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UC-000

Atmospheric Pathway Dosimetry Report, 1944 – 1992

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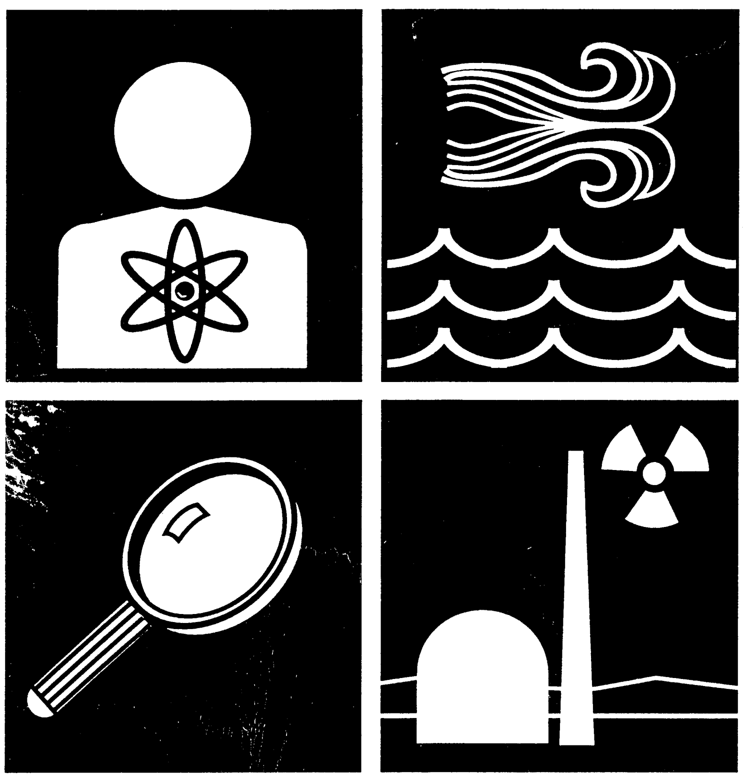
October 1994



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Battelle
Pacific Northwest Laboratories

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Hanford Environmental Dose Reconstruction Project

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Richland, Washington 99352

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October 1994

This document has been reviewed and approved by the Technical Steering Panel.

M. L. Blazek, Chair
Technical Steering Panel
Hanford Environmental
Dose Reconstruction Project

12/1/94
Date

Preface

In 1987, the U.S. Department of Energy (DOE) directed the Pacific Northwest Laboratory, which is operated by Battelle Memorial Institute, to conduct the Hanford Environmental Dose Reconstruction (HEDR) Project. The DOE directive to begin project work followed a 1986 recommendation by the Hanford Health Effects Review Panel (HHERP). The HHERP was formed to consider the potential health implications of past releases of radioactive materials from the Hanford Site near Richland, Washington.

Members of a Technical Steering Panel (TSP) were selected to direct the HEDR Project work. The TSP consists of experts in the various technical fields relevant to HEDR Project work and representatives from the states of Washington, Oregon, and Idaho; Native American tribes; and the public. The technical members on the panel were selected by the vice presidents for research at major universities in Washington and Oregon. The state representatives were selected by the respective state governments. The Native American tribes and public representatives were selected by the other panel members.

A December 1990 Memorandum of Understanding between the Secretaries of the DOE and the U.S. Department of Health and Human Services (DHHS) transferred responsibility for managing the dose reconstruction and exposure assessment studies to the DHHS. This transfer resulted in the current contract between Battelle, Pacific Northwest Laboratories and the Centers for Disease Control and Prevention (CDC), an agency of the DHHS.

The purpose of the HEDR Project is to estimate the radiation dose that individuals could have received as a result of radionuclide emissions since 1944 from the Hanford Site. A major objective of the HEDR Project is to estimate doses to the thyroid of individuals who were exposed to airborne releases of a radioactive form of iodine, iodine-131. A principal exposure pathway for many of these individuals was milk from cows that ate vegetation contaminated by iodine-131 released into the air from Hanford facilities.

The HEDR Project work is conducted under several technical and administrative tasks, among which is the Environmental Pathways and Dose Estimates Task. The staff on this task provide the computer codes and dose calculation tools required for estimating doses to individuals who may have been exposed to radioactive releases from the Hanford Site. The dose estimates are the primary objective of the project. Estimates of radionuclide releases, atmospheric transport, and environmental accumulation all led to the estimation of radiation doses.

This effort includes a brief description of the methods used to estimate doses to representative individuals who consumed foodstuffs, inhaled air, or were directly exposed to radioactive materials released from the Hanford Site. The significant amount of information necessary to estimate doses has been documented in other reports published by the HEDR Project. Table P.1 summarizes the key sources of information used by the HEDR Project to estimate doses. A reader should consult these sources for detailed information on a given subject.

Table P.1. Key Sources of Information for the Atmospheric Pathway

Type of Information	HEDR Project Document
General Project Planning	Shipler, D.B. 1993. *Integrated Task Plans for the Hanford Environmental Dose Reconstruction Project, June 1992 through May 1994.* PNWD-2187 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.
Radionuclide Releases to the Atmosphere	Heeb, C.M. 1993. *Iodine-131 Releases from the Hanford Site, 1944 through 1947, Vol. 1: Text, Vol. 2: Data.* PNWD-2033 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington. Heeb, C.M. 1994. *Radionuclide Releases to the Atmosphere from Hanford Operations, 1944-1972.* PNWD-2222 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.
Radionuclide Transport in the Atmosphere	Ramsdell, J.V., Jr., C.A. Simonen, and K.W. Burk. 1994. *Regional Atmospheric Transport Code for Hanford Emission Tracking (RATCHET).* PNWD-2224 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.
Environmental Historical Measurements Related to the Atmosphere	Denham, D.H., R.L. Dirkes, R.W. Hanf, T.M. Poston, M.E. Thiede, and R.K. Woodruff. 1993. *Phase I Summaries of Radionuclide Concentration Data for Vegetation, River Water, Drinking Water, and Fish.* PNWD-2145 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington. Mart, E.I., D.H. Denham, and M.E. Thiede. 1993. *Conversion and Correction Factors for Historical Measurements of Iodine-131 in Hanford-Area Vegetation, 1945-1947.* PNWD-2133 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington. Gilbert, R.O., E.I. Mart, D.L. Strenge, and T.B. Miley. 1994. *Uncertainty and Sensitivity Analysis of Historical Measurements of Iodine-131 for Vegetation in 1945-1947.* PNWD-1978 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington. Hanf, R.W., J.P. Duncan, and M.E. Thiede. 1993. *Iodine-131 in Vegetation Collected near the Hanford Site: Concentration and Count Data for 1948-1951.* PNWD-2177 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington. Denham, D.H., and E.I. Mart. 1993. *Conversion and Correction Factors for Historical Measurements of Iodine-131 in Hanford Area Vegetation, 1948-1951.* PNWD-2176 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.
Methodology for Estimating Doses	Shipler, D.B., and B.A. Napier. 1994. *HEDR Modeling Approach.* PNWD-1983 HEDR Rev. 1, Battelle, Pacific Northwest Laboratories, Richland, Washington.

Table P.1. (contd)

Type of Information	HEDR Project Document
Equations and Parameter Values Used in Environmental Accumulation and Dose Estimates	Snyder, S.F., W.T. Farris, B.A. Napier, T.A. Ikenberry, and R.O. Gilbert. 1994. *Parameters Used in the Environmental Pathways and Radiological Dose Modules (DESCARTES, CIDER, and CRD Codes) of the Hanford Environmental Dose Reconstruction Integrated Codes (HEDRIC).* PNWD-2023 HEDR Rev. 1, Battelle, Pacific Northwest Laboratories, Richland, Washington.
Demographic Data	Deonigi, D.E., D.M. Anderson, and G.L. Wilfert. 1994. *Commercial Milk Distribution Profiles and Production Locations.* PNWD-2218 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington
	Anderson, D.M., D.J. Bates, and T.L. Marsh. 1993. *Estimation of 1945 to 1957 Food Consumption.* PNWD-2113 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.
	Marsh, T.L., D.M. Anderson, W.T. Farris, T.A. Ikenberry, B.A. Napier, and G.L. Wilfert. 1992. *Commercial Production and Distribution of Fresh Fruits and Vegetables: A Scoping Study on the Importance of Produce Pathways to Dose.* PNWD-2022 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.
Methods for Conducting Model Uncertainty and Sensitivity Analyses	Simpson, J.C., and J.V. Ramsdell, Jr. 1993. *Uncertainty and Sensitivity Analyses Plan.* PNWD-2124, HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.
	Hoffman, F.O., W.J. Conover, M. Henrion, E. Hofer, and S. Simon. 1993. *Peer Review of HEDR Uncertainty and Sensitivity Analyses Plan.* PNWD-2162 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.
Previous HEDR Dose Estimates for the Atmospheric Pathway	Napier, B.A. 1991b. *Selection of Dominant Radionuclides for Phase I of the Hanford Environmental Dose Reconstruction Project.* PNL-7231 HEDR, Pacific Northwest Laboratory, Richland, Washington.
	PNL - Pacific Northwest Laboratory. 1991. *Air Pathway Report: Phase I of the Hanford Environmental Dose Reconstruction Project.* PNL-7412 HEDR Rev. 1, Pacific Northwest Laboratory, Richland, Washington.
	Napier, B.A. 1992a. *Determination of Radionuclides and Pathways Contributing to Cumulative Dose.* BN-SA-3673 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.
	Napier, B.A. 1992b. *Determination of Radionuclides and Pathways Contributing to Dose in 1945.* BN-SA-3674 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.
Validation of HEDR Models	Napier, B.A., J.C. Simpson, P.W. Eslinger, J.V. Ramsdell, Jr., M.E. Thiede, and W.H. Walters. 1994. *Validation of HEDR Models.* PNWD-2221 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.

The computer model, Calculation of Individual Doses from Environmental Radionuclides (CIDER), developed by BNW to estimate potential doses to representative individuals via the atmosphere will be turned over to CDC. The CIDER model will be used for the Hanford Thyroid Disease Study to estimate potential doses to specific individuals.

This report completes HEDR Project Milestones 0705A and 0705C. It is the final report, replacing the previous version dated April 1994. Appendix F is a record of the TSP comments and BNW responses that have been addressed in this final report. Changes made in response to the comments are denoted by numbers in the left margin and italicized text.

Summary

9 The purpose of the Hanford Environmental Dose Reconstruction (HEDR) Project is to estimate the radiation dose that individuals could have received as a result of radionuclide emissions since 1944 from the Hanford Site. The HEDR Project is conducted by Battelle, Pacific Northwest Laboratories. This report describes the estimated doses resulting from the release of radionuclides to the atmosphere. Exposures to radioactive materials released to the atmosphere from Hanford were primarily from the consumption of food containing radioactivity, inhalation of contaminated air, or direct exposure to radioactivity in soil or air. *Scoping studies indicated that atmospheric doses resulting from exposures to surface water, irrigation water, and drinking water were minor in comparison to the other exposure routes and, therefore, not studied in detail.*

10 To estimate doses, it is necessary to estimate the quantity of radioactivity released to the atmosphere, *to calculate the* atmospheric transport, and *to develop* models to simulate the uptake and movement of radionuclides in the environment. This document briefly addresses the approaches used for each of these steps.

Scope of Work

The greatest contributors to dose from the atmospheric pathway were the chemical separations plants. The first plant began operations December 26, 1944. Major separations plant activities ceased in November 1972. The PUREX plant operated for a limited time in the late 1980s. Because there were only 6 days of operations in 1944, the data from those 6 days have been incorporated in the 1945 dose estimations. Once the last chemical separations plant ceased operations radioactive releases to the atmosphere decreased dramatically. Detailed studies were, therefore, undertaken to estimate doses for the years 1944-1972. Because of the lower radioactive releases after 1972, the doses published in the Hanford annual environmental report are used to complete the dose history for 1973-1992.

The dose estimates for 1944-1972 are made for representative individuals in a 75,000 square mile area surrounding the Hanford Site, including eastern Washington, northeastern Oregon, and western Idaho. For dose estimates from iodine-131, twelve categories of representative individuals are distinguished by age, sex, and lifestyle determinants for the maximum release years (1944-1951), over a total of 1102 locations within the HEDR study area. Doses from five additional key radionuclides as well as a second, less detailed dose for iodine-131 are estimated for a maximum representative adult in nine locations for the years 1944-1972. In addition to iodine-131, the other radionuclides from which doses are estimated are strontium-90, ruthenium-103, ruthenium-106, cerium-144, and plutonium-239.

Technical Approach

The process for estimating the doses from the atmospheric pathway included the estimation of the discharge of radionuclides to the atmosphere from the separations plants at the Hanford Site.

Following these estimates, the concentrations of key radionuclides in the air and deposited on the soil were estimated by simulating radionuclide transport in the atmosphere. These simulations were performed using computer models. Once the radionuclide concentrations in the air and soil were estimated, the accumulation in other environmental media was determined. Dose estimates were then made using lifestyle information for representative individuals. Characteristics of the output of these computer models were examined using uncertainty and sensitivity analyses.

Results

Doses estimated for the atmospheric pathway are presented as absorbed dose to the thyroid for iodine-131 and as effective dose equivalent (EDE) for all six key radionuclides, including iodine-131, when included in the key radionuclide dose estimates for 1944-1972. Absorbed dose to the thyroid is measured in "rad" and EDE is measured in "rem."

14 The doses estimated for locations near the Hanford Site are larger than those farther from the site and correspond to the iodine-131 deposition at each location. The distribution of commercial milk and leafy vegetables has some impact on the pattern of doses. *The doses from the atmospheric pathway are dominated by exposures to iodine-131 in the years 1945 through 1951.* The EDE to a maximum representative (maximally exposed) adult at the highest impact offsite location (*Ringold,* Washington) for the years 1945 through 1992 is shown in Figure S.1. The cumulative EDE for this location is approximately 1.2 rem over the 48-year period.

13,15,77 The thyroid dose to the same maximum representative individual (adult) for the period 1945 through 1972 is shown in Figure S.2. The cumulative thyroid dose is estimated to be approximately *39* rad for an adult. For a maximum representative child *at Ringold, Washington, during the maximum years of 1945-1951,* the *median of the* absorbed cumulative dose to the thyroid is approximately *230* rad. *The range is from the 5th percentile of 60 rad to the 95th percentile of 840 rad.*

On average, 55 percent of the iodine-131 released from Hanford is estimated to have been deposited within the 75,000 square mile area under study. Some 10 percent decayed during atmospheric transport within the study area. The remaining 35 percent was either deposited or decayed outside of the HEDR Project study area.

8(4) Uncertainty and sensitivity analyses were conducted to estimate the range of possible doses that a representative individual could have received and to identify the importance of the key parameters in the models. *When milk is consumed* at any location, the *90-percent confidence interval* is a factor of *15 for most representative individuals. The 90-percent confidence interval can also be approximated as a factor of 4 above and below the median.* While this range may seem large, it acknowledges the uncertainty inherent in dose estimates 50 years in the past that are based on radionuclide movement in an environment that is highly variable.

16 The parameters that contribute most to the uncertainty in the estimated dose depend upon the type of representative individual and, sometimes, on the exposure location. For any child who consumed milk *from cows fed fresh pasture* (for whom the estimated dose is the largest), the two parameters that are the most *influential* are the ingestion dose conversion factor (i.e., the factor that

estimates the radiation dose from the ingestion of radioactivity) for iodine-131 and the *feed-to-milk transfer factor (i.e., the* amount of iodine transferred from the cow's feed to the cow's milk).

A feasibility study for the atmospheric pathway conducted in 1991 (PNL 1991), estimated doses for airborne releases of iodine-131 from the Hanford separations plants. Many of the doses presented in that report have been re-estimated for this report. The doses in this report can be considered more complete and detailed compared to those of the feasibility study because of calculational tools and information on human exposure parameters, food product distribution patterns, and animal diet information, which were determined by the HEDR Technical Steering Panel and Battelle, Pacific Northwest Laboratories to be improved and more complete.

14 The use of the new enhanced calculational methods resulted in doses that are, in general, lower than those presented in the feasibility study. For example, the highest *95th percentile* dose reported in the feasibility study *for a single exposure pathway* was the estimated thyroid dose of *2900* rad for 1944-*1947* to an infant near *Ringold*, Washington. That dose was the result of consumption only of milk from a backyard cow fed fresh pasture. However, the estimates using the updated calculational methods and data indicate a *95th percentile* thyroid dose to the same infant *for 1944-1947* to be *820* rad.

Conclusions

- Reliable and useful doses and their uncertainties have been reconstructed for potential exposures to representative individuals from historical releases of radioactive materials from the Hanford Site to the atmosphere.
- The most important contributor to dose was iodine-131 released from the chemical separations plants during the year 1945.
- The most important means of exposure from the atmospheric pathway was the consumption of fresh milk.
- The highest estimated dose was from the consumption of milk produced by cows fed fresh pasture near Ringold, Washington.
- The commercial distribution of milk had an effect on doses. An important impact resulted in lower doses in what otherwise would have been a high impact location (e.g., Richland, Washington).

65
- For *most* representative individuals at any location, 90 percent of the estimates are within a factor of *15*.

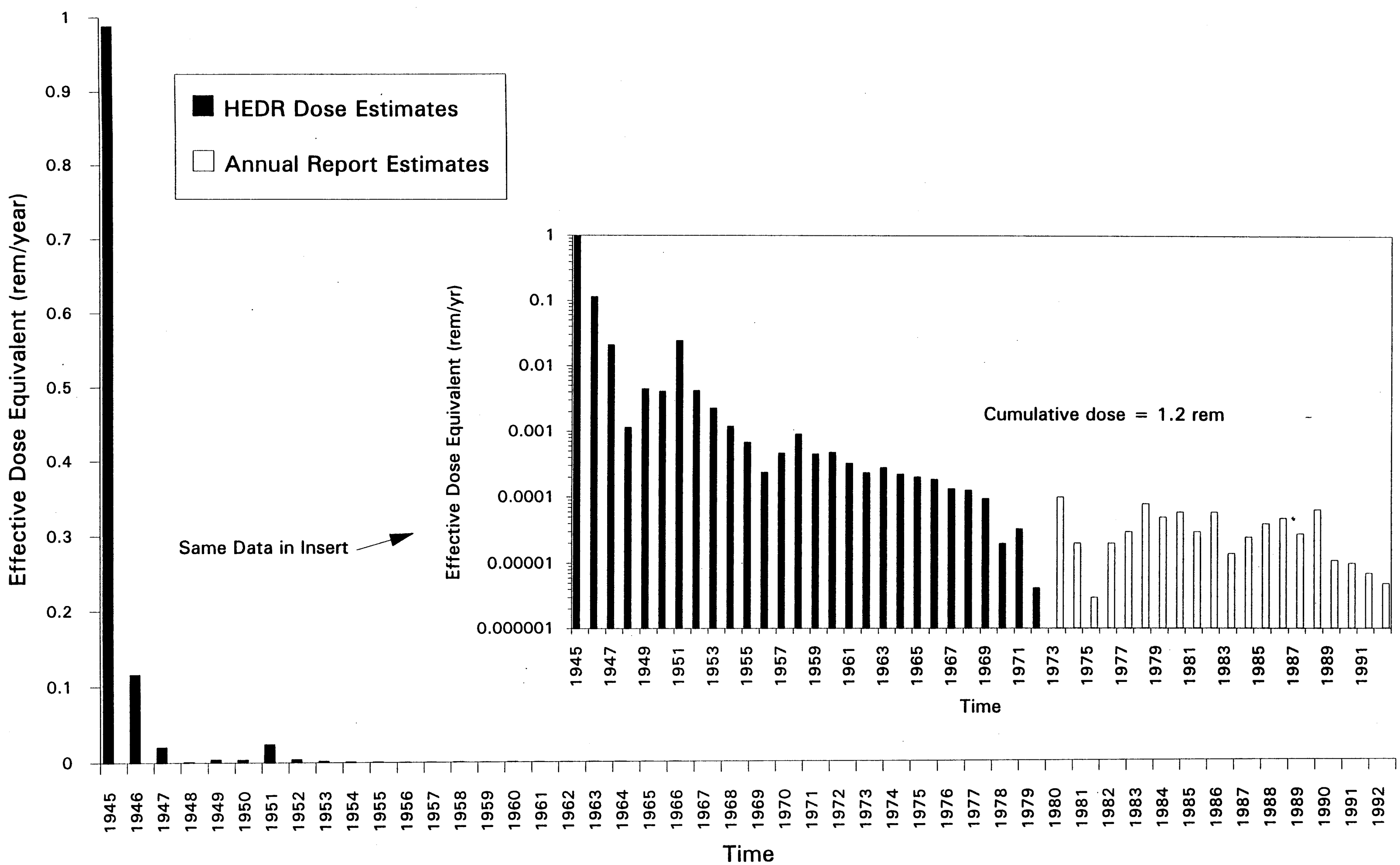

Figure S.1. Estimated Dose to an Adult Maximum Representative Individual from Key Radionuclides at the Highest Impact Offsite Location, 1945-1992

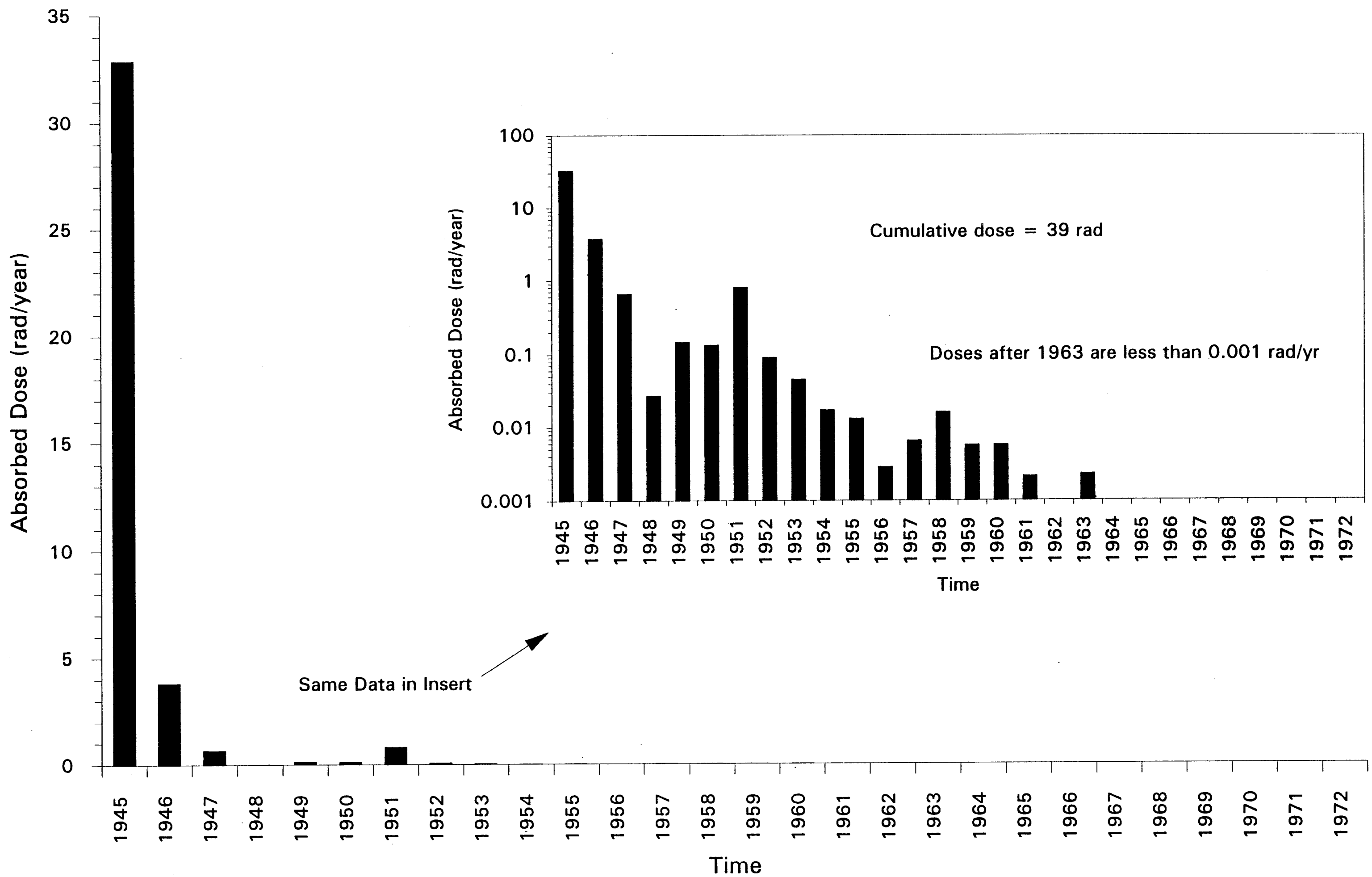

Figure S.2. Estimated Thyroid Dose to an Adult Maximum Representative Individual from Iodine-131 at the Highest Impact Offsite Location, 1945-1972

Glossary

backcasting ratios - factors used to convert 1977-1978 diet data to the years of interest for which individual diet data were available.

body burden - amount of a given radionuclide in humans; typically measured in nanocuries.

boxplot - graphical representation of the distribution of values in which a box shows the middle 50 percent of the distribution and the "whiskers" indicate the lower and upper 5 percent of the distribution.

Ci - abbreviation for curie.

CIDER - Calculation of Individual Doses from Environmental Radionuclides, computer code that estimates radiation doses to representative individuals.

code - computer implementation of equations. Codes can also retrieve, manipulate, display, store data, etc.

composite sample - sample composed of small portions collected from several locations or from a single location over an extended time period.

concentration - amount of a specified substance (e.g., a radioactive element) in a unit amount of another substance (e.g., milk).

confidence interval - statistical range with a specified probability that a given parameter lies within the range.

curie - unit of radioactivity corresponding to 3.7×10^{10} (37 billion) disintegrations per second (abbreviated Ci).

DESCARTES - Dynamic EStimates of Concentrations and Accumulated Radionuclides in Terrestrial EnvironmentS, computer code that provides estimates of concentrations of radionuclides in soil, vegetation, and animal products.

deterministic - estimation method where a single-point estimate is calculated (contrast with "stochastic").

dose - radiation dose; often distinguished as absorbed dose, dose equivalent, or effective dose equivalent.

> **absorbed dose** - amount of energy deposited by radiation in a given amount of material, such as tissue, measured in rad.

dose equivalent - quantity calculated to compare relative biological effectiveness of different kinds of radiation, using a common numerical scale; determined by multiplying absorbed dose by a quality factor and other modifying factors, measured in rem (a millirem is one-thousandth of a rem).

20 **effective dose equivalent (EDE)** - value used *to account for the fact that a rem of radiation to one organ in the body does not have the same potential health impact as a rem of dose to another organ.* It is the *weighted* sum of the dose *to all organs of the body* from internal deposition of radionuclides and the dose from external radiation *exposure measured in rem.*

dose decision levels - thresholds below which research efforts to define dose are minimized. The dose decision levels were determined by the TSP.

effluent plume - spread of contaminants in air, surface water, or ground water released from a contaminant source.

feasibility study - initial HEDR Project study to determine if a retrospective assessment were possible and to determine the magnitude of possible radiation doses.

61 ***geometric standard deviation (GSD)*** - *statistical parameter that describes the uncertainty of the dose estimates.*

20 **gross beta** - total activity of beta-emitting radionuclides that could not be distinguished separately by instrumentation.

half-life - time required for an initial number of radioactive atoms to be reduced to half that number by transformations.

isotope - one of two or more atoms having the same atomic number but different mass.

mean - average value of a set of numbers.

median - middle value in a series of values arranged in order of size.

model - conceptual representation of a physical/biological process. The representation may be graphical or a set of mathematical equations that simulate the process being modeled.

modules - sections of a computer code.

Monte Carlo technique - method that represents the effect of uncertainty in one or more contributing parameters on the overall uncertainty by randomly sampling distribution functions which express parameter uncertainty.

mrad - millirad, one-thousandth of a rad.

mrem - millirem, one-thousandth of a rem.

nCi - nanocurie, one-billionth of a curie.

neutron flux - rate of neutron bombardment *passing through a unit cross-sectional area.*

order of magnitude - power of 10, term used to describe relative size. For example, two orders of magnitude are equal to two powers of 10, or 100.

propagated distribution - distribution of values that begins in one operation and affects succeeding, linked operations.

rad - radiation absorbed dose, unit of measurement used to describe absorbed dose.

radionuclide - isotope of an element that exhibits radioactivity.

RATCHET - Regional Atmospheric Transport Code for Hanford Emission Tracking, computer code that models the air transport of radionuclides and provides daily integrated value of air concentration and surface contamination.

realization - particular pass through a Monte Carlo simulation in which all stochastic parameters have been assigned a value; the simulation represents a "possible reality."

release factor - ratio of radionuclide amount released to the atmosphere to the radionuclide amount processed in the separations plants.

rem - roentgen equivalent man, unit of measurement to describe dose equivalent.

representative individuals - hypothetical individuals sharing similar characteristics significant for estimating dose; in this report, representative individuals are defined by age and sex and are assigned to areas surrounding the Hanford Site. A maximum representative individual is one who by virtue of location and living habits could have received one of the highest possible radiation doses from Hanford releases.

sensitivity - determination of the parameters and pathways that contribute most to uncertainty in calculations.

separations plants - facilities where plutonium from irradiated reactor fuel was separated from other fuel rod components and fission products (T Plant, B Plant, C Plant, REDOX, and PUREX).

single-pass reactors - plutonium production reactors (B, C, D, DR, F, H, KE, KW reactors) that did not recirculate Columbia River water but instead discharged it into retention basins and, after a holdup time, into the Columbia River.

source term - amount of radioactivity (curies) of a radionuclide released to the environment from a facility at a given time.

stochastic - method of estimating possible values that incorporate the variability in input parameters to arrive at a corresponding set of possible results (contrast with "deterministic").

STRM - Source Term Release Model, computer code that provides estimates of iodine-131 releases to the atmosphere from the separations plants that occurred between 1944-1947.

uncertainty - measure of variability in model parameters or dose estimates.

validation - model validation, comparison of estimated values to historical measurements as a test of the reliability of the model estimates.

Contents

Figures

Tables

1.0 Introduction

This report presents estimations of radiation doses that representative individuals may have received from releases of radionuclides to the atmosphere. These releases were the result of operations at the Hanford Site in Washington State in the years 1944 through 1992. The area studied included 75,000 square miles, covering eastern Washington, northeastern Oregon, and western Idaho. Figure 1.1 shows the Hanford Environmental Dose Reconstruction (HEDR) Project study area.

Based on the results of a feasibility study (PNL 1991), the studies listed in Table P.1, and the instructions of the HEDR Technical Steering Panel (TSP), this atmospheric pathway dose assessment is primarily concerned with the detailed investigation of iodine-131 doses for the years 1945 through 1951. Doses from five other radionuclides (strontium-90, ruthenium-103, ruthenium-106, cerium-144, and plutonium 239) were included for completeness.

Several different methods were used to estimate radiation doses for various time periods and radionuclides. Doses from atmospheric releases in 1944 through 1951 were estimated with the most detail. The doses during this period were greater than in any other time period and were dominated by the contribution from a single radionuclide, iodine-131. Doses from the other five radionuclides noted above as well as iodine-131 have also been estimated for the period 1944 through 1972. The years 1944-1972 constitute the period during which the four Hanford separations plants operated. It is primarily from the separations plants that radionuclides were released to the atmosphere. Information on radiation doses for the period 1973 through 1992 is also presented.

1.1 Background of Atmospheric Releases

The Hanford Site in southeastern Washington State was selected in 1943 as the location for the facilities used to produce plutonium for atomic weapons in World War II (Groves 1962). Three plutonium production reactors (B, D, and F) began operating in 1944 and 1945. After World War II ended in 1945, these reactors continued to be used to produce plutonium. From 1949 through 1963, six new reactors (H, DR, C, KW, KE, and N) began operating (Ballinger and Hall 1991).

24 To produce plutonium, it is necessary to irradiate uranium with neutrons. The neutrons are absorbed by the uranium nucleus, eventually leading to the production of plutonium. The production of neutrons by the process of nuclear fission also produces a large number of radionuclides from the fragmentation of uranium and plutonium nuclei. Once produced in the reactors, the plutonium was separated from other radioactive materials in one of four chemical separations plants (T, B, REDOX, and PUREX) at the Hanford Site. The separations plants operated at various times from 1944 through 1972 (Gydesen 1992). The PUREX separations plant restarted in 1983 and was in operational status until 1989. During the separation process, a portion of the total radioactivity was released to the atmosphere. Once in the atmosphere, the radionuclides were dispersed throughout eastern Washington and into neighboring states. The dominant direction of atmospheric transport from the Hanford Site was to the northeast.

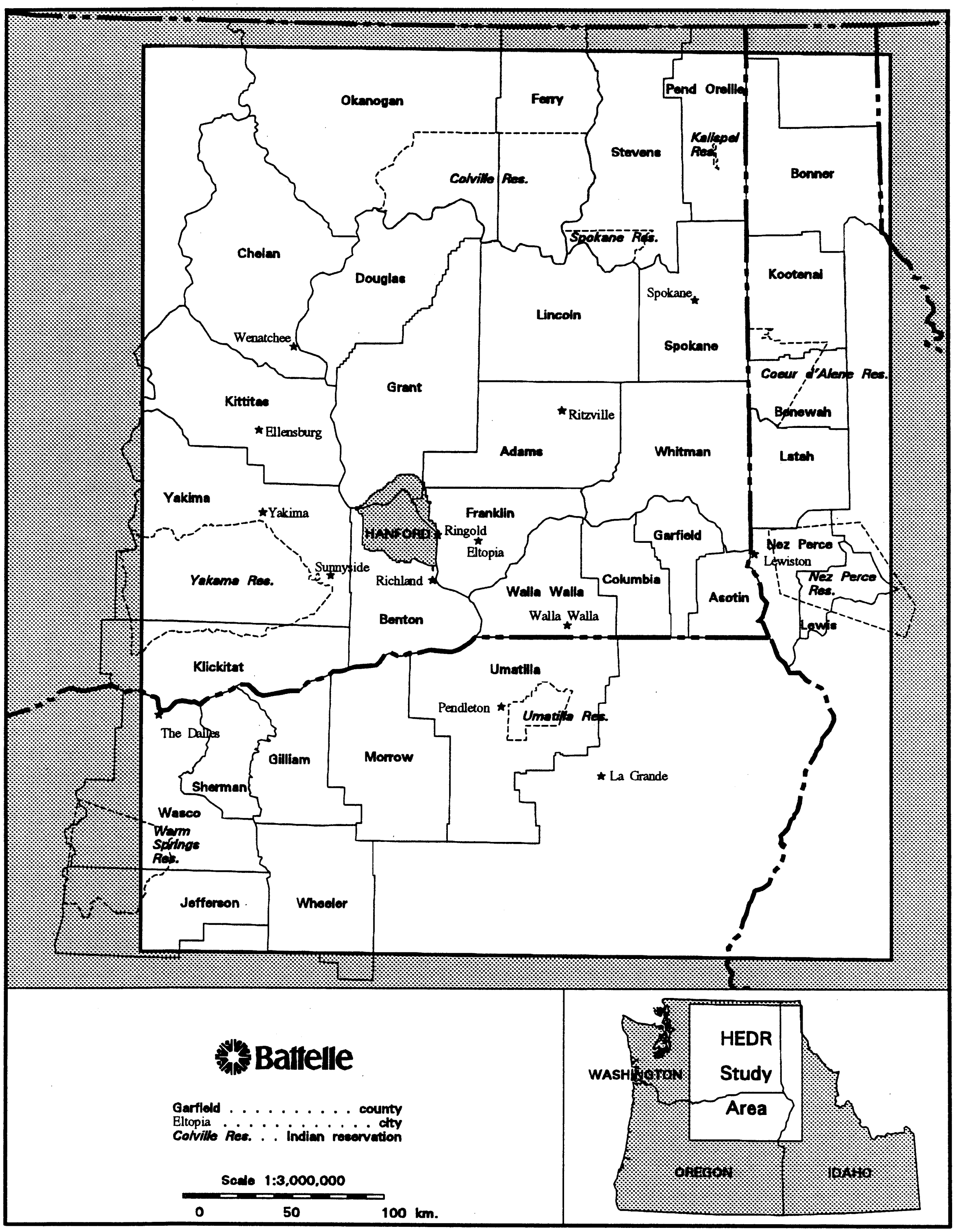

Figure 1.1. Hanford Environmental Dose Reconstruction Project Study Area

27, 28 Individuals who lived in the Columbia Basin and other areas of eastern Washington, northeastern Oregon, and western Idaho may have been exposed to the radionuclides released to the atmosphere from the Hanford Site. Radiation exposure could have occurred from ingestion of contaminated food, inhalation, and external exposure. The magnitude of the dose received was highly dependent on the location of the individual and the amount of contaminated food consumed. Of the radionuclides released from the Hanford Site from 1944 through 1992, the one that would lead to the highest radiation dose was iodine-131. Once iodine-131 settles out of the air, it may be taken up by milk cows that graze on contaminated pasture. Iodine-131 is transferred to the cows' milk, which is then consumed by people (Whicker and Kirchner 1987). Because iodine-131 constituted such a large proportion of the atmospheric releases and was transferred through cows' milk, the radiation dose to an individual was dependent upon the source of milk and the amount of milk consumed.

1.2 HEDR Dose Estimation Studies for Atmospheric Pathway

29 A feasibility study for the atmospheric pathway (PNL 1991) was conducted in 1991 to determine if a retrospective assessment *was* possible and to determine the magnitude of possible radiation doses. The scope of the feasibility study was narrow and included limited time periods and locations. It was found that sufficient historical information could be retrieved and reconstructed, computer codes for dose assessment could be developed, and a modeling approach could produce credible dose estimates.

After publication of the feasibility study, the methods used to determine the statistical uncertainty in doses were found to have produced unrealistic estimates of uncertainty (Simpson 1991a, 1991b). For this report, the methods of propagating uncertainty through the dose calculations were completely revised. Uncertainty analysis techniques that preserved the spatial and temporal correlations in dose estimates were used as described in Napier et al. (1992).

The purpose of the dose assessment documented in this report is to expand and refine the modeling approach used in the feasibility study. An estimate of the radionuclide emissions, more detailed than that in the feasibility study, was prepared and coupled to a more detailed air transport model. The numerical methods were modified and a complex environmental accumulation and dose model was designed (Ikenberry et al. 1992; Napier et al. 1992; Napier 1992c). The time period covered in the feasibility study was expanded from 1944-1947 to 1944-1951 for the detailed iodine-131 estimates in this study. See Appendix A for further discussion of the differences between the conceptual model in the feasibility study (PNL 1991) and this report.

1.3 Preview of Report

The following sections describe the methods used to estimate doses for the atmospheric pathway, beginning in Section 2.0 with the overall data quality objectives for the air pathway dose estimations. Section 3.0 includes a discussion of the modeling approach used to estimate radiation doses. The dose estimates are presented in Section 4.0. Section 5.0 discusses model uncertainty and parameter sensitivity. Additional information covering comparison to the feasibility study, calculational methods, detailed dose estimates, sensitivity analyses, user's guide, and comments and responses are presented in Appendixes A through F, respectively.

2.0 Data Quality Objectives

The data quality objectives (DQOs) for estimating radiation doses from the atmospheric pathway are defined in Shipler (1993). The doses estimated and presented in this document are based upon the data provided by other tasks and subtasks in the HEDR Project. Therefore, the DQOs developed by other tasks affect the overall quality of the estimated dose. The DQOs for the other HEDR tasks are also presented in Shipler (1993).

2.1 Accuracy

The objective of accuracy is to estimate doses using computer models that have been evaluated and refined through validation studies and sensitivity/uncertainty analyses. Doses presented in this document were estimated using models and derived computer codes that were tested for numerical accuracy as well as for their ability to estimate results that compare with historical measurements. The results of the validation studies of all the HEDR models are documented in Napier et al. (1994). That report states that, in general, the estimated results are within an order of magnitude of the historical measurements. The final determination of accuracy has been made by HEDR Project and TSP review of this report and Napier et al. (1994). Uncertainty and sensitivity analyses were conducted to estimate the range of possible doses and to determine those parameters that contribute most to the uncertainty in doses.

2.2 Precision

The objective of precision is to quantify the precision of dose estimates for a specific representative individual by conducting uncertainty analyses using estimated parameter uncertainties and appropriate uncertainty analysis procedures. The uncertainty analyses were conducted using Monte Carlo random sampling techniques that were approved by the TSP. The detailed results of the analyses are presented in Section 5.0 of this report. The final determination of precision has been made by project and TSP review of this report.

2.3 Completeness

The objective of completeness is to include key radionuclides, exposure pathways, and other information that could have a significant effect on the estimated doses. The HEDR modeling approach, developed by Shipler and Napier (1994), was used to estimate doses based on the quality and abundance of historical data available for source term and environmental transport radionuclide measurements. The doses were estimated using the specific methods described in Shipler and Napier (1994). The doses presented in this report cover the history of Hanford Site operations from 1944 through 1992. Twelve-hundred radionuclides and a number of exposure pathways were investigated for their contribution to dose (see Section 3.1). Doses from key radionuclides and exposure pathways are included in this report. The estimated doses were prepared for 1102 specific locations within a 75,000 square mile area.

2.4 Representativeness

The representativeness of dose estimates was determined by comparing environmental historical measurements with the HEDR model estimates. The doses presented in this document have been converted to body burden estimates and compared, where possible, to measured human radionuclide body burdens. This comparison is documented in Napier et al. (1994). In general, estimated body burdens were within the range of measured values.

2.5 Comparability

A comparison of the estimated doses presented in this report has been made with doses estimated earlier in the HEDR Project (PNL 1991). Estimated doses were also compared with doses presented in annual environmental reports produced by Hanford contractors since 1957 (Soldat et al. 1986). The doses presented in this report are very similar to the doses presented in the earlier annual monitoring reports. The small differences in doses were primarily due to different assumptions regarding internal dosimetry or human ingestion values. When similar assumptions were made, the estimated doses are nearly identical.

3.0 Modeling Approach

This section outlines the technical approach used to estimate radiation doses, briefly addressing the approaches used to estimate the quantity of radioactivity released to the air, the calculation of atmospheric transport, the development of models and parameters used to simulate the uptake and movement of radioactivity in the terrestrial environment, the production and distribution of commercial foodstuffs, and the estimation of radiation dose to people. The methods described in this section are those approved by the TSP and used by HEDR staff to estimate final doses for representative individuals (Shipler and Napier 1994). These methods will also be used to estimate doses to real individuals included in the Hanford Thyroid Disease Study. The modeling methods are described in greater detail in Appendix B.

Shipler and Napier (1992) discussed the modeling methods originally under consideration by the HEDR Project. The methods were refined, however, as the project developed and the existing data, scope of pathways, and magnitudes of dose estimates were evaluated through scoping studies. By 1994, the modeling sequence chosen by Shipler and Napier (1994) for the major environmental transport pathways (the atmosphere, Columbia River, and ground water) was based on a level of resolution deemed appropriate for the various pathways and for the time periods being considered.

As a result of existing information and scoping studies, it was decided that for the atmospheric pathway more detailed reconstruction (and consequently more effort) should be expended on the earlier, rather than the later, periods of Hanford operations (Shipler and Napier 1994). The iodine-131 release estimates shown in Figure 3.1 illustrate why this assumption was made. The releases estimated for 1945 are greater than the releases estimated for all other years combined. The release estimates in Figure 3.1 are based on the operating histories of individual reactors and on records of individual batches of fuel processed through the separations plants (Heeb 1994).

31 Because the largest releases of radionuclides to the air occurred during the mid-1940s, the modeling approach for the atmospheric pathway required a very fine temporal resolution. By contrast, progressively less detailed modeling *was required* for the middle and later periods of Hanford operations. Decreasing emphasis on the later years in dose reconstruction is justified by a variety of factors besides the lower releases of radioactive materials during those later years: better historical measurements, more technically defensible dose estimates during the middle period (1952-1972), increasing reliability of dose estimates during the later period (1973-1992), and shutdown of the eight single-pass reactors and their reprocessing plants by the end of 1972. Shipler and Napier (1994) define the study period based on the availability of historical measurements, the confidence in analytical techniques and results, and the magnitude of potential doses that individuals might have received.

3.1 Determination of Key Radionuclides and Pathways

Radionuclides and pathways of interest were first selected in Napier (1991a). Approximately 1200 radionuclides were screened for their relative atmospheric releases and importance to dose. More than 150 radionuclides were identified to be of greatest interest. The pathways considered in

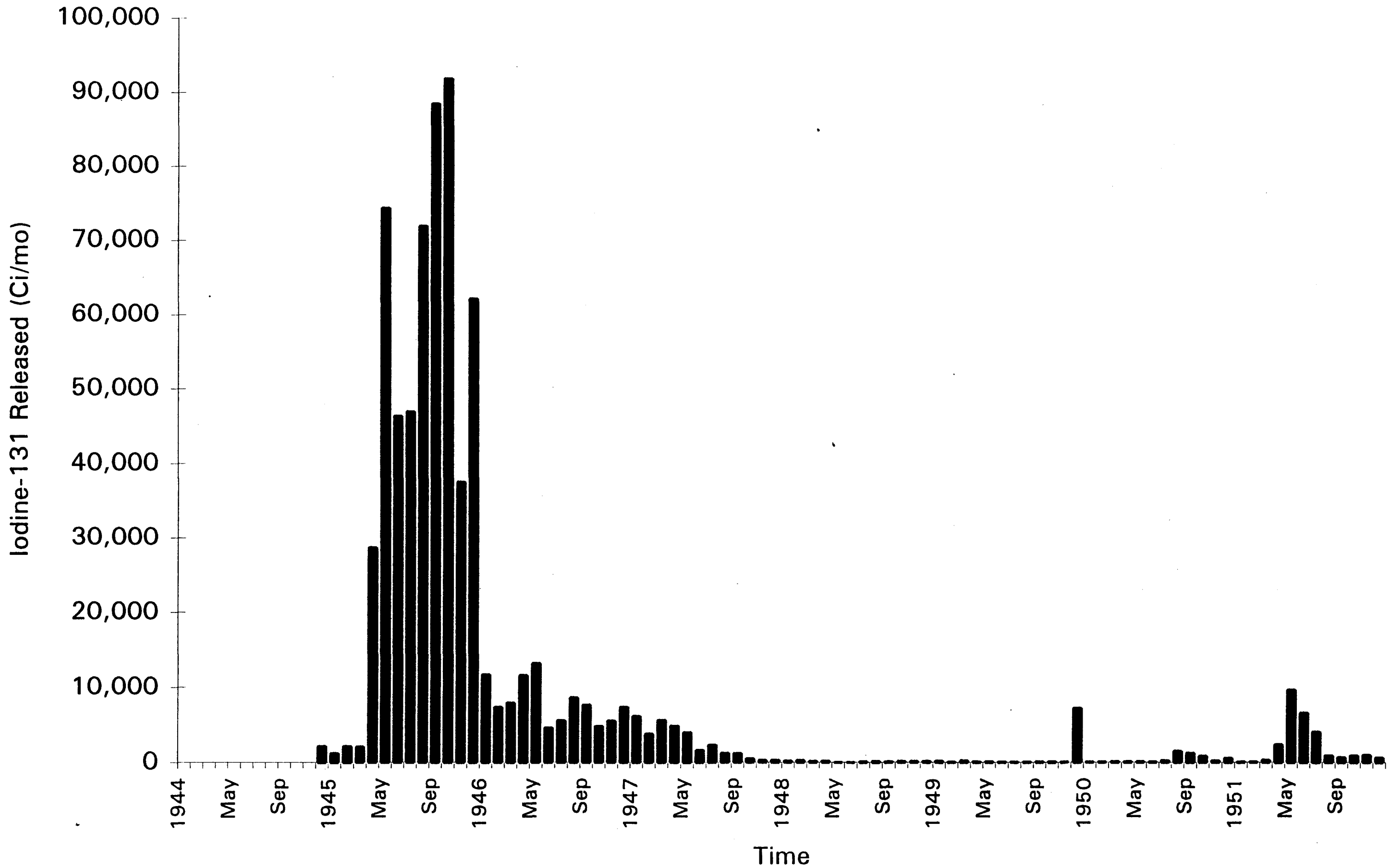

Figure 3.1. Iodine-131 Releases, 1944-1951

Napier (1991a) included external dose from submersion in contaminated air or exposure to contaminated soils, inhalation, and ingestion of food crops and animal products. Of the radionuclides investigated, iodine-131 was identified as contributing over 90 percent of the dose, with ruthenium-103 and ruthenium-106 both considered to be of marginal importance.

The HEDR Phase I model design specification (Napier 1991b) considered the results of the previous study (Napier 1991a) and included in the Phase I calculations only iodine-131. The exposure pathways considered were the same as those of Napier (1991a). The pathway of ingestion of cows' milk was expanded to include both commercial and private milk sources and grocery sources, with four possible feeding regimes for the cows. The doses resulting from this modeling were presented in the *Air Pathway Report* (PNL 1991).

The "dose decision levels" adopted by the TSP helped to determine when certain pathways should be included in modeling dose.[(a)] Dose decision levels are thresholds below which research efforts to define dose should be minimized. These levels were incorporated into the *HEDR Modeling Approach* for the atmospheric pathway by stating that "if, upon consideration, it is determined that any given pathway has the potential to add more than 5% to the total annual dose for any individual at a time when the dose exceeds the TSP guidelines, it will be ... added to the main models" (Shipler and Napier 1992, p. 9). A draft set of equations establishing the "main models" was presented in Napier et al. (1992) and finalized by Snyder et al. (1994).

A series of scoping studies was undertaken to re-evaluate the radionuclides and the detail of the pathways prior to final code implementation. Marsh et al. (1992) provided evidence to support the inclusion of a commercial leafy vegetable distribution system in the "main models" and the exclusion of other commercial distribution systems. Ikenberry and Napier (1992) and Ikenberry et al. (1992) detailed the necessary components of the milk cow pathway, including deposition on stored feed, soil ingestion by cows, and inclusion of an air-water-cow pathway.

A set of detailed source term inputs for the early years was developed during 1992 by Heeb (1993). Napier (1992b) addressed the pathways described in Snyder et al. (1994) using the new source term data and milk cow information of Ikenberry and Napier (1992). As a result of these scoping studies, the final selection of detailed calculations for iodine-131 and additional consideration of five radionuclides (strontium-90, ruthenium-103, ruthenium-106, cerium-144, and plutonium-239) for the separations plants and three other radionuclides (tritium, carbon-14, and argon-41) for the reactors was made by the TSP.[(b)]

3.2 Computational Models for Iodine-131 Doses, 1944-1951

The overall HEDR computational model for estimating doses attributable to atmospheric releases consists of four linked models for source term, atmospheric transport, environmental accumulation,

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(a) Unpublished report (HEDR Project Document No. 12910094), *Scoping Document for Determination of Temporal and Geographic Domains for the HEDR Project* by B. Shleien (TSP), adopted by the TSP on February 20-22, 1992.

(b) Letter (HEDR Project Document No. 09930260) from J. E. Till (TSP) to D. B. Shipler (BNW), June 29, 1993.

and individual dose. These four models were translated into computer codes for the purpose of quantifying the radiation dose to representative individuals exposed to airborne releases from Hanford.

These computer codes (shown in Figure 3.2) are the main set of computational tools used to estimate doses for the years 1944 through 1951.

- Detailed hourly release estimates of iodine-131 were prepared to model the source term using the computer code, STRM (Source Term Release Model) (Heeb 1993, 1994).
- Daily integrated values of air concentration and surface contamination were prepared to model air transport using the computer code, RATCHET (**R**egional **A**tmospheric **T**ransport Code for **H**anford **E**mission **T**racking) (Ramsdell et al. 1994).

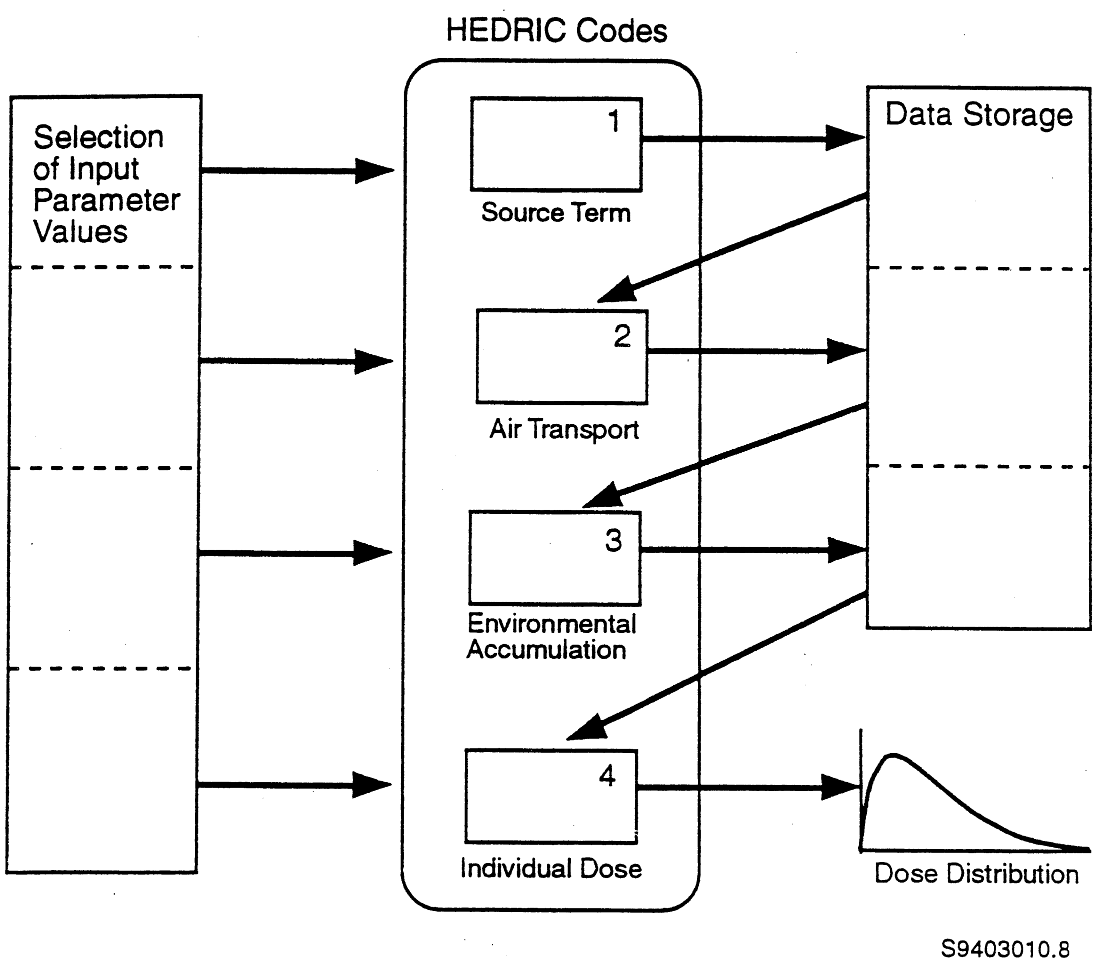


Figure 3.2. Organization of the Atmospheric Pathway Computer Codes

- Concentrations of radionuclides in soil, vegetation, and animal products were estimated for each grid location to model environmental accumulation using the computer code, DESCARTES (**D**ynamic **E**stimates of **C**oncentrations and **A**ccumulated **R**adionuclides in **T**errestrial **E**nvironment**s**).

- Radiation doses to representative individuals were estimated using the computer code, CIDER (**C**alculation of **I**ndividual **D**oses from **E**nvironmental **R**adionuclides).

Each of these models is discussed below. See Appendix B for a detailed discussion of the models.

3.2.1 STRM Code

The source term code STRM provided estimates of historical hourly radionuclide releases to the atmosphere from the Hanford Site (Heeb 1993, 1994). The release estimates were based upon operating histories from Hanford and effluent control technologies in use at the time of the releases. Uncertainties in the actual amounts released were addressed through multiple simulations, each of which represents an alternative release history that is consistent with existing information about source term releases. Together, these alternative release histories represent the range of releases that could have occurred. One hundred separate realizations of the complete hourly release history were prepared by STRM. One realization for a single radionuclide for the period January 1, 1945, through December 31, 1945, would contain over 15,000 hourly release estimates (including separate calculations for the two separations plants, B and T, operating at the time).

3.2.2 RATCHET Code

33 The set of hourly release histories from STRM together with hourly meteorological data constituted the input to the atmospheric transport code RATCHET and provided estimates of the concentrations of radionuclides in the air and the deposition of radionuclides on the ground. These estimates were made for *all* locations within the HEDR study area on a daily basis. Uncertainties in the source term and the imprecision of the meteorological records (wind speed, wind direction, etc.) were combined during the RATCHET calculations. As with the STRM calculations for source term, 100 realizations were prepared in RATCHET. Each realization was internally consistent and represented a possible set of conditions consistent with all available information. One realization of RATCHET for a single radionuclide for the period January 1, 1945, through December 31, 1945, would contain over 1,500,000 estimates of air concentrations and depositions within the HEDR study area.

Historical measurements from the Hanford Meteorological Station and sometimes from Pasco, Washington, are not available for the 1950-1951 period. Surrogate data for this period were derived from random sampling of daily data (grouped by months) from the years 1944-1949.

3.2.3 DESCARTES Code

The output of the RATCHET code (in the form of daily radionuclide air concentrations and depositions) was used as input to the environmental accumulation code DESCARTES, which estimated time-dependent concentrations of radionuclides in soil, plants, and animal products. The code was operated on a daily time step, allowing for the detailed simulation of radionuclide movement in the environment. DESCARTES estimated the radionuclide concentrations in significant environmental media and food products at each location within the HEDR study area. The 2091 RATCHET locations were converted to 1102 locations where media concentrations were estimated. Information on the animal husbandry practices and the distribution of milk, fresh fruits, and fresh vegetables in the region was used by the DESCARTES code to estimate the concentration of radionuclides in home-grown and commercially produced foodstuffs. Radionuclide concentrations were estimated for approximately 20 different media that may be contacted by or consumed by people. Although DESCARTES estimates media concentrations on a daily time-step, the code output is on a monthly basis. One realization of DESCARTES for a single radionuclide for the period January 1, 1945, through December 31, 1945, would contain over 370,000 estimates of media concentrations.

The codes associated with source term, atmospheric transport, and environmental accumulation generate large databases of possible environmental radionuclide concentrations in time and space. The output of the DESCARTES code contains all this information, including uncertainty regarding environmental media concentrations.

3.2.4 CIDER Code

The final computer code for the atmospheric pathway is CIDER. CIDER simulates individual people living in the environment around Hanford and accounts for the temporally and spatially varying contamination levels. CIDER uses individual physical characteristics, living patterns, and food consumption habits in the estimation of representative individual dose. A dose estimate for any one representative individual consists of 100 realizations. That means that a representative individual is "exposed" to each of the 100 random alternative representations of the environment surrounding Hanford. The 100 dose estimates will then be used to reconstruct the likely dose that an individual may have received. As a result of the 100-realization approach, information on the uncertainty in the dose estimates can be made.

34 The first three codes for the atmospheric pathway (STRM, RATCHET, and DESCARTES) need only be run once to create 100 sets of concentrations of radionuclides in environmental media. Once these data sets are prepared, CIDER can access the data and perform dose calculations based solely on lifestyle data input. CIDER dose estimates can account for changing residences, food sources, food *consumption*, and individual aging. For the purposes of the dose estimates presented in this report, a set of representative individuals is defined as having certain lifestyles and food consumption habits. The representative individuals are assumed to have lived at a single location throughout the study period.

3.3 Calculational Methods for Doses, 1944-1972

As described in Shipler and Napier (1994) radiation doses for key radionuclides and later time periods were to be estimated using other methods than for iodine-131. The radiation doses were found to be lower than for iodine-131 and a less detailed methodology was warranted.

A set of monthly atmospheric dispersion factors was developed for selected locations using the RATCHET atmospheric transport code and the meteorological data for 1944 through 1949. These atmospheric dispersion factors were used for each year from 1944 through 1972. The monthly dose estimates were based on environmental accumulation of radionuclides and human exposure via a number of pathways. The pathways included ingestion of milk, fresh eggs from free-ranging chickens, beef, fruits, and vegetables, all from a backyard source. The milk was assumed to be produced by a backyard cow that was fed fresh pasture. The commercial distribution was not included in the key radionuclide calculations. Additional exposure pathways included incidental ingestion of soil by humans, inhalation, and external exposure.

Monthly doses were estimated using enhanced versions of the spreadsheets from prior HEDR scoping calculations (Ikenberry and Napier 1992, Napier 1992a, 1992b). All monthly dose estimates were aggregated to annual totals for presentation. The radiation doses for nine specific locations were estimated and are representative of the dose within the HEDR study area. The doses were estimated for an adult who was assumed to live at the same location over the 1944-1972 time period. Because dose estimates for iodine-131 from 1944-1951 were available from the CIDER code, spreadsheets were not used for that radionuclide in that time period.

3.4 Methods of Ensuring Model Reliability

An important element in the development and application of the methods used to estimate dose is the concept of model reliability. Model reliability includes computer code testing and verification, uncertainty and sensitivity analyses, and validation studies. All these elements have been addressed by the HEDR Project in one or more documents (see Table P.1). The uncertainty and sensitivity analyses, which help to determine the precision with which dose estimates can be made and the parameters and pathways that contribute most to the uncertainties, are included in this report (see Section 5.0 and Appendix D). A comprehensive analysis of the ability of the HEDR models to accurately simulate radionuclide releases, environmental transport, and human exposure is provided in a model validation report (Napier et al. 1994).

4.0 Dose Estimates for Representative Individuals

Doses to representative individuals are presented here for the years 1944 through 1992. (Note that because the first separations plant, T Plant, did not begin operations until December 26, 1944, the radionuclide releases during the last six days of 1944 were attributed to 1945 for all dose estimates.) These doses are the result of atmospheric releases from the separations plants at the Hanford Site. Six radionuclides make up 99 percent of the potential radiation dose from the atmospheric pathways (Napier 1992a): strontium-90, ruthenium-103, ruthenium-106, iodine-131, cerium-144, and plutonium-239.

35, 36 Because atmospheric radiation doses for 1944 through 1951 were dominated by exposure to iodine-131 for which the thyroid is the critical organ, dose to the human thyroid is the best indicator of radiation exposure. The thyroid dose is reported in terms of absorbed dose (rad). Age-dependent dose conversion factors are used to convert iodine-131 intake to absorbed dose (ICRP 1989). Releases of radionuclides other than iodine-131 also occurred. The radiation dose estimated for these other radionuclides is the effective dose equivalent (EDE), for which methods are described in ICRP Publication *56 (1989)*. The EDE is a measure of dose that attributes weighting factors to body organs and tissues to produce an estimate of total risk from exposure to multiple radionuclides.

Detailed iodine-131 dose estimates were prepared for the years 1944 through 1951. These estimates cover 1102 locations within the HEDR study area. Doses to 12 different representative individuals, distinguished by age and gender, were estimated using a series of food source scenarios. The results of these dose estimates are presented in this section in a series of maps showing both annual and cumulative absorbed dose to the thyroid. Maps showing the absorbed dose to the thyroid from consumption of commercial milk and leafy vegetables are also provided. The iodine-131 doses are presented as the median absorbed dose to the thyroid using the Monte Carlo techniques described in Section 5.0.

37, 38 Simpler implementations of the models *other* than those for iodine-131 in 1944-1951 were used for the five, less significant radionuclides, and for iodine-131 in less significant years (described in Section 3.3). Doses to representative individuals from the six key radionuclides have also been estimated for the years 1944 through 1972. The doses were estimated for a single representative individual for nine selected locations within the HEDR study area. These doses are presented as EDE. Also, dose estimates previously published in Hanford annual offsite monitoring reports were summarized for the period 1973 through 1992.

4.1 Representative Individual Definition

Representative individuals approximate the significant characteristics of selected segments of the general population and the doses to these population segments. It is possible that a real individual may have been exposed to greater amounts of Hanford derived radionuclides than a representative individual defined here as maximally exposed. Doses were estimated for 12 age and gender categories, which break the general population into smaller, more homogeneous classifications. Significant life-style characteristics of these representative individuals are further distinguished by sets of parameters applied to each age/gender division. The parameters include dietary habits of consumption, dose conversion factors, estimated time spent outdoors, and breathing rate. The sources of information used to develop the parameter values are presented in detail in Snyder et al. (1994). The parameter values were reviewed by the TSP prior to their use in the dose estimates.

The most important set of parameters is the diet specification. Table 4.1 shows the daily consumption rates for the 12 representative individuals. The dietary information is derived from United States Department of Agriculture data (USDA 1979) as described in Anderson et al. (1993). These USDA data, which were collected in 1977, were translated into the 1945 time frame through the use of backcasting ratios (Anderson et al. 1993). For instance, people consumed generally more milk, eggs, and vegetables and less beef and poultry in 1945 than in 1977. By using a numerical ratio, the 1977 dietary data can be extrapolated to 1945 consumption habits.

43 **Table 4.1**. Median Daily Consumption Rates for 1945 (grams/day)[(a)]

Sex/Age	Fresh Milk	Stored Milk	Leafy Vegetables	Other Vegetables	Fruit	Grain	Beef and Pork	Eggs	Poultry
All, < 1 year	740	190	0.56	56	170	77	2.8	6.8	0
All, 1 to 4 years	710	27	14	93	84	140	34	20	4.6
Male, 5 to 9 years	950	36	27	130	91	210	48	17	7.1
Female, 5 to 9 years	860	34	25	130	110	180	52	16	6.5
Male, 10 to 14 years	1000	38	32	170	98	230	75	22	7.9
Female, 10 to 14 years	810	33	30	140	93	200	57	16	7.4
Male, 15 to 19 years	1000	49	35	200	87	270	94	32	10
Female, 15 to 19 years	660	27	31	140	70	160	60	13	5.5
Male, 20 to 34 years	580	36	44	190	72	220	95	38	10
Female, 20 to 34 years	360	25	39	140	60	130	61	21	9.7
Male, > 34 years	410	37	42	210	110	220	92	41	10
Female, > 34 years	300	29	45	170	110	150	62	24	7.9

(a) Approximately 450 grams equals 1 pound.

4 The dose estimates presented in this section were calculated using general assumptions regarding the source of foodstuffs consumed and the type of feed provided to milk-producing cows. Milk is important in estimating doses from atmospheric releases because the thyroid dose from iodine-131 is highly dependent upon the amount of milk consumed and the source of that milk. The thyroid doses were determined to be the largest for representative individuals consuming large amounts of milk from cows that grazed on fresh pasture. Doses were much lower for representative individuals who consumed less milk or whose milk was obtained from a cow that was fed stored feed. The radioactivity in milk from a cow that was fed stored feed would have been lower than that of a cow on fresh pasture because iodine-131 would have decayed during the time that the feed was stored.

Because of this difference between fresh and stored foods, representative individual dose estimates were prepared for three general food source scenarios:

- All foods including milk, leafy vegetables, other vegetables, fruit, grain, eggs, poultry, and beef come from the same location at which the representative individual lives; i.e., grown in a backyard garden or on a farm. The cow that provides all the milk for this representative individual is on a fresh pasture feeding regime.
- The second food source scenario is identical to the first except that the representative individual obtains milk from a cow fed with stored feed.
- The representative individual consumes milk and leafy vegetables obtained from a local commercial source such as a grocery store or other market.

4.2 Iodine-131 Doses, 1944-1951

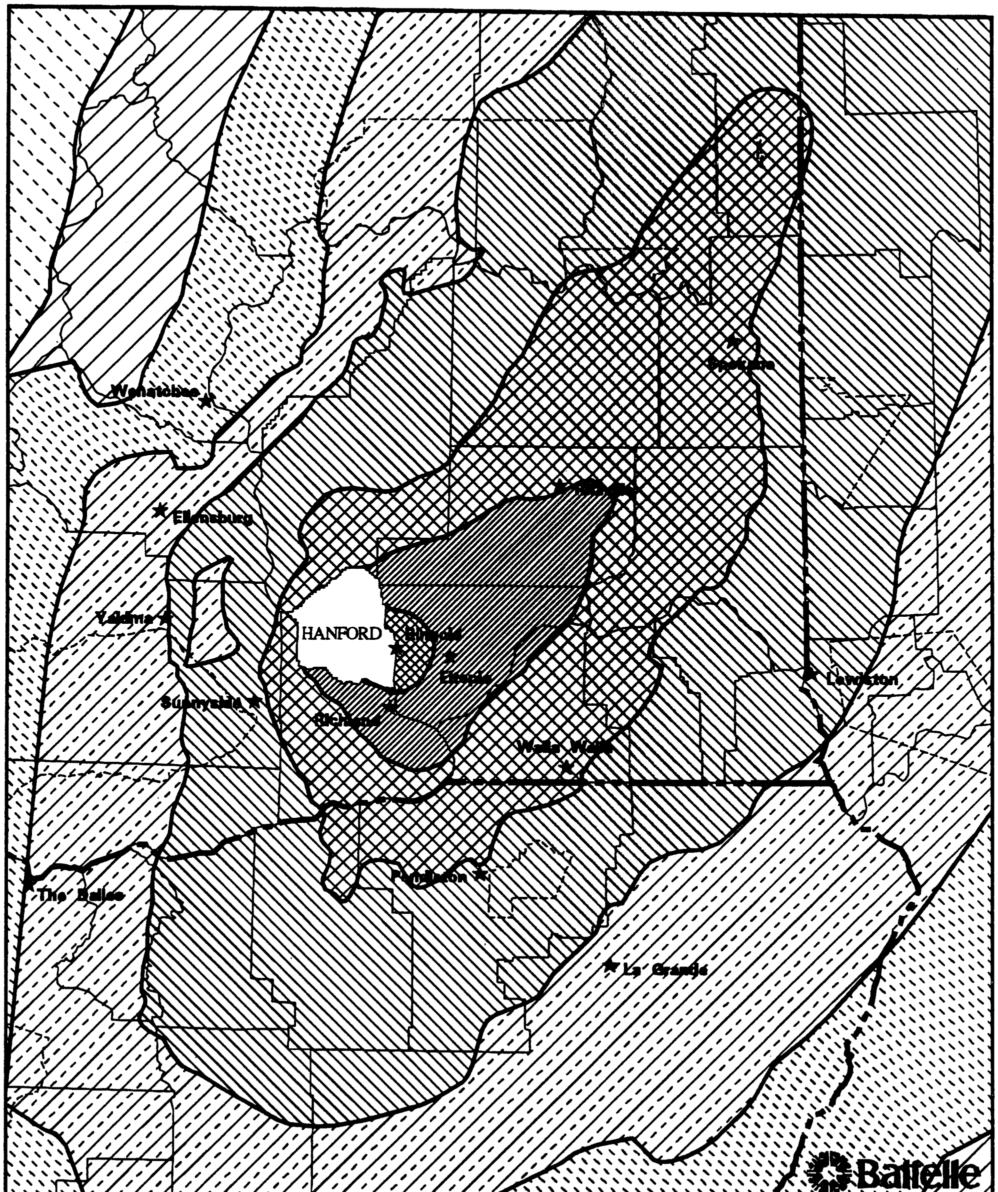
45 The *median* doses received by representative individuals at each of 1102 locations are shown in a series of maps. The base map for each dose map is that of the HEDR study area (see Figure 1.1). Each map allows the specification of the thyroid dose at a given location for each type of representative individual specific combination of food sources, and animal feeding practices. The doses for iodine-131 are presented as ranges for each map. Note that the range represents the range of *median* doses over a geographic area and does not indicate uncertainty in the dose estimate itself. (The uncertainty in dose estimates is discussed in Section 5.0.) The reader can interpolate within a given dose range to obtain a more accurate estimate of the dose at any specific location.

4.2.1 Annual Iodine-131 Doses, 1944-1951

40 Two sets of figures (4.1 through 4.7 and 4.8 through 4.14) estimate thyroid doses for two dietary scenarios involving freshly grown foods and stored foods obtained from backyard gardens or farms. Figures 4.15 through 4.18 estimate doses for commercially distributed milk and leafy vegetables and for inhalation of iodine-131. To read the dose maps, pinpoint the location of interest, note the shading, and then consult the legend on the adjoining page. The intersection of the shading (column) and the sex/age classification of interest (row) shows the expected median dose to that type of representative individual at that location in the year of that particular map. All doses are in terms of annual absorbed dose to the thyroid in units of rad per year. *For more specific information on how to use the dose maps, see Appendix E.*

4.2.1.1 Doses from Foods Consumed Directly from Backyard Gardens and Farms

47 The estimated doses in Figures 4.1 through 4.14 were based on the assumption that all food was produced at the location of consumption and food was not distributed from location to location within the HEDR study area. *Seasonally dependent production and consumption data were used in the dose estimates. These seasonally dependent consumption data include increased consumption of fresh fruits and vegetables when in season.*



4.1

Figure 4.1. 1945 Iodine-131 Thyroid Dose from All Air Exposure Pathways - Milk Cows on Fresh Pasture

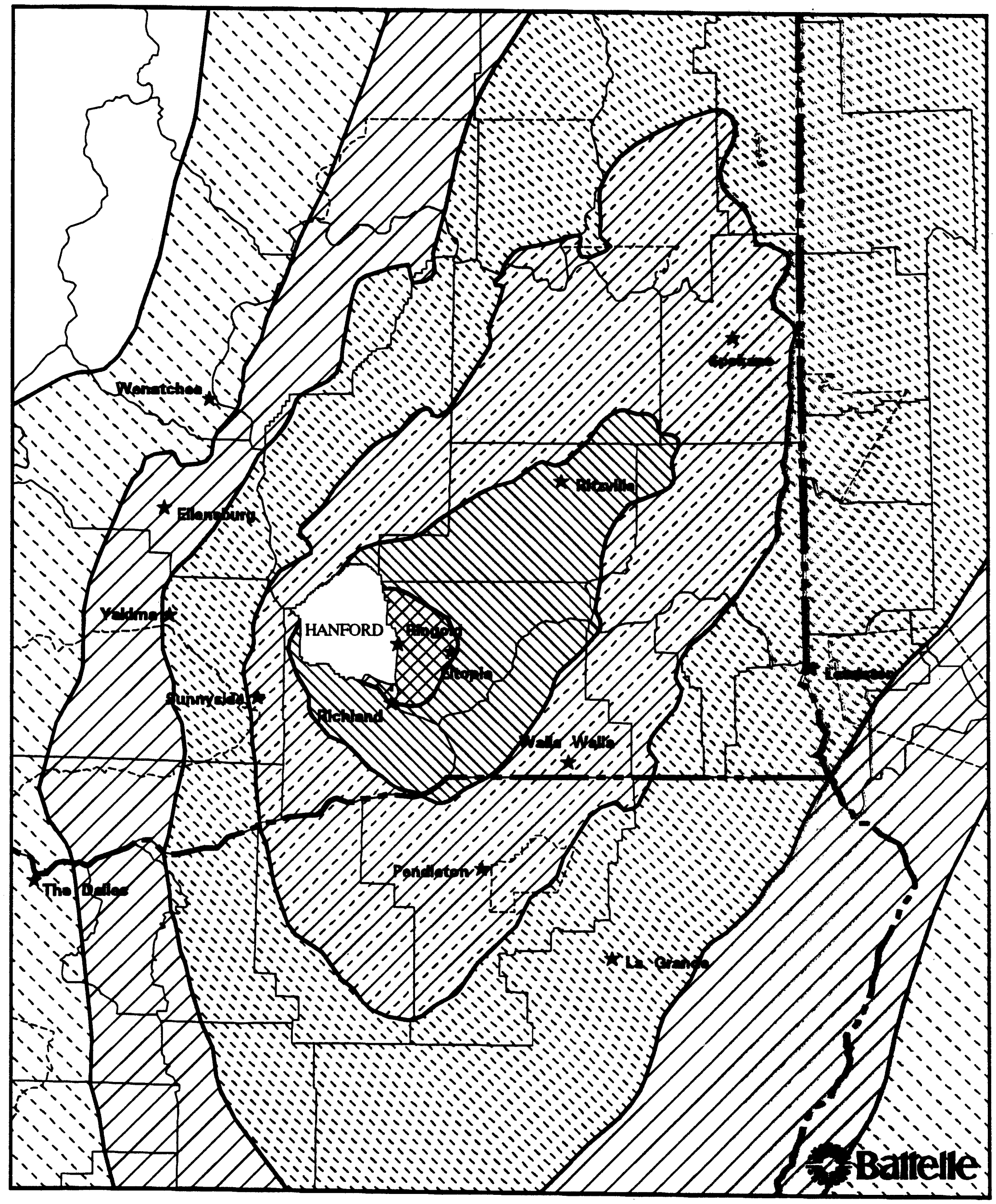
Note: Doses shown are the total annual median dose to the thyroid from all exposure pathways including consumption of foodstuffs (milk, fresh fruits, vegetables, eggs, poultry, and beef), inhalation, and external exposure. All foodstuffs were assumed to be from a backyard source. The milk was produced by a cow that was grazing on fresh pasture. The dose for the year 1945 includes the dose received in the last six days of 1944. To use the figure, pinpoint the location of interest, note the shading, and consult the legend on the adjoining page. The intersection of the shading (column) and sex/age classification of interest (row) shows the dose to that type of individual at that location.

Figure 4.1 Legend. 1945 Iodine-131 Thyroid Dose (rad) from All Air Exposure Pathways - Milk Cows on Fresh Pasture[a]

Sex/Age Category				
All <1 year	0.026 - 0.08	0.08 - 0.26	0.26 - 0.82	0.82 - 2.6
All 1-4 years	0.015 - 0.05	0.05 - 0.15	0.15 - 0.48	0.48 - 1.5
Male 5-9 years	0.010 - 0.03	0.03 - 0.1	0.1 - 0.32	0.32 - 1
Female 5-9 years	0.008 - 0.03	0.03 - 0.08	0.08 - 0.26	0.26 - 0.82
Male 10-14 years	0.006 - 0.02	0.02 - 0.06	0.06 - 0.2	0.2 - 0.63
Female 10-14 years	0.006 - 0.02	0.02 - 0.06	0.06 - 0.18	0.18 - 0.55
Male 15-19 years	0.004 - 0.01	0.01 - 0.04	0.04 - 0.13	0.13 - 0.4
Female 15-19 years	0.003 - 0.01	0.01 - 0.03	0.03 - 0.1	0.1 - 0.32
Male 20-34 years	0.003 - 0.01	0.01 - 0.03	0.03 - 0.09	0.09 - 0.27
Female 20-34 years	0.002 - 0.01	0.01 - 0.02	0.02 - 0.07	0.07 - 0.22
Male >35 years	0.002 - 0.01	0.01 - 0.02	0.02 - 0.08	0.08 - 0.24
Female >35 years	0.002 - 0.01	0.01 - 0.02	0.02 - 0.07	0.07 - 0.22

Sex/Age Category				
All <1 year	2.6 - 8.2	8.2 - 26	26 - 82	82 - 200
All 1-4 years	1.5 - 4.8	4.8 - 15	15 - 48	48 - 120
Male 5-9 years	1 - 3.2	3.2 - 10	10 - 32	32 - 77
Female 5-9 years	0.82 - 2.6	2.6 - 8.2	8.2 - 26	26 - 63
Male 10-14 years	0.63 - 2	2 - 6.3	6.3 - 20	20 - 48
Female 10-14 years	0.55 - 1.8	1.8 - 5.5	5.5 - 18	18 - 42
Male 15-19 years	0.4 - 1.3	1.3 - 4	4 - 13	13 - 31
Female 15-19 years	0.32 - 1	1 - 3.2	3.2 - 10	10 - 24
Male 20-34 years	0.27 - 0.87	0.87 - 2.7	2.7 - 8.7	8.7 - 21
Female 20-34 years	0.22 - 0.72	0.72 - 2.2	2.2 - 7.2	7.2 - 17
Male >35 years	0.24 - 0.76	0.76 - 2.4	2.4 - 7.6	7.6 - 18
Female >35 years	0.22 - 0.72	0.72 - 2.2	2.2 - 7.2	7.2 - 17

(a) The dose estimates are the range of median doses over a geographic area and do not indicate uncertainty in the dose estimates.

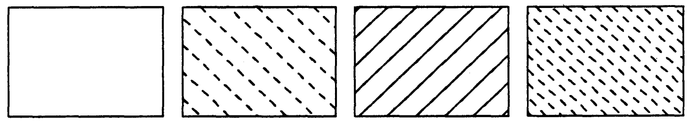


4.2

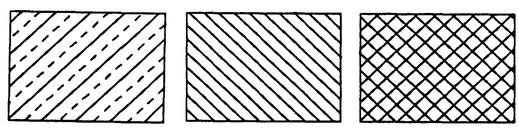
Figure 4.2. 1946 Iodine-131 Thyroid Dose from All Air Exposure Pathways - Milk Cows on Fresh Pasture

Note: Doses shown are the total annual median dose to the thyroid from all exposure pathways including consumption of foodstuffs (milk, fresh fruits, vegetables, eggs, poultry, and beef), inhalation, and external exposure. All foodstuffs were assumed to be from a backyard source. The milk was produced by a cow that was grazing on fresh pasture. To use the figure, pinpoint the location of interest, note the shading, and then consult the legend on the adjoining page. The intersection of the shading (column) and sex/age classification of interest (row) shows the dose to that type of individual at that location.

Figure 4.2 Legend. 1946 Iodine-131 Thyroid Dose (rad) from All Air Exposure Pathways - Milk Cows on Fresh Pasture[a]



Sex/Age Category				
All <1 year	< 0.021	0.021 - 0.07	0.07 - 0.21	0.21 - 0.67
All 1-4 years	< 0.015	0.015 - 0.05	0.05 - 0.15	0.15 - 0.47
Male 5-9 years	< 0.010	0.010 - 0.03	0.03 - 0.1	0.1 - 0.32
Female 5-9 years	< 0.008	0.008 - 0.03	0.03 - 0.08	0.08 - 0.26
Male 10-14 years	< 0.006	0.006 - 0.02	0.02 - 0.06	0.06 - 0.19
Female 10-14 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.17
Male 15-19 years	< 0.004	0.004 - 0.01	0.01 - 0.04	0.04 - 0.12
Female 15-19 years	< 0.003	0.003 - 0.01	0.01 - 0.03	0.03 - 0.1
Male 20-34 years	< 0.003	0.003 - 0.01	0.01 - 0.03	0.03 - 0.09
Female 20-34 years	< 0.002	0.002 - 0.01	0.01 - 0.02	0.02 - 0.08
Male >35 years	< 0.002	0.002 - 0.01	0.01 - 0.02	0.02 - 0.08
Female >35 years	< 0.002	0.002 - 0.01	0.01 - 0.02	0.02 - 0.07



Sex/Age Category			
All <1 year	0.67 - 2.1	2.1 - 6.7	6.7 - 20
All 1-4 years	0.47 - 1.5	1.5 - 4.7	4.7 - 14
Male 5-9 years	0.32 - 1	1 - 3.2	3.2 - 9.4
Female 5-9 years	0.26 - 0.8	0.8 - 2.6	2.6 - 7.5
Male 10-14 years	0.19 - 0.61	0.61 - 1.9	1.9 - 5.7
Female 10-14 years	0.17 - 0.53	0.53 - 1.7	1.7 - 5
Male 15-19 years	0.12 - 0.39	0.39 - 1.2	1.2 - 3.7
Female 15-19 years	0.1 - 0.32	0.32 - 1	1 - 3
Male 20-34 years	0.09 - 0.29	0.29 - 0.91	0.91 - 2.7
Female 20-34 years	0.08 - 0.24	0.24 - 0.78	0.78 - 2.3
Male >35 years	0.08 - 0.24	0.24 - 0.77	0.77 - 2.3
Female >35 years	0.07 - 0.22	0.22 - 0.72	0.72 - 2.1

(a) The dose estimates are the range of median doses over a geographic area and do not indicate uncertainty in the dose estimates.

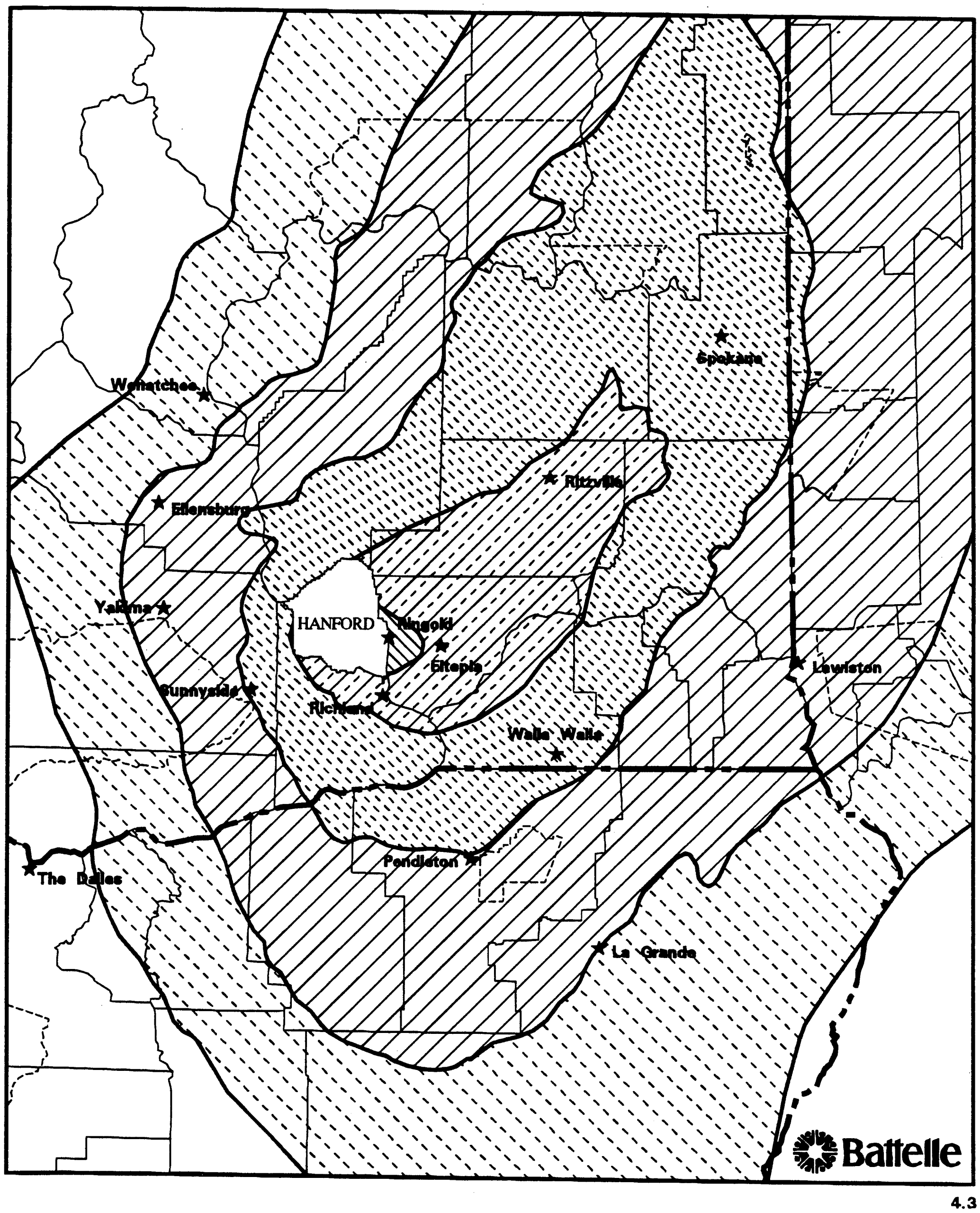
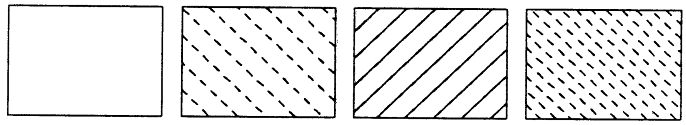


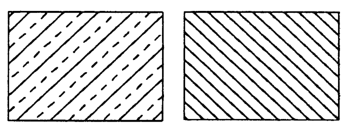
Figure 4.3. 1947 Iodine-131 Thyroid Dose from All Air Exposure Pathways - Milk Cows on Fresh Pasture

Note: Doses shown are the total annual median dose to the thyroid from all exposure pathways including consumption of foodstuffs (milk, fresh fruits, vegetables, eggs, poultry, and beef), inhalation, and external exposure. All foodstuffs were assumed to be from a backyard source. The milk was produced by a cow that was grazing on fresh pasture. To use the figure, pinpoint the location of interest, note the shading, and then consult the legend on the adjoining page. The intersection of the shading (column) and sex/age classification of interest (row) shows the dose to that type of individual at that location.

Figure 4.3 Legend. 1947 Iodine-131 Thyroid Dose (rad) from All Air Exposure Pathways - Milk Cows on Fresh Pasture[(a)]



Sex/Age Category				
All <1 year	< 0.018	0.018 - 0.06	0.06 - 0.18	0.18 - 0.57
All 1-4 years	< 0.015	0.015 - 0.05	0.05 - 0.15	0.15 - 0.47
Male 5-9 years	< 0.010	0.010 - 0.03	0.03 - 0.1	0.1 - 0.32
Female 5-9 years	< 0.008	0.008 - 0.03	0.03 - 0.08	0.08 - 0.26
Male 10-14 years	< 0.006	0.006 - 0.02	0.02 - 0.06	0.06 - 0.2
Female 10-14 years	< 0.006	0.006 - 0.02	0.02 - 0.06	0.06 - 0.18
Male 15-19 years	< 0.004	0.004 - 0.01	0.01 - 0.04	0.04 - 0.13
Female 15-19 years	< 0.003	0.003 - 0.01	0.01 - 0.03	0.03 - 0.11
Male 20-34 years	< 0.003	0.003 - 0.01	0.01 - 0.03	0.03 - 0.1
Female 20-34 years	< 0.003	0.003 - 0.01	0.01 - 0.03	0.03 - 0.09
Male >35 years	< 0.003	0.003 - 0.01	0.01 - 0.03	0.03 - 0.08
Female >35 years	< 0.002	0.002 - 0.01	0.01 - 0.02	0.02 - 0.08



Sex/Age Category		
All <1 year	0.57 - 1.8	1.8 - 4
All 1-4 years	0.47 - 1.5	1.5 - 3.3
Male 5-9 years	0.32 - 1	1 - 2.3
Female 5-9 years	0.26 - 0.8	0.8 - 1.8
Male 10-14 years	0.2 - 0.62	0.62 - 1.4
Female 10-14 years	0.18 - 0.55	0.55 - 1.2
Male 15-19 years	0.13 - 0.41	0.41 - 0.92
Female 15-19 years	0.11 - 0.33	0.33 - 0.75
Male 20-34 years	0.1 - 0.3	0.3 - 0.67
Female 20-34 years	0.09 - 0.27	0.27 - 0.6
Male >35 years	0.08 - 0.25	0.25 - 0.57
Female >35 years	0.08 - 0.24	0.24 - 0.54

(a) The dose estimates are the range of median doses over a geographic area and do not indicate uncertainty in the dose estimates.

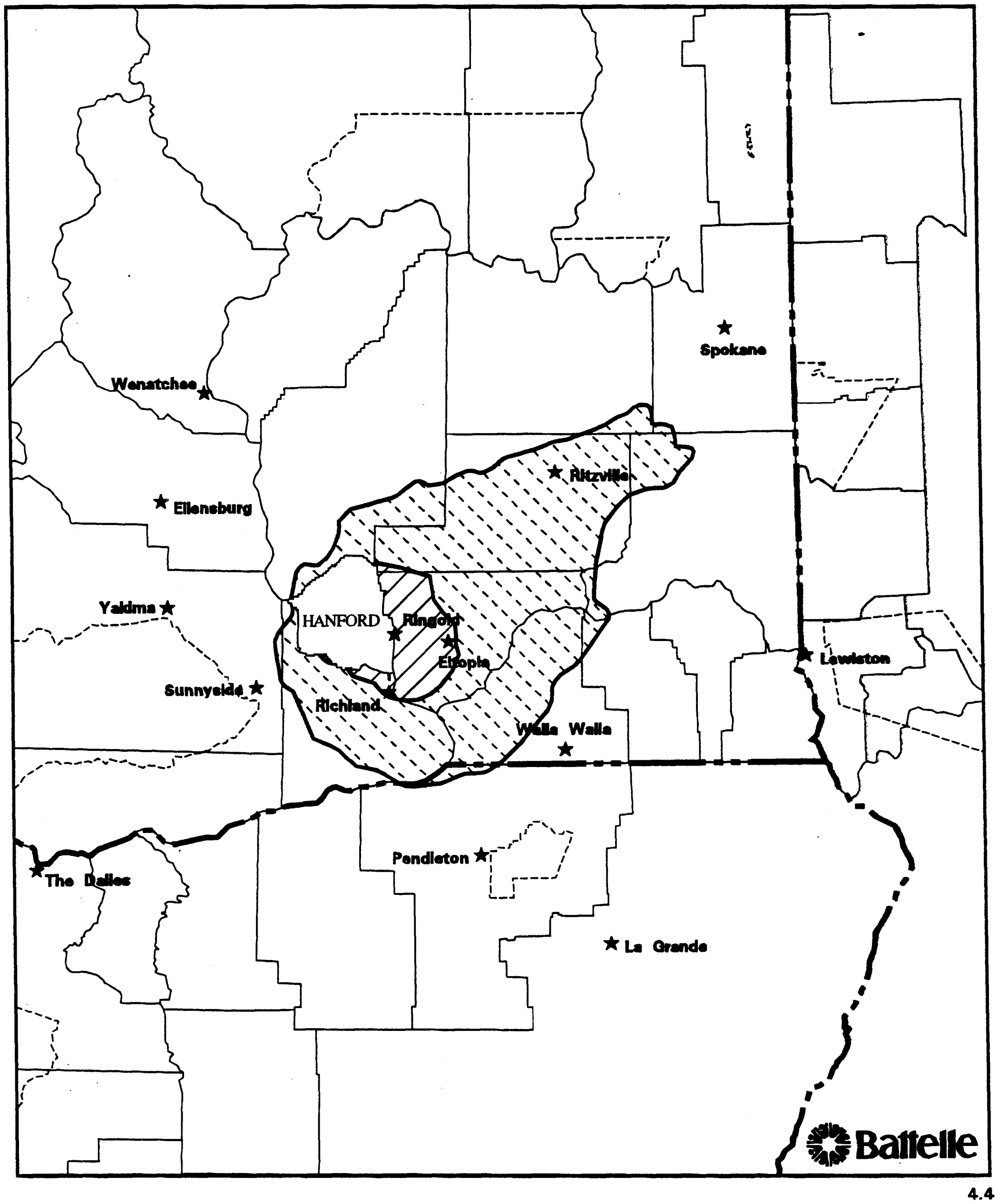
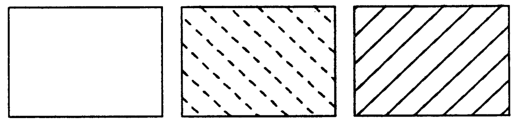


Figure 4.4. 1948 Iodine-131 Thyroid Dose from All Air Exposure Pathways - Milk Cows on Fresh Pasture

Note: Doses shown are the total annual median dose to the thyroid from all exposure pathways including consumption of foodstuffs (milk, fresh fruits, vegetables, eggs, poultry, and beef), inhalation, and external exposure. All foodstuffs were assumed to be from a backyard source. The milk was produced by a cow that was grazing on fresh pasture. To use the figure, pinpoint the location of interest, note the shading, and then consult the legend on the adjoining page. The intersection of the shading (column) and sex/age classification of interest (row) shows the dose to that type of individual at that location.

Figure 4.4 Legend. 1948 Iodine-131 Thyroid Dose (rad) from All Air Exposure Pathways - Milk Cows on Fresh Pasture[a]



Sex/Age Category			
All <1 year	< 0.024	0.024 - 0.08	0.08 - 0.2
All 1-4 years	< 0.015	0.015 - 0.05	0.05 - 0.13
Male 5-9 years	< 0.010	0.010 - 0.03	0.03 - 0.09
Female 5-9 years	< 0.009	0.009 - 0.03	0.03 - 0.07
Male 10-14 years	< 0.006	0.006 - 0.02	0.02 - 0.05
Female 10-14 years	< 0.006	0.006 - 0.02	0.02 - 0.05
Male 15-19 years	< 0.004	0.004 - 0.01	0.01 - 0.04
Female 15-19 years	< 0.003	0.003 - 0.01	0.01 - 0.03
Male 20-34 years	< 0.003	0.003 - 0.01	0.01 - 0.03
Female 20-34 years	< 0.003	0.003 - 0.01	0.01 - 0.02
Male >35 years	< 0.003	0.003 - 0.01	0.01 - 0.02
Female >35 years	< 0.003	0.003 - 0.01	0.01 - 0.02

(a) The dose estimates are the range of median doses over a geographic area and do not indicate uncertainty in the dose estimates.

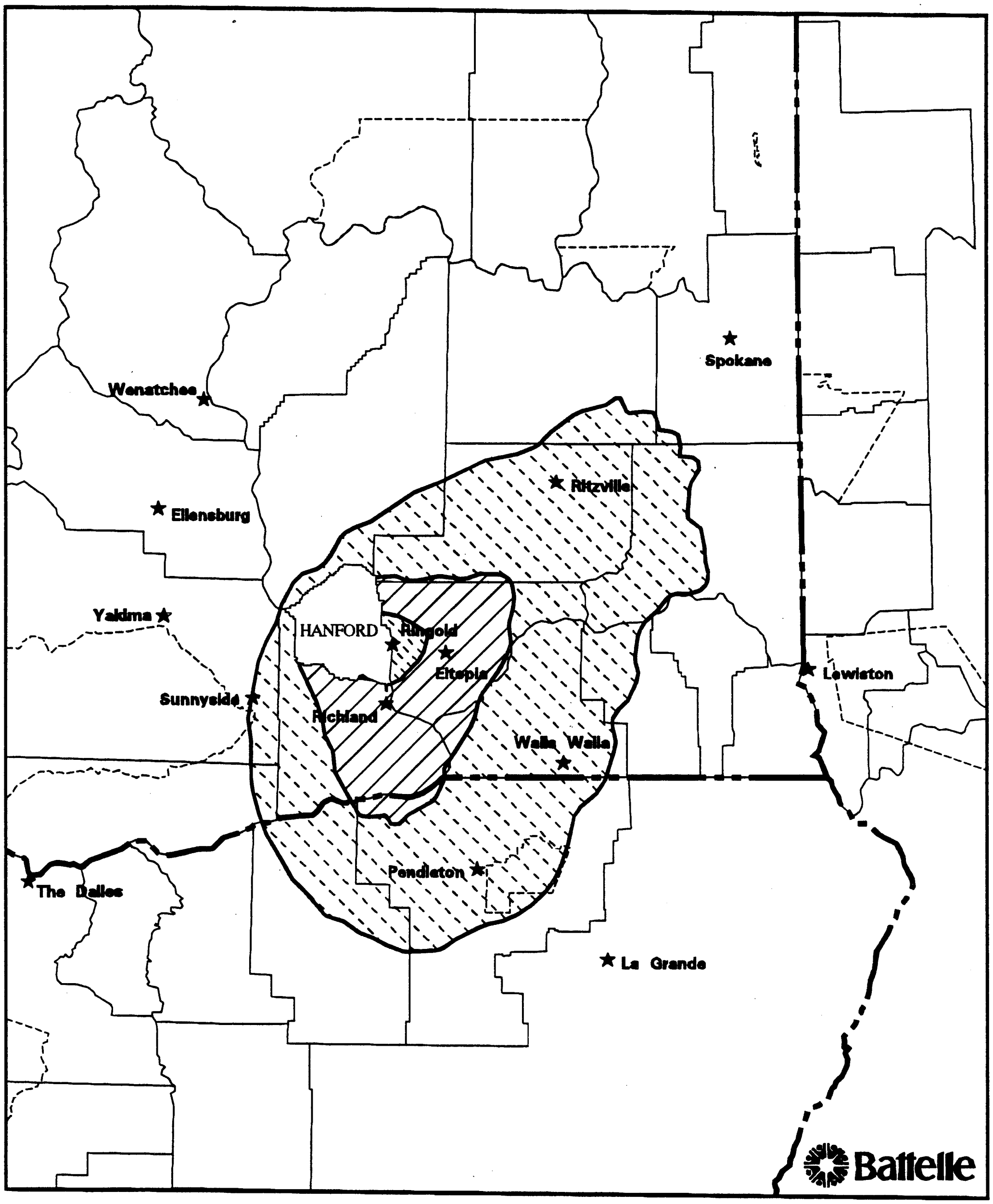
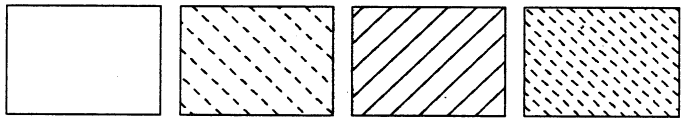


Figure 4.5. 1949 Iodine-131 Thyroid Dose from All Air Exposure Pathways - Milk Cows on Fresh Pasture

Note: Doses shown are the total annual median dose to the thyroid from all exposure pathways including consumption of foodstuffs (milk, fresh fruits, vegetables, eggs, poultry, and beef), inhalation, and external exposure. All foodstuffs were assumed to be from a backyard source. The milk was produced by a cow that was grazing on fresh pasture. To use the figure, pinpoint the location of interest, note the shading, and then consult the legend on the adjoining page. The intersection of the shading (column) and sex/age classification of interest (row) shows the dose to that type of individual at that location.

Figure 4.5 Legend. 1949 Iodine-131 Thyroid Dose (rad) from All Air Exposure Pathways - Milk Cows on Fresh Pasture[a]



Sex/Age Category				
All <1 year	< 0.024	0.024 - 0.08	0.08 - 0.24	0.24 - 0.6
All 1-4 years	< 0.014	0.014 - 0.05	0.05 - 0.14	0.14 - 0.35
Male 5-9 years	< 0.010	0.010 - 0.03	0.03 - 0.1	0.1 - 0.25
Female 5-9 years	< 0.009	0.009 - 0.03	0.03 - 0.09	0.09 - 0.22
Male 10-14 years	< 0.008	0.008 - 0.02	0.02 - 0.08	0.08 - 0.19
Female 10-14 years	< 0.007	0.007 - 0.02	0.02 - 0.07	0.07 - 0.17
Male 15-19 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.13
Female 15-19 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.11
Male 20-34 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.11
Female 20-34 years	< 0.004	0.004 - 0.01	0.01 - 0.04	0.04 - 0.11
Male >35 years	< 0.004	0.004 - 0.01	0.01 - 0.04	0.04 - 0.11
Female >35 years	< 0.005	0.005 - 0.01	0.01 - 0.05	0.05 - 0.11

(a) The dose estimates are the range of median doses over a geographic area and do not indicate uncertainty in the dose estimates.

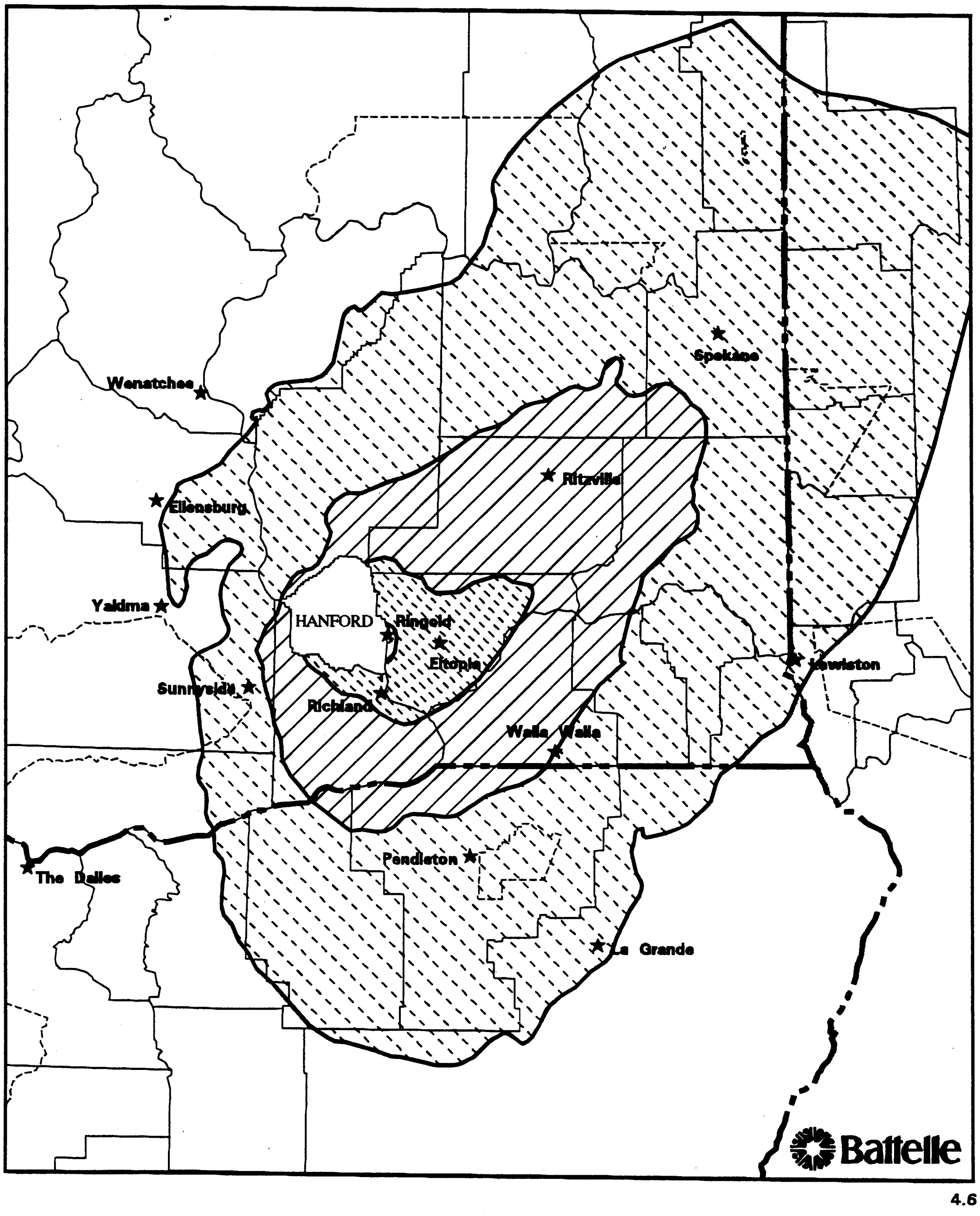


Figure 4.6. 1950 Iodine-131 Thyroid Dose from All Air Exposure Pathways - Milk Cows on Fresh Pasture

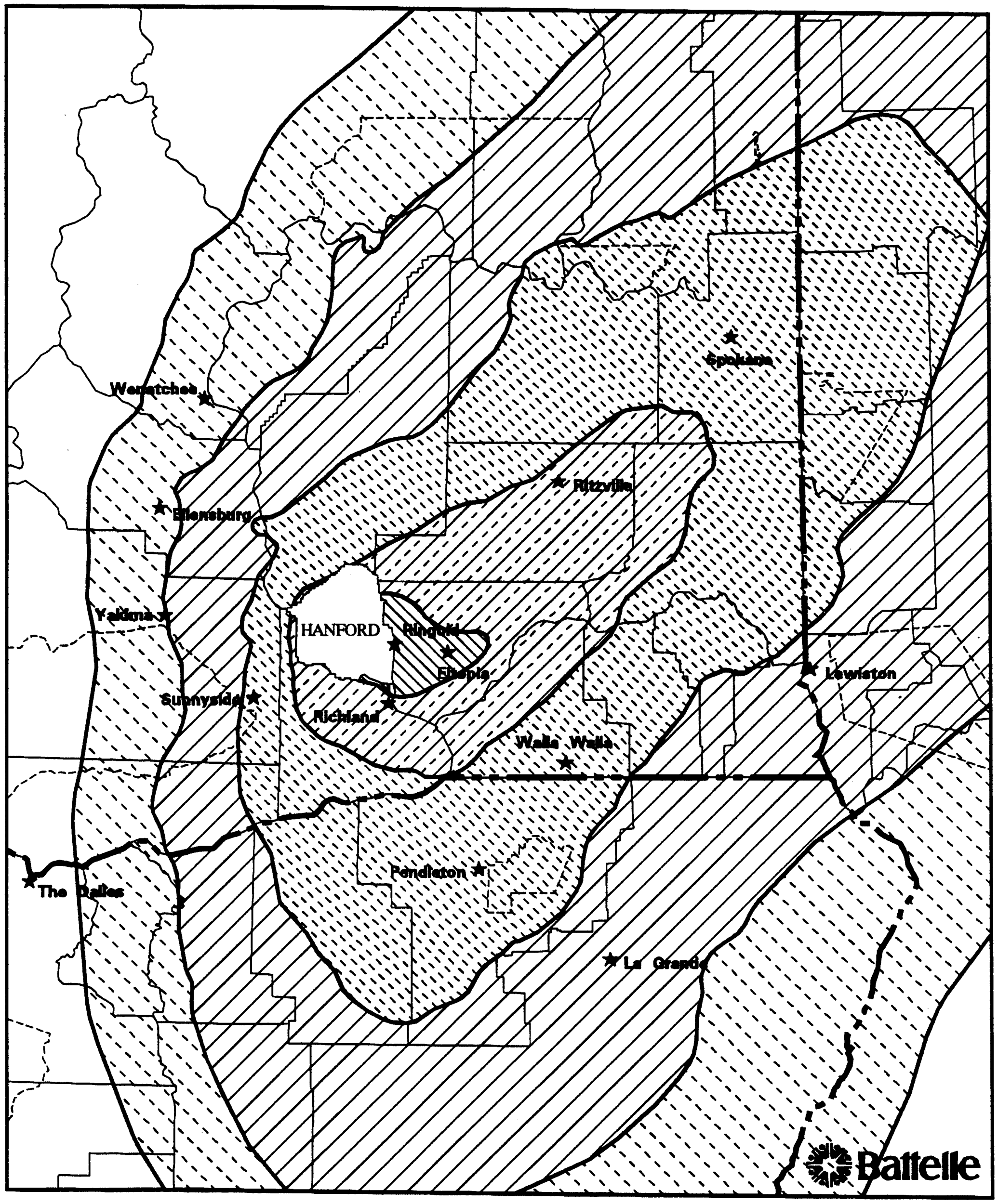
Note: Doses shown are the total annual median dose to the thyroid from all exposure pathways including consumption of foodstuffs (milk, fresh fruits, vegetables, eggs, poultry, and beef), inhalation, and external exposure. All foodstuffs were assumed to be from a backyard source. The milk was produced by a cow that was grazing on fresh pasture. To use the figure, pinpoint the location of interest, note the shading, and then consult the legend on the adjoining page. The intersection of the shading (column) and sex/age classification of interest (row) shows the dose to that type of individual at that location.

Figure 4.6 Legend. 1950 Iodine-131 Thyroid Dose (rad) from All Air Exposure Pathways - Milk Cows on Fresh Pasture[(a)]

Sex/Age Category				
All <1 year	< 0.033	0.033 - 0.11	0.11 - 0.33	0.33 - 1.1
All 1-4 years	< 0.016	0.016 - 0.05	0.05 - 0.16	0.16 - 0.51
Male 5-9 years	< 0.010	0.010 - 0.03	0.03 - 0.1	0.1 - 0.32
Female 5-9 years	< 0.010	0.010 - 0.03	0.03 - 0.1	0.1 - 0.31
Male 10-14 years	< 0.007	0.007 - 0.02	0.02 - 0.07	0.07 - 0.22
Female 10-14 years	< 0.007	0.007 - 0.02	0.02 - 0.07	0.07 - 0.21
Male 15-19 years	< 0.004	0.004 - 0.01	0.01 - 0.04	0.04 - 0.14
Female 15-19 years	< 0.003	0.003 - 0.01	0.01 - 0.03	0.03 - 0.11
Male 20-34 years	< 0.003	0.003 - 0.01	0.01 - 0.03	0.03 - 0.1
Female 20-34 years	< 0.003	0.003 - 0.01	0.01 - 0.03	0.03 - 0.08
Male >35 years	< 0.003	0.003 - 0.01	0.01 - 0.03	0.03 - 0.09
Female >35 years	< 0.003	0.003 - 0.01	0.01 - 0.03	0.03 - 0.09

Sex/Age Category	
All <1 year	1.1 - 1.4
All 1-4 years	0.51 - 0.65
Male 5-9 years	0.32 - 0.41
Female 5-9 years	0.31 - 0.39
Male 10-14 years	0.22 - 0.29
Female 10-14 years	0.21 - 0.27
Male 15-19 years	0.14 - 0.18
Female 15-19 years	0.11 - 0.14
Male 20-34 years	0.1 - 0.13
Female 20-34 years	0.08 - 0.11
Male >35 years	0.09 - 0.12
Female >35 years	0.09 - 0.11

(a) The dose estimates are the range of median doses over a geographic area and do not indicate uncertainty in the dose estimates.

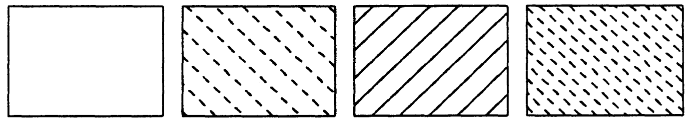


4.7

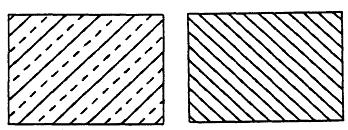
Figure 4.7. 1951 Iodine-131 Thyroid Dose from All Air Exposure Pathways - Milk Cows on Fresh Pasture

Note: Doses shown are the total annual median dose to the thyroid from all exposure pathways including consumption of foodstuffs (milk, fresh fruits, vegetables, eggs, poultry, and beef), inhalation, and external exposure. All foodstuffs were assumed to be from a backyard source. The milk was produced by a cow that was grazing on fresh pasture. To use the figure, pinpoint the location of interest, note the shading, and then consult the legend on the adjoining page. The intersection of the shading (column) and sex/age classification of interest (row) shows the dose to that type of individual at that location.

Figure 4.7 Legend. 1951 Iodine-131 Thyroid Dose (rad) from All Air Exposure Pathways - Milk Cows on Fresh Pasture[a]



Sex/Age Category				
All <1 year	< 0.018	0.018 - 0.06	0.06 - 0.18	0.18 - 0.58
All 1-4 years	< 0.014	0.014 - 0.05	0.05 - 0.14	0.14 - 0.46
Male 5-9 years	< 0.010	0.010 - 0.03	0.03 - 0.1	0.1 - 0.32
Female 5-9 years	< 0.010	0.010 - 0.03	0.03 - 0.1	0.1 - 0.3
Male 10-14 years	< 0.007	0.007 - 0.02	0.02 - 0.07	0.07 - 0.21
Female 10-14 years	< 0.006	0.006 - 0.02	0.02 - 0.06	0.06 - 0.19
Male 15-19 years	< 0.004	0.004 - 0.01	0.01 - 0.04	0.04 - 0.14
Female 15-19 years	< 0.003	0.003 - 0.01	0.01 - 0.03	0.03 - 0.11
Male 20-34 years	< 0.003	0.003 - 0.01	0.01 - 0.03	0.03 - 0.09
Female 20-34 years	< 0.002	0.002 - 0.01	0.01 - 0.02	0.02 - 0.07
Male >35 years	< 0.002	0.002 - 0.01	0.01 - 0.02	0.02 - 0.07
Female >35 years	< 0.002	0.002 - 0.01	0.01 - 0.02	0.02 - 0.07



Sex/Age Category		
All <1 year	0.58 - 1.8	1.8 - 5.3
All 1-4 years	0.46 - 1.4	1.4 - 4.1
Male 5-9 years	0.32 - 1	1 - 2.9
Female 5-9 years	0.3 - 0.95	0.95 - 2.7
Male 10-14 years	0.21 - 0.65	0.65 - 1.9
Female 10-14 years	0.19 - 0.59	0.59 - 1.7
Male 15-19 years	0.14 - 0.43	0.43 - 1.2
Female 15-19 years	0.11 - 0.33	0.33 - 0.97
Male 20-34 years	0.09 - 0.28	0.28 - 0.82
Female 20-34 years	0.07 - 0.23	0.23 - 0.67
Male >35 years	0.07 - 0.23	0.23 - 0.67
Female >35 years	0.07 - 0.21	0.21 - 0.6

(a) The dose estimates are the range of median doses over a geographic area and do not indicate uncertainty in the dose estimates.

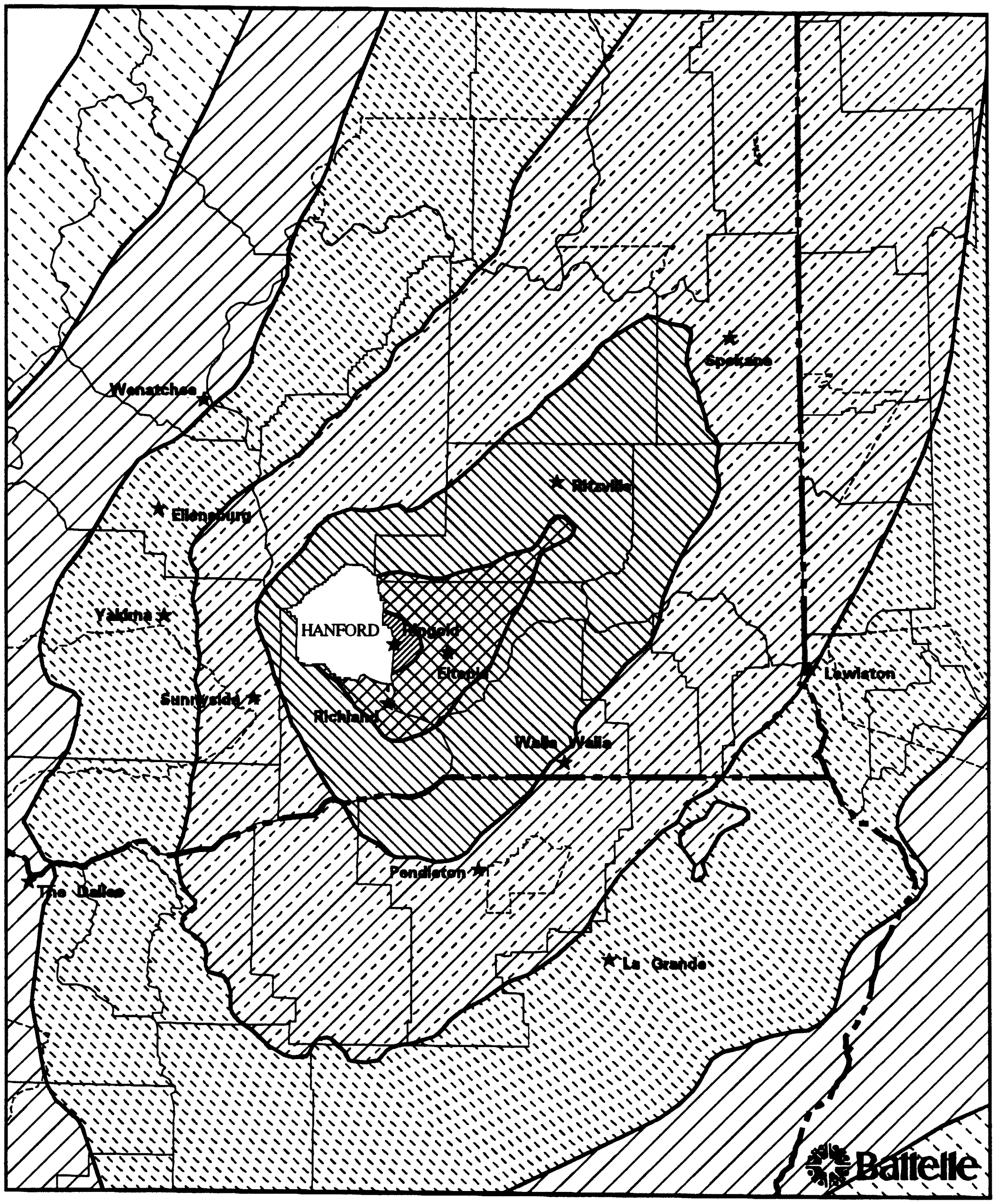


Figure 4.8. 1945 Iodine-131 Thyroid Dose from All Air Exposure Pathways - Milk Cows on Stored Feed

Note: Doses shown are the total annual median dose to the thyroid from all air exposure pathways including consumptions of foodstuffs (milk, fresh fruits, vegetables, eggs, poultry, and beef), inhalation, and external exposure. All foodstuffs were assumed to be from a backyard source. The milk was produced by a cow that was fed stored feed. The dose for the year 1945 includes the dose received in the last six days of 1944. To use the figure, pinpoint the location of interest, note the shading, and then consult the legend on the adjoining page. The intersection of the shading (column) and sex/age classification of interest (row) shows the dose to that type of individual at that location.

Figure 4.8 Legend. 1945 Iodine-131 Thyroid Dose (rad) from All Air Exposure Pathways - Milk Cows on Stored Feed[(a)]

Sex/Age Category				
All <1 year	< 0.030	0.030 - 0.1	0.1 - 0.3	0.3 - 0.95
All 1-4 years	< 0.015	0.015 - 0.05	0.05 - 0.15	0.15 - 0.49
Male 5-9 years	< 0.010	0.010 - 0.03	0.03 - 0.1	0.1 - 0.32
Female 5-9 years	< 0.010	0.010 - 0.03	0.03 - 0.1	0.1 - 0.31
Male 10-14 years	< 0.008	0.008 - 0.02	0.02 - 0.08	0.08 - 0.24
Female 10-14 years	< 0.007	0.007 - 0.02	0.02 - 0.07	0.07 - 0.23
Male 15-19 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.16
Female 15-19 years	< 0.004	0.004 - 0.01	0.01 - 0.04	0.04 - 0.14
Male 20-34 years	< 0.005	0.005 - 0.01	0.01 - 0.05	0.05 - 0.14
Female 20-34 years	< 0.004	0.004 - 0.01	0.01 - 0.04	0.04 - 0.14
Male >35 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.15
Female >35 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.16

Sex/Age Category				
All <1 year	0.95 - 3	3 - 9.5	9.5 - 30	30 - 57
All 1-4 years	0.49 - 1.5	1.5 - 4.9	4.9 - 15	15 - 29
Male 5-9 years	0.32 - 1	1 - 3.2	3.2 - 10	10 - 19
Female 5-9 years	0.31 - 0.97	0.97 - 3.1	3.1 - 9.7	9.7 - 19
Male 10-14 years	0.24 - 0.75	0.75 - 2.4	2.4 - 7.5	7.5 - 14
Female 10-14 years	0.23 - 0.72	0.72 - 2.3	2.3 - 7.2	7.2 - 14
Male 15-19 years	0.16 - 0.5	0.5 - 1.6	1.6 - 5	5 - 9.7
Female 15-19 years	0.14 - 0.43	0.43 - 1.4	1.4 - 4.3	4.3 - 8.4
Male 20-34 years	0.14 - 0.45	0.45 - 1.4	1.4 - 4.5	4.5 - 8.6
Female 20-34 years	0.14 - 0.44	0.44 - 1.4	1.4 - 4.4	4.4 - 8.5
Male >35 years	0.15 - 0.48	0.48 - 1.5	1.5 - 4.8	4.8 - 9.3
Female >35 years	0.16 - 0.51	0.51 - 1.6	1.6 - 5.1	5.1 - 9.8

(a) The dose estimates are the range of median doses over a geographic area and do not indicate uncertainty in the dose estimates.

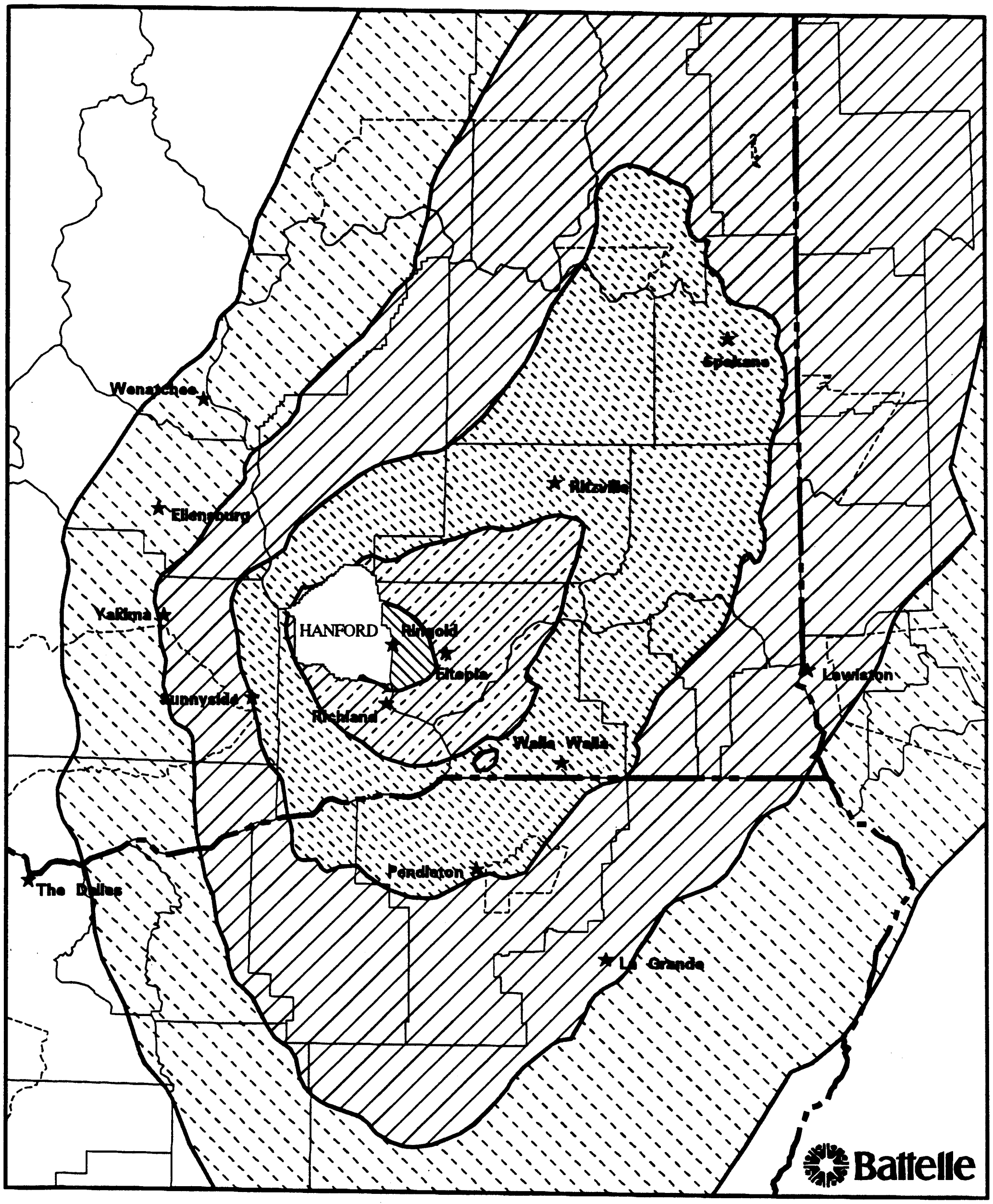


Figure 4.9. 1946 Iodine-131 Thyroid Dose from All Air Exposure Pathways - Milk Cows on Stored Feed

Note: Doses shown are the total annual median dose to the thyroid from all air exposure pathways including consumption of foodstuffs (milk, fresh fruits, vegetables, eggs, poultry, and beef), inhalation, and external exposure. All foodstuffs were assumed to be from a backyard source. The milk was produced by a cow that was fed stored feed. To use the figure, pinpoint the location of interest, note the shading, and then consult the legend on the adjoining page. The intersection of the shading (column) and sex/age classification of interest (row) shows the dose to that type of individual at that location.

Figure 4.9 Legend. 1946 Iodine-131 Thyroid Dose (rad) from All Air Exposure Pathways - Milk Cows on Stored Feed[a]

Sex/Age Category				
All <1 year	< 0.023	0.023 - 0.07	0.07 - 0.23	0.23 - 0.74
All 1-4 years	< 0.015	0.015 - 0.05	0.05 - 0.15	0.15 - 0.49
Male 5-9 years	< 0.010	0.010 - 0.03	0.03 - 0.1	0.1 - 0.32
Female 5-9 years	< 0.010	0.010 - 0.03	0.03 - 0.1	0.1 - 0.32
Male 10-14 years	< 0.008	0.008 - 0.03	0.03 - 0.08	0.08 - 0.25
Female 10-14 years	< 0.007	0.007 - 0.02	0.02 - 0.07	0.07 - 0.23
Male 15-19 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.17
Female 15-19 years	< 0.004	0.004 - 0.01	0.01 - 0.04	0.04 - 0.14
Male 20-34 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.16
Female 20-34 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.16
Male >35 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.16
Female >35 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.17

Sex/Age Category		
All <1 year	0.74 - 2.3	2.3 - 5.3
All 1-4 years	0.49 - 1.5	1.5 - 3.5
Male 5-9 years	0.32 - 1	1 - 2.3
Female 5-9 years	0.32 - 0.99	0.99 - 2.2
Male 10-14 years	0.25 - 0.77	0.77 - 1.8
Female 10-14 years	0.23 - 0.71	0.71 - 1.6
Male 15-19 years	0.17 - 0.53	0.53 - 1.2
Female 15-19 years	0.14 - 0.44	0.44 - 1
Male 20-34 years	0.16 - 0.49	0.49 - 1.1
Female 20-34 years	0.16 - 0.49	0.49 - 1.1
Male >35 years	0.16 - 0.5	0.5 - 1.1
Female >35 years	0.17 - 0.54	0.54 - 1.2

(a) The dose estimates are the range of median doses over a geographic area and do not indicate uncertainty in the dose estimates.

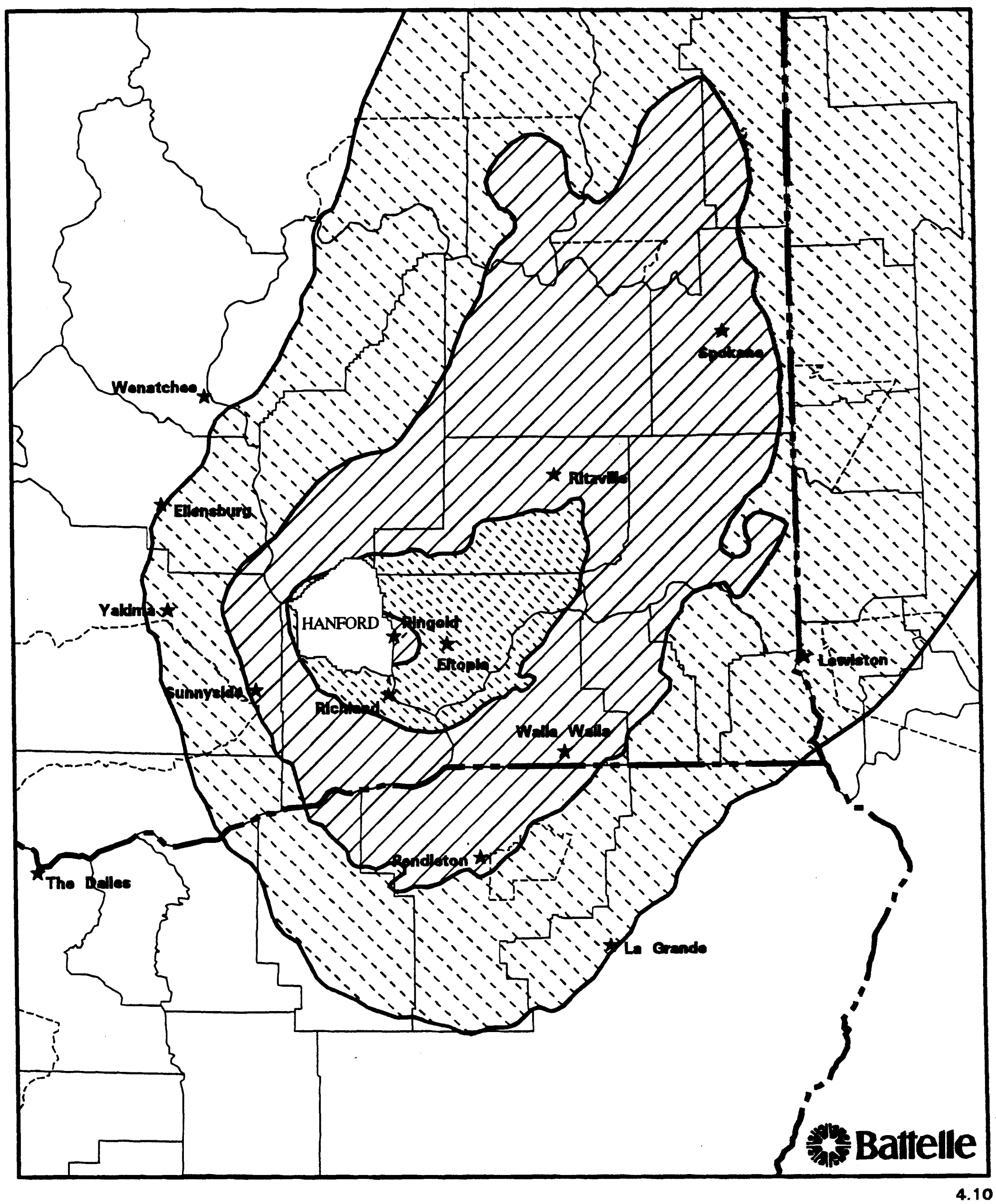
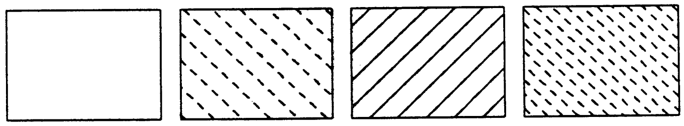


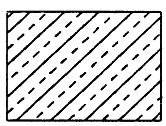
Figure 4.10. 1947 Iodine-131 Thyroid Dose from All Air Exposure Pathways - Milk Cows on Stored Feed

Note: Doses shown are the total annual median dose to the thyroid from all exposure pathways including consumption of foodstuffs (milk, fresh fruits, vegetables, eggs, poultry, and beef), inhalation, and external exposure. All foodstuffs were assumed to be from a backyard source. The milk was produced by a cow that was fed stored feed. To use the figure, pinpoint the location of interest, note the shading, and then consult the legend on the adjoining page. The intersection of the shading (column) and sex/age classification of interest (row) shows the dose to that type of individual at that location.

Figure 4.10 Legend. 1947 Iodine-131 Thyroid Dose (rad) from All Air Exposure Pathways - Milk Cows on Stored Feed[a]



Sex/Age Category				
All <1 year	< 0.018	0.018 - 0.06	0.06 - 0.18	0.18 - 0.58
All 1-4 years	< 0.015	0.015 - 0.05	0.05 - 0.15	0.15 - 0.49
Male 5-9 years	< 0.010	0.010 - 0.03	0.03 - 0.1	0.1 - 0.32
Female 5-9 years	< 0.010	0.010 - 0.03	0.03 - 0.1	0.1 - 0.31
Male 10-14 years	< 0.008	0.008 - 0.03	0.03 - 0.08	0.08 - 0.25
Female 10-14 years	< 0.007	0.007 - 0.02	0.02 - 0.07	0.07 - 0.23
Male 15-19 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.17
Female 15-19 years	< 0.005	0.005 - 0.01	0.01 - 0.05	0.05 - 0.14
Male 20-34 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.15
Female 20-34 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.16
Male >35 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.15
Female >35 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.17



Sex/Age Category	
All <1 year	0.58 - 1.1
All 1-4 years	0.49 - 0.91
Male 5-9 years	0.32 - 0.6
Female 5-9 years	0.31 - 0.57
Male 10-14 years	0.25 - 0.47
Female 10-14 years	0.23 - 0.42
Male 15-19 years	0.17 - 0.32
Female 15-19 years	0.14 - 0.27
Male 20-34 years	0.15 - 0.29
Female 20-34 years	0.16 - 0.3
Male >35 years	0.15 - 0.28
Female >35 years	0.17 - 0.31

(a) The dose estimates are the range of median doses over a geographic area and do not indicate uncertainty in the dose estimates.

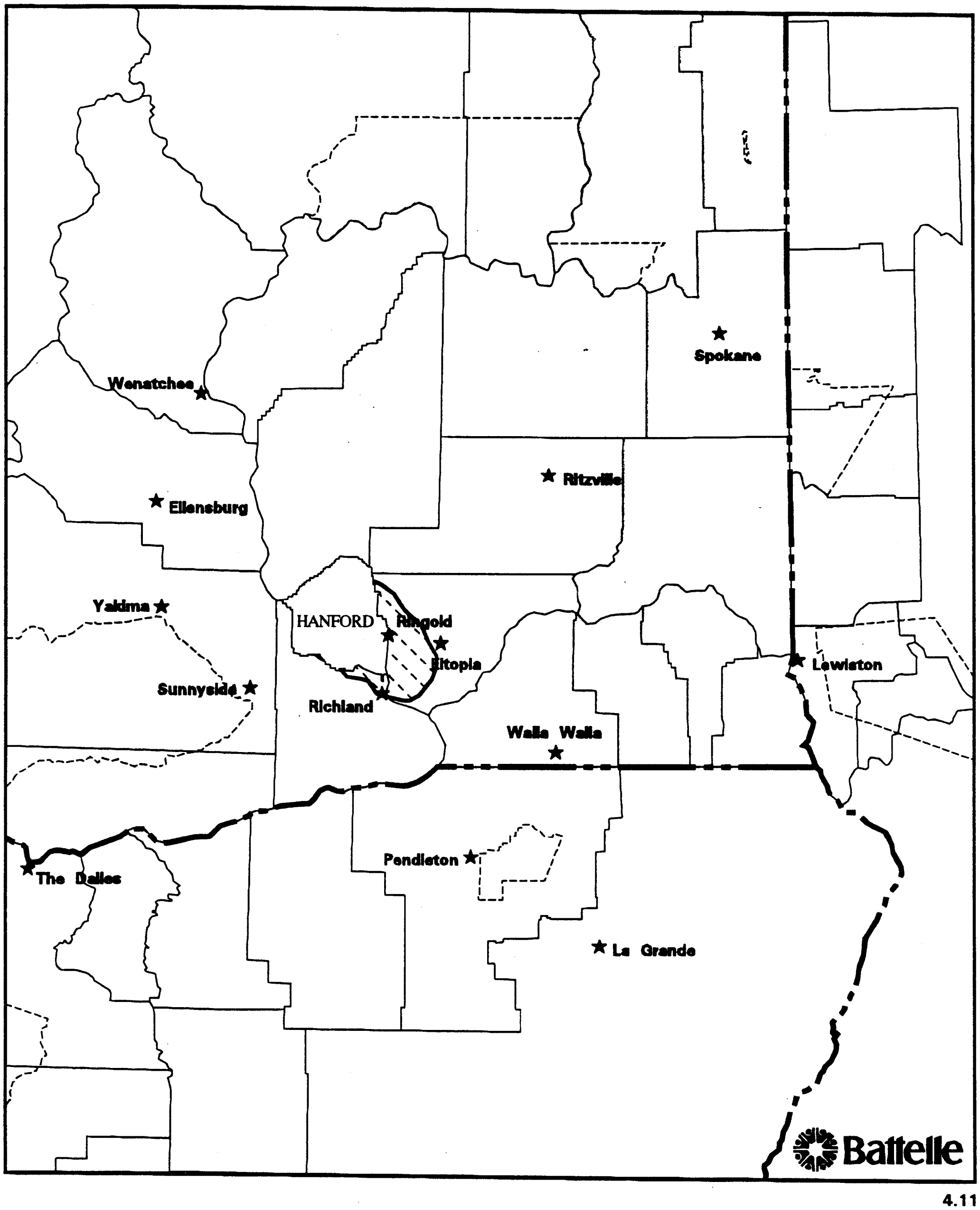
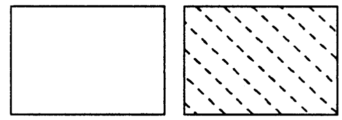


Figure 4.11. 1948 Iodine-131 Thyroid Dose from All Air Exposure Pathways - Milk Cows on Stored Feed

Note: Doses shown are the total annual median dose to the thyroid from all exposure pathways including consumption of foodstuffs (milk, fresh fruits, vegetables, eggs, poultry, and beef), inhalation, and external exposure. All foodstuffs were assumed to be from a backyard source. The milk was produced by a cow that was fed stored feed. To use the figure, pinpoint the location of interest, note the shading, and then consult the legend on the adjoining page. The intersection of the shading (column) and sex/age classification of interest (row) shows the dose to that type of individual at that location.

Figure 4.11 Legend. 1948 Iodine-131 Thyroid Dose (rad) from All Air Exposure Pathways - Milk Cows on Stored Feed[a]



Sex/Age Category		
All <1 year	< 0.027	0.027 - 0.06
All 1-4 years	< 0.015	0.015 - 0.03
Male 5-9 years	< 0.010	0.010 - 0.02
Female 5-9 years	< 0.010	0.010 - 0.02
Male 10-14 years	< 0.008	0.008 - 0.02
Female 10-14 years	< 0.008	0.008 - 0.02
Male 15-19 years	< 0.006	0.006 - 0.01
Female 15-19 years	< 0.005	0.005 - 0.01
Male 20-34 years	< 0.005	0.005 - 0.01
Female 20-34 years	< 0.006	0.006 - 0.01
Male >35 years	< 0.006	0.006 - 0.01
Female >35 years	< 0.006	0.006 - 0.01

(a) The dose estimates are the range of median doses over a geographic area and do not indicate uncertainty in the dose estimates.

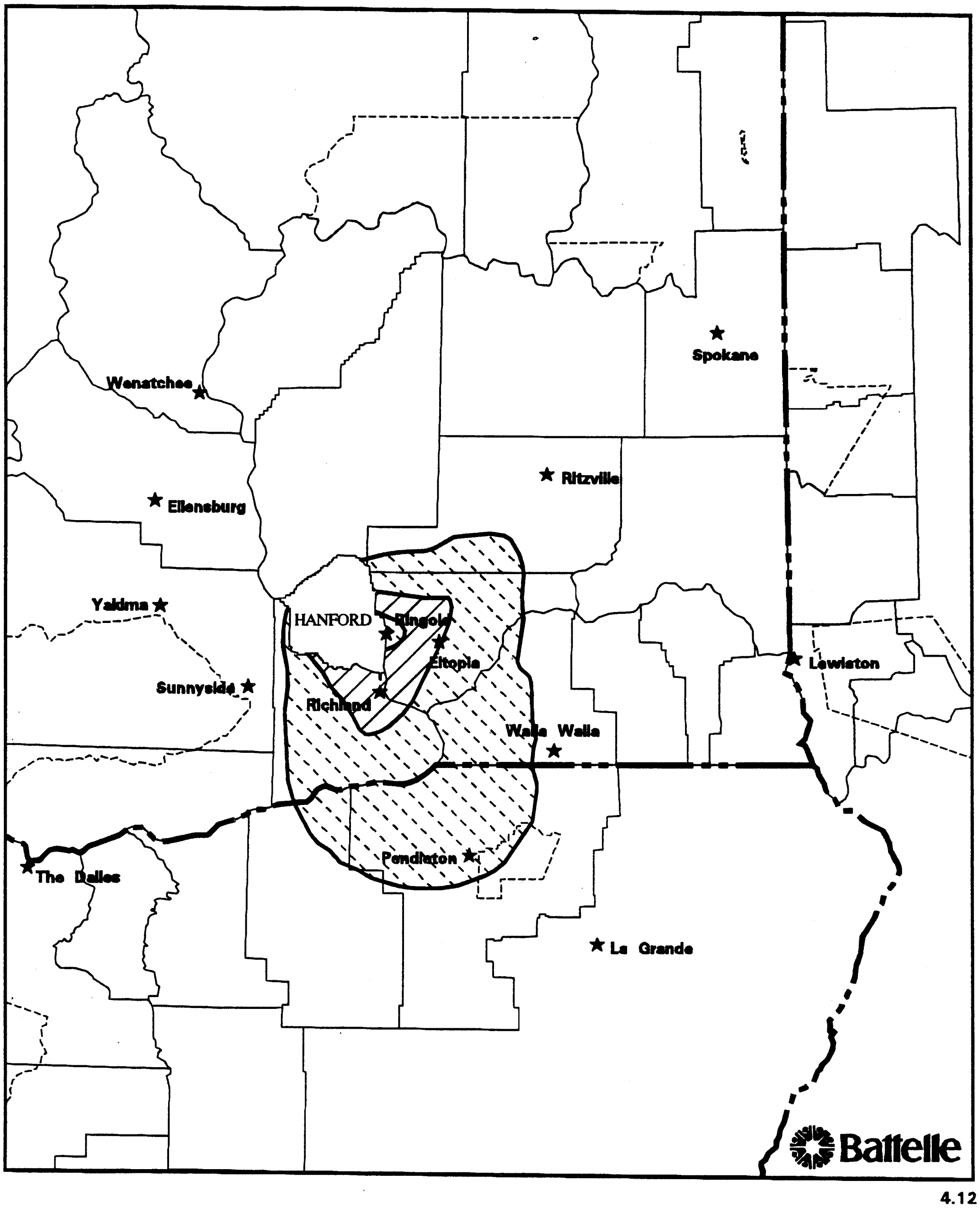


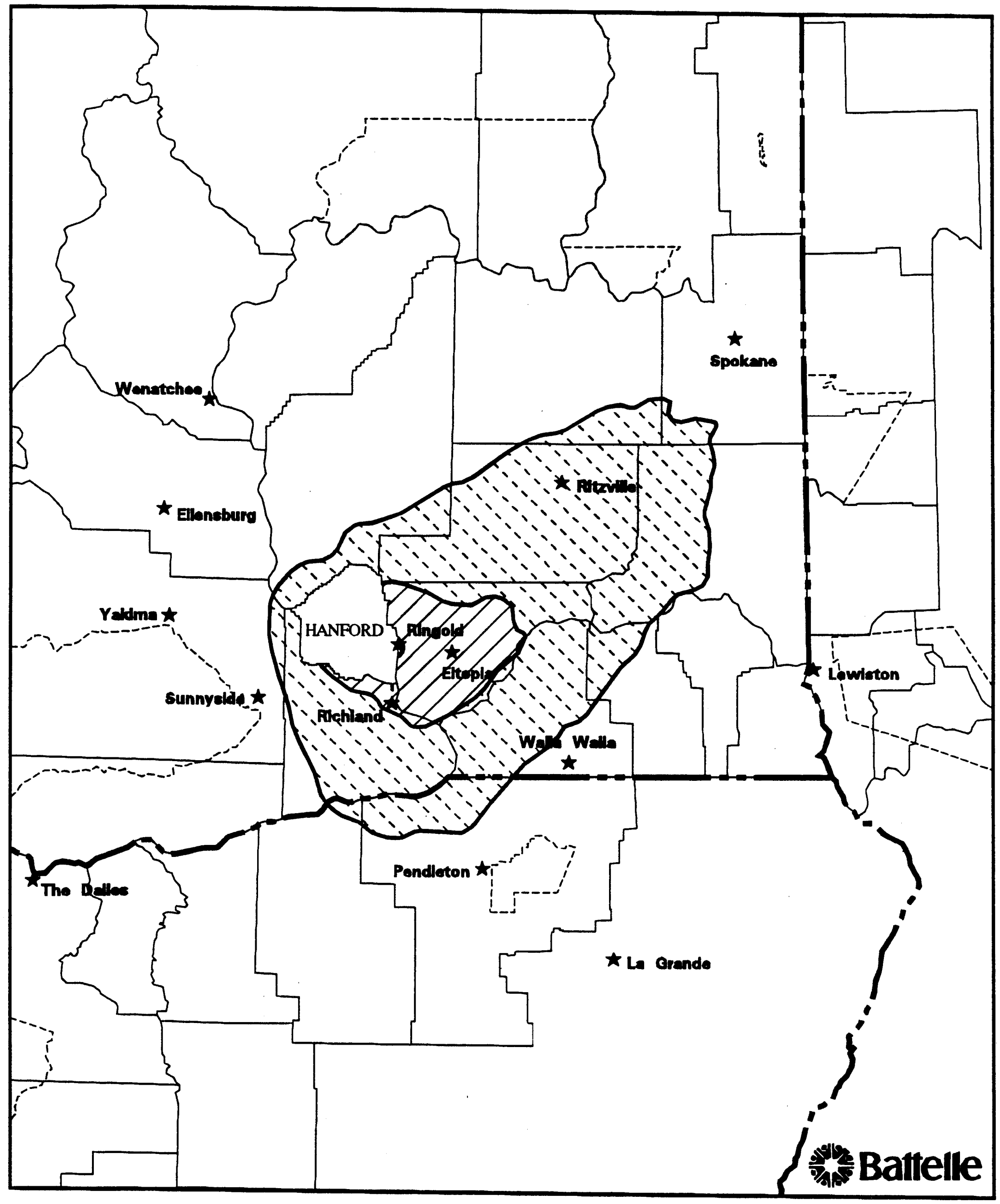
Figure 4.12. 1949 Iodine-131 Thyroid Dose from All Air Exposure Pathways - Milk Cows on Stored Feed

Note: Doses shown are the total annual median dose to the thyroid from all exposure pathways including consumption of foodstuffs (milk, fresh fruits, vegetables, eggs, poultry, and beef), inhalation, and external exposure. All foodstuffs were assumed to be from a backyard source. The milk was produced by a cow that was fed stored feed. To use the figure, pinpoint the location of interest, note the shading, and then consult the legend on the adjoining page. The intersection of the shading (column) and sex/age classification of interest (row) shows the dose to that type of individual at that location.

Figure 4.12 Legend. 1949 Iodine-131 Thyroid Dose (rad) from All Air Exposure Pathways - Milk Cows on Stored Feed[(a)]

Sex/Age Category				
All <1 year	< 0.026	0.026 - 0.08	0.08 - 0.26	0.26 - 0.43
All 1-4 years	< 0.014	0.014 - 0.04	0.04 - 0.14	0.14 - 0.23
Male 5-9 years	< 0.010	0.010 - 0.03	0.03 - 0.1	0.1 - 0.17
Female 5-9 years	< 0.009	0.009 - 0.03	0.03 - 0.09	0.09 - 0.16
Male 10-14 years	< 0.009	0.009 - 0.03	0.03 - 0.09	0.09 - 0.15
Female 10-14 years	< 0.008	0.008 - 0.03	0.03 - 0.08	0.08 - 0.13
Male 15-19 years	< 0.006	0.006 - 0.02	0.02 - 0.06	0.06 - 0.1
Female 15-19 years	< 0.006	0.006 - 0.02	0.02 - 0.06	0.06 - 0.1
Male 20-34 years	< 0.006	0.006 - 0.02	0.02 - 0.06	0.06 - 0.11
Female 20-34 years	< 0.006	0.006 - 0.02	0.02 - 0.06	0.06 - 0.1
Male >35 years	< 0.006	0.006 - 0.02	0.02 - 0.06	0.06 - 0.11
Female >35 years	< 0.007	0.007 - 0.02	0.02 - 0.07	0.07 - 0.11

(a) The dose estimates are the range of median doses over a geographic area and do not indicate uncertainty in the dose estimates.



4.13

Figure 4.13. 1950 Iodine-131 Thyroid Dose from All Air Exposure Pathways - Milk Cows on Stored Feed

Note: Doses shown are the total annual median dose to the thyroid from all exposure pathways including consumption of foodstuffs (milk, fresh fruits, vegetables, eggs, poultry, and beef), inhalation, and external exposure. All foodstuffs were assumed to be from a backyard source. The milk was produced by a cow that was fed stored feed. To use the figure, pinpoint the location of interest, note the shading, and then consult the legend on the adjoining page. The intersection of the shading (column) and sex/age classification of interest (row) shows the dose to that type of individual at that location.

Figure 4.13 Legend. 1950 Iodine-131 Thyroid Dose (rad) from All Air Exposure Pathways - Milk Cows on Stored Feed[(a)]

Sex/Age Category				
All <1 year	< 0.033	0.033 - 0.1	0.1 - 0.33	0.33 - 0.36
All 1-4 years	< 0.016	0.016 - 0.05	0.05 - 0.16	0.16 - 0.18
Male 5-9 years	< 0.010	0.010 - 0.03	0.03 - 0.1	0.1 - 0.11
Female 5-9 years	< 0.010	0.010 - 0.03	0.03 - 0.1	0.1 - 0.11
Male 10-14 years	< 0.008	0.008 - 0.03	0.03 - 0.08	0.08 - 0.09
Female 10-14 years	< 0.008	0.008 - 0.03	0.03 - 0.08	0.08 - 0.08
Male 15-19 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.06
Female 15-19 years	< 0.004	0.004 - 0.01	0.01 - 0.04	0.04 - 0.05
Male 20-34 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.05
Female 20-34 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.05
Male >35 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.05
Female >35 years	< 0.006	0.006 - 0.02	0.02 - 0.06	0.06 - 0.06

(a) The dose estimates are the range of median doses over a geographic area and do not indicate uncertainty in the dose estimates.

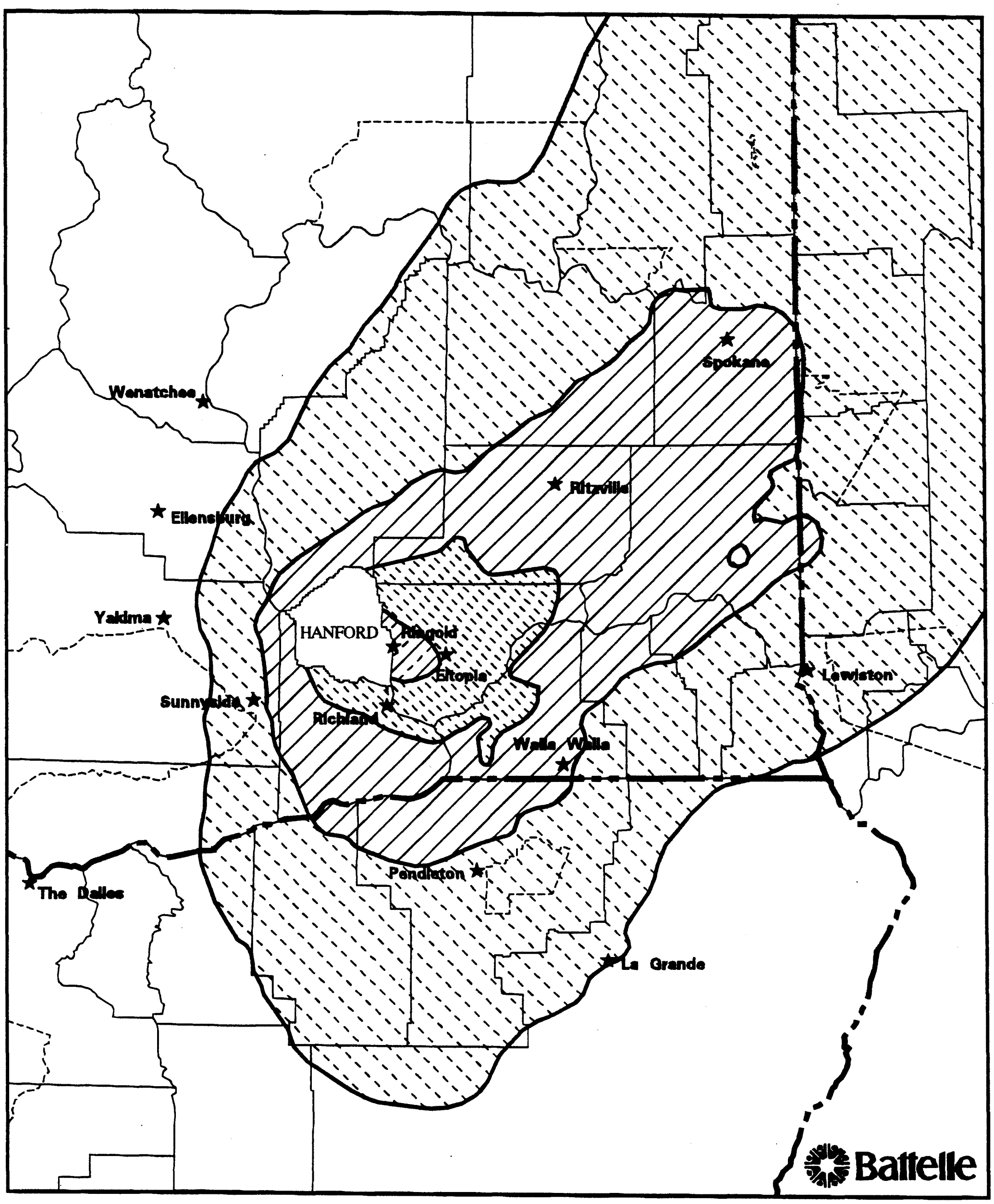


Figure 4.14. 1951 Iodine-131 Thyroid Dose from All Air Exposure Pathways - Milk Cows on Stored Feed

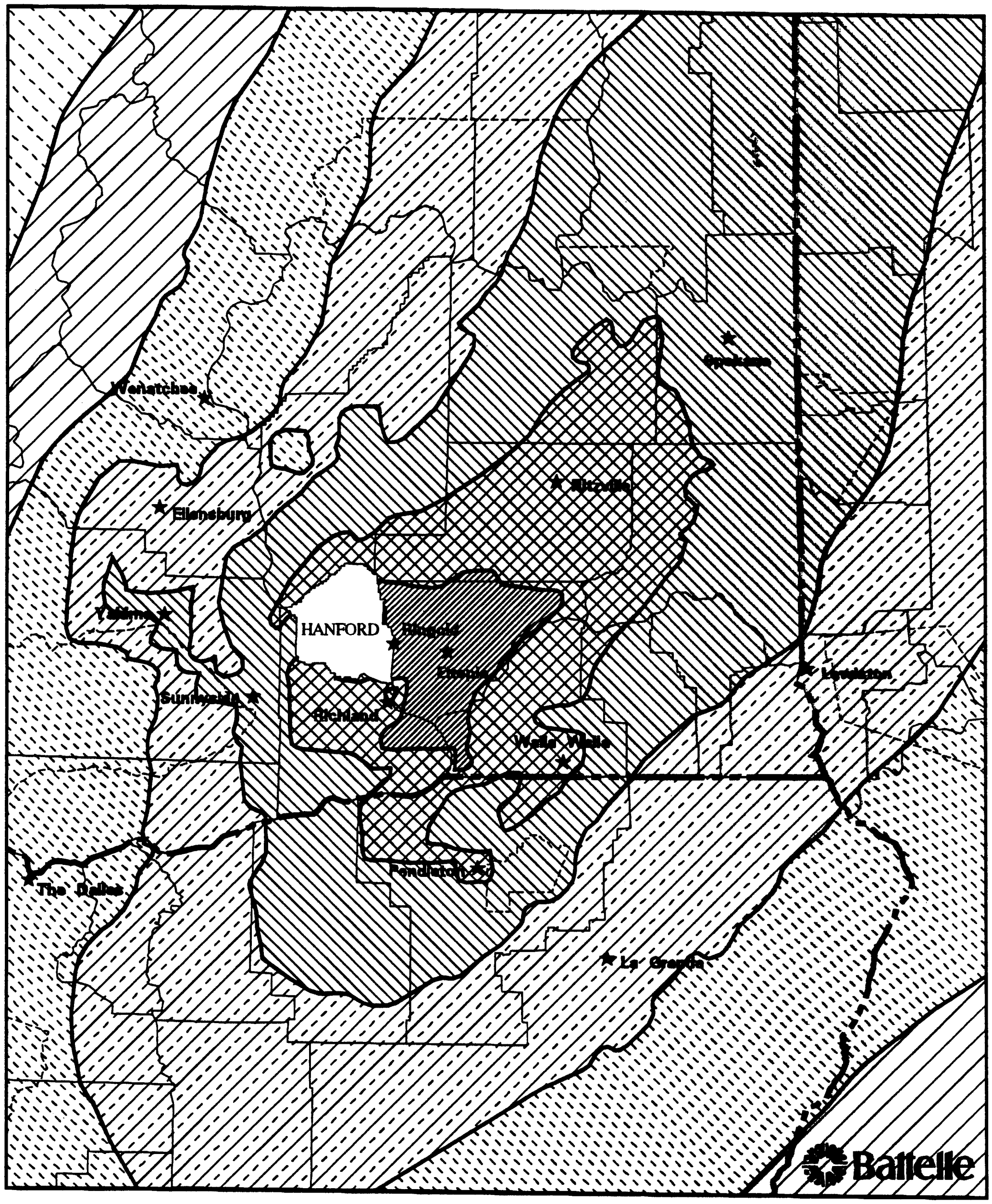
Note: Doses shown are the total annual median dose to the thyroid from all exposure pathways including consumption of foodstuffs (milk, fresh fruits, vegetables, eggs, poultry, and beef), inhalation, and external exposure. All foodstuffs were assumed to be from a backyard source. The milk was produced by a cow that was fed stored feed. To use the figure, pinpoint the location of interest, note the shading, and then consult the legend on the adjoining page. The intersection of the shading (column) and sex/age classification of interest (row) shows the dose to that type of individual at that location.

Figure 4.14 Legend. 1951 Iodine-131 Thyroid Dose (rad) from All Air Exposure Pathways - Milk Cows on Stored Feed[a]

Sex/Age Category				
All <1 year	< 0.023	0.023 - 0.07	0.07 - 0.23	0.23 - 0.72
All 1-4 years	< 0.014	0.014 - 0.05	0.05 - 0.14	0.14 - 0.45
Male 5-9 years	< 0.010	0.010 - 0.03	0.03 - 0.1	0.1 - 0.32
Female 5-9 years	< 0.010	0.010 - 0.03	0.03 - 0.1	0.1 - 0.31
Male 10-14 years	< 0.007	0.007 - 0.02	0.02 - 0.07	0.07 - 0.23
Female 10-14 years	< 0.007	0.007 - 0.02	0.02 - 0.07	0.07 - 0.23
Male 15-19 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.16
Female 15-19 years	< 0.004	0.004 - 0.01	0.01 - 0.04	0.04 - 0.14
Male 20-34 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.15
Female 20-34 years	< 0.005	0.005 - 0.01	0.01 - 0.05	0.05 - 0.14
Male >35 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.15
Female >35 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.16

Sex/Age Category	
All <1 year	0.72 - 1.6
All 1-4 years	0.45 - 0.98
Male 5-9 years	0.32 - 0.7
Female 5-9 years	0.31 - 0.68
Male 10-14 years	0.23 - 0.51
Female 10-14 years	0.23 - 0.5
Male 15-19 years	0.16 - 0.36
Female 15-19 years	0.14 - 0.29
Male 20-34 years	0.15 - 0.32
Female 20-34 years	0.14 - 0.31
Male >35 years	0.15 - 0.33
Female >35 years	0.16 - 0.34

(a) The dose estimates are the range of median doses over a geographic area and do not indicate uncertainty in the dose estimates.

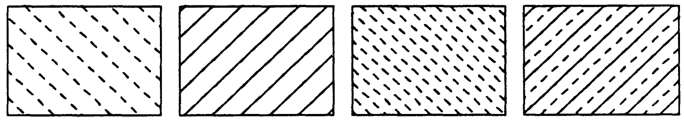


4.15

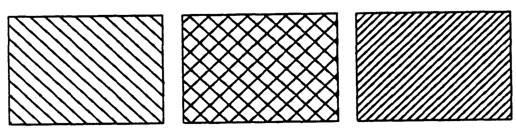
Figure 4.15. 1945 Iodine-131 Thyroid Dose from Consumption of Commercial Milk

Note: Doses shown are the total annual median dose to the thyroid from consumption of commercial milk from a grocery store or local informal market. To use the figure, pinpoint the location of interest, note the shading, and then consult the legend on the adjoining page. The intersection of the shading (column) and sex/age classification of interest (row) shows the dose to that type of individual at that location.

Figure 4.15 Legend. 1945 Iodine-131 Thyroid Dose (rad) from Consumption of Commercial Milk[a]



Sex/Age Category				
All <1 year	0.023 - 0.07	0.07 - 0.23	0.23 - 0.74	0.74 - 2.3
All 1-4 years	0.014 - 0.05	0.05 - 0.14	0.14 - 0.46	0.46 - 1.4
Male 5-9 years	0.010 - 0.03	0.03 - 0.1	0.1 - 0.32	0.32 - 1
Female 5-9 years	0.009 - 0.03	0.03 - 0.09	0.09 - 0.28	0.28 - 0.89
Male 10-14 years	0.006 - 0.02	0.02 - 0.06	0.06 - 0.2	0.2 - 0.62
Female 10-14 years	0.005 - 0.02	0.02 - 0.05	0.05 - 0.16	0.16 - 0.5
Male 15-19 years	0.004 - 0.01	0.01 - 0.04	0.04 - 0.13	0.13 - 0.41
Female 15-19 years	0.003 - 0.01	0.01 - 0.03	0.03 - 0.09	0.09 - 0.29
Male 20-34 years	0.002 - 0.01	0.01 - 0.02	0.02 - 0.07	0.07 - 0.23
Female 20-34 years	0.002 - 0.01	0.01 - 0.02	0.02 - 0.05	0.05 - 0.16
Male >35 years	0.002 - 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.16
Female >35 years	0.001 - 0.004	0.004 - 0.01	0.01 - 0.04	0.04 - 0.12



Sex/Age Category			
All <1 year	2.3 - 7.4	7.4 - 23	23 - 61
All 1-4 years	1.4 - 4.6	4.6 - 14	14 - 38
Male 5-9 years	1 - 3.2	3.2 - 10	10 - 26
Female 5-9 years	0.89 - 2.8	2.8 - 8.9	8.9 - 23
Male 10-14 years	0.62 - 2	2 - 6.2	6.2 - 16
Female 10-14 years	0.5 - 1.6	1.6 - 5	5 - 13
Male 15-19 years	0.41 - 1.3	1.3 - 4.1	4.1 - 11
Female 15-19 years	0.29 - 0.94	0.94 - 2.9	2.9 - 7.8
Male 20-34 years	0.23 - 0.74	0.74 - 2.3	2.3 - 6.1
Female 20-34 years	0.16 - 0.52	0.52 - 1.6	1.6 - 4.3
Male >35 years	0.16 - 0.51	0.51 - 1.6	1.6 - 4.2
Female >35 years	0.12 - 0.39	0.39 - 1.2	1.2 - 3.2

(a) The dose estimates are the range of median doses over a geographic area and do not indicate uncertainty in the dose estimates.

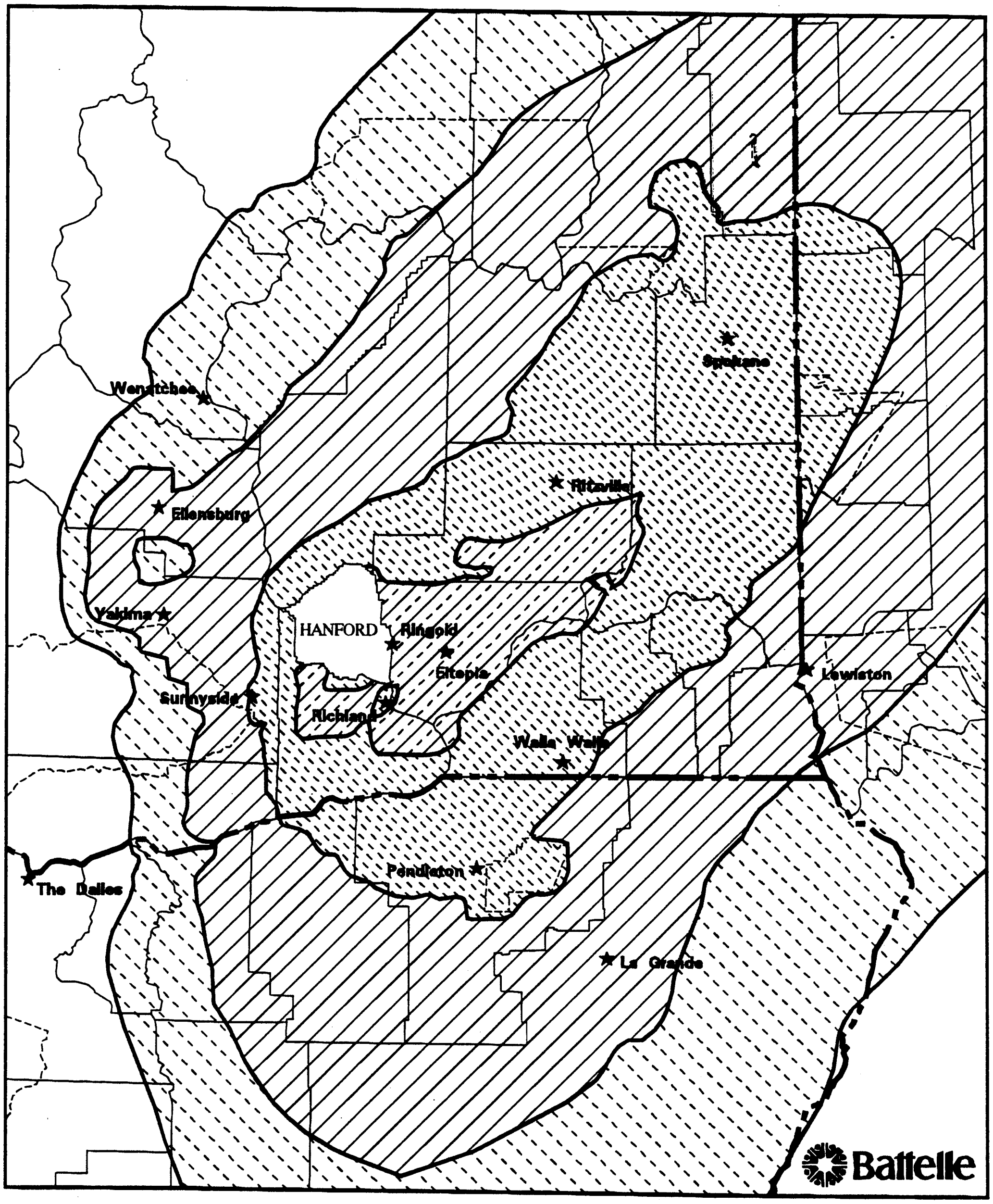
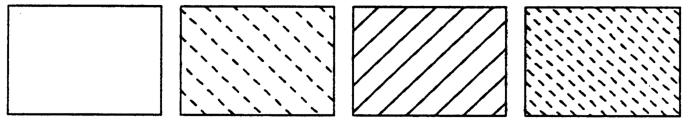


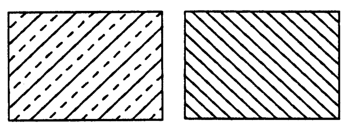
Figure 4.16. 1951 Iodine-131 Thyroid Dose from Consumption of Commercial Milk

Note: Doses shown are the total annual median dose to the thyroid from consumption of commercial milk from a grocery store or local informal market. To use the figure, pinpoint the location of interest, note the shading, and then consult the legend on the adjoining page. The intersection of the shading (column) and sex/age classification of interest (row) shows the dose to that type of individual at that location.

Figure 4.16 Legend. 1951 Iodine-131 Thyroid Dose (rad) from Consumption of Commercial Milk[(a)]



Sex/Age Category				
All <1 year	< 0.019	0.019 - 0.06	0.06 - 0.19	0.19 - 0.62
All 1-4 years	< 0.016	0.016 - 0.05	0.05 - 0.16	0.16 - 0.5
Male 5-9 years	< 0.010	0.010 - 0.03	0.03 - 0.1	0.1 - 0.32
Female 5-9 years	< 0.010	0.010 - 0.03	0.03 - 0.1	0.1 - 0.31
Male 10-14 years	< 0.007	0.007 - 0.02	0.02 - 0.07	0.07 - 0.23
Female 10-14 years	< 0.006	0.006 - 0.02	0.02 - 0.06	0.06 - 0.18
Male 15-19 years	< 0.004	0.004 - 0.01	0.01 - 0.04	0.04 - 0.13
Female 15-19 years	< 0.003	0.003 - 0.01	0.01 - 0.03	0.03 - 0.1
Male 20-34 years	< 0.003	0.003 - 0.01	0.01 - 0.03	0.03 - 0.08
Female 20-34 years	< 0.002	0.002 - 0.01	0.01 - 0.02	0.02 - 0.06
Male >35 years	< 0.002	0.002 - 0.01	0.01 - 0.02	0.02 - 0.06
Female >35 years	< 0.001	0.001 - 0	0 - 0.01	0.01 - 0.04



Sex/Age Category		
All <1 year	0.62 - 1.9	1.9 - 1.9
All 1-4 years	0.5 - 1.6	1.6 - 1.5
Male 5-9 years	0.32 - 1	1 - 0.97
Female 5-9 years	0.31 - 0.95	0.95 - 0.93
Male 10-14 years	0.23 - 0.71	0.71 - 0.69
Female 10-14 years	0.18 - 0.56	0.56 - 0.54
Male 15-19 years	0.13 - 0.41	0.41 - 0.39
Female 15-19 years	0.1 - 0.33	0.33 - 0.32
Male 20-34 years	0.08 - 0.26	0.26 - 0.25
Female 20-34 years	0.06 - 0.18	0.18 - 0.18
Male >35 years	0.06 - 0.17	0.17 - 0.17
Female >35 years	0.04 - 0.13	0.13 - 0.12

(a) The dose estimates are the range of median doses over a geographic area and do not indicate uncertainty in the dose estimates.

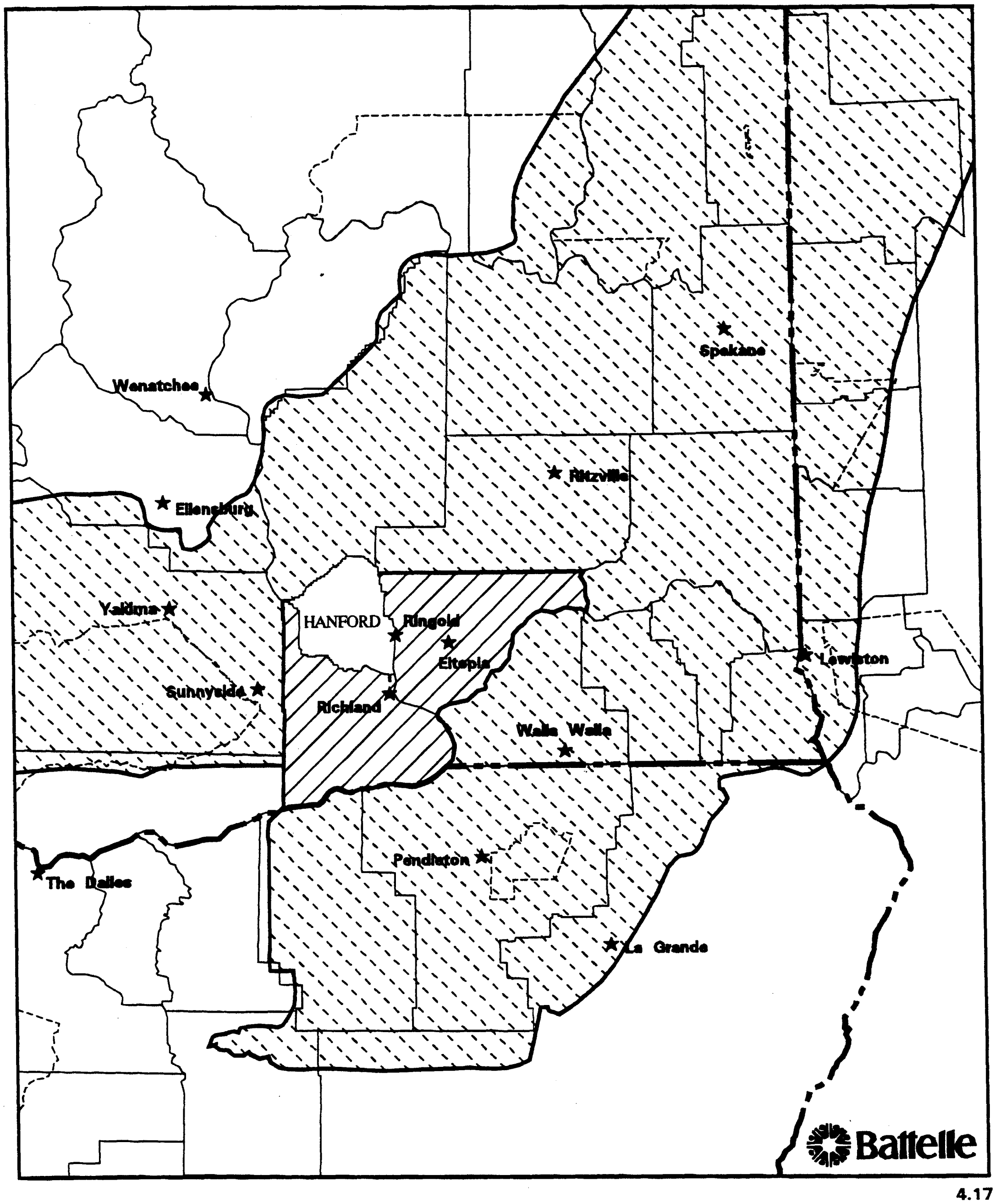
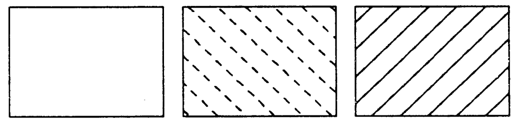


Figure 4.17. 1945 Iodine-131 Thyroid Dose from Consumption of Commercial Leafy Vegetables

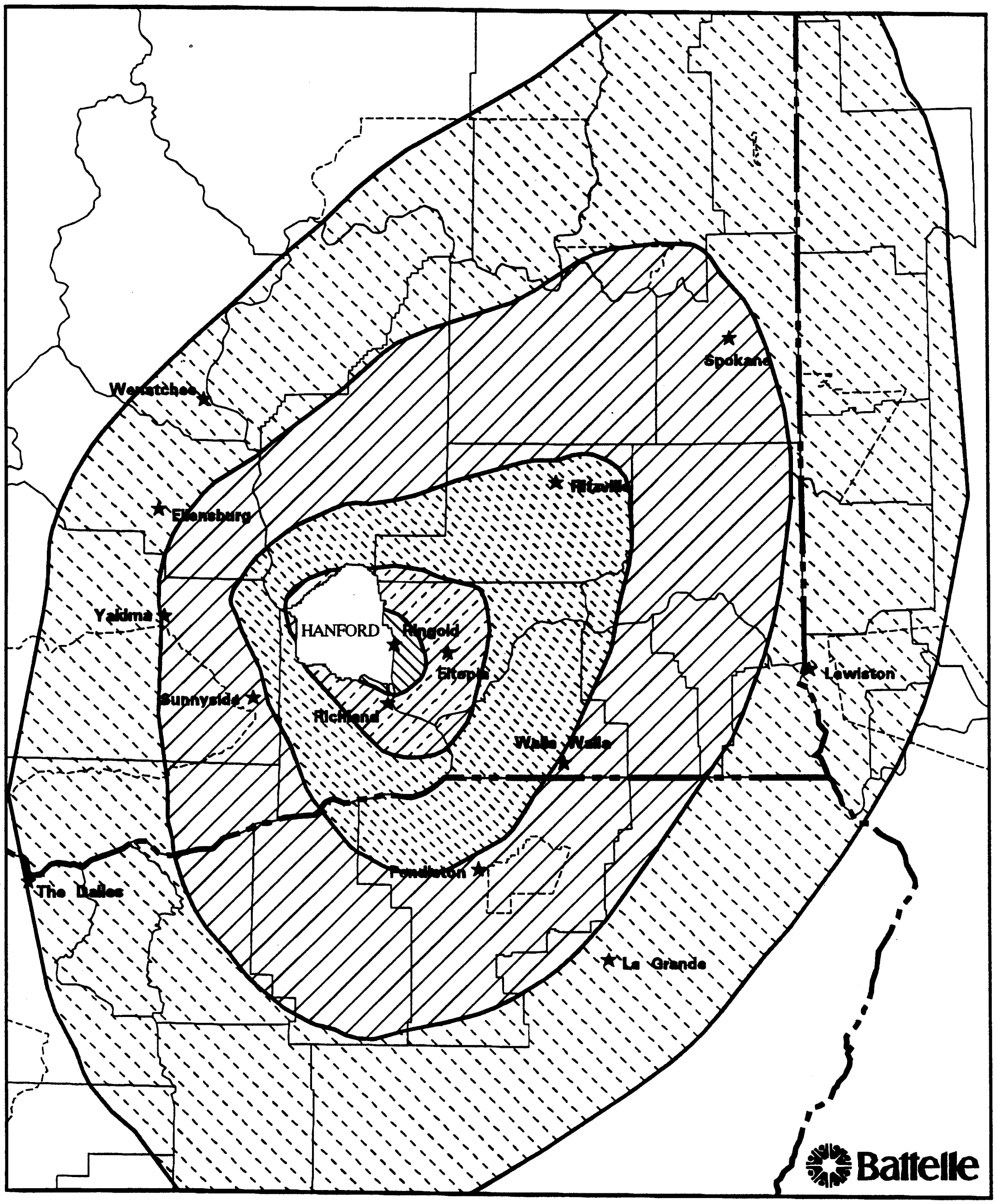
Note: Doses shown are the total annual median dose to the thyroid from consumption of commercial leafy vegetables from a grocery store or local informal market. To use the figure, pinpoint the location of interest, note the shading, and then consult the legend on the adjoining page. The intersection of the shading (column) and sex/age classification of interest (row) shows the dose to that type of individual at that location.

Figure 4.17 Legend. 1945 Iodine-131 Thyroid Dose (rad) from Consumption of Commercial Leafy Vegetables[(a)]



Sex/Age Category			
All <1 year	< 0.003	0.003 - 0.01	0.01 - 0.02
All 1-4 years	< 0.011	0.011 - 0.04	0.04 - 0.07
Male 5-9 years	< 0.010	0.010 - 0.03	0.03 - 0.06
Female 5-9 years	< 0.009	0.009 - 0.03	0.03 - 0.05
Male 10-14 years	< 0.007	0.007 - 0.02	0.02 - 0.05
Female 10-14 years	< 0.008	0.008 - 0.03	0.03 - 0.05
Male 15-19 years	< 0.005	0.005 - 0.02	0.02 - 0.03
Female 15-19 years	< 0.004	0.004 - 0.01	0.01 - 0.03
Male 20-34 years	< 0.005	0.005 - 0.02	0.02 - 0.03
Female 20-34 years	< 0.006	0.006 - 0.02	0.02 - 0.04
Male >35 years	< 0.005	0.005 - 0.02	0.02 - 0.03
Female >35 years	< 0.007	0.007 - 0.02	0.02 - 0.05

(a) The dose estimates are the range of median doses over a geographic area and do not indicate uncertainty in the dose estimates.



4.18

Figure 4.18. 1945 Iodine-131 Thyroid Dose from Inhalation

Note: Doses shown are the total annual median dose to the thyroid from inhalation. To use the figure, pinpoint the location of interest, note the shading, and then consult the legend on the adjoining page. The intersection of the shading (column) and sex/age classification of interest (row) shows the dose to that type of individual at that location.

Figure 4.18 Legend. 1945 Iodine-131 Thyroid Dose (rad) from Inhalation[(a)]

Sex/Age Category				
All <1 year	< 0.003	0.003 - 0.01	0.01 - 0.03	0.03 - 0.11
All 1-4 years	< 0.010	0.010 - 0.03	0.03 - 0.1	0.1 - 0.32
Male 5-9 years	< 0.010	0.010 - 0.03	0.03 - 0.1	0.1 - 0.32
Female 5-9 years	< 0.010	0.010 - 0.03	0.03 - 0.1	0.1 - 0.32
Male 10-14 years	< 0.009	0.009 - 0.03	0.03 - 0.09	0.09 - 0.28
Female 10-14 years	< 0.009	0.009 - 0.03	0.03 - 0.09	0.09 - 0.28
Male 15-19 years	< 0.006	0.006 - 0.02	0.02 - 0.06	0.06 - 0.2
Female 15-19 years	< 0.006	0.006 - 0.02	0.02 - 0.06	0.06 - 0.2
Male 20-34 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.17
Female 20-34 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.17
Male >35 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.17
Female >35 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.17

Sex/Age Category		
All <1 year	0.11 - 0.33	0.33 - 0.71
All 1-4 years	0.32 - 1	1 - 2.1
Male 5-9 years	0.32 - 1	1 - 2.2
Female 5-9 years	0.32 - 1	1 - 2.2
Male 10-14 years	0.28 - 0.88	0.88 - 1.9
Female 10-14 years	0.28 - 0.88	0.88 - 1.9
Male 15-19 years	0.2 - 0.64	0.64 - 1.4
Female 15-19 years	0.2 - 0.64	0.64 - 1.4
Male 20-34 years	0.17 - 0.53	0.53 - 1.1
Female 20-34 years	0.17 - 0.53	0.53 - 1.1
Male >35 years	0.17 - 0.53	0.53 - 1.1
Female >35 years	0.17 - 0.53	0.53 - 1.1

(a) The dose estimates are the range of median doses over a geographic area and do not indicate uncertainty in the dose estimates.

Figures 4.1 through 4.7 show the absorbed doses to the thyroids of representative individuals who consumed food (e.g., milk, eggs, poultry and beef) directly from a backyard garden or a farm. In order to present a value for total dose, the contributions to dose from inhalation and external exposure were also included in these calculations. However, the most numerically important assumption for Figures 4.1 through 4.7 is that the milk was produced by a backyard cow that was fed fresh pasture supplemented by alfalfa and grain.

The thyroid dose to an infant who was born on January 1, 1945 is estimated to be as high as 200 rad at the maximum impact location (Ringold, Washington) for all exposure pathways for the year 1945. By contrast, the dose to an identical infant in the northwest corner of the HEDR study area is estimated to be 0.026-0.08 rad (see Figure 4.1). The doses in 1945 were larger than in any other year. In general, the magnitude of the doses is directly proportional to the amount of iodine-131 released during the year. The estimated annual iodine-131 releases are shown as curies per year (Ci/yr) in Table 4.2. The doses shown in Figures 4.1 through 4.7 generally reflect this trend, with a dramatic decrease in doses after 1945 through 1948, then an increase from 1949 to 1951. The doses after 1951 drop sharply (see Section 4.3).

40 **Table 4.2.** Estimated Iodine-131 Releases, 1944/1945 through 1951

Year	Estimated Iodine-131 Releases, Ci/yr
1944-1945	*560,000*
1946	96,000
1947	32,000
1948	1,800
1949	8,700
1950	5,400
1951	27,000
Rounded Total	*730,000*

Figures 4.8 through 4.14 show the same sort of information as Figures 4.1 through 4.7, with the exception of the source of feed for the milk cows. The milk cow feeding regime for this series of maps is one in which the cows producing milk for human consumption were fed only stored feed. As a result of the storage time for the feed, iodine-131 present in the feed at the time of harvest had decayed to a lower concentration level. In general, the doses to children from the milk of a cow fed stored feed were a factor of 5 less than those from milk produced by a cow that was fed fresh pasture. These two feeding regimes represent the range of possible feeding regimes. That is, one is largely fresh pasture and the other is entirely stored feed.

44 The feeding regimes used to describe the feeding practices for milk cows, both for backyard-produced and commercial milk, were provided by the TSP.[(a)] The feeding regimes were based upon information from dairy experts and TSP research. Four feeding regimes were used for backyard cows:

- regime 1, fresh pasture
- regime 2, non-irrigated grass and wheat stubble
- regime 3, non-irrigated grass
- regime 4, stored feed (alfalfa).

Each of the four backyard regimes includes some grain and alfalfa supplements. The impact of the four separate feeding regimes on absorbed thyroid dose to a child is shown in Table 4.3. The thyroid dose to a child was estimated for each of the four regimes at six locations where all four regimes are thought to have been in use in 1945. The doses in decreasing order of dose were regime 1, regime 2, regime 3, and regime 4. The ratios of doses for each regime to the dose from regime 1 (irrigated pasture) are also shown. The dose from regime 4 is 20 percent of the dose from regime 1.

41 **Table 4.3.** Impact of Milk Cow Feeding Regime on the Absorbed Thyroid Dose to a 2-Year-Old Child

Location	Regime 1[(a)] Thyroid Dose (rad)	Regime 2 Thyroid Dose (rad)	Ratio of *Regime 2: Regime 1*	Regime 3 Thyroid Dose (rad)	Ratio of *Regime 3: Regime 1*	Regime 4 Thyroid Dose (rad)	Ratio of *Regime 4: Regime 1*
Spokane	3.9	3.0	0.8	2.5	0.7	0.88	0.2
Walla Walla	3.9	2.5	0.6	1.9	0.5	0.97	0.3
North Pasco	25	16	0.6	13	0.5	5.7	0.2
Moses Lake	2.8	1.8	0.6	1.3	0.4	0.59	0.2
Hooper	5.2	3.2	0.6	2.4	0.4	1.3	0.2
Ellensburg	0.63	0.40	0.6	0.26	0.4	0.17	0.3

(a) Regime 1 refers to fresh pasture; regime 2 refers to non-irrigated grass and wheat stubble; regime 3 refers to non-irrigated grass; regime 4 refers to stored feed.

4, 54 *For some individuals, goat's milk may have been consumed instead of cow's milk. Doses have been estimated for children whose only source of milk was goat's milk. The goat's milk consumption rate for a five year old child was assumed to be the same as for cow's milk, 950 grams per day of fresh milk (Table 4.1). Dose estimates for several locations indicate that the thyroid dose from the*

(a) Letter (HEDR Project Document No. 03940425) from J. E. Till (TSP) to D. B. Shipler (BNW), March 4, 1994; unpublished report (HEDR Project Document No. 12940001), *Dairy Cow Feeding Regimes for Representative Doses: HEDR Project* by D. W. Price (TSP), submitted to the TSP in August 1994.

consumption of goat's milk could have been 2.1 to 2.6 times that from consumption of milk from a cow fed fresh pasture. The higher dose estimate results from the higher transfer of iodine from feed to milk in goats (Snyder et al. 1994).

4.2.1.2 Doses from Commercially Distributed Food, Leafy Vegetables, and Inhalation

Information on the commercial distribution of milk and leafy vegetables has been collected by the HEDR Project (Beck et al. 1992; Marsh et al. 1992; Deonigi et al. 1994). Transport of milk and leafy vegetables between areas of high and low iodine-131 deposition can alter the pattern of radiation doses across the HEDR study area.

Figures 4.15 through 4.18 present the iodine-131 thyroid doses from two pathways involving commercial milk as well as for commercial leafy vegetables and inhalation. Figure 4.15 shows the dose from consumption of commercially produced milk; i.e., milk obtained from a grocery store or, in the case of an isolated rural location, from an informal local market.

Commercial milk is one of the pathways that demonstrates the impact of the distribution network on doses received. In areas of widely differing iodine depositions or where there was movement of milk between two contrasting areas, knowledge of the distribution system is important in determining iodine-131 dose. For instance, in comparing Figures 4.1 and 4.15, it can be seen that the pattern of doses is very similar, with the dose decreasing with distance from the Hanford Site and the trend of higher doses to the northeast of the site. However, there are some subtle differences: the doses in Figure 4.15 from commercial milk are slightly smaller than those in Figure 4.1. This is because of an increased delay time between milk production and consumption attributable to the distribution system. Much of the milk that was consumed in Richland during 1945 was produced by the Carnation Dairy in Sunnyside, Washington. As a result, the doses from commercial milk in Richland are lower than they would have been if the milk had been produced by cows in the Richland area. On the other hand, the distribution system also could increase dose: milk that was produced in the Yakima area was consumed in the Ellensburg area, thereby slightly increasing the dose there.

A large milk distribution system existed in the Spokane area and served the largest population within the HEDR study area. This distribution, however, had almost no impact on the doses in the Spokane area because of the small iodine-131 deposition gradient in that part of the HEDR study area (see Appendix B). The milk in both the Spokane area and the area surrounding Spokane contained nearly the same concentration of iodine-131. Therefore, the mixing and distribution of milk with similar iodine concentrations resulted in no areas of dissimilar dose.

55 Figure 4.16 provides the same information as that in Figure 4.15 except that it is for the year 1951. By 1951, the distribution network had changed and the milk consumed in Richland was no longer from a single dairy in Sunnyside. A few distribution-related impacts can be seen. The commercial milk in north Franklin County in 1951 was *primarily* from *the Twin City Dairy in Kennewick, Washington*. Because the milk distribution data provided by experts (Deonigi et al. 1994) were often on a county-by-county basis, some artificial contrast may have been produced. Milk distribution would not have changed drastically at county boundaries as is indicated by Figures 4.15 and 4.16. This contrast is evident at the north Franklin County/south Adams County boundary. The

distribution of uncontaminated milk from the Portland, Oregon, area up the Columbia River Gorge is evident in the lower doses in northern Gilliam and Morrow counties (see Figure 1.1 for county locations).

Figure 4.17 shows the doses from the consumption of commercial leafy vegetables for the year 1945. The impact of the distribution system was to create large areas where concentrations in the leafy vegetables consumed were very similar. The commercial leafy vegetable doses for 1951 were calculated for comparison, but because all the doses were below 100 millirad, they are not shown in this report.

The thyroid doses in 1945 from the inhalation pathway are shown in Figure 4.18. The inhalation dose is a function of the iodine-131 concentration in air and the breathing rate and dose factor of the representative individual.

4.2.1.3 Contributions to Thyroid Dose by Pathway

The absorbed dose to the thyroid resulted from a number of different exposure pathways. Ingestion of foods containing iodine-131 contributes the most to the thyroid dose when compared to inhalation and external exposure. Table 4.4 shows the percent contribution by pathway for representative males of six different age groups at two locations of high impact for 1945. Pathway contributions are shown for males only. Contributions by pathway were similar for females. The table includes the percentage contribution to dose by exposure pathway. The fruit and vegetable pathways shown are for fruits and vegetables with the highest iodine-131 content, those consumed fresh from the backyard. Eggs were assumed to be from free-ranging chickens. The milk pathway shown is for milk from a backyard cow grazing on fresh pasture. When milk from a cow fed fresh pasture is consumed, the radiation dose is dominated by the milk pathway. When milk from a cow fed stored feed is consumed, the radiation dose is much lower than that from cows on fresh pasture as shown in Figures 4.8 through 4.14. As the milk dose decreases, the dose from the other pathways remains the same but the importance relative to milk increases.

14 When foods are from a commercial source, the impact of the commercial distribution becomes evident. The contribution from the milk pathway in Richland is smaller because milk was supplied from a less contaminated area (Sunnyside, Washington). As a result, the contribution from the inhalation, beef, and fruit pathways in Richland increases in importance. At *Ringold*, milk is still the dominant pathway, and the percentage of contributions from commercial foods and backyard foods with a cow on fresh pasture are nearly identical. The commercial distribution of milk is from an area with similar deposition of iodine-131, so the milk contribution from backyard (fresh pasture) and commercial sources is similar.

Table 4.4 shows that for all age groups and locations milk is the dominant exposure pathway in most cases. An example of when milk is not the dominant exposure pathway is for infants, ages 0-1 years. The percentages in Table 4.4 for 0-1 year olds show that when commercial milk or milk from a cow fed stored feed is consumed, the dose is dominated by pathways other than milk consumption. The consumption rates used for Table 4.4 are those shown in Table 4.1. The exposure parameters used are those documented in Snyder et al. (1994). The percentage of contributions by pathway will be different for real individuals if their consumption patterns and food sources differ from those of the representative individuals.

Table 4.4. Percent Contribution to Thyroid Dose by Exposure Pathway, 1945

Male <1 Years Old

	Richland			Eltopia		
Pathway	Milk, Regime 1[a] % Contrib.	Milk, Regime 4 % Contrib.	Commercial Food % Contrib.	Milk, Regime 1 % Contrib.	Milk, Regime 4 % Contrib.	Commercial Food % Contrib.
1 external	0.01	0.02	0.02	0.01	0.02	0.01
2 inhalation	2.4	10.6	9.5	1.8	6.5	2
3 beef	0.3	1.5	1.4	0.3	1.3	0.4
4 leafy vegetables	0.1	0.4	0.1	0.1	0.3	0.03
5 other vegetables	0.2	0.8	0.7	0.2	0.7	0.2
6 fruit	12.4	54	48.4	11.8	42.8	12.9
7 grain	0.2	0.7	0.6	0.2	0.8	0.2
8 poultry	0	0.01	0.01	0	0.01	0
9 eggs	1.6	7.2	6.4	1.5	5.3	1.6
10 milk	82.8	24.8	32.8	84.1	42.4	82.6

Male 1-4 Years Old

	Richland			Eltopia		
Pathway	Milk, Regime 1 % Contrib.	Milk, Regime 4 % Contrib.	Commercial Food % Contrib.	Milk, Regime 1 % Contrib.	Milk, Regime 4 % Contrib.	Commercial Food % Contrib.
1 external	0.01	0.1	0	0.01	0.04	0.01
2 inhalation	3	14.2	13.2	2.1	7.8	2.5
3 beef	2.3	10.9	10.1	2.2	8.3	2.7
4 leafy vegetables	0.5	2.6	0.7	0.5	1.9	0.2
5 other vegetables	0.3	1.6	1.5	0.3	1.1	0.4
6 fruit	6.2	29.2	27.2	5.3	19.9	6.4
7 grain	0.2	1	0.9	0.2	0.8	0.3
8 poultry	0.01	0	0.05	0.01	0.04	0.01
9 eggs	2.1	9.8	9.2	2	7.4	2.4
10 milk	85.1	30.7	37.1	87.3	52.7	85.1

Male 5-9 Years Old

	Richland			Eltopia		
Pathway	Milk, Regime 1 % Contrib.	Milk, Regime 4 % Contrib.	Commercial Food % Contrib.	Milk, Regime 1 % Contrib.	Milk, Regime 4 % Contrib.	Commercial Food % Contrib.
1 external	0.02	0.1	0.1	0.02	0.1	0.02
2 inhalation	4	19.5	17.7	2.9	11.2	3.5
3 beef	2.4	11.8	10.7	2.4	9.1	2.8
4 leafy vegetables	0.7	3.6	1	0.7	2.5	0.3
5 other vegetables	0.3	1.3	1.2	0.3	1	0.3
6 fruit	4.9	24	21.8	4.6	17.4	5.4
7 grain	0.2	0.9	0.8	0.2	0.7	0.2
8 poultry	0.01	0.1	0.05	0.01	0.04	0.01
9 eggs	1.5	7.4	6.7	1.5	5.6	1.7
10 milk	85.9	31.4	40	87.4	52.4	85.7

(a) Regime 1 refers to milk from cows on fresh pasture; regime 4 refers to milk from cows on stored feed.

Table 4.4. (contd)

	Male 10-14 Years Old					
	Richland			Eltopia		
Pathway	Milk, Regime 1 % Contrib.	Milk, Regime 4 % Contrib.	Commercial Food % Contrib.	Milk, Regime 1 % Contrib.	Milk, Regime 4 % Contrib.	Commercial Food % Contrib.
1 external	0.02	0.1	0.1	0.02	0.07	0.03
2 inhalation	4.8	21.8	20.9	3.47	12.45	4.39
3 beef	3	13.6	13	3.1	11.1	3.92
4 leafy vegetables	0.8	3.8	1	0.74	2.66	0.32
5 other vegetables	0.3	1.5	1.4	0.35	1.24	0.44
6 fruit	5.1	23.4	22.4	4.67	16.72	5.9
7 grain	0.2	0.7	0.7	0.21	0.74	0.26
8 poultry	0.01	0.05	0.05	0.01	0.04	0.01
9 eggs	1.3	6	5.8	1.24	4.44	1.57
10 milk	84.4	29.1	34.6	86.2	50.56	83.17

	Male 15-19 Years Old					
	Richland			Eltopia		
Pathway	Milk, Regime 1 % Contrib.	Milk, Regime 4 % Contrib.	Commercial Food % Contrib.	Milk, Regime 1 % Contrib.	Milk, Regime 4 % Contrib.	Commercial Food % Contrib.
1 external	0.04	0.2	0.2	0.04	0.1	0.05
2 inhalation	7.2	27.9	26.8	5.3	18	6.4
3 beef	3.9	15.3	14.7	4	13.3	4.7
4 leafy vegetables	0.8	3.2	0.9	0.8	2.8	0.3
5 other vegetables	0.4	1.5	1.5	0.4	1.3	0.5
6 fruit	4.7	18.3	17.6	4.2	14.1	5
7 grain	0.2	0.9	0.8	0.3	0.9	0.3
8 poultry	0.01	0	0	0.01	0.04	0.01
9 eggs	1.9	7.3	7	1.9	6.4	2.3
10 milk	80.8	25.5	30.6	83.1	42.9	80.4

	Male 20-34 Years Old					
	Richland			Eltopia		
Pathway	Milk, Regime 1 % Contrib.	Milk, Regime 4 % Contrib.	Commercial Food % Contrib.	Milk, Regime 1 % Contrib.	Milk, Regime 4 % Contrib.	Commercial Food % Contrib.
1 external	0.1	0.2	0.2	0.1	0.2	0.1
2 inhalation	13.4	36.9	36.3	10.1	26.5	11.7
3 beef	6.2	17	16.7	6.4	16.8	7.4
4 leafy vegetables	1.4	4	1.2	1.4	3.7	0.5
5 other vegetables	0.6	1.5	1.5	0.6	1.5	0.7
6 fruit	5.2	14.2	14	4.7	12.5	5.5
7 grain	0.3	0.8	0.7	0.3	0.9	0.4
8 poultry	0.02	0.1	0.1	0.02	0	0.02
9 eggs	3.5	9.8	9.6	3.5	9.3	4.1
10 milk	69.4	15.6	19.8	72.9	28.7	69.5

4.2.2 Cumulative Iodine-131 Doses, 1944-1951

6 Cumulative thyroid doses over the period beginning December 26, 1944 and ending December 31, 1951 are shown in Figures 4.19 through 4.21. The doses were estimated for specific combinations of representative individuals, exposure pathways, and food sources. Figure 4.19 is a map of the median thyroid doses to representative individuals who were born on the first day plutonium was separated at the T Plant (December 26, 1944). The dose calculation was based on the child's age in each succeeding year. By the end of the calculation, the child had just turned 7 years old. The calculation assumes that the child remained at the same location over this time period and consumed food from the same backyard source. The only source of milk assumed was a backyard cow that grazed on fresh pasture. Figure 4.19, then, is essentially the sum of the doses presented in Figures 4.1 through 4.7. The cumulative absorbed dose to the thyroid of a child at the maximum impact location is estimated to be *230* rad. The lowest estimated dose within the study area is *0.07* rad (*70* millirad). The cumulative dose estimates for a child shown in Figure 4.19 are larger than any other cumulative dose estimate for any other age group or set of exposure pathways. *The highest median cumulative dose to a child located at the northern most extent of the study area nearest the Canadian border is estimated to be 8.8 rad, 2.0 rad and 35 rad (5th and 50th percentiles). The highest median cumulative dose to a child in Montana is estimated to be 5.1 rad, 1.3 rad and 20 rad (5th and 50th percentiles).*

The same type of conditions were used to estimate the dose to an adult who was 18 years old on December 26, 1944. The results of these dose calculations are shown in Figure 4.20. The cumulative absorbed dose to the thyroid of an adult at the maximum impact location is 39 rad. The lowest estimated dose within the study area is 0.013 rad (13 millirad).

Figure 4.21 shows cumulative thyroid doses to children consuming commercially available foods. Many of the same milk distribution effects shown in Figures 4.15 and 4.16 can be seen here, most notably for milk distributed from Sunnyside to Richland, from Yakima to Ellensburg, and from Portland to the Columbia River Gorge. Again, no impact is seen from the milk distribution in the Spokane area.

4.3 Key Radionuclide Doses, 1944-1972

57 The annual and cumulative EDEs for a representative adult from 1944-1972 were estimated for six atmospheric pathway radionuclides determined to be the major contributors to dose from the atmosphere: iodine-131, strontium-90, ruthenium-103, ruthenium-106, cerium-144, and plutonium-239. Note that radionuclide releases occurring in late December 1944 were combined with January 1945 releases because the first separations plant did not begin operations until December 26, 1944. *Nine* locations within the HEDR study area were selected to provide representative upwind and downwind locations: Eltopia, Richland, Ringold, Ritzville, Spokane, Sunnyside, and Wenatchee, Washington; Pendleton, Oregon; and Lewiston, Idaho. Complete annual and cumulative *EDE* values for all radionuclides and locations are provided in Appendix C.

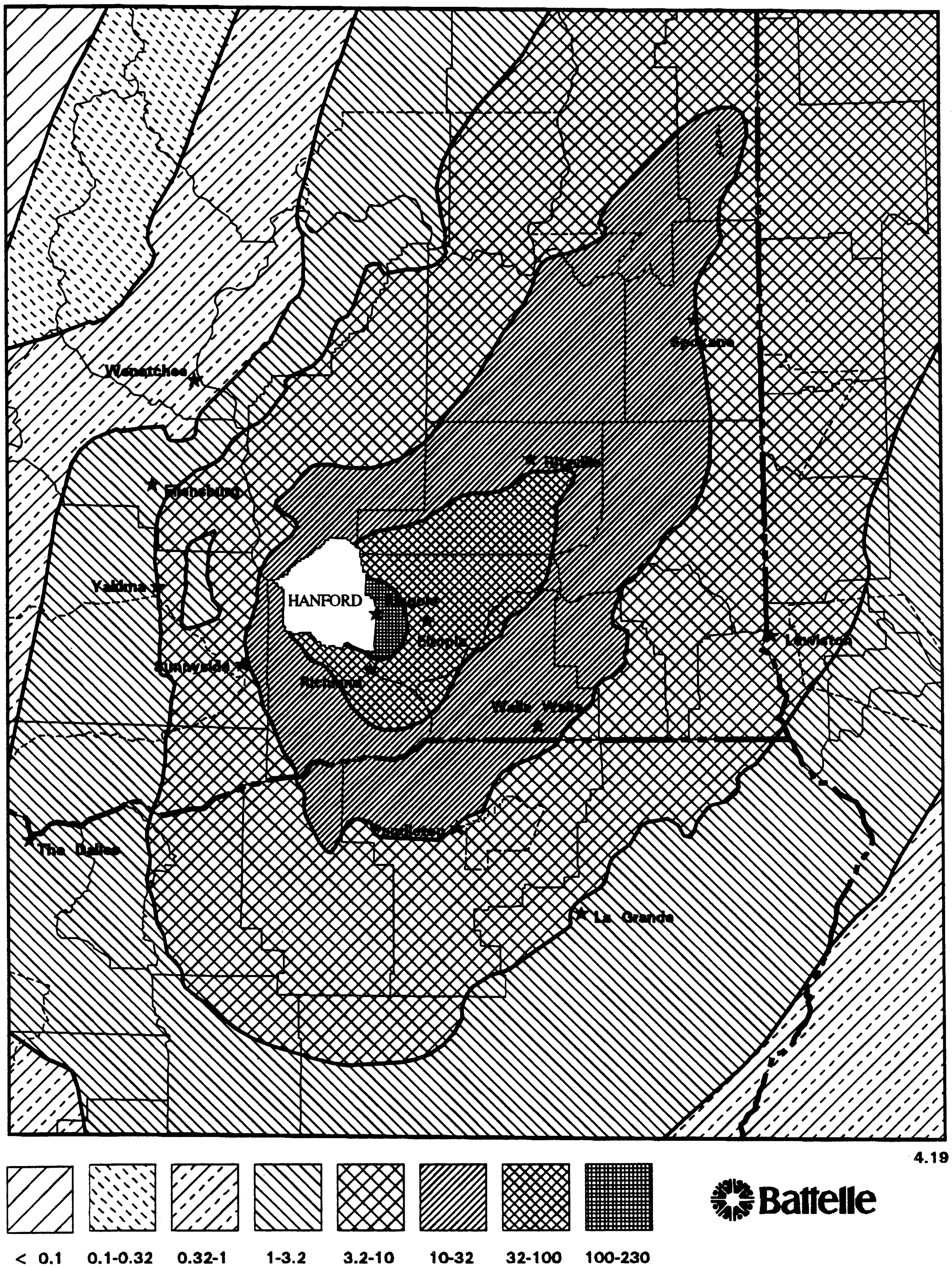


Figure 4.19. Cumulative Iodine-131 Thyroid Dose (rad) to a Child from All Air Exposure Pathways, 1944-1951 - Milk Cows on Fresh Pasture

Note: Doses shown are the total cumulative median dose to the thyroid of a child born December 26, 1944. The doses are from all exposure pathways including consumption of foodstuffs (milk, fresh fruits, vegetables, eggs, poultry, and beef), inhalation, and external exposure. All foodstuffs were assumed to be from a backyard source. The milk was produced by a cow that was grazing on fresh pasture.

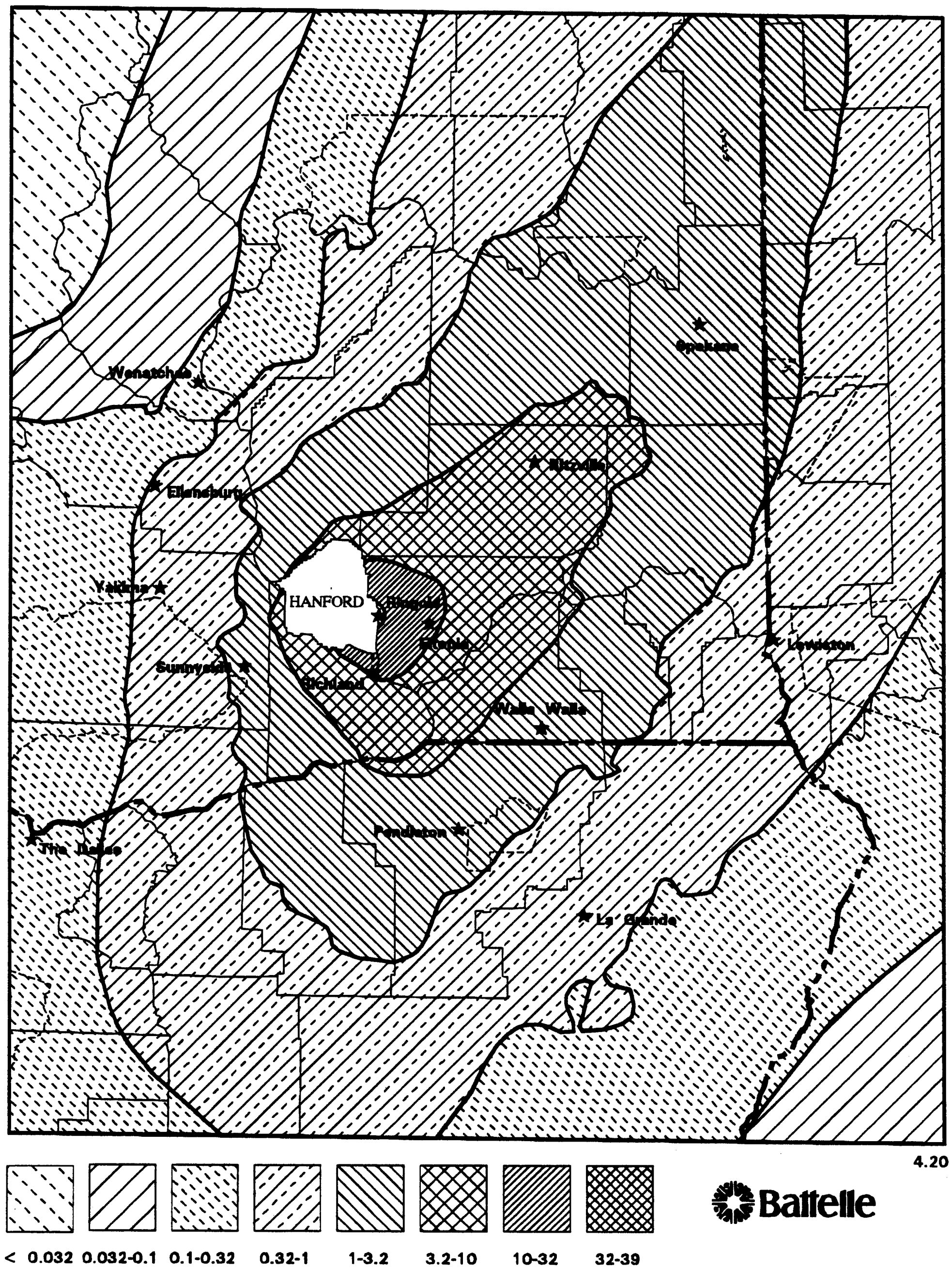


Figure 4.20. Cumulative Iodine-131 Thyroid Dose (rad) to an Adult from All Air Exposure Pathways, 1944-1951 - Milk Cows on Fresh Pasture

Note: Doses shown are the total cumulative median dose to the thyroid of an adult male who was 18 years old on December 26, 1944. The doses are from all exposure pathways including consumption of foodstuffs (milk, fresh fruits, vegetables, eggs, poultry, and beef), inhalation, and external exposure. All foodstuffs were assumed to be from a backyard source. The milk was produced by a cow that was grazing on fresh pasture.

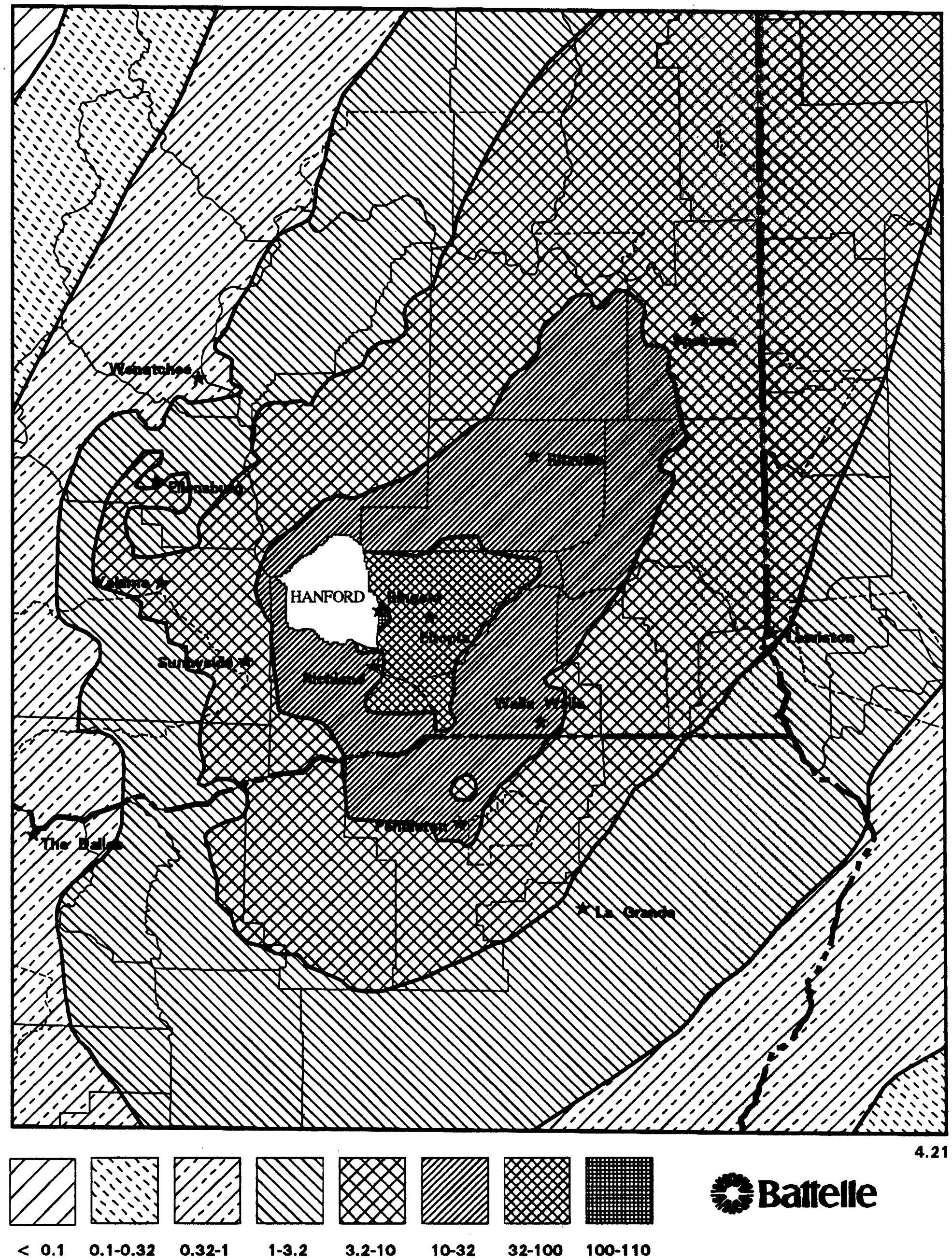


Figure 4.21. Cumulative Iodine-131 Thyroid Dose (rad) to a Child from Consumption of Commercial Foods, 1944-1951

Note: Doses shown are the total cumulative median dose to the thyroid of a child born on December 26, 1944. The doses are from consumption of commercial foods from a grocery store or informal local market.

Estimates were performed using an enhanced version of the spreadsheet from prior HEDR scoping calculations (Ikenberry and Napier 1992; Napier 1992a, 1992b). The CIDER code was used to estimate the doses from iodine-131 for 1944-1951. Source terms for all radionuclides were the final estimates for the HEDR Project developed by Heeb (1994). The set of monthly atmospheric dispersion factors for all years were those developed using the RATCHET atmospheric transport code (Ramsdell et al. 1994) and meteorological data for 1944 through 1949 (Stage et al. 1993). The atmospheric dispersion factors were used for each year from 1945-1972.

Annual and cumulative effective dose equivalents were estimated using methods described in the International Commission on Radiological Protection (ICRP) Publication 56 (ICRP 1989). Dose estimation techniques are constantly being updated. Since the publication of ICRP 56, a new dosimetry model has been developed by the ICRP. This new model was documented in ICRP 60 (ICRP 1990), which proposed new organ weighting factors to use for combining the radiation doses to different tissues. Ingestion dose conversion factors using these new weighting factors were documented in ICRP 67 (ICRP 1994), which was not published until after the draft of this document. Inhalation dose conversion factors have not been published at this time. For this reason, the methods included in ICRP Publication 56 were used for this report. The radiation doses resulting from the releases of radioactivity from Hanford are overwhelmingly dominated by the absorbed dose to the thyroid from iodine-131. In this case, the study properly focuses on the absorbed dose to the thyroid. The changes in the tissue weighting factors have no particular effect on the thyroid dose.

The ingestion dose conversion factors for all six key radionuclides were modified in ICRP 67 (ICRP 1994). However, only the ingestion dose conversion factor for plutonium-239 changed significantly from ICRP Publication 56. It is now a factor of 4 less than before. As stated previously in Section 4.0, the effective dose equivalent is used to estimate the combined effect of the intake of multiple radionuclides. Using radiation exposure of various organs and organ weighting factors, the effect of internal exposures can be related to the effect of a whole body dose from external irradiation by penetrating gamma or x-rays. The best information on effects in humans from radiation doses comes from data on external exposure of the whole body to penetrating radiation.

4.3.1 Annual Doses, 1944-1972

Annual EDEs at all locations were the highest in 1945. Approximately 75 percent of the cumulative dose from 1944 through 1972 occurred in 1945. The annual dose declined steeply each year from 1946 to 1948, increased slightly until 1951, then decreased sharply again until 1957. By 1957, the annual dose received had decreased overall by a factor of approximately 1500 from 1945. During the late 1950s and 1960s, annual doses remained relatively constant, with further decreases taking place in the early 1970s. The annual total dose and contribution from each of the six radionuclides for an adult at Ringold from 1945-1972 are shown in Figure 4.22.

Iodine-131 was the dominant radionuclide contributing to dose during all of the 1940s and 1950s. In 1945, iodine-131 exposure was responsible for 99.8 percent of the dose to an adult in Ringold. Plutonium-239 and cerium-144 were the next largest contributors at about 0.1 percent each (see Appendix C for percentage details). By 1961, iodine-131 releases had decreased to the point where cerium-144 became the dominant contributor to dose and was dominant for the remainder of the time period examined. Cerium-144 releases generally increased slightly each year over the period

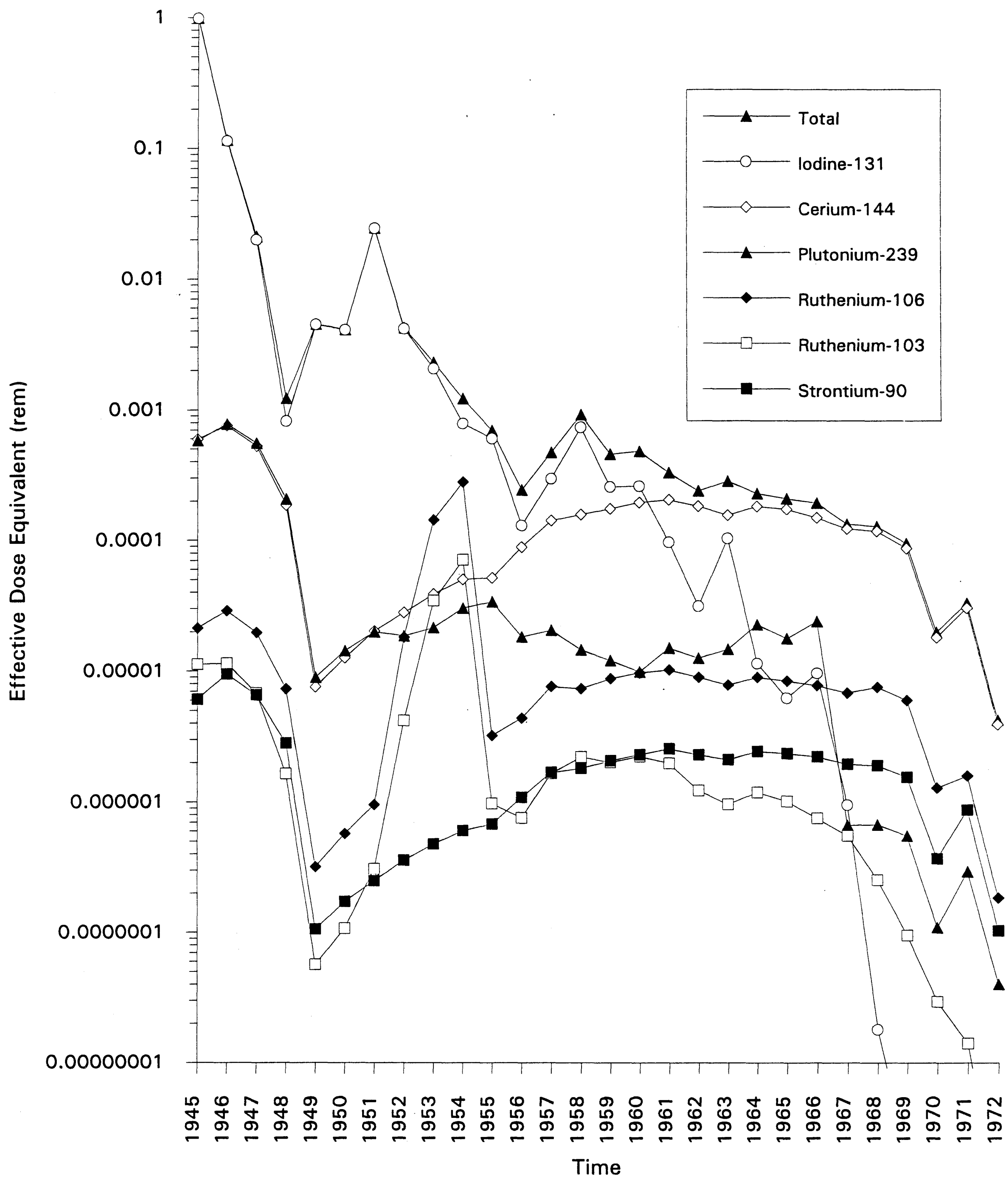


Figure 4.22. Annual Doses to an Adult at Ringold, 1945-1972

from 1949 to 1961, but were obscured by the large iodine-131 releases in the 1940s and 1950s. Plutonium-239 releases remained relatively constant from 1949 to 1967, after which they decreased sharply. By 1965, cerium-144 accounted for about 82 percent of the annual dose to an adult in Richland from airborne radionuclides from the Hanford Site. Plutonium-239 was the next largest contributor at about 9 percent. Each of the other radionuclides contributed 4 percent or less. By 1965, the total annual dose received was approximately 3,000 times less than the dose in 1945.

The importance of the various exposure pathways is directly related to the dominant radionuclides. During 1945, the dominant exposure pathway was ingestion of fresh milk (see Table 4.4). By comparison, by 1965 the overwhelmingly dominant exposure pathway was inhalation (94 percent), reflecting the dominant exposure pathways of cerium-144 (82 percent of the annual dose in 1965) and plutonium-239. In 1965, however, the overall dose was significantly lower than in 1945.

4.3.2 Cumulative Doses, 1944-1972

As previously determined and reported in other HEDR Project documents (PNL 1991; Napier 1992a, 1992b), iodine-131 was by far the most dominant radionuclide contributing to dose received during the 1945-1972 period for the air pathway. Iodine-131 contributed 99 percent of the EDE potentially received by an adult in Richland, followed by cerium-144 at 0.6 percent and plutonium-239, ruthenium-106, ruthenium-103, and strontium-90, at 0.3 percent, 0.1 percent, 0.02 percent, and 0.01 percent, respectively.

The cumulative EDEs calculated at the nine locations studied for this report ranged from approximately 3 millirem (0.003 rem) at Wenatchee to approximately 1.2 rem at Ringold. The estimated doses at Ringold, Richland, and Eltopia (three locations directly downwind from Hanford releases) were significantly higher than the other six cities included in the calculations. Figure 4.23 shows the results estimated at the nine locations.

4.3.3 Annual Report Doses, 1973-1992

Annual reports summarizing environmental monitoring and offsite radiation impacts have been prepared by Hanford contractors since 1957 (Soldat et al. 1986). These reports have all been publicly available and are published 1 to 2 years after the subject year. Each report contains an estimate of the radiation dose to a maximum (maximally exposed) representative individual.

The maximum representative individual reported in the Hanford annual reports is a hypothetically extreme case and not an actual person. The food consumption and exposure rates are assumed to be greater than for any known individual. As a result, the doses would be higher than those received by any real individual. The location assumed for the maximum representative individual is different for different years, depending upon the location of the maximum deposition.

The methods for estimating the doses provided in the annual reports have evolved over the years. For the annual reports, different assumptions regarding dosimetry, exposure parameters, and modeling have been used during the 1973-1992 period. Although the doses were estimated using evolving methods, they do allow a reader to understand the overall magnitude and trend.

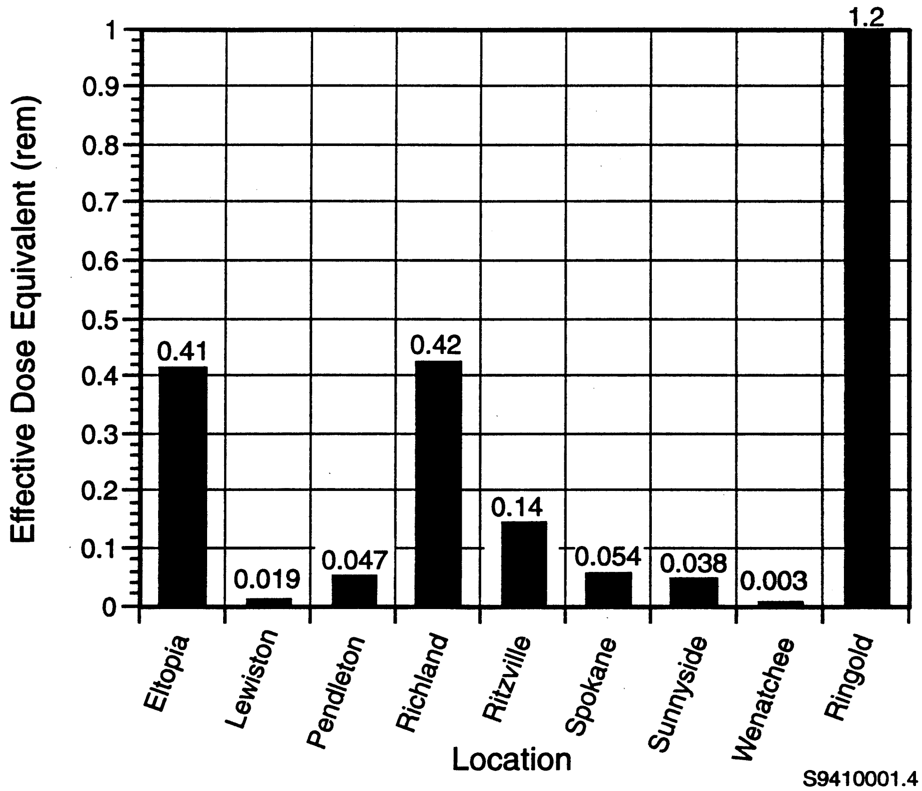


Figure 4.23. Cumulative Doses to an Adult at Selected Locations, 1945-1972

The doses presented in Table 4.5 are for the years 1973 through 1992. The year 1992 is the last year for which a Hanford annual environmental monitoring report is available. (The report for the year 1993 will be available in late 1994.) The annual report doses were estimated for releases of all radionuclides from all known sources on the Hanford Site. Note that the doses presented in Table 4.5 are for the atmospheric pathway only. Doses to the Columbia River pathway are also included in the annual reports. A summary of those doses can be found in Farris et al. (1994).

4.4 Doses from Airborne Releases from Reactors

60 The potential has been estimated for radiation dose to individuals from the releases of tritium, carbon-14, and argon-41 from the Hanford single-pass reactors *using the GENII computer code (Napier et al. 1988)*. Radionuclide release rates are included in Heeb (1994) and summarized for the maximum year in Table 4.6.

During the 1980s, the N Reactor released between 65,000 and 120,000 Ci/yr of argon-41 (see Table 4.5 above for relevant Hanford annual environmental reports containing releases from reactors

Table 4.5. Hanford Annual Report Atmospheric Pathway Doses, 1973-1992

Year	Maximum Representative Individual Total Body or Effective Dose Equivalent (mrem)	Reference
1973	<0.1	Soldat et al. 1986. PNL-5795
1974	0.02	Fix 1975. BNWL-1910
1975	0.003	Speer et al. 1976. BNWL-1979
1976	0.02	Fix et al. 1977. BNWL-2142
1977	0.03	Houston and Blumer 1978. PNL-2614
1978	0.08	Houston and Blumer 1979. PNL-2932
1979	0.05	Houston and Blumer 1980. PNL-3283
1980	<0.06[a]	Sula and Blumer 1981. PNL-3728
1981	*0.03*	Sula et al. 1982. PNL-4211
1982	0.06	Sula et al. 1983. PNL-4657
1983	0.014	Soldat. 1989. PNL-7135
1984	0.025	Soldat. 1989. PNL-7135
1985	0.04	Soldat. 1989. PNL-7135
1986	0.04	Pacific Northwest Laboratory 1987. PNL-6120
1987	0.02	Jaquish and Mitchell 1988. PNL-6464
1988	0.065	Jaquish and Bryce 1989. PNL-6825
1989	0.011	Jaquish and Bryce 1990. PNL-7346
1990	0.01	Woodruff and Hanf 1991. PNL-7930
1991	0.007	Woodruff and Hanf 1992. PNL-8148
1992	0.0049	Woodruff and Hanf 1993. PNL-8682

(a) Annual report presents doses from consumption of foods containing radioactivity released via the combined air and river pathways, and it is not possible to separate doses by source. Doses presented here are the sum of air and river releases and are an overestimate of the atmospheric pathway dose.

Table 4.6. Radionuclide Releases from Hanford Reactors to Atmosphere in Year of Largest Releases, 1964

Radionuclide	Ci/day	Ci/yr
tritium (hydrogen-3)	1.4	511
carbon-14	0.1	36.5
argon-41	1480	540,200

to the air). This compares to the roughly 68,000 Ci/yr per reactor cited in Heeb (1994). Atmospheric releases of argon-41 from the N Reactor were the dominant contributor to dose from Hanford in the 1980s.

The doses to individuals are dominated by the argon-41 air submersion component. Because argon-41 has a half-life of only 110 minutes, the average transit time from the release point to the individual location is an important parameter. For modeling purposes, it was assumed that the representative individual was living downwind of the Hanford Site, along Highway 24 on the Wahluke Slope. This location is slightly farther away from the Hanford reactors than some other Hanford boundary locations. However, it is the location of the highest annual average air concentrations because winds blow primarily from west-southwest to the east-northeast (Stone et al. 1983, p. A.IV-2).

The highest dose rate to an individual living at the maximum potential exposure location occurred when all eight single-pass reactors were operating, 1955-1964. The dose rate to the representative individual on the Wahluke Slope from all reactors together was 2 to 4 mrem/yr. For the years in which fewer reactors were operating, the doses scale approximately linearly with the number of reactors online. The actual annual dose contribution by each reactor ranges from about 0.2 to 0.8 mrem at the maximum impact location.

4.5 Dose History

Dose results from the key radionuclides and annual reports were combined in Figure S.1. The doses are presented for a maximum representative individual located directly adjacent to the Hanford Site in western Franklin County, Washington. The doses by decade are 1.1 rem (1944-1949), 0.04 rem (1950-1959), 0.002 rem (1960-1969), 0.0004 rem (1970-1979), 0.0004 rem (1980-1989), and 0.00002 rem (1990-1992). Over 95 percent of the cumulative EDE is estimated to have occurred during the 1945-1947 time period. The doses at all other locations within the HEDR study area would be lower than the presented doses. Adult doses are shown because the consumption patterns and dose factors used in the calculation could be assumed to be constant over the 48-year time frame. The cumulative EDE over this time period is estimated to be 1.2 rem.

Thyroid doses for the same location were estimated for 1945-1972 and are presented in Figure S.2. The doses are presented for a maximum representative individual located directly adjacent to the Hanford Site at Ringold, Washington. At that location, the cumulative absorbed dose to the thyroid of an adult is estimated to be 39 rad.

5.0 Model Uncertainty and Sensitivity Analyses

The HEDR Project has conducted uncertainty and sensitivity analyses for the atmospheric pathway model. The uncertainty analyses help to determine the precision with which dose estimates can be made. The sensitivity analyses determine the parameters and pathways that contribute most to the uncertainties. The methods for conducting the uncertainty and sensitivity analyses were documented in Simpson and Ramsdell (1993). Those methods were reviewed by the TSP and by a peer review panel convened by the Centers for Disease Control and Prevention (CDC) and the TSP. The methods described in Simpson and Ramsdell (1993) and the enhancements recommended by the CDC/TSP peer reviewers (Hoffman et al. 1993) were used to conduct the uncertainty and sensitivity analyses.

The uncertainty in a dose estimate is defined by its calculated distribution. Each stage of the atmospheric dose calculation can contribute to statistical uncertainty in the final value. The source term release model, STRM (Heeb 1993), provides distributions of hourly estimates of the release of radionuclides to the atmosphere from Hanford operations. The atmospheric transport model, RATCHET (Ramsdell et al. 1994), uses those hourly input distributions to provide distributions of daily estimates of air concentration and surface contamination throughout the HEDR atmospheric transport study area. The environmental accumulation model, DESCARTES, uses the daily inputs from RATCHET to estimate distributions of monthly averaged concentrations of iodine-131 in soil, several types of vegetation, crops, and animal products. Then, the model for calculation of individual dose, CIDER, uses these distributions to estimate exposure and dose for people living within the HEDR study area. The distributions of values are thus spread through each stage of the calculations, with each stage contributing values to the uncertainty of the final dose calculation of CIDER. Sensitivity analyses are made on the doses and the various intermediate results to determine the parameters contributing most to those uncertainties. The hierarchical method applied to sensitivity analysis for iodine-131 thyroid dose is explained in more detail in Appendix D.

5.1 Uncertainties in Dose Estimates

All representative individual dose estimates prepared for this report have an uncertainty associated with them. Because it would be nearly impossible to discuss the complete distributions for each type of representative individual at each location for each time, only the uncertainties in the iodine-131 thyroid dose estimates are illustrated here.

Uncertainties in the iodine-131 thyroid dose estimates were evaluated for the years 1945 and 1946. These evaluations provide uncertainty estimates that can be related to the iodine-131 doses for other years. The uncertainty estimates were prepared for representative individuals of two age categories at eight locations for three different potential sources of milk. The two age categories were young children between the ages of 2 and 5 and adult males between the ages of 20 and 34. The eight locations were Eltopia, Richland, Ritzville, Spokane, Sunnyside, and Wenatchee, Washington; Pendleton, Oregon; and Lewiston, Idaho. These locations were selected to illustrate potential differences between locations near the center of the main deposition pattern, along the eastern and western edges of the main deposition pattern, and upwind of the main deposition pattern. The three sources of milk were family cows fed mainly fresh pasture (feeding regime 1), family cows fed stored alfalfa hay (feeding regime 4), and the commercial milk distribution system (grocery stores). (See Section 4.2.1 for further information on feeding regimes.)

8(3) The estimated uncertainty ranges are illustrated in this document through the use of boxplots. The boxplots show the annual absorbed dose to the thyroid of representative individuals for 1945 and 1946. An example of a boxplot is shown in Figure 5.1. The box portion of a boxplot contains the middle 50 percent of the estimated values, between the 25th and 75th percentiles. Within the box, the median (50th percentile) and mean are shown. The ends of the whiskers *(straight lines extending from the box)* are the 5th and 95th percentiles *of the estimated values.* The minimum and maximum estimated dose values are shown by circles at either end of the boxplot.

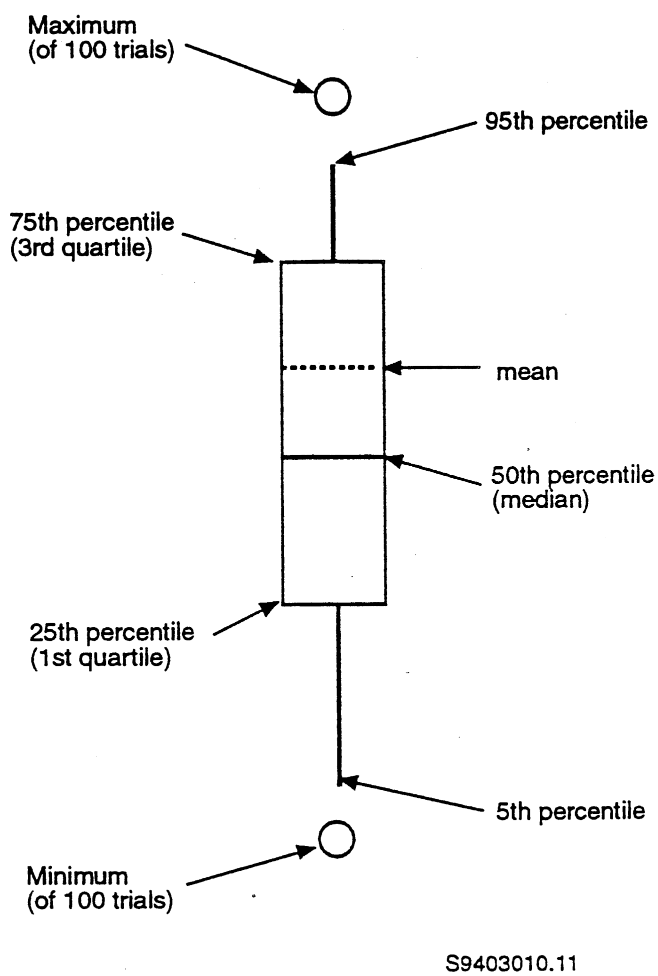


Figure 5.1. Example of a Boxplot Used to Display Uncertainty Ranges for Dose Estimates (adapted from Simpson and Ramsdell 1993)

The statistics are based on the use of 100 realizations of a Monte Carlo calculation. The Monte Carlo technique provides an estimate of the statistical distribution of dose to an individual. The accuracy of this technique is known to be inversely proportional to the square root of the number of realizations processed. Using a confidence interval analysis based on the theory of random sampling, the estimated median of 100 realizations is expected to be within 10 percent of the true but unknown median value. However, the estimated 95th percentile is only expected to be within 50 percent of the true but unknown value. Obtaining the same accuracy on the 95th percentile as the median would have required approximately 2500 realizations instead of 100 realizations. Because many of the variables in the analyses were generated using a stratified sampling technique rather than simple random sampling, the accuracy of the estimated percentiles is better than the values quoted here.

Estimated uncertainties for thyroid doses for the two representative individuals at each location for each milk source are shown in Figure 5.2 for 1945 and in Figure 5.3 for 1946. Note that the axes of the figures are logarithmic: each interval is a factor of 10 times larger than the one below it. The shape of the boxplots on logarithmic scales indicates that the dose distributions can be described as approximating a lognormal distribution. The results shown in these two figures are extensions of those discussed in Section 4.0. The medians shown on the boxplots fit within the ranges described in Section 4.0. (Note that the ranges described in Section 4.0 are ranges of medians based on geographic location, not the full range of uncertainty.)

8(3) These plots indicate that thyroid dose to young children drinking milk from individual backyard cows in 1945 ranges over about a factor of *15*. The 95th percentile is about *15* times higher than the 5th percentile. The *inter-quartile range* (the middle two quartiles) covers about a factor of 3. The distribution of thyroid doses for this category of representative individual is about the same in 1946 (Figure 5.3) although about a factor of 10 lower in absolute magnitude. For both years, the thyroid dose to children drinking milk from cows eating stored feed is lower than the dose to children drinking milk from cows on fresh pasture, and the uncertainties are also slightly less: the *95th to 5th percentile range* is about a factor of 8 to 10 rather than a factor of *15* or more. The thyroid doses to children drinking milk from the commercial supply are midway between the other two types in magnitude but have the least uncertainty. The *inter-quartile range* covers about a factor of 2, and the *95th to 5th percentile range is* from 5 to 10. Again, the distribution shapes are very similar from year to year.

A similar pattern is seen in thyroid doses estimated for adults. Doses and uncertainties are greatest for consumers of milk from individual family cows on fresh pasture. Doses are lowest for those whose milk source is a family cow fed stored feed and intermediate for those consuming milk from the commercial system. Uncertainties are about the same for these latter two categories. Although the magnitude of the doses is less in 1946, the range of the uncertainties is about the same for the two years.

Within an individual category, the shapes of the probability distributions are remarkably similar for each location. This is largely because the factors determining the uncertainty are more related to the individual than to the environment. The total thyroid doses shown in Figures 5.2 and 5.3 are made up of contributions from several pathways of exposure including ingestion, inhalation, and external exposure. Each pathway has uncertainty associated with it.

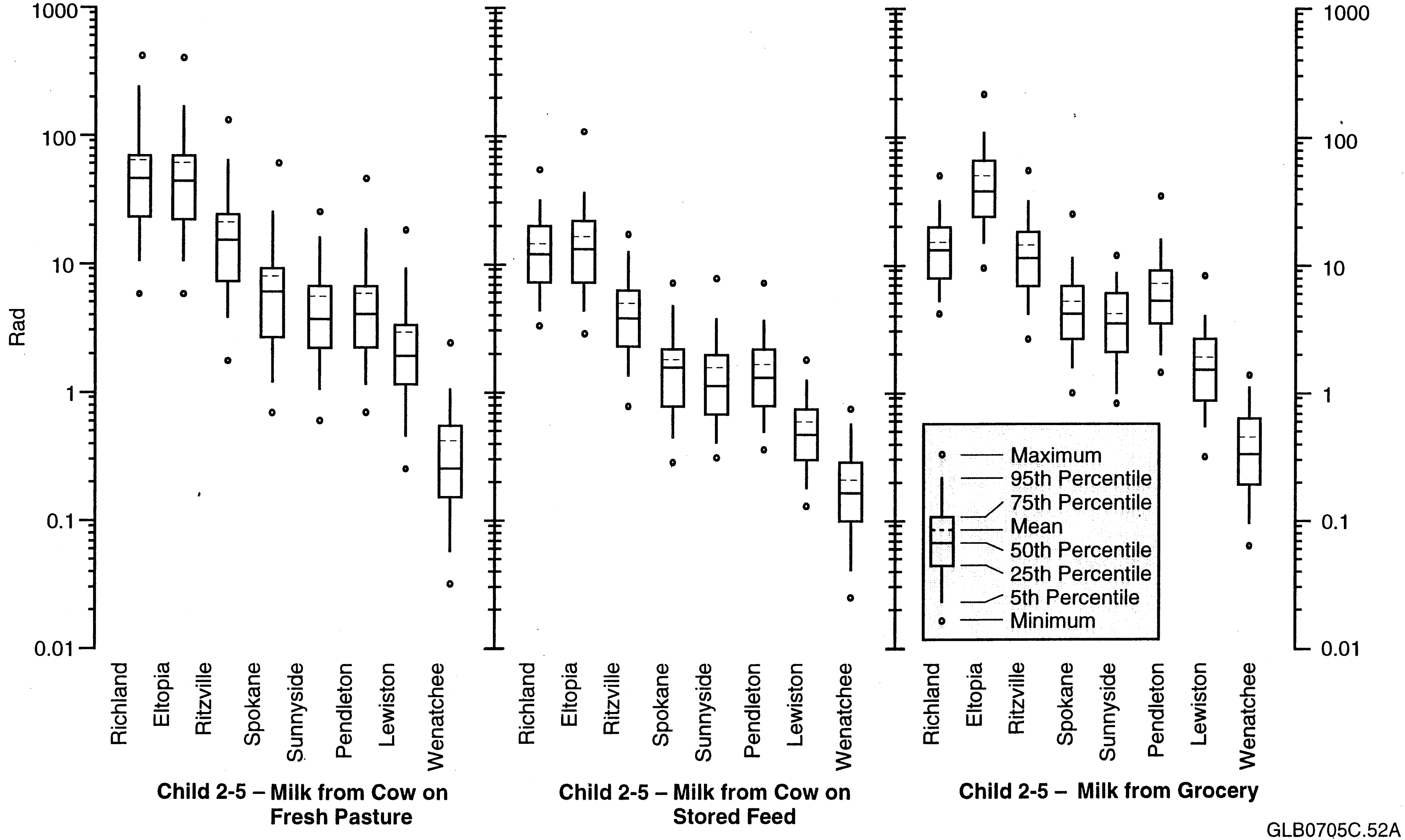


Figure 5.2. 1945 Uncertainty Estimates for Thyroid Doses at Selected Locations - Two Representative Individuals and Three Milk Sources

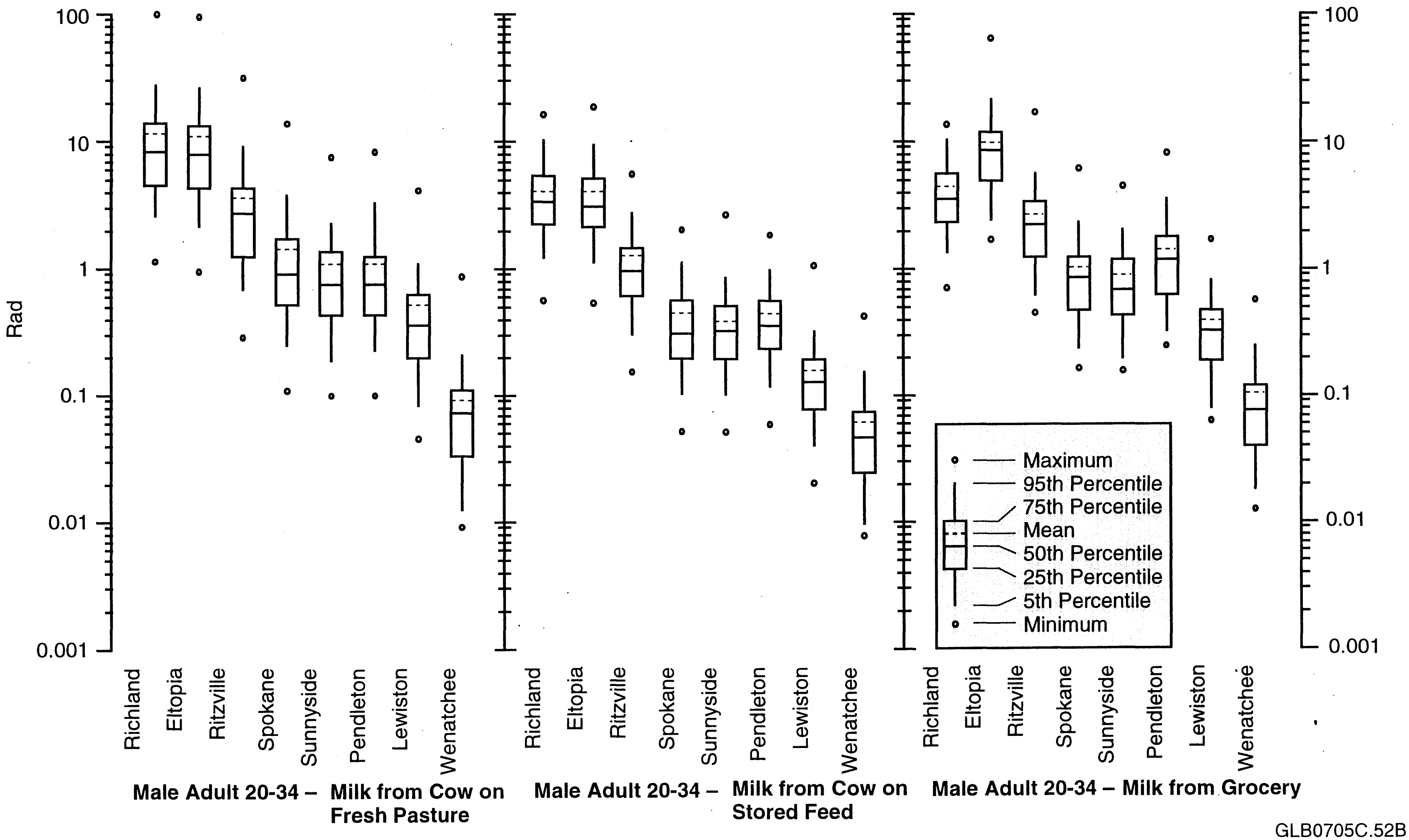


Figure 5.2. (contd)

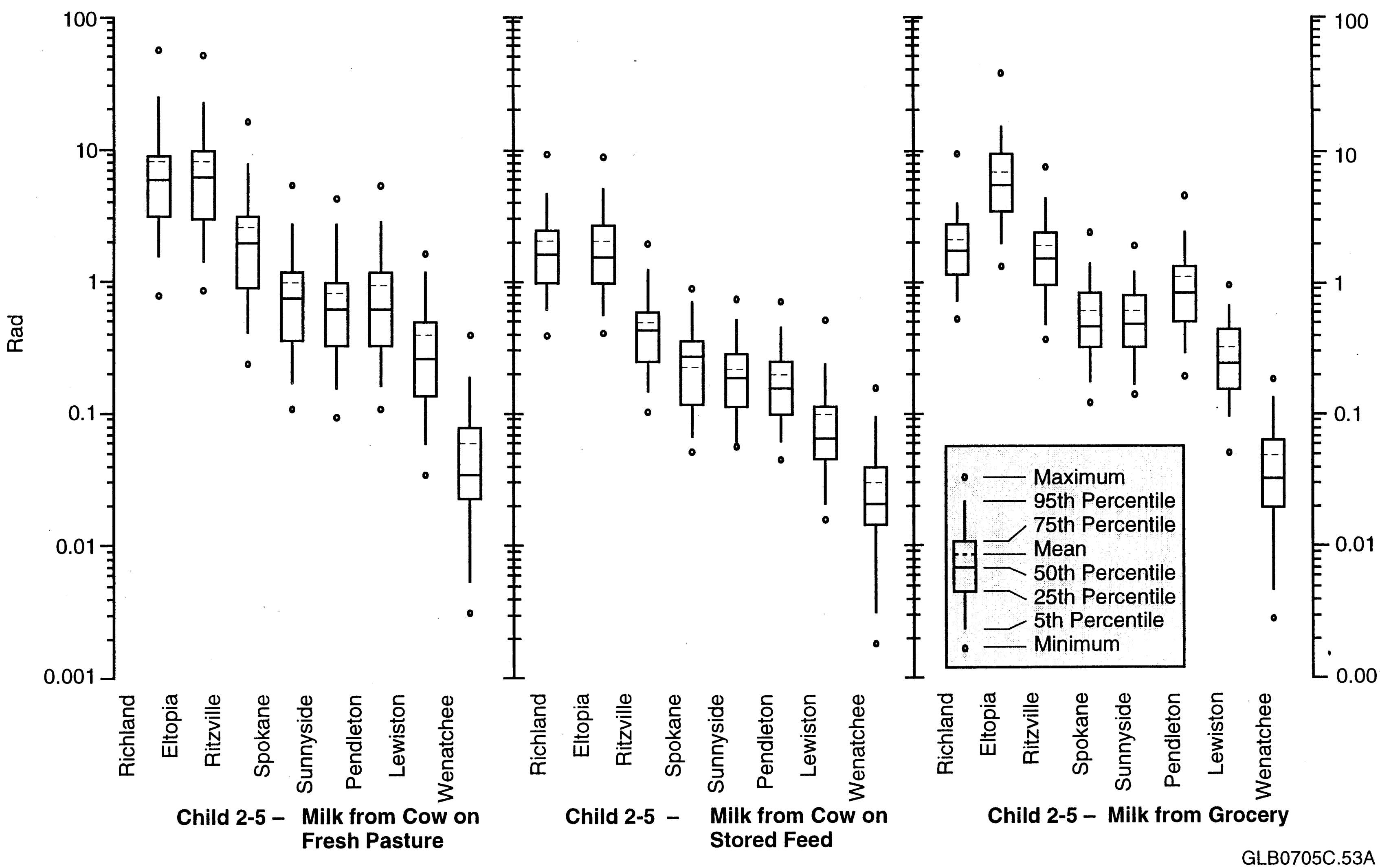


Figure 5.3. 1946 Uncertainty Estimates for Thyroid Doses at Selected Locations - Two Representative Individuals and Three Milk Sources

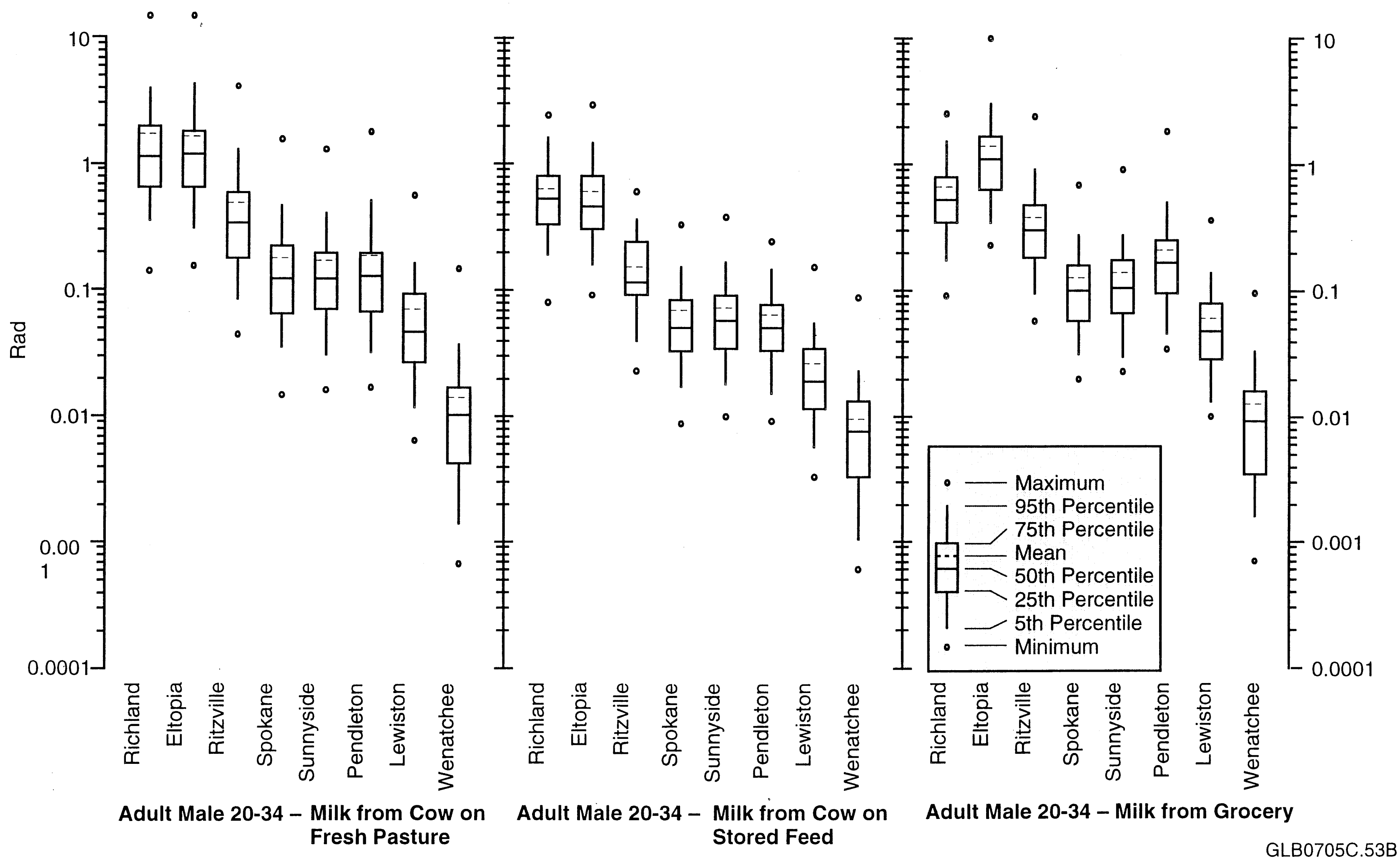


Figure 5.3. (contd)

Median dose estimates and the geometric standard deviation (GSD) for the 12 different representative individuals for three selected locations are shown in Table 5.1. The GSD is a statistical parameter that describes the relative uncertainty of the dose estimates. A GSD of 2 indicates less uncertainty than a GSD of 2.5. The GSDs are somewhat smaller for adults and slightly greater for teenagers. The GSD was not found to be correlated with location and the average GSD for each location in Table 5.1 is in the range of 2.25 to 2.29.

The uncertainty in the estimated doses is related to the magnitude of the estimated dose. Figure 5.4 shows the range of uncertainty for the doses presented in Figure 4.1. The 100 dose estimates for a 5-year-old child at each location were calculated. The inter-quartile range (25th percentile dose value subtracted from the 75th percentile dose value) was then mapped over the HEDR study area. Where the dose estimates are the highest, the absolute uncertainty in those results are the highest. For example, the estimated thyroid dose in 1945 to a 5-year-old child at Eltopia is 28 rad and the inter-quartile range is 32 rad. At Spokane, the estimated dose is 3.7 rad and the inter-quartile range is 4.4 rad.

Table 5.1. Median and Geometric Standard Deviation of Absorbed Thyroid Dose (rad) at Selected Locations[a]

Sex/Age		Eltopia Median	Eltopia GSD	Richland Median	Richland GSD	Pendleton Median	Pendleton GSD
All	<1 year	67	2.31	82	2.29	7.2	2.33
All	1 - 4 years	43	2.43	43	2.37	3.9	2.35
Male	5 - 9 years	28	2.33	30	2.30	2.7	2.30
Female	5 - 9 years	23	2.22	24	2.23	2.2	2.24
Male	10 - 14 years	17	2.59	18	2.54	1.7	2.53
Female	10 - 14 years	16	2.31	16	2.27	1.5	2.26
Male	15 - 19 years	11	2.37	11	2.34	1.0	2.35
Female	15 - 19 years	9.3	2.35	10	2.32	0.79	2.27
Male	20 - 34 years	8.0	2.23	8.1	2.19	0.76	2.21
Female	20 - 34 years	7.0	2.17	7.5	2.13	0.64	2.09
Male	>35 years	6.5	2.09	7.3	2.06	0.68	2.08
Female	>35 years	6.4	2.10	7.6	2.08	0.71	2.01

(a) Doses are from consumption of backyard foods including milk from a backyard cow on fresh pasture.

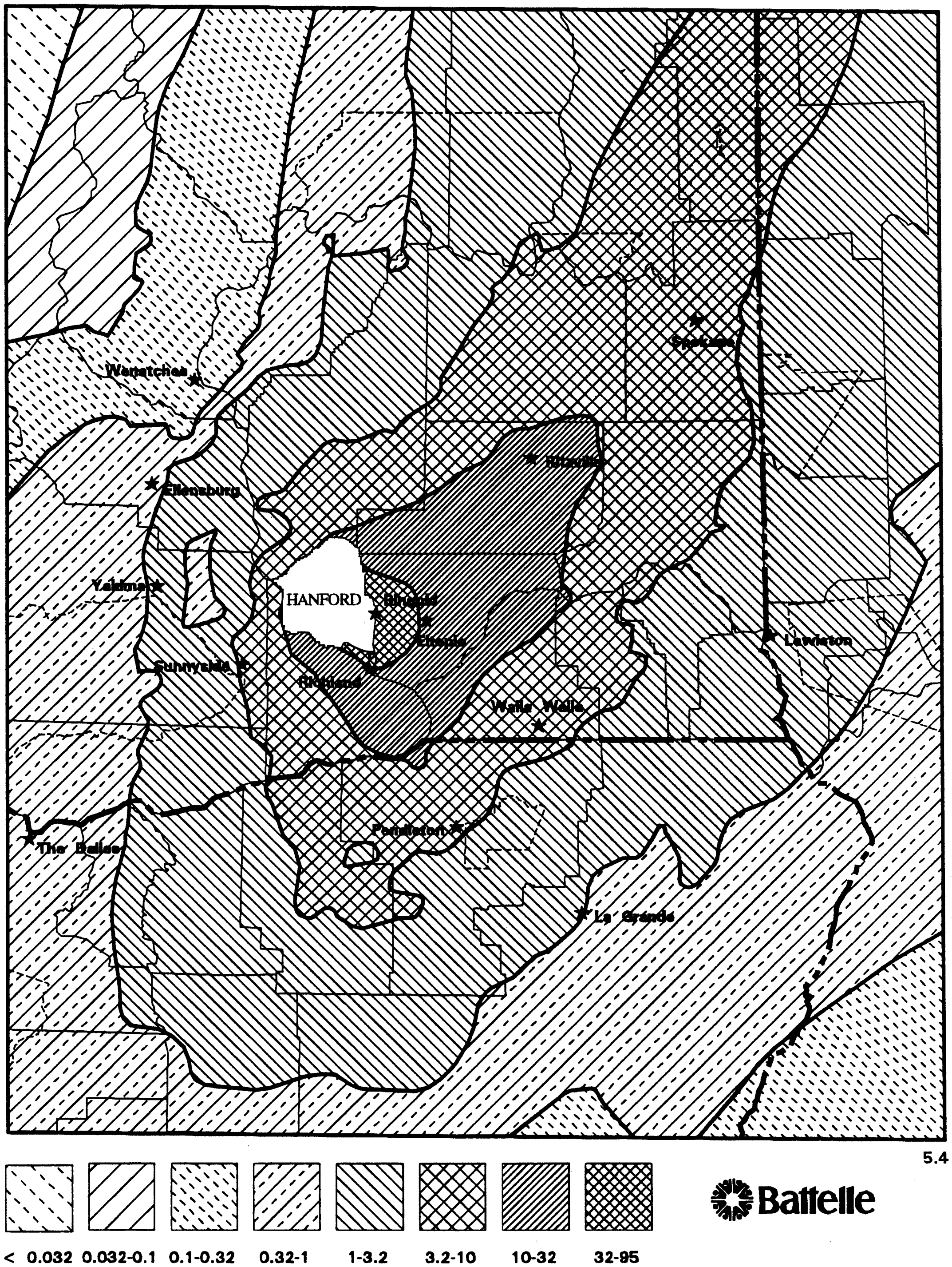


Figure 5.4. Inter-Quartile Range of Thyroid Dose to a Child in 1945

5.2 Sensitivity Analysis Techniques

Numerous input parameters are required for the atmospheric pathway models in order to provide dose estimates. These include parameters that describe the relationship between release rate and concentration of iodine-131 in air and between concentrations of iodine-131 in air and concentrations in crops, animal feed, milk, eggs, and other pathways by which humans might be exposed. In addition, there are those that directly describe the habits and activities of the representative individual. For the HEDR Project, these parameters were developed with data from the available scientific literature (Snyder et al. 1994). Each parameter was developed as a probability distribution function to specify the uncertainty about that parameter. The computer simulation of dose consisted of repeating calculations of the models 100 times to generate 100 estimates of absorbed thyroid dose for each representative individual. Each time the dose calculations were repeated, a new value for each uncertain input parameter was randomly generated from its specified probability distribution function. Thus, the parameter uncertainties have a direct impact on the variability (spread or uncertainty) exhibited by the 100 estimates of dose computed with atmospheric pathway models.

The 100 estimates of thyroid dose for the various types of representative individuals, along with the 100 sets of input parameters used to estimate them, served as the starting point for the sensitivity analyses. A stepwise multiple linear regression was performed on the results of the 100 calculations and also on the ranks of the estimates and parameters. The atmospheric pathway models are complex and, in many instances, the inputs to a given equation or model are themselves the outputs of earlier equations or models. Thus, to locate the most influential parameters in the uncertainty of final dose estimates, a top-down hierarchical analysis was performed (Simpson and Ramsdell 1993). In this approach, the first tier of analysis considered the major contributing inputs to the thyroid dose estimation equation. If the uncertainty in the thyroid dose was sensitive to one or more of the derived (previously modeled) parameters going into the equation, then the sensitivity analysis proceeded to the second tier, related to the calculation of the derived parameters. Additional sensitive inputs thus determined were then followed through a third or more tiers.

The hierarchical approach was applied to the atmospheric pathway models and followed downward to five successive tiers. The hierarchical approach is preferred when the computational model is complex and contains many model parameters (Simpson and Ramsdell 1993). At each tier, it was possible to define the parameters that were important to the various intermediate results within the dose calculation. The hierarchical approach to sensitivity analysis allows an understanding of the relative importance of the various parameters to the uncertainty in the iodine-131 thyroid dose estimates. A relative handful of parameters determines the general distribution of the thyroid dose results. Interestingly, the most important of these parameters relates to the individual (the ingestion and inhalation dose conversion factors) rather than to the source term, environmental transport, or environmental accumulation portions of the atmospheric pathway models.

To summarize the total sensitivity analysis, the various levels of the analysis are combined and presented in Figure 5.5 for children and Figure 5.6 for adults. For all cases, the single parameter contributing the most to the uncertainty (30 to 70 percent) is the individual ingestion dose conversion factor. For representative individuals consuming milk from individual family cows fed fresh pasture

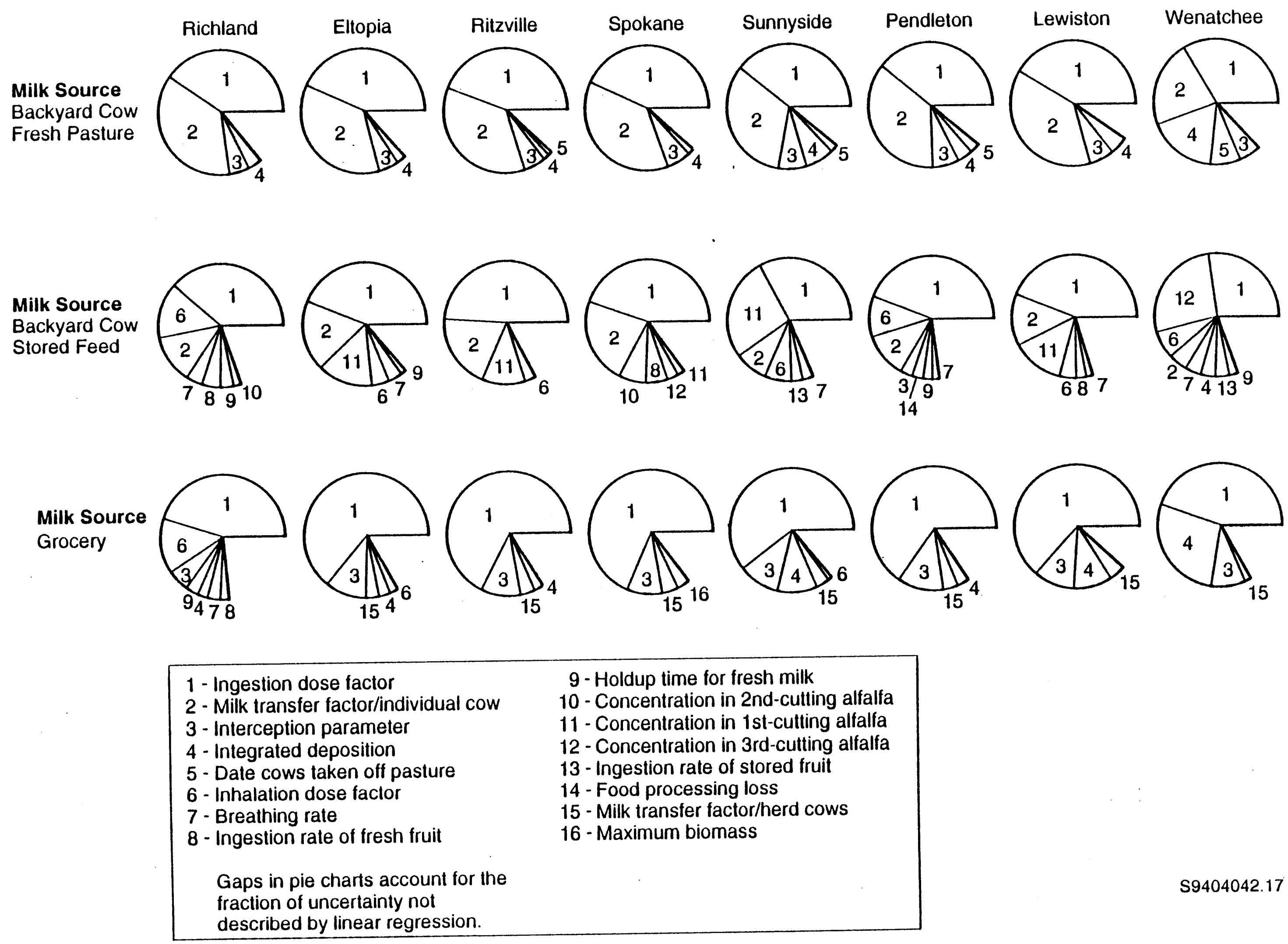


Figure 5.5. Relative Importance of Parameters Contributing to the Uncertainty of Total Iodine-131 Dose for a Child in 1945

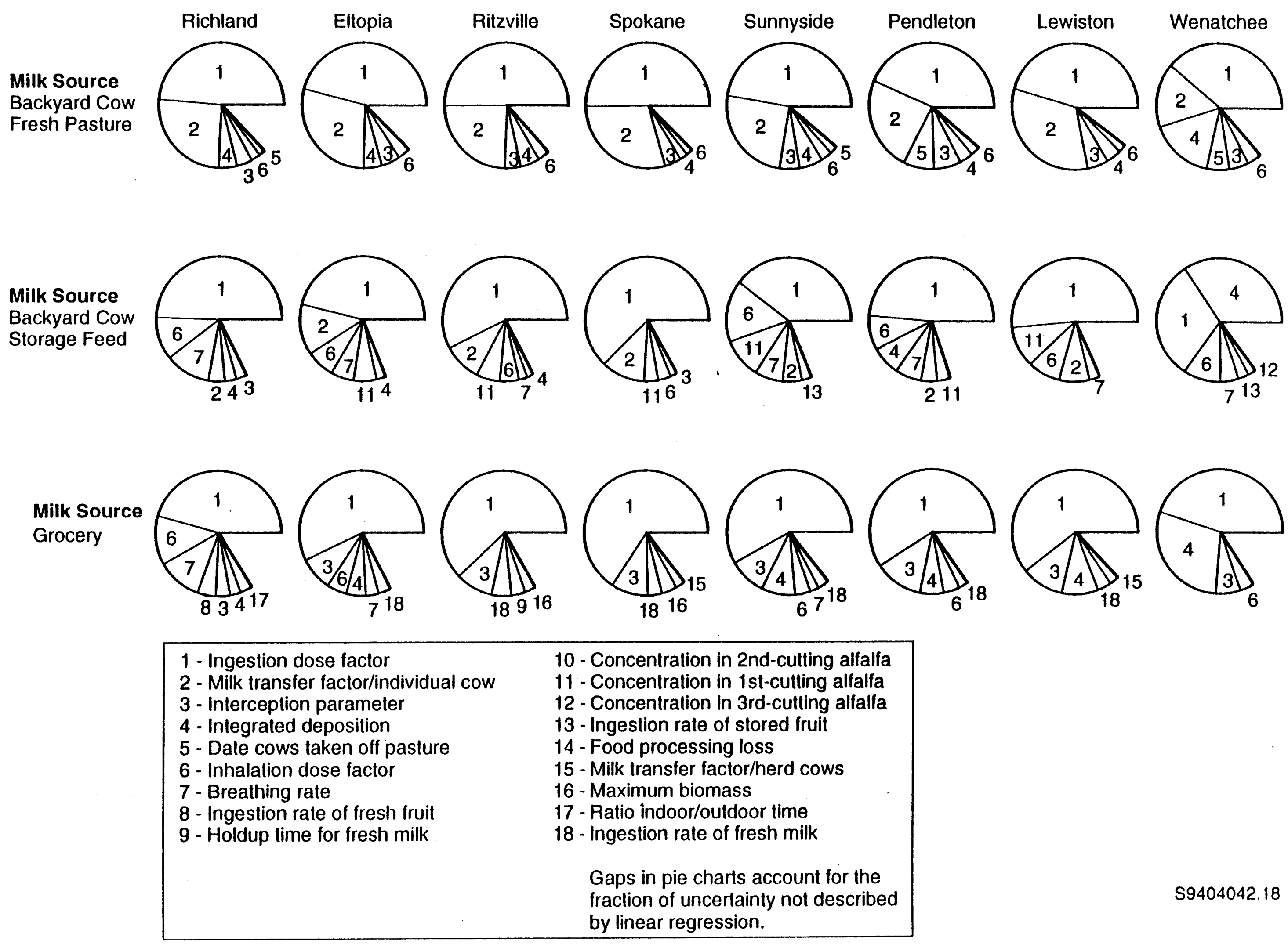


Figure 5.6. Relative Importance of Parameters Contributing to the Uncertainty of Total Iodine-131 Dose for an Adult in 1945

(feeding regime 1), the second most important parameter (contributing 35 to 40 percent of the overall uncertainty) is the individual cow feed-to-milk transfer coefficient. Representative individuals feeding their family cows stored feed had a slightly different breakdown, reflecting the decreased importance of milk to thyroid dose and the relative increase in proportion of inhalation. For representative individuals consuming milk from the commercial distribution system, the emphasis changed somewhat. The parameters relating total deposition of iodine-131 and the interception of deposition by plants tend to rise in importance. This trend is not followed at the Richland location where the thyroid dose from commercial milk is much lower because of its upwind source. In Richland, the second most influential parameter is the individual inhalation dose conversion factor or the breathing rate, reflecting the relative importance of the inhalation pathway in that location. For most combinations of representative individual category, location, and year, as many as 10 to 12 parameters must be considered to describe 90 percent of the uncertainty in the representative individual thyroid dose estimates.

64 *The two major sources of uncertainty are the ingestion dose conversion factor and the feed-to-milk transfer coefficient. Both of these parameters were assigned lognormal distributions in the Monte Carlo analysis. The selection of the distributions and sources of information on these parameters is included in Snyder et al. (1994). The uncertainty in each of these factors is primarily due to variation in natural systems. The dose conversion factor uncertainty results from the variability in thyroid mass, the uptake of iodine in the gastrointestinal tract, the transfer of iodine to the thyroid and the biological half-time. All of these parameters can be measured in human subjects. However, none of this information was collected on specific individuals at the time of exposure, and if these parameters were measured today in a specific individual, they would not necessarily be good indicators of what the parameters would have been nearly 50 years ago. As a result, the distribution used in the analysis is broad enough to account for the natural variation. The uncertainty in the feed-to-milk transfer is due to variability in biokinetic factors (gut uptake, excretion, biological half-life) and the variability between different breeds and seasons.*

6.0 Conclusions

- Reliable and useful doses and their uncertainties have been reconstructed for potential exposures to representative individuals from historical releases of radioactive materials from the Hanford Site to the atmosphere.

- The most important contributor to dose was iodine-131 released from the chemical separations plants during the year 1945.

- The most important means of exposure from the atmospheric pathway was the consumption of fresh milk.

- The highest estimated dose was from the consumption of milk produced by cows fed fresh pasture near Ringold, Washington.

- The commercial distribution of milk had an impact on doses. An important impact resulted in lower doses in what otherwise would have been a high impact location (e.g., Richland, Washington).

65 - For *most* representative individuals at any location, 90 percent of the estimates are within a factor of *15*.

This report is the culmination of technical work performed to reconstruct radiation doses. Such doses may have been received by persons affected by emissions of radionuclides to the atmosphere from the Hanford Site. The report summarizes the efforts to estimate 1) the quantity and timing of releases of radioactive materials to the atmosphere, 2) the atmospheric transport of radioactive materials within the HEDR study area, 3) the accumulation of radioactive materials in the environment, and 4) the doses that representative individuals may have received from 1944-1992.

The HEDR Project staff have been able to identify and retrieve sufficient historical information to reconstruct, through modeling, the operational history of each of the four chemical separations plants. The results of this modeling along with recorded atmospheric measurements and analytical data have allowed releases of radioactive materials to the atmosphere to be quantified. The modeling and historical measurements have also allowed the major sources of uncertainty both in the variability of parameters needed for calculations and in areas where information was missing to be identified and quantified.

Historical environmental measurements and weather station data have been used to reconstruct the atmospheric transport of radionuclides during the period of the chemical separations plants operations, 1944-1972. The calculations were performed using an atmospheric transport model that incorporated uncertainty in transport mechanisms and weather data and allowed for the propagation of the uncertainties associated with the radionuclide releases.

The use of historical environmental measurements alone was inadequate for determining concentrations of radioactive materials. A model was developed to reconstruct the concentrations of radionuclides in soil, vegetation, and animal products. The propagation of uncertainty continued and the estimated environmental concentrations include uncertainties in radionuclide releases, atmospheric transport, and environmental accumulation.

The reconstruction of concentrations of radioactive materials, as well as the determination of the uncertainties in these estimated concentrations, provide a basis for estimating doses that persons may have received from exposure to radioactivity released to the atmosphere from the Hanford Site. The computer codes used to estimate the doses have been peer reviewed by the TSP and other experts. The conceptual model and parameter values used in the computer calculations were based on information in open literature publications and have also been peer reviewed. Validation studies (Napier et al. 1994) using historical environmental measurements have demonstrated the acceptability of using the computer codes to estimate doses resulting from releases to the atmosphere for important times and locations.

The independent testing of computer codes, statistical analyses of data presented in this report, uncertainty and sensitivity analyses presented in this report, and validation studies (Napier et al. 1994) demonstrate that the reconstruction of the chemical separations plants operations, the releases of radioactive materials to the atmosphere, the transport of radioactive materials in the atmosphere, the accumulation of radioactive materials, and the estimation of doses resulting from the atmospheric pathway to representative individuals are appropriate and fully meet the objectives of the HEDR Project.

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Appendix A

Comparison to Feasibility Study Doses

Appendix A

Comparison to Feasibility Study Doses

A feasibility study for the atmospheric pathway was conducted in 1991 (PNL 1991). The purpose of the feasibility study was to determine if a retrospective assessment of the atmospheric pathway was possible and to determine the magnitude of possible radiation doses. Dose estimates were presented in the feasibility study for airborne releases of iodine-131 from the Hanford separations facilities. Many of the doses presented in that report have been repeated with new calculational methods and data. These new dose estimates are presented in this report. The doses in this report can be considered an improvement over those of the feasibility study for several reasons discussed below.

A.1 Primary Differences in Input Information and Conceptual Models

An expanded and more detailed iodine-131 source term has been prepared using information that was not available for the feasibility study. For information on the expansion and detail, see Heeb (1993, 1994). The conceptual models and computer codes used to estimate atmospheric transport, environmental accumulation, and dose have been enhanced since the feasibility study. Input data have also been enhanced by the addition of more detailed information on human exposure parameters, food product distribution patterns, and animal diet information. These enhanced calculational tools and input data have resulted in the dose estimates presented in this report. Some problems, primarily in the treatment of uncertainty, were noted in the feasibility study conceptual models used for the atmospheric pathway (Simpson 1991a, 1991b). The lessons learned in the feasibility study were applied in this report.

The primary conceptual model differences between this assessment and the feasibility study are shown in Table A.1. The expected impact on the doses for the year 1945 is also presented.

A.2 Differences in Doses

The doses that were presented in the feasibility study were compared to those estimated for this report. Figures A.1 through A.5 compare the results of this study and those of the feasibility study for infants and adults. Doses are shown for five separate pathways: inhalation, milk from cows using irrigated pasture, milk from cows eating stored feed, grocery milk, and fruit and vegetables. The comparisons in the figures are presented for five locations, with the doses for this study and those for the feasibility study presented as pairs for each location: Ringold (FR4), Richland (location BE7 in the feasibility study), Ritzville (AD2), Pendleton (UM6), and Sunnyside (YA9). Feasibility study estimates were not made for all five locations for all pathways. For example, feasibility study estimates were not made at Ritzville for cows on fresh pasture. Therefore, no comparison with the newer doses could be made.

Table A.1. Differences Between this Study and the Feasibility Study (PNL 1991)

Model Component	Change	Effect on Doses in this Study when Compared to the Feasibility Study (PNL 1991)
Source Term	The feasibility study source term for iodine-131 was 340,000 curies in 1945. The doses in this study are based upon the release of 555,000 curies during 1945.	All doses would have been higher as a result of the larger source term. However, other changes from the feasibility study result in lower doses.
Atmospheric Transport	For this study, a more detailed assessment of the iodine *speciation* was made. The iodine released was partitioned into nonreactive gas, reactive gas, and particulate components. The deposition is estimated as the weighted average.	Lower doses near the Hanford Site and higher at distance.
Environmental Accumulation	An entirely new environmental accumulation model derived from Whicker and Kirchner (1987) was used in this study. Many parameters that describe the movement of radionuclides in the environment were further researched and given new values in this study.	No systematic increase or decrease in doses.
Milk Distribution Information	The milk distribution network was expanded from 10 counties to 22.	Some impact on doses for areas where no distribution was available for the feasibility study.
Milk Cow Feeding Regimes	This study redefined the feeding regimes for backyard and commercial milk cows based on data provided by dairy experts.	Doses are slightly higher due to increased pasture season in some key locations.
Representative Individual Dose Assessment	The methods used to estimate representative individual dose have not changed substantially, while many of the parameters used to describe a representative individual's exposure have been modified (e.g., some changes in dose factors, consumption rates, and lifestyle parameters).	Doses, based on dose factors, consumption rates, and lifestyle parameters alone, are largely unchanged. Doses from some pathways, such as fruit and vegetable ingestion, have decreased.

The dose estimates shown in Figures A.1-A.5 as well as the estimates shown in Section 5.1 represent the uncertainty estimates for specific individuals and locations. The dose estimates shown in Figures 4.1-4.21 represent median doses over a geographic range and so do not reflect the uncertainty.

The statistics are based on the running of 100 realizations of a Monte Carlo calculation. The doses are presented as whisker plots, with the ends of the whiskers at the 5th and 95th percentiles. The median (50th percentile) is shown as a horizontal dash.

67 As the figures *in this report* show, the doses *in the areas nearest to the Hanford Site* are generally lower than those presented in the feasibility study. *However, doses further from the Hanford Site were higher.* The highest dose reported in the feasibility study was the dose to an infant near Ringold, Washington. The thyroid dose in 1945 from the consumption of milk from a backyard cow fed fresh pasture was estimated to be 374 rad (median dose) with a range from 54 to 2333 rad (5th and 95th percentile values). The dose estimated using the updated calculational methods and data indicated a median thyroid dose to the same infant in 1945 to be 153 rad, ranging from 30 to 670 rad (5th and 95th percentile values). See Figure A.2 for these comparisons of 1945 dose ranges between the feasibility study (PNL 1991) and this study.

Several other points are noteworthy about specific differences in dose estimates. Although the release estimate for iodine-131 increased in this study from that of the feasibility study, decreased iodine deposition lowered the doses near the Hanford Site. At the Ritzville location, one of the more distant locations estimated in the feasibility study, the doses in this study are now generally higher (see Figure A.3). The thyroid dose to an infant in 1945 from the consumption of milk from a backyard cow fed stored feed was estimated to be 0.23 rad (median dose), with a range from 0.029 to 1.7 rad (5th and 95th percentile values). The dose estimated using the updated calculational methods and data indicated a median thyroid dose to the same infant in 1945 to be 2.2 rad, ranging from 0.32 to 10 rad (5th and 95th percentile values).

The inhalation doses for infants and adults are similar in both studies at most locations (see Figure A.1). The doses from consumption of grocery milk and milk from backyard cows fed fresh pasture are lower in this study. The decrease is due to the decreased deposition as well as the redefined cow-feeding regimes.

The largest difference between the two studies is seen in the dose from vegetables (both leafy and other vegetables) and fruit. The doses in this study are significantly lower for vegetables and fruit at most locations than those in the feasibility study. The human exposure parameters are similar for both studies, and the decreased deposition does not account for the total difference. The loss of correlation effects that existed in the feasibility study model (see Simpson 1991a, 1991b) resulted in the overestimate of doses from fruits and vegetables.

5 *When the HEDR Project released previous dose estimates in 1991, the highest dose reported was 2900 rad (PNL 1991). This was the 95th percentile thyroid dose to an infant in the Franklin County census tract (FR4) for the period 1944-1947. The dose estimate was for an infant consuming fresh milk from a cow on fresh pasture. The analogous dose to an adult at that same location was estimated to be 190 rad. Using the latest data and calculational methods, the dose is now estimated to be 820 rad and 140 rad to the infant and adult, respectively. Table A.2 shows the dose estimates for both this and the 1991 study for infants and adults at three locations.*

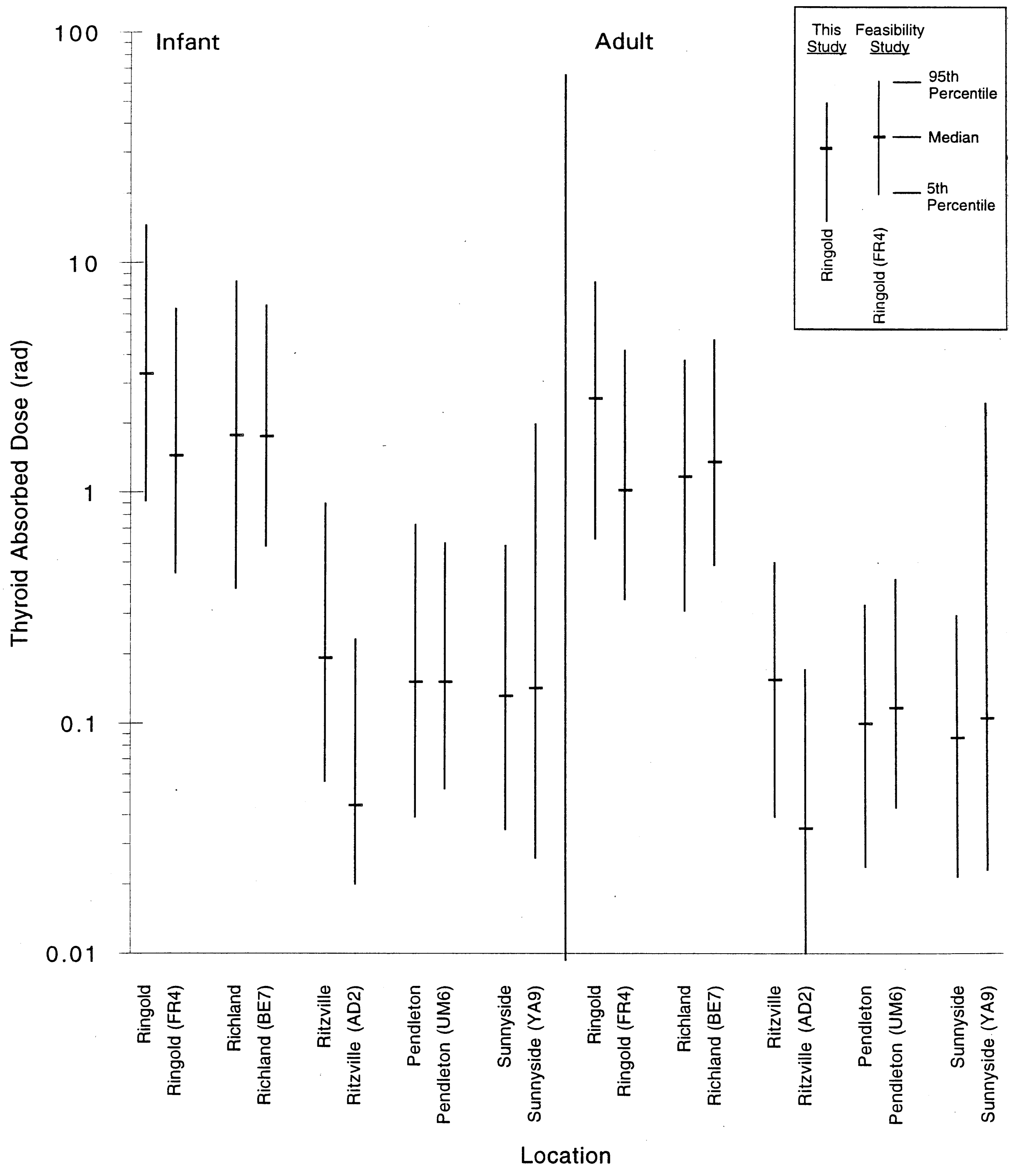


Figure A.1. 1945 Dose Ranges (Infant and Adult) for Inhalation - This Study versus Feasibility Study (PNL 1991)

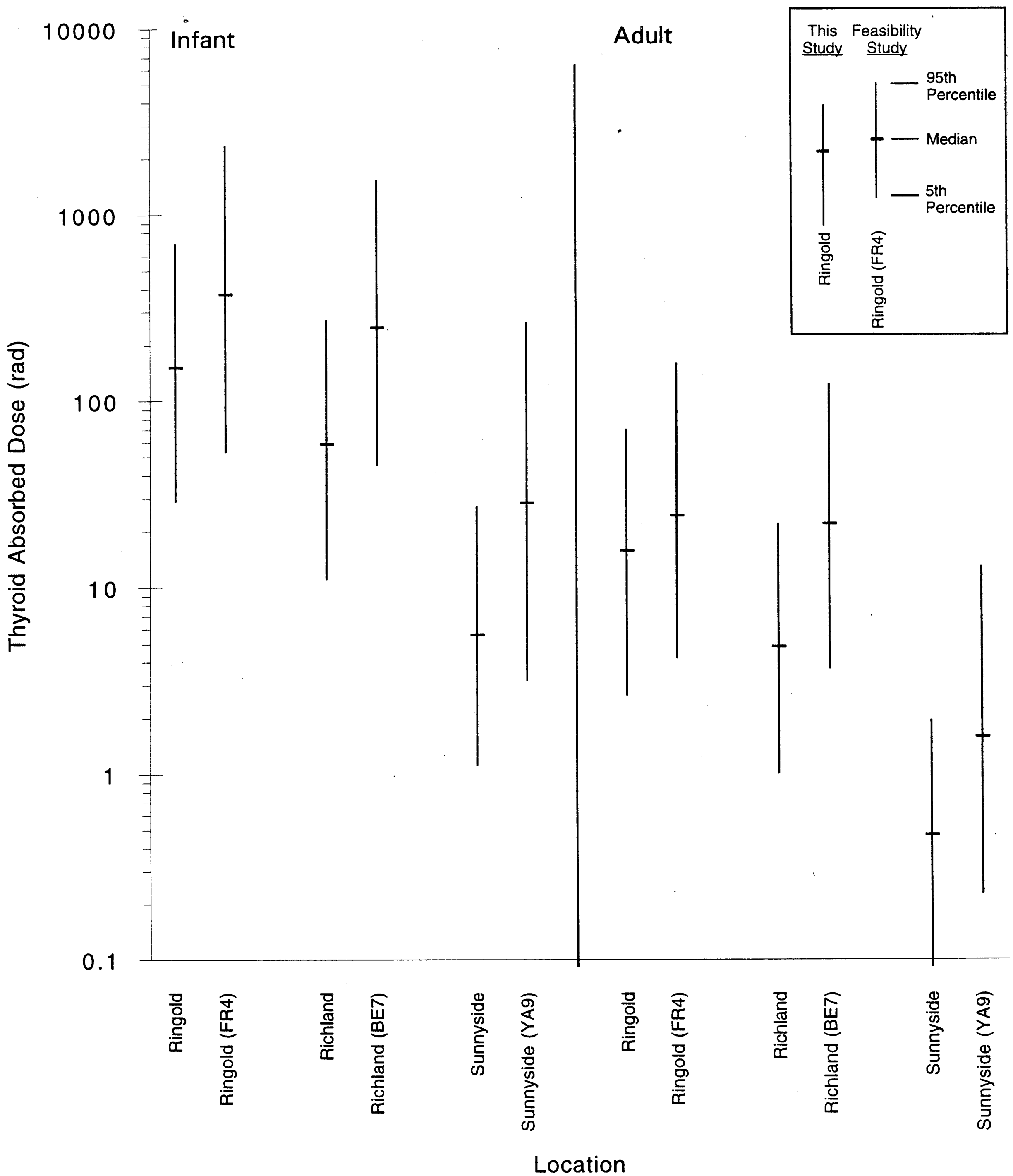


Figure A.2. 1945 Dose Ranges (Infant and Adult) for Milk from Cow on Fresh Pasture - This Study versus Feasibility Study (PNL 1991)

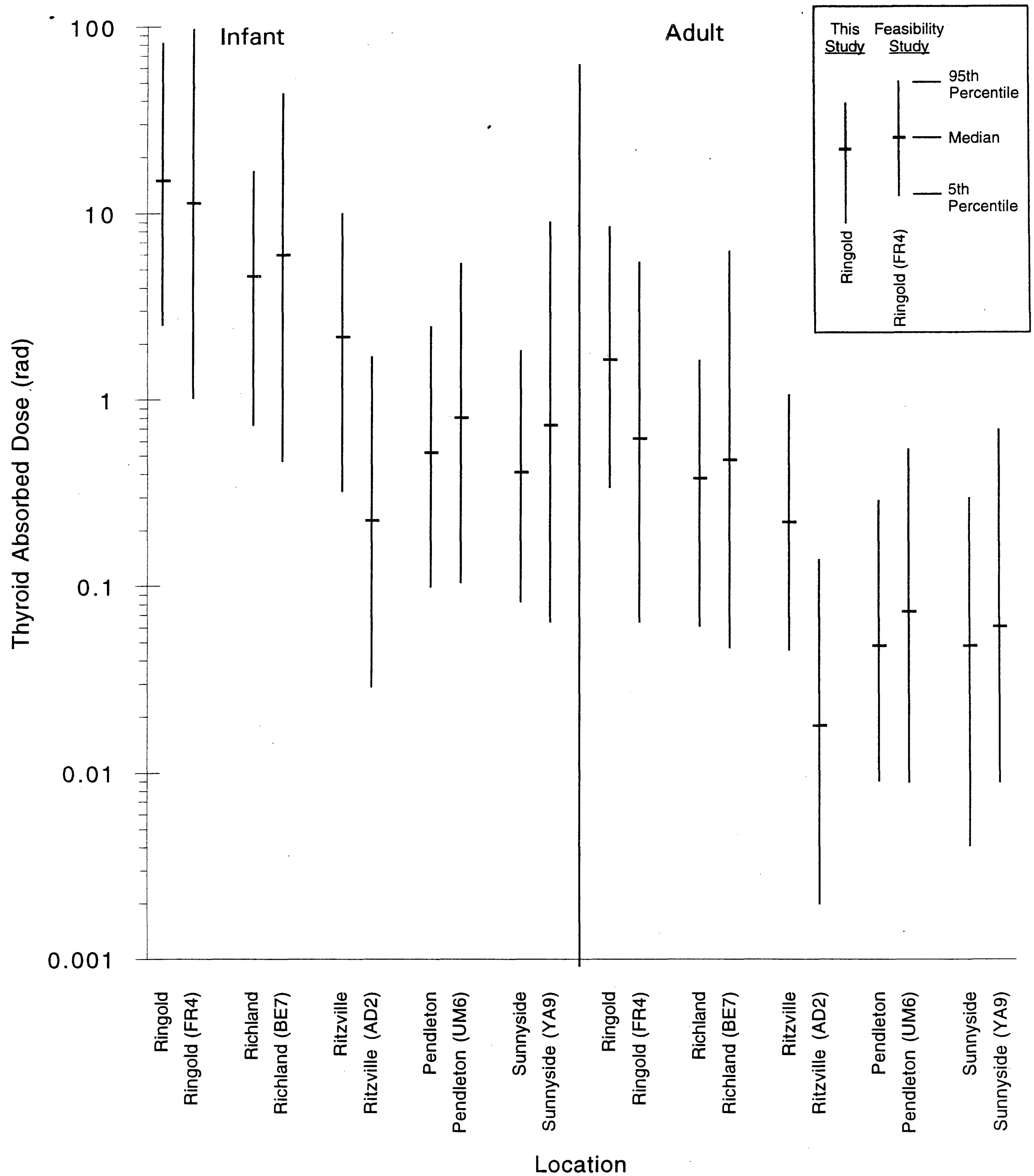


Figure A.3. 1945 Dose Ranges (Infant and Adult) for Milk from Cow on Stored Feed - This Study versus Feasibility Study (PNL 1991)

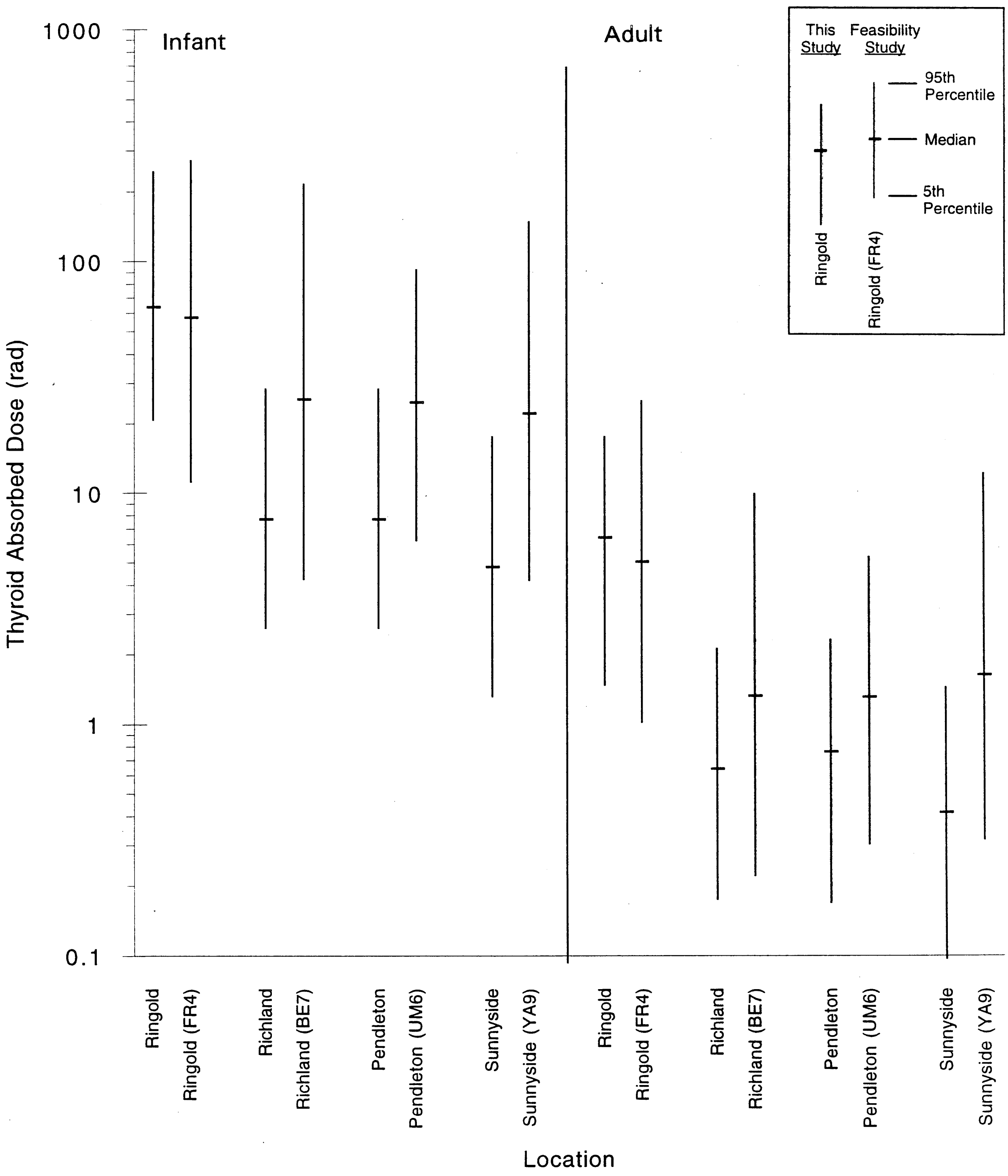


Figure A.4. 1945 Dose Ranges (Infant and Adult) for Commercial (Grocery) Milk - This Study versus Feasibility Study (PNL 1991)

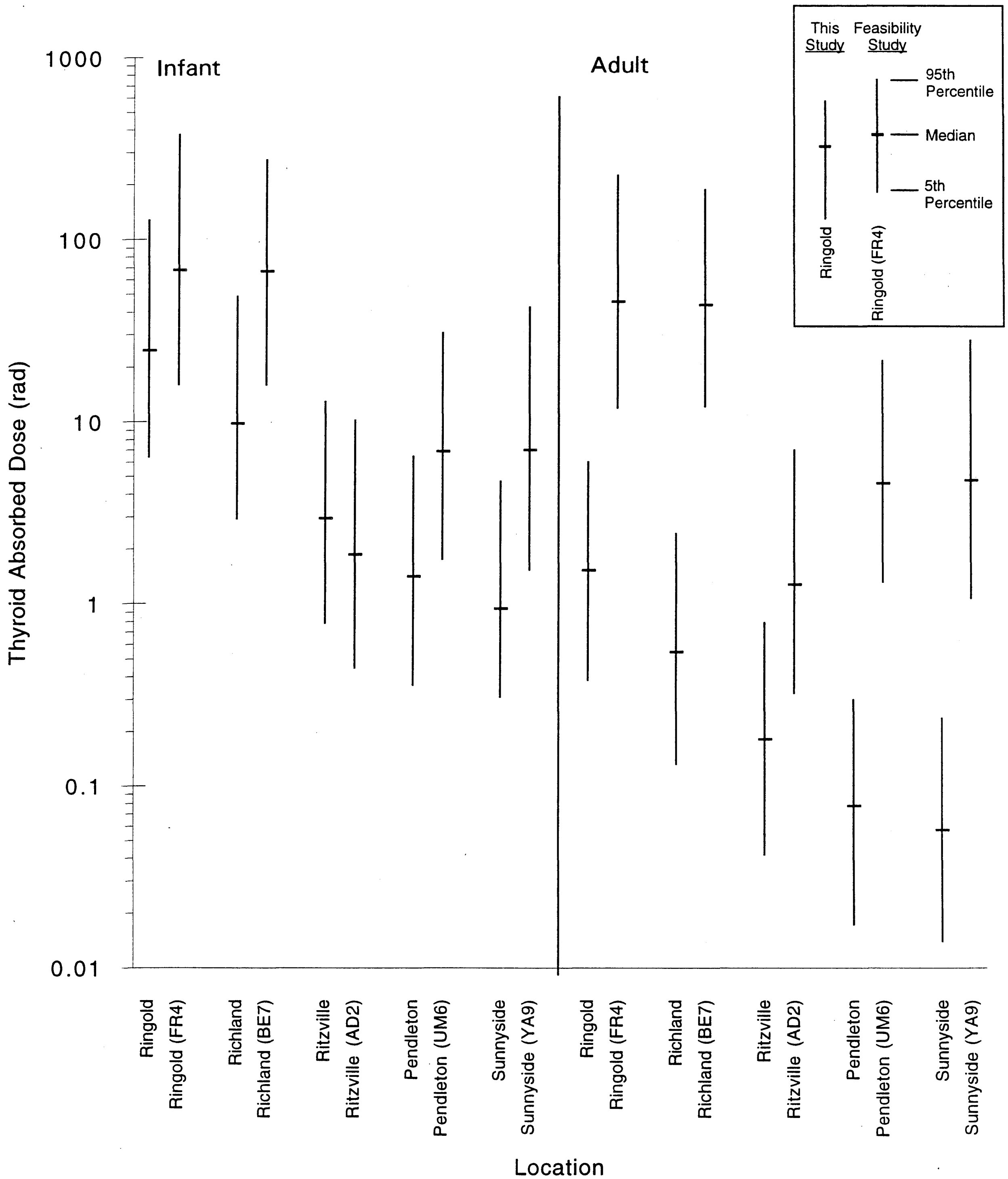


Figure A.5. 1945 Dose Ranges (Infant and Adult) from Consumption of Leafy Vegetables and Fruit - This Study versus Feasibility Study (PNL 1991)

Table A.2. Comparison of Feasibility Study Dose Estimates to this Study - Consumption of Milk from a Cow Fed Fresh Pasture (1945-1947)

	This Study			(PNL 1991)		
	5th Percentile	50th Percentile	95th Percentile	5th Percentile	50th Percentile	95th Percentile
Infant						
Ringold/FR4	59	220	820	120	540	2900
Richland/BE7	24	94	330	100	350	1600
Sunnyside/YA9	2.1	8	33	7.2	41	280
Adult						
Ringold/FR4	8.8	37	140	8.6	34	190
Richland/BE7	3.5	13	53	7.6	32	120
Sunnyside/YA9	0.27	1.3	4	0.63	2.5	18

Appendix B

HEDR Atmospheric Pathway Computer Codes

Appendix B

HEDR Atmospheric Pathway Computer Codes

The combined set of computational tools used to estimate doses from the atmospheric pathway for 1945-1951 consists of four codes: STRM (**S**ource **T**erm **R**elease **M**odel) for source term values; RATCHET (**R**egional **A**tmospheric **T**ransport **C**ode for **H**anford **E**mission **T**racking) for concentrations of radionuclides in the air and deposition of radionuclides on the ground; DESCARTES (**D**ynamic **Es**timates of **C**oncentrations and **A**ccumulated **R**adionuclides in **T**errestrial **E**nvironment**s**) for concentrations of radionuclides in soil, plants, and animal products; and CIDER (**C**alculation of **I**ndividual **D**oses from **E**nvironmental **R**adionuclides) for estimates of representative individual doses.

The following sections discuss the development and significant features of the four computer codes.

B.1 Source Term Model

During the course of Hanford Site operations, some by-product radionuclides were released to the air. The detailed reconstruction of the historic releases of radionuclides from Hanford separations facilities is documented in Heeb (1993, 1994). These estimates were derived from the large amount of information concerning radioactive releases from Hanford facilities that exists in government and contractor documents, as well as articles in technical journals. From this information, source term estimates were prepared as detailed hourly iodine-131 source term for the years of highest release.

B.1.1 Iodine-131 Source Term, 1944-1951

Releases of radionuclides to the air from the separations plants were an object of concern from the startup of the first separations plant, T Plant, in December 1944 (Ballinger and Hall 1991). Operation of T Plant was followed by the operation of B Plant in April 1945. Both of these plants employed the bismuth phosphate process to separate plutonium from production reactor spent fuel.

The release history for 1944 through 1949 was generated by using STRM in the stochastic mode to produce 100 hourly source term realizations of iodine-131 releases. One run was made for T Plant, another for B Plant. These runs produced the source term for input into the atmospheric transport code RATCHET (Ramsdell et al. 1994).

Unusual release events such as the 1949 Green Run were also modeled in STRM. That non-standard release from the T Plant occurred in December 1949 when a dissolver was loaded with 2 metric tons of fuel that had been discharged from the reactor only 16 days previously (normal fuel-cooling times during this period were 90 to 110 days). The aluminum cladding was removed by caustic chemicals, nitric acid sufficient to dissolve 1 metric ton of fuel was added, and the remaining metric ton of fuel was stored in the dissolver until March. STRM was modified to handle this non-standard mode of operation.

The algorithms and computer codes used to estimate hourly iodine releases from reactor and separations plant operations are described in Heeb (1993), a reference which provides iodine-131 release estimates for 1944 through 1947. Hourly release estimates from the B and T Plants during 1948 and 1949 were estimated using dissolver cut information from the Metal History Records (General Electric 1948a). The Metal History Records include information on the number of slugs loaded into the dissolver, the number of cuts taken from each load, the reactor of origin, and the discharge date of the slugs. The records also provide the date that each cut moved into the extraction phase of the separation process.

Records of reactor discharges (pushes) for 1948 were taken from the P Department records (General Electric 1948b). Records of reactor discharges for 1949 were taken from the monthly reports (General Electric Company 1949) because the P Department reports stop at the end of 1948. A total of 400 pushes were reprocessed in whole or in part from 1944 through 1949, 226 in 1944 through 1947, and 174 in 1948 and 1949.

For the period 1950 through 1951, original records were not available in sufficient detail to allow hourly release estimates. However, sufficient information was found to allow monthly estimates. The time sequences of release within these months were simulated using the results of the 1944-1949 calculations.

The iodine-131 releases total nearly 730,000 curies during the 1944-1951 time period. The December 1949 Green Run accounts for 7,000 curies of this iodine-131 activity. There were 17 months during the period from December 1944 to November 1949 when monthly releases were greater than the 1949 Green Run.

B.1.2 Key Radionuclide Source Term, 1944-1972

68 The hourly results for iodine-131 estimated using the STRM code were aggregated into monthly mean releases for 1944 through 1949. This repetition of the earlier data provides a single data source for iodine-131 air releases. Monthly releases of strontium-90, ruthenium-103, ruthenium-106, cerium-144, and plutonium-239, plus iodine-131 releases after 1949, were also estimated. With the exception of plutonium-239, all of the six key radionuclides are fission products. Plutonium-239 is formed *by activation of uranium-238 and subsequent decay to neptunium-239 in reactor fuel.* Neptunium-239 decays by beta particle emission with a 2.4-day half-life to plutonium-239. Because they were created within the fuel element, the six radionuclides remained within the spent reactor fuel when it went to the separations plants. When the fuel was dissolved at the separations plant, some fraction of the radionuclides was released to the air.

The releases can be estimated by

- determining the amount of fuel processed each month

- accounting for its radionuclide content (curies per ton)

- accounting for the decay that occurred in the time between shutdown of the reactor for discharge of the fuel and processing of the fuel at the separations plant

- applying a release factor to the amount processed.

Records were kept of the amount of uranium fuel dissolved, the burnup of the fuel, and the average cooling time. Enough of these records survived to permit a daily reconstruction of T and B Plant operations through the end of 1949. This level of detail was used to reconstruct iodine-131 releases for that period. Thereafter, monthly summary records exist in sufficient detail to permit a monthly reconstruction of the amount of fuel dissolved, the average burnup of the dissolved fuel, and the average cooling time of the fuel throughout the operating life of each separations plant. The main sources of data used in the reconstruction of the monthly source term are Jungfleisch (1992), Gydesen (1992), Jaech (1957), Roberts (1957), Heeb (1993) and the Hanford Works Monthly Reports for April, June, August, October, and December 1952 (General Electric Company 1952a, b, c, d and 1953).

The release factor is defined as the ratio of the activity released to the activity processed. A monthly release factor value was estimated for each of the six radionuclides under study in this report (strontium-90, ruthenium-103, ruthenium-106, iodine-131, cerium-144, and plutonium-239) for each separations plant in operation. An estimate of the number of curies released from each operating separations plant during the month was also estimated. In every case, this estimate was based on measurements made at some time during the operation of the separations plant. Release factors based on measurements from a given time period were assumed to apply to all other time periods when the same release control equipment was in service.

Table B.1 shows the annual release estimates for the six radionuclides under study from all four separations plants. The estimates are based upon the monthly calculations aggregated to annual totals for ease of presentation. The monthly release totals can be found in Appendix B of Heeb (1994).

Releases were estimated for the entire period of separations plant processing of single-pass reactor fuel. Separations were started at the T Plant in 1944 and the last of the single-pass reactor fuel was processed at PUREX in 1972. Some fuel from the ninth Hanford reactor, the N Reactor, was processed at the PUREX Plant in the 1980s.

Table B.1. Annual Summary of Radionuclide Releases to the Atmosphere from Separations Plant Operations, 1944-1972 (Ci/yr)

Year	Iodine-131	Ruthenium-103	Ruthenium-106	Strontium-90	Plutonium-239	Cerium-144
1944	2100	0.49	0.035	0.021	0.0012	1.6
1945	560000	87	12	6.9	0.39	460
1946	96000	87	18	11	0.58	650
1947	32000	51	12	7.4	0.41	450
1948	1800	12	4.6	2.9	0.16	170
1949	8700	0.42	0.19	0.12	0.0063	6.2
1950	5400	0.81	0.35	0.2	0.01	10
1951	27000	2.4	0.58	0.28	0.014	17
1952	5100	32	11	0.4	0.013	23
1953	1700	270	89	0.52	0.015	31
1954	830	480	170	0.67	0.021	41
1955	670	6.9	2	0.78	0.025	43
1956	120	5.8	2.6	1.2	0.014	73
1957	270	13	4.6	1.9	0.015	120
1958	820	17	4.4	2	0.011	130
1959	230	15	5.3	2.3	0.0084	140
1960	230	17	5.8	2.6	0.0072	160
1961	92	15	6.2	2.8	0.011	170
1962	29	9.1	5.4	2.6	0.0091	150
1963	78	7.5	5.1	2.5	0.011	140
1964	11	9.3	5.8	2.8	0.015	160
1965	6.1	7.8	5.4	2.7	0.014	150
1966	9.1	5.4	4.7	2.5	0.018	130
1967	1.3	3.8	4.4	2.1	0.00051	110
1968	0.021	2	4.8	2.2	0.00051	100
1969	0.0013	0.73	3.6	1.7	0.0004	73
1970	0.0011	0.19	0.89	0.42	0.000092	17
1971	0.000063	0.11	1.1	1.1	0.00025	30
1972	<0.000001	0.0049	0.12	0.11	0.000032	3.5
Sum	740000	1200	390	64	1.8	3800

B.2 Atmospheric Transport Model

The atmospheric transport calculations are the link between the iodine releases and the environmental accumulation calculations. The atmospheric transport activities have included:

- development of an atmospheric model capable of describing the transport, diffusion, and deposition of material over an area of about 75,000 square miles in the vicinity of Hanford
- preparation of the meteorological database required to calculate the dispersion of material released from December 1944 through December 1949
- calculation of daily time-integrated air concentrations and surface contamination for the area and time period described above.

Ramsdell et al. (1994) describe the atmospheric model and computer code RATCHET developed for use in these calculations. RATCHET was the end of the model development process that began with the MESOILT2 code (Ramsdell and Burk 1991) and continued with development of an initial version of the RATCHET code (Ramsdell and Burk 1992). The meteorological database prepared for use with RATCHET is described by Stage et al. (1993).

A range of atmospheric modeling alternatives was considered for the first phase of the HEDR Project (Ramsdell 1991). The recommended approach that was accepted by the TSP was to use a Lagrangian puff model. The results of the initial phase of the HEDR Project demonstrate the feasibility of the puff modeling approach. Phase I results showed that MESOILT2 provided reasonable estimates of average time-integrated air concentrations and deposition. However, the results also show that the method of estimating uncertainty in the air concentrations and deposition needed refinement and that the spatial and temporal averaging in the initial phase masked important information (Simpson 1991a, 1991b).

The RATCHET code was closely scrutinized during its development. Experts were convened to provide recommendations for the most appropriate formulations (Ramsdell 1992). In addition, the TSP and CDC coordinated a review of the completed code by other outside experts in 1993.

The RATCHET computer code implements a Lagrangian-trajectory, Gaussian-puff dispersion model. In the model, sequences of Gaussian puffs represent plumes from ground-level and elevated sources. As the puffs move through the model study area, time-integrated air concentrations and surface contamination are estimated at locations called nodes by summing the contributions from puffs moving past the nodes. Transport, diffusion, and deposition of material in the puffs are controlled by wind, stability, precipitation, and mixing-layer depth fields that describe the spatial and temporal variations of meteorological conditions throughout the study area. RATCHET is diagnostic in the sense that it estimates puff movement and diffusion based on observed meteorological data. The model does not have the capability to predict future changes in meteorological conditions.

B.2.1 Model Study Area

The atmospheric model study area is a rectangular area. It is fixed in space and is tied to a specific location on the earth's surface by specifying the latitude and longitude for a reference point in the grid system. For the HEDR Project, the study area is centered at 46°40'N, 118°45'W, and extends approximately 306 miles from north to south and 246 miles from east to west. The center of the model study area is offset from the release points at Hanford to better fit the study area within the major topographic features of the area and to place more of the study area on the side of Hanford that is downwind in the prevailing wind direction. Geographically, the study area covers an area of 75,000 square miles that extends from central Oregon to northern Washington and from the crest of the Cascade Mountains to the eastern edge of northern Idaho.

B.2.2 Meteorological Data

Wind, atmospheric stability, mixing-layer depth, and precipitation vary in time and space throughout the study area. Atmospheric transport, diffusion, and deposition calculations in RATCHET are based on observed meteorological data. RATCHET requires the following meteorological data:

- surface-level wind direction and speed at one or more stations
- atmospheric stability class at one or more stations
- current weather (e.g., light rain, moderate snow, etc.)
- wind direction and speed at release height
- ambient air temperature at release height.

These data are entered from a meteorological data file. Surface wind data, stability, and current weather may be entered for each station. When missing data are encountered for a station, that station is temporarily dropped from consideration in the preparation of meteorological data fields.

B.2.3 Transformation, Deposition, Depletion, and Decay

MESOILT2 (Ramsdell and Burk 1991) used simple methods for calculating dry and wet deposition. The original purpose for including deposition in the MESOI family of models was to identify areas where field teams should be sent to measure surface contamination. In that context, simple deposition models were adequate. For the purpose of dose estimation, more sophisticated methods of calculating deposition were added to RATCHET. The model is now capable of treating four types of material: noble gases, slightly nonreactive gases, reactive gases, and particulates. Noble gases are not allowed to deposit. The remaining types of material deposit at rates that depend on the material. Iodine is treated as a special type of material. The mass of iodine released to the atmosphere may be partitioned into nonreactