981). Although the uncertainty associated with these calculations was not specified, it was relatively large. As a result, the doses calculated using these models were conservative estimates (i.e., overestimates) of the potential doses resulting from 1983 Hanford operations. This was also true of the doses calculated for the MI in the years 1974 through 1982. Although the report for 1983 was the first to specify direct exposure to radionuclides deposited on the ground as a separate dose pathway, it was, in fact, routinely included in all assessments performed after 1973.

References

Price, K. R., J. M. V. Carlile, R. L. Dirkes, R. E. Jaquish, M. S. Trevathan and R. K. Woodruff. 1985. Environmental Monitoring at the Hanford Site for CY-1984. PNL-5407, Pacific Northwest Laboratory, Richland, Washington.

U.S. Department of Energy (USDOE). 1981. Environmental Protection, Safety, and Health Protection Program for DOE Operations. DOE 5480.1A, Washington, D.C.

1984

Price, K. R., J. M. V. Carlile, R. L. Dirkes, R. E. Jaquish, M. S. Trevathan and R. K. Woodruff. 1985. Environmental Monitoring at the Hanford Site for CY-1984. PNL-5407, Pacific Northwest Laboratory, Richland, Washington.

Once dispersed into the offsite environment, the quantities of radionuclides released from Hanford operations in 1984 were in most cases too small to be measured. A few radionuclides could be detected in the Columbia River and in the air at locations on the perimeter of the Site.

Gross beta radionuclide concentrations in airborne particulate material at all sampling locations were lower in 1984 than during 1983 because of a continued decline in worldwide fallout. The PUREX plant completed the first year of operation following restart, and slightly elevated levels of krypton-85 and iodine-129 were noted at several onsite and offsite locations. Increased concentrations of tritium were also detected at the air sampling locations near the PUREX plant. All concentrations both onsite and offsite were well below applicable concentration guides. Very low levels of the radionuclides tritium, strontium-90, iodine-129, cesium-137, uranium and plutonium were detected in samples of Columbia River water during 1984. Except for cesium-137 and plutonium, concentrations of these radionuclides were slightly higher at the downstream sampling site than at the upstream site. However, downstream concentrations were considerably below applicable concentration guides (USDOE 1981). The major source of radionuclides added to the river was assumed to be ground water moving beneath the site into the Columbia River. All radionuclides detected in the Columbia River also occur naturally or are present in worldwide fallout.

Low levels of radionuclides observed in samples of soil and foodstuffs were attributed to worldwide fallout and naturally occurring materials. There was no indication in any of the analyses that radionuclides associated with Hanford were present.

Samples of deer, rabbits, game birds, waterfowl and fish were collected onsite or in the Columbia River at locations where the potential for radionuclide uptake by these animals was most likely. Radionuclide levels observed were low enough that any radiation dose resulting from the consumption of the edible portion of an animal containing even the highest observed concentration was well below the applicable radiation protection standard.

The potential offsite doses were estimated by using environmental models and codes to predict the concentrations of radioactive materials in the environment from 1984 effluent releases. Standard dietary parameters and exposure data were provided by the Hanford Dose Overview Program (McCormack, Ramsdell and Napier 1984). The doses estimated by these models were quite small and well below the sensitivity of direct measurement. A comparison of the measured and calculated concentrations of radionuclides at several locations was provided in the report.

Calculated 50-year cumulative doses are summarized in Table 57 for the maximum individual (MI) and in Table 58 for the population. The tabulated doses included contributions from exposure to liquid and airborne effluents released during 1984 as well as the potential exposure that could occur beyond 1984 from that portion of the 1984 effluents estimated to still be present in the environment. All potential doses calculated for the MI for 1984 were well below the applicable Radiation Protection Standards in DOE Order 5480.1A.

TABLE 57. Calculated 50-Year Cumulative Doses to the Maximum Individual from Effluents Released from Hanford Facilities During 1984 (mrem)

	Whole Body	GI-LLI	Bone	Lung	Thyroid	
					Adult	Infant
50-Year Cumulative Dose	2	0.3	8	0.02	0.8	3

TABLE 58. Calculated 50-Year Cumulative Doses to the Population from Effluents Released from Hanford Facilities During 1984 (man-rem)

	Whole Body	GI-LLI	Bone	Lung	Thyroid
50-Year Cumulative Dose	5	3	13	4	43

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Analyses of Hanford Data: Delayed Effects of Small Doses of Radiation Delivered at Slow-Dose Rates

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This presentation describes the work of Mancuso and his associates, who spent more than 10 years assembling Hanford data from work records, social security transactions, and death certificates before reporting the findings that are now in dispute.

THE MANCUSO-STEWART-KNEALE ANALYSES

The general reaction to our 1977 paper in *Health Physics* (Mancuso et al. 1977) (see MSK I, Table 1) began by being, and has remained, one of total disbelief. Yet much of what this report contains might have been deduced from known effects of pregnancy X-rays (Kneale and Stewart 1976a, b) and much since has been confirmed by research workers who were asked, either by the Department of Energy or the General Accounting Office, to check our findings (Hutchinson et al. 1979; General Accounting Office 1981). Furthermore, if the International Commission on Radiological Protection (ICRP) had realized that the trend of noncancer mortality for A-bomb survivors has always been steeper than normal, they would have hesitated before assuming that risk estimates for this population were applicable directly to workers in radiation medicine or the nuclear industry (Fig. 1).

MSK I (Mancuso, Stewart, and Kneale) was concerned with men and women who worked at Hanford after 1943 and died before 1973, and the first finding was that, at two very low-dose levels (one for males and the other for females), the mean cumulative dose was significantly higher for workers whose deaths were ascribed to cancers than for other nonsurvivors. Shortly before

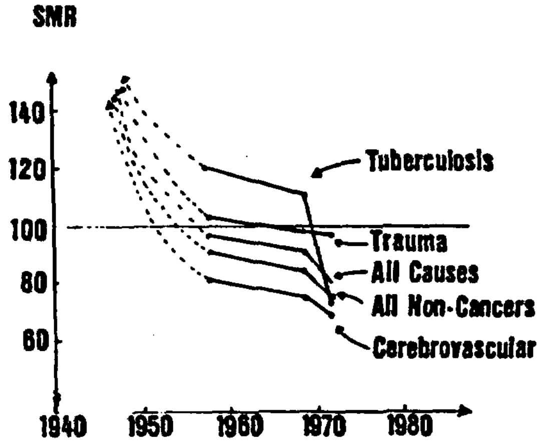

Figure 1
Mortality trends of A-bomb survivors.

this, Milham (1976) had found a high proportion of cancer deaths among the workers whose deaths were reported to the Washington State Health Department and Gilbert (1976) had found that the cancer death rate was dose related. Therefore, it only remained for us to include all certified deaths in a comparative mean dose (CMD) analysis and thus discover which types of cancer were most affected and obtain some provisional estimates of relative risk, cancer latency, and exposure age.

The first test of these estimates was made by ourselves (Kneale et al. 1978) (see MSK II in Table 1) after we had:

1. achieved a separation between workers with zero doses and workers who were not issued film badges;
2. identified a larger sample of deaths (1944-1977);
3. discovered that in relation to Hanford data a CMD analysis had at least four times the power of a conventional standardized mortality ratio (SMR) analysis;
4. found that an independent classification of tissue sensitivity to cancer induction by radiation existed (ICRP 1969) which made it possible to

Table 1
MSK Analyses of Hanford Data

MSK series	Published reports	Data base
I	Mancuso et al. (1977)	1944-1972 deaths
II	Kneale et al. (1978)	1944-1977 deaths
	Stewart et al. (1980)	
III	Kneale et al. (1981)	1944-1977 deaths and 1944-1978 survivors

Table 2
Specifications of A and B Cancers Included in MSK III

Group	Tissue	ICD numbers (8th rev.)	Cases[a] male	Cases[a] female
A cancers (sensitive tissues)	pharynx	145-149	10	–
	digestive	150-159	201	19
	respiratory	160-163	215	10
	female breast	174	–	19
	thyroid	193	1	–
	hemopoietic	200-209	76	10
		remainder		
B cancers (other tissues)	other sites	140-209	199	28
	other unspecified	195-199	41	3

[a]Excluding cases that were never issued film badges.

work with only two cancer groups, namely, cancers of sensitive and insensitive tissues (so-called A and B cancers, see Table 2);

5. obtained a nonskewed distribution of the film-badge doses by fitting them to a scale of natural logarithms (Fig. 2); and
6. devised a scale of bioassay levels for use in distinguishing between safe and dangerous occupations (Table 3).

The main findings of MSK II have been available since 1978. They include evidence of a radiation effect for cancers in a Mantel-Haenszel analysis of certified causes of death, higher mean cumulative doses for A than B cancers, evidence that the radiation effect for lung cancer was unlikely to be a by-product of smoking habits (Stewart et al. 1980), and signs of underreporting

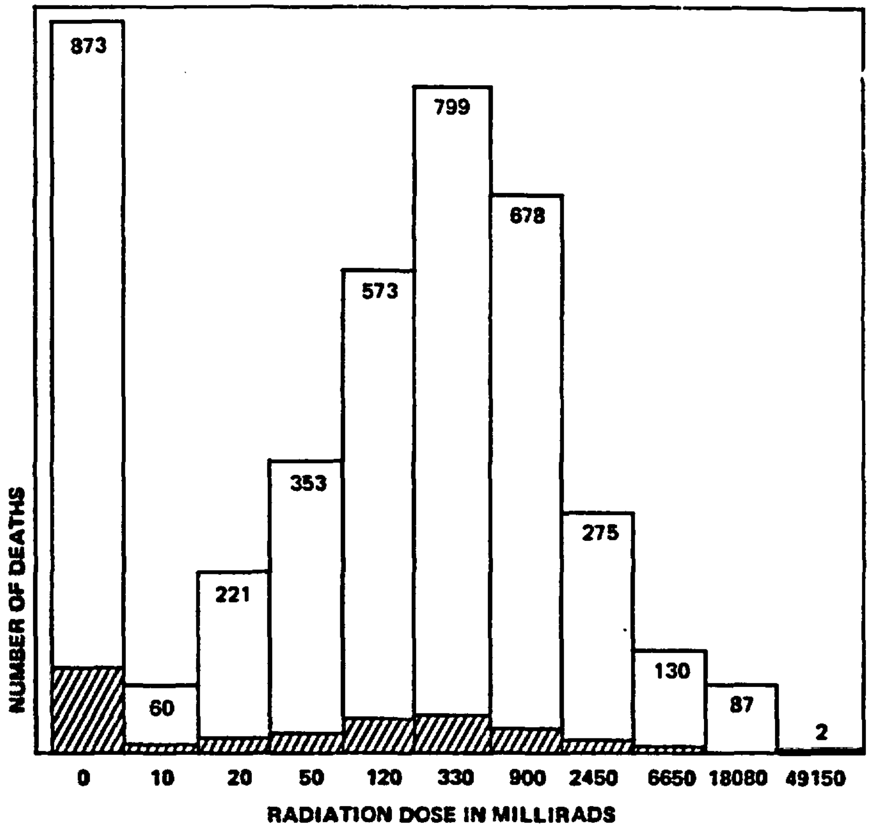

Figure 2
Log distribution of radiation doses. (■) Females.

Table 3
Specifications of Bioassay Levels

Level	Specifications
1	no testing of urine or blood
2	tested with wholly negative findings
3	tested with false positive findings
4	either false positive findings and a whole-body count or definite evidence of internal radiation[a]

[a]Only 225 male workers were ever suspected of having an internal deposition of plutonium.

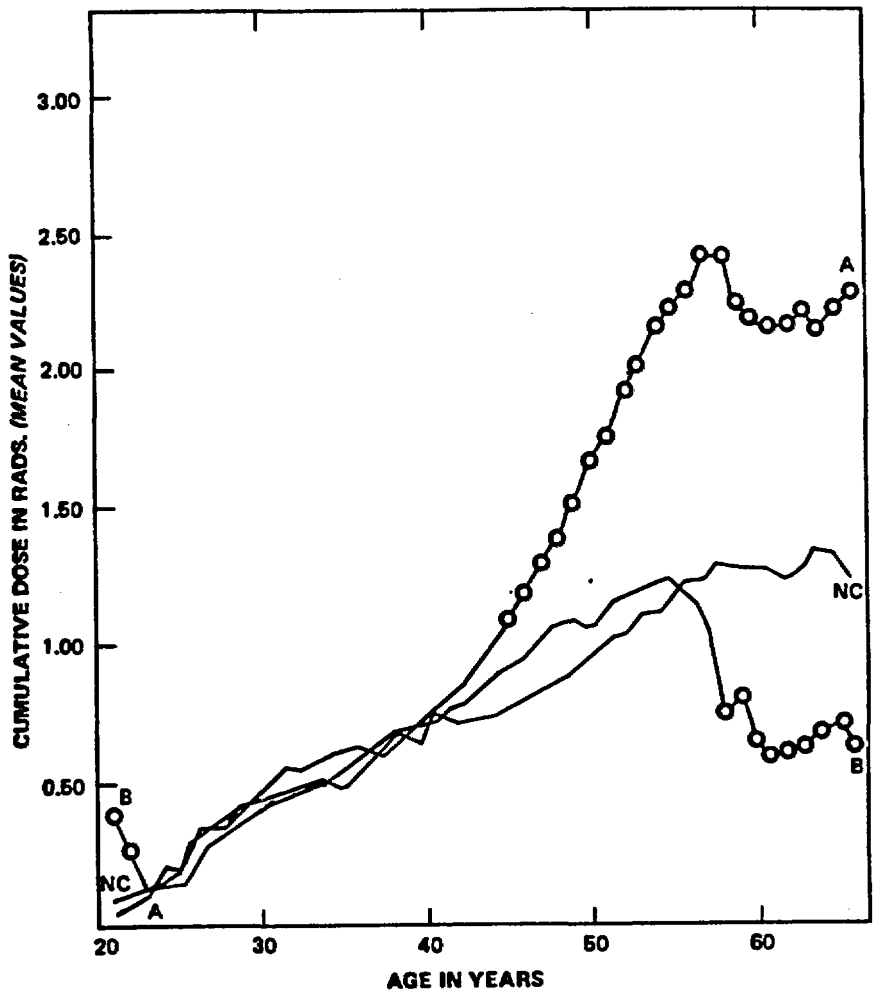

Figure 3
Age trend of cumulative radiation for the groups of male workers. (NC) Noncancers; (A) sensitive cancers; (B) other cancers; (o) any cancer dose that differs by a significant amount from the corresponding dose for noncancers.

of cancers after 56 years of age with more involvement of B than A cancers in the underreporting (Fig. 3).

Nevertheless, there remained two unsolved problems: (1) Even after standardization for sex, dates of birth, and hire, and employment period, the mean cumulative dose was higher for live than dead workers and (2) also higher for noncancer deaths than B cancers (Table 4). The difference between live and

Table 4
Radiation Doses of Live and Dead Workers

Group	All workers	Never monitored	Mean radiation dose in rads
Alive in 1977	29,251	5,486	2.03
1944-1977 deaths			
A cancers	754	193	1.77
B cancers	371	100	0.87
Noncancers	4,472	1,107	1.18
All deaths	5,597	1,400	1.24

dead workers was well known to us, as were the following facts: The first difference (between live and dead workers) was much reduced by having as one of the controlling variables a three-point scale of bioassay levels (Mancuso et al. 1977), and for Hanford workers the risk of dying from natural causes was 25% below the national average (Marks and Gilbert 1978). These findings were suggestive of selective recruitment of workers who combined exceptional health with being born less than 25 years before Hanford began to manufacture plutonium (1944) and obtaining jobs either as production managers or operatives.

A test of this hypothesis required for each occupation a healthy-worker scale (i.e., a scale that measured relative levels of general mortality) as well as a classification of occupations that separated production workers from supporting staff and separated highly paid workers from lowly paid workers. This required a long period of preparation for the following reasons. Although there had been coding of Hanford jobs (according to the 1970 Census classification), there had been little or no supervision of this work, which was error prone, because there was no flagging of production workers in the original records and no clear distinction between these workers and supporting staff in the Census classification. Furthermore, workers often changed their jobs and this made it extremely difficult to be sure that even the most obvious mistakes had been fully corrected. However, after months of screening for punching and coding errors, there finally emerged an occupational classification that had separate positions for production workers and supporting staff at two salary levels (Table 5). A healthy-worker scale, based on all certified deaths, could then be used to show the effects on general mortality of working for 1 year in each of the occupational groups. Thus, we have discovered that, at Hanford, the healthy-worker effect is positively correlated with radiation dose.

Though MSK III is not yet in print (Kneale et al. 1981), the analysis predated the search for errors in the recording of occupations and, therefore, had as the only indication of the work being done by individuals, the four-point

Table 5
Job Specifications of Hanford Workers Related to Dose and Fitness Levels

Job specifications	Mean dose in centirads	Fitness levels index	Fitness levels rank
Producers			
Scientists	14.2	-2.41	1
Technicians	35.1	-1.50	2
Operatives	46.1	-0.17	4
Supporting staff			
Managers	22.0	-0.46	3
Clerical	3.4	+0.56	5
Others	6.2	+0.95	6

Table 6
MSK III Summary Statistics

Controlling factors: usual	Controlling factors: extra	t values: All deaths	t values: A cancers
Sex and date of birth Date of hire Employment period	nil	-3.59[a]	0.33
	bioassay levels	-0.48	2.47[a]
	job fitness levels	-0.61	1.69
	job fitness levels exposure age latency		2.63[a]

[a]Significant at the 5% level.

scale of bioassay levels in Table 3. Originally, we had intended this measure to be a temporary expedient, but we are now reasonably certain that the bioassay data are reliable, as well as convenient, guides to the dangerousness of work at Hanford. We can say this because in the MSK III test of the null hypothesis (of no radiation effect for cancers of sensitive tissues) the temporary expedient proved to be a better indicator of the healthy worker effect than even the revised occupational classification (Table 6).

The statistical procedures used in MSK III, which are illustrated in Figure 4 and Table 7, were developed from first principles by George Kneale. But essentially the same method had already been developed by Cox for the express purpose of measuring the beneficial effects of drugs in a therapeutic trial (Cox 1972). When the procedures are applied to Hanford data without control for

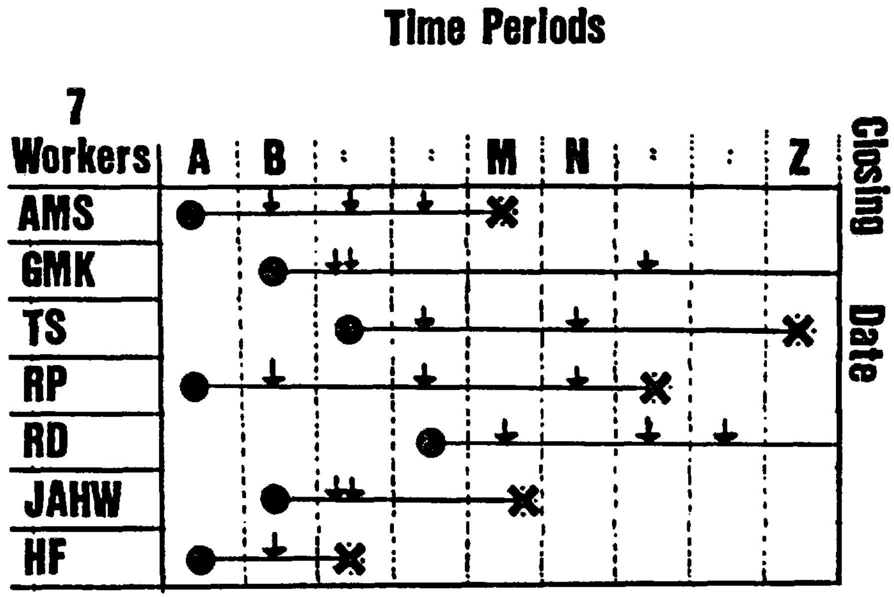

Figure 4
Follow-up of hypothetical study subgroup. (•) Hire; (‡) death; (↓) exposure.

Table 7
Statistics Relating to Hypothetical Study Subgroup Described in Figure 4

		Cumulative exposures by start of period			
Period	Quantity	0	1	2	3
A-L	–	–	–	–	–
M	At risk	1	1	3	1
	Deaths observed	0	0	1	1
	Deaths expected	0.33	0.33	1.0	0.33
N-Z	–	–	–	–	–
Total	Observed	0	1	2	2
	Expected	0.74	1.18	1.83	1.25

bioassay levels or job specifications, literal interpretation of the findings requires the radiation to have unbelievably strong life-saving effects. But with either of these factors as a controlling variable, the method produces definite evidence of a radiation effect for A cancers (Table 6). Therefore we were free to apply

Table 8
Results of Model Testing after Confirming a Radiation Effect

Radiation effects	Maximum likelihood estimate
Dose response (E)	nonlinear, with $E = 0.5$ ($E = 1.0$ rejected at the 1% level)
Doubling dose (D)	$D = 15$ rads with 95%; confidence interval of 2-150 rads
Latency (L)	where L = interval between cancer induction and death $L = 25$ years (type of cancer not specified)
Exposure age (S)	where S = the age increase needed to increase sensitivity to cancer induction by e (the base of natural logarithms); $S = 8$ years ($S = \infty$ rejected at 1% level)

maximum likelihood theory to our data with the results shown in Table 8. According to these results, there is (1) nonlinearity of dose response, with the curve obeying the square root law, (2) a cancer latency effect with an optimal interval of 25 years, and (3) an exposure age effect which implies that a 40-year-old worker is twice as vulnerable (to the cancer induction effects of radiation) as a 32-year-old worker.

An opportunity to test our MSK III estimates has been provided by a follow-up of 1110 women who worked in the radium luminizing industry in World War II and were still alive in 1961 (Baverstock et al. 1981). During the next 16 years, there was a significant excess of deaths from breast cancer (16 observed and 10.2 expected) that was largely the result of women who were under 30 years of age when first exposed, who had an average absorbed dose of 51 rads of gamma radiation, and who died between 1971 and 1977 (high-risk group with 10 observed and 3.05 expected deaths). Therefore, it is possible to calculate the MSK III risk for a typical woman in the high-risk group, i.e., a woman who (1) worked from 1940-1945 and was 26 years of age in 1940, (2) had a mean absorbed dose of 50 rads in equal amounts each year, and (3) died from a breast cancer in 1972 (Table 9). For this hypothetical worker, the actual dose (50 rads) was much higher than the cancer-effective dose (14.6 rads), but even so the extra risk was equal to 98% of the normal risk. Because this estimate of relative risk is much lower than the ratio of observed to expected deaths (3.28), there is no question of the MSK III estimate exaggerating the cancer effect of the gamma radiation, though we are left with the possibility that, in females, the rule of low sensitivity (to cancer induction) between 20 and 30 years of age does not apply to breast tissue.

Other examples of how cancer-effective doses can be derived from actual doses are shown in Tables 10-12. To these we have added two tables that show,

Table 9
Application of Hanford Estimates to Individuals: A Typical Radium Luminizer

Year	Age[a]	Dose in rads		Relative risk
		actual	transformed	
1940	26	8.5	1.7	
1941	27	8.5	2.0	
1942	28	8.5	2.2	
1943	29	8.5	2.5	
1944	30	8.5	2.9	
1945	31	8.5	3.3	
Total		51.0	14.6	1.98

After Baverstock et al. (1981).
[a]Age at death–58 years; cause of death–breast cancer.

Table 10
Application of Hanford Estimates to Individuals: A Process Worker at Hanford

Year	Age[a]	Dose in rads		Relative risk
		actual	transformed	
1960	41	0.9	0.8	
1961	42	2.3	2.3	
1962	43	2.5	2.7	
1963	44	1.5	2.0	
1964	45	2.0	2.3	
1965	46	5.1	6.1	
1966	47	4.4	5.3	
Total		18.7	21.5	2.20

[a]Age at death–53; cause of death–stomach cancer.

Table 11
Application of Hanford Estimates to Individuals: A Process Worker at Windscale

Year	Age[a]	Dose in rads		Relative risk
		actual	transformed	
1951-1955	31-35	32.4	15.4	
1956-1960	36-40	32.9	24.8	
1961-1965	41-45	22.8	29.8	
1966-1970	46-50	21.9	43.3	
1971-1975	51-55	29.5	63.2	
Total		139.6	176.5	4.0

[a]Age at death–56 years; cause of death–pancreatic cancer.

Table 12
Application of Hanford Estimates to Individuals: A Chargehand at Windscale

Year	Age[a]	Dose in rads		Relative risk
		actual	transformed	
1959-1963	38-42	14.3	14.0	
1964-1968	43-47	15.9	27.3	
1969-1973	48-52	22.4	51.9	
1974-1978	53-57	15.4	36.0	
1979	58	1.8	1.8	
Total		69.8	131.0	4.0

[a]Age at death–59 years; cause of death–lung cancer.

first, that cancer mortality in 329 Japanese cities was related to background radiation (Ujeno 1978) (Table 13) and, second, what proportion of A cancers would be caused by a background radiation dose of 0.1 rads per annum if the mortality experiences of Hanford workers have been correctly interpreted in MSK III (Table 14).

Finally, everyone who has had an opportunity to examine Hanford data, including Darby and Reissland (1981), has found evidence of higher doses for noncancer deaths than B cancers. Therefore it should be noted that, in MSK III, inclusion of place of death among the controlling variables and exclusion of two groups of sudden death (myocardial infarction and accidents) left the positive findings for A cancers unchanged and removed the negative findings for B cancers (Kneale et al. 1981). Since writing this paper, we have examined the records relating to primary and secondary causes of death of Hanford workers and thus discovered how the cancers that do not feature in any analysis

Table 13
Cancer Mortality and Background Radiation in 329 Japanese cities

Sex	Background radiation	Cancer mortality[a]
Males	under 60	753
	60-79	839
	80-99	840
	100+	868
Females	under 60	464
	60-79	541
	80-99	554
	100+	567

Data from Ujeno (1978).
[a]Deaths over 40 years in the period 1969-1970.

Table 14
Background Radiation (0.1 rads per annum) and Cancers of Sensitive Tissues

Death age	Cumulative dose: actual	Cumulative dose: transformed	Radiogenic[a] cases (%)
40	4.0	2.6	30
45	4.5	2.8	31
50	5.0	3.3	32
55	5.5	4.2	35
60	6.0	6.8	40
65	6.5	9.9	45
70	7.0	15.0	50

Sensitive tissues include digestive, hemopoetic, respiratory, and breast.
[a]As proportion of all sensitive cancers.

Table 15
Certified and Uncertified Cancers: Age at Death

Age (years)	Cancers: certified (%)	Cancers: uncertified (%)
Under 50	15.3	2.4
50-59	26.1	7.1
60-69	37.3	27.4
70+	21.3	63.1
Number of cases	743	84

Table 16
Certified and Uncertified Cancers: Cancer Sites

Cancers	Certified (%)	Uncertified (%)
Prostate	7.0	22.6
Other B cancers	21.8	15.5
A cancers	71.2	61.9

of Hanford data (because they were not certified causes of death) differ from the certified cases. The uncertified cases were distinctly older than the certified ones (Table 15). They were also biased in favor of prostate cancer and other cancers of insensitive tissues (Table 16) and the commonest cause of death was a cardiovascular disease (Table 17). Therefore, the fact that all investigators have recorded negative findings for B cancers is probably an artefact caused by

Table 17
Certified and Uncertified Cancers: Stated Cause of Death

D/C diagnosis	Uncertified cancers prostate (%)	other (%)	Other deaths
Cardiovascular	73.7	9.2	65.5
Other causes	26.3	.8	34.5

underreporting of nonfatal cancers whose effects included high blood pressure and other damage to the cardiovascular system.

Other Analyses of Hanford Data

According to Hutchinson et al. (1979) "the excess proportional mortality [of Hanford workers] at doses above 10 rems for cancer of pancreas and multiple myeloma is likely to be explainable in terms of a correlate of dose rather than in terms of radiation." Equally lame conclusions have been drawn by other investigators, but they are probably the result of using methods that were capable of recognizing some but not all the effects of Hanford exposures. For example, critics of our findings have always insisted upon using the International Classification of Diseases (ICD) classification of cancers. This classification makes no concessions to radiosensitivity. Therefore, without reference to the ICRP classification of tissue sensitivity (ICRP 1969), one is left either with groups that are too small to draw firm conclusions or consist of a mixture of sensitive and insensitive cancers. In view of everyone's findings for group-B cancers, this is peculiarly unfortunate.

The idea that Hanford workers are exceptionally healthy is not a new one. However, the possibility of differences between production workers and supporting staff has been overlooked by our critics, as has also the possibility that (because the nuclear industry has only been in existence for 36 years) the long-term consequences of these differences are still in the future. But the main reasons for finding excuses for all findings that smack of a cancer effect from the Hanford exposures can be found in Atomic Bomb Casualty Commission (ABCC) publications relating to A-bomb survivors who were still alive in October 1950.

Both the study population of Hanford workers and the study population of A-bomb survivors are biased in favor of disease-resistant persons. But for Hanford workers, the selection predated the exposures (healthy-worker effect) and for A-bomb survivors it was radiation-induced (survival of the fittest). Therefore, detection of delayed effects of Hanford exposures is much easier than detection of delayed effects of A-bomb radiation. In ABCC data, the selection effects are so strongly correlated with dose levels that a relative risk analysis of 1950-1974 deaths failed to recognize any extra noncancer deaths apart from blood diseases (Beebe et al. 1977). However, there must have been many deaths due to nonstochastic effects of the radiation after, as well as before, 1950 because an SMR analysis of 1950-1972 deaths (Moriyama and Kato 1973) disclosed the significant differences between A-bomb survivors and other Japanese citizens (which are here depicted in Fig. 1).

SUMMARY

Following the discovery of relatively high doses for Hanford workers who subsequently died from cancer, Mancuso, Stewart, and Kneale first established a connection between this finding and tissues that are sensitive to cancer induction by radiation and then used the method of regression models in life tables to show (1) that for cancers of these tissues there was nonlinearity of dose-response (with the curve obeying the square root law), (2) that the cancer risk increased progressively with adult age (doubling of the risk every 8 years), (3) that the commonest interval between induction and death was 25 years, and (4) that for a man aged 40 years the doubling dose was 15 rads (with a 95% confidence interval of 2-150 rads).

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APPENDIX: EXACT ESTIMATES OF JOB-ASSOCIATED HEALTH RISKS

Let cohorts be indexed by g and let age be indexed by a, so that P_{ag} = probability of dying at age a in cohort g. Let workers be indexed by i; let d_i = 1 if worker i is dead, 0 otherwise. Let jobs be indexed by k and j; let N_{ika} = total number of years (not necessarily consecutive) for which worker i

has held job k by time he has reached age a. Let r_k = health index of job k be so defined that if

$$S_{ia} \left(= \sum_k N_{ika} r_k\right) \tag{1}$$

is cumulative health index score of worker i by age a, then corrected probability of dying (taking into account special risks of jobs and also any special healthy-worker effects due to selective recruitment) is given by

$$P_{ag}\exp(S_{ia})/[1 + P_{ag}\exp(S_{ia}) - P_{ag}], \tag{2}$$

or in other words S_{ia} is the change in the logit of the probability of dying. Then it can be shown by Cox's method of regression models in life tables that if the r_k are all small compared with 1, the maximum likelihood estimates of the r_k satisfy the equation

$$\sum_k V_{kj} r_k = Y_j \tag{3}$$

where

$$V_{kj} = \sum_i \left[\sum_{a=1}^{A_i} N_{ika} N_{ija} P_{aG_i} (1 - P_{aG_i})\right] \tag{4}$$

and

$$Y_j = \sum_i \left[N_{ijA_i} d_i - \sum_{a=1}^{A_i} N_{ija} P_{aG_i}\right] \tag{5}$$

and A_i = final age of worker i and G_i = cohort of worker i.

Because of the complexity of the calculations to obtain the matrix V and the necessity to invert it, these exact estimates of health risks can only be obtained if there are fewer than about 20 jobs in the whole classification of jobs. On the other hand, the approximate method can deal with several thousand jobs at once.

COMMENTS

NICHOLSON: One thing that bears upon the former presentation as well as yours is the method of follow-up. If you rely on Social Security, there may be deaths occurring, particularly before 1967, that were unknown to the system. This might have a greater effect on workers with short employment periods than other workers and thus give rise to what was seen by Darby as a healthy-worker effect of a significant magnitude throughout the exposed group. Can you make a comment about how it might affect what you would do? And would it also be greater for women than for men?

STEWART: I think the point about the healthy-worker effect is that it would be important if we had compared Hanford workers with an outside population as was done by Darby.

NICHOLSON: But how about "lost to follow-up."

STEWART: This too is unimportant for a survey that relies upon internal comparisons. Nevertheless, it is true that there are two subgroups of unidentified deaths not identified.

R. PETO: Your standardization procedures included a factor that changed with time, i.e., the bioassay factor, but this is not permissible in a life-table analysis. In a proper life-table analysis standardized for the monitoring of individuals, an individual whose monitoring status changes at a certain point in time should contribute to all contingency tables relating to previous times and as a monitored individual to all subsequent tables. One person's category is not fixed, but variable in time, and the only way to avoid bias is to take this variation into account in your analysis. You cannot categorize people by what may happen to them in the future or serious biases may be engendered.

STEWART: We had this difficulty pointed out to us before. The best sensitive index is something like the final stage of this thing because you are going to be at risk for a time before you actually show positive results in a testing. But this point has been taken, and of course doesn't apply to the job classification. Those are just your man-years in the job. I believe George can explain this to you in detail.[1]

[1] Following private discussion between G. Kneale and R. Peto, they jointly wrote the following statement: Because the various groups analyzing the Hanford data now have adopted statistical methods which in principle resemble each other, their conclusions should ultimately converge, if they apply their methods to the same set of data.

George Kneale has recently been working with a set of data including all deaths up to mid-1977, while Sarah Darby has been working with a set of data that include only deaths up to mid-1974. Moreover, Kneale has standardized for a detailed measure of job category (see below) before estimating the role of radiation, while Darby has not. Both Kneale and Darby agree that the relationship of myelomatosis to dose is highly significant statistically. Unless this finding is due to some other cause of myeloma in the chemical manipulation of the various components of the nuclear fuel cycle, it indicates that some of the cases of myeloma are radiogenic, a conclusion supported by the recent Cuzick (1981) article.

Moreover, although the suggestive excess of "A-cancers" other than myeloma found in Kneale's most recent analysis is not statistically significant, this does not imply that none of these cases of "A-cancers" were radiogenic. For example, one or two of the pancreatic cancers among men exposed to more than 10 rems might well have been radiogenic. (After standardization by a Cox-type model for calendar year of death, sex, age at hire, length of continuous employment, and job fitness by indices which, in contrast with those used by Stewart and Kneale previously (1981) varied with time, and depended logistically on job hazard the t-value for the "A-cancers," including myelomatosis, was +1.8, indicating somewhat more cases among irradiated workers; the t-value for the "B-cancers" was −2.7; the t-value for the aggregate of all A or B cancers was approximately zero.)

It would be particularly desirable, in the interests of resolving the previous divergence of interpretations, for the National Radiological Protection Board to be willing to analyze exactly the same data that Stewart and Kneale have studied, rather than to continue to obtain their data from different sources.

J. PETO: Did you standardize for the period since first employed or not?

STEWART: Yes, also for sex, date of hire, and either bioassay level or general mortality rating (fitness rating).

KNEALE: I should make it clear that the diagram relating to seven people was supposed to be one of the 480 cohorts. Also note that the Cox methodology is just a minor generalization of your own log-rank tests for testing differences between drugs in clinical trials. The only difference is that workers have radiation exposures through their employment years and patients usually have only short treatment periods. There might be a spread of about 5 years for each subset.

R. PETO: Apart from your bioassay standardization, your analysis seems to be virtually the same as that of Sarah Darby. Why are the findings so different?

STEWART: Did you notice that she was working with 400 deaths from the years 1944-1972 and we with 1100 deaths from the years 1944-1977?

WAXWEILER: Were all your comparisons among monitored workers?

STEWART: Yes, monitored for external radiation, that is.

WAXWEILER: I think this is an important point to make, because what we found in the Portsmouth nuclear shipyard was that there was an ultrahealthy-worker effect. There was a double selection. First, there was a selection to get into the shipyard and, second, selection to become a monitored worker.

STEWART: We think that is happening in Hanford.

MILHAM: I now have all deaths through 1979 in Hanford workers who died in Washington State. The pancreatic cancer excess is still there. There has been no change over time in the RR. There is the same ratio of observed to expected now as men dying, say, between 1950 and 1960. For men dying between ages 45 to 49 of bowel cancer, there are six deaths observed to one expected. I don't know what that means yet.

As you well know, a lot of men worked at Hanford who aren't in your file. J. A. Jones, the construction group, had fairly heavy radiation exposures and these people are not in the data set. I wish they were.

ACHESON: Could I ask for clarification about cases of cancer that were not the cause of death? Are we talking about registered cases on a cancer register or are we talking about cancers in part 2 of the death certificate?

STEWART: Part 2.

ENTERLINE: I would like to make an observation that Hanford is one of the few studies that I know of where two research teams are studying the same population almost totally independently of each other–separate clearance with Social Security, separate procuring of death certificates, and so on.

My question is related to hidden prostatic cancers. Were you implying that if they had been coded as cancer, there would have been a dose effect?

STEWART: I can't say that for certain.

ENTERLINE: Would you be able to do so eventually?

STEWART: Yes.

BLOT: The interesting aspect of Dr. Darby's presentation was the excess of myeloma, which I think is intriguing in view of the Windscale findings and in view of the recent evidence from Japan that myeloma is indeed a high-dose radiation effect.

You mentioned that you are dealing with something like 1100 deaths, whereas Dr. Darby had 400 deaths. So you obviously must have a much bigger cohort. If you take Dr. Darby's finding as a hypothesis, i.e., that myeloma is increased, can you use the additional information you have, whether it is in terms of follow-up or whatever it is that causes more deaths, to test that hypothesis in this particular data set?

In other words, can you use part of this large data set to test an hypothesis generated by another part?

STEWART: It isn't true that all data collecting processes were different. They were in fact the same but I don't know exactly what was or was not included on the tape sent to Darby by the DOE.

ENTERLINE: You never matched the two tapes?

STEWART: Well, not in detail, but they must be much the same. All the dose data come from the same source (Hanford) and all the death benefit claims come from the same source (Social Security).

DARBY: I'd like to comment on this presentation. The paper presented by Dr. Stewart at this meeting discusses the third analysis of mortality in the Hanford work force that has been carried out by MSK. In their first analysis, based on deaths that occurred between 1944 and 1972, MSK reported that fatal malignancies were induced in radiosensitive tissues with a much higher frequency per unit radiation dose than was accepted generally. It was also estimated that 6% of all cancers and 1% of all certified deaths among Hanford workers were radiation-induced, and doubling doses were given for some tumors that would be less than cumulative background exposure for most workers. The authors rightly asserted that these estimates differed from the recommendations of the ICRP by an order of magnitude. MSK's second analysis was based on deaths that occurred between 1944 and 1977, and it was reported that approximately 5% of the cancer deaths of Hanford workers were radiation-induced. Somewhat higher doubling doses were quoted in this analysis than previously, although they still differed from the ICRP estimates by an order of magnitude, and a RR for all cancers of 1.26 was estimated for those with doses of 5.11 rads or more. The third MSK analysis is also based on mortality between 1944 and 1977, but the conclusions reached in it differ somewhat from those reached in the previous analyses. This latest analysis finds no evidence of radiation-related effects when deaths from all causes are considered together, and it makes no claim to find excesses when deaths from all types of cancer are taken as a single group; any excesses are found to be confined to a particular group of cancers.

The methodology used in this latest analysis also differs from that used in the previous two in that available information on members of the work force who survived to the end of the follow-up period is taken into account together with information on those who have died. This methodology is actually very similar to that used by ourselves (Darby and Reissland, in this volume) and others (Gilbert and Marks 1979, 1980), despite initial appearances to the contrary due to the differing nomenclature and somewhat unusual presentation used by the MSK team. The change in methodological approach allows for more detailed comparison among the various analyses and their corresponding conclusions. Thus, there now seems to be a general consensus of opinion that there is no evidence of radiation-related excesses when considering either mortality from all causes or from all cancers when taken as a single group.

There are however, still important differences between the conclusions reached in the third MSK analysis and other analyses of the Hanford data. These are due chiefly to the different controlling factors used. The extreme sensitivity of analyses of this type of data to the controlling factors is well illustrated in Table 6 of Mancuso et al. (this volume). Here it can be seen that there is only evidence of an excess of type A cancers when either bioassay level or a combination of job fitness levels, exposure age, and latency are included among the controlling factors. The various bioassay levels are specified in Table 3 of Mancuso et al. (this volume) and represent levels of monitoring for internal contamination. On general grounds, it seems likely that those who are more thoroughly monitored for internal contamination are likely to be those who work in contaminated areas of the plant and consequently are likely to be exposed to higher levels of external radiation. Hence, it is to be expected that there is a strong correlation between the bioassay level and external radiation dose. This expectation is confirmed in Table 2 of Kneale et al. (1981). Thus, the inclusion of bioassay level as a controlling factor is to a large extent controlling for radiation dose because those at bioassay level 4 (which includes almost everyone in the highest external dose categories) are not then compared with those at bioassay level 1 (which includes the majority of those in the lowest external dose category). The implications of including such a variable as a controlling factor are unclear as it potentially obscures a large part of the relevant information. An additional difficulty is that each worker is classified right from the start of his employment by the highest level of bioassay that he will ever reach, rather than progressing through the bioassay levels changing at the appropriate dates (see Kneale et al. 1981 for details). By comparing the results given in Table 7 of Mancuso et al. (this volume) with the results given in Kneale et al. (1981), it seems clear that bioassay level has been included as a controlling factor throughout the model-fitting procedure used in this latest paper and thus casts doubt upon many of its conclusions.

The original justification for using bioassay level as a controlling factor given in Stewart et al. (1980) was that it distinguished between safe and dangerous occupations, and in Kneale et al. (1981) it was claimed that switching from using bioassay levels to a job hazard index would have made very little difference to the results. Table 6 of Mancuso et al. (this volume) indicates that this claim was not entirely justified because the inclusion of job fitness instead of bioassay levels as a controlling factor now gives a test statistic for A cancers that is not significant at the 5% level, and it is only when exposure age and latency are also included as controlling factors that the test statistic for A cancers again becomes significant. Clearly job fitness, latency, and exposure age are potentially useful factors to control for in an analysis of this type. It would be interesting to see the full details of how the job fitness index has been constructed and also how exposure age and latency were taken into account. Unfortunately these details have not been given in their paper. Obviously, it is unacceptable to continue to add further controlling factors until a significant result is achieved. Therefore, before accepting the significant result in the bottom line of Table 6 it is particularly important to know how the decision to include these extra factors was reached.

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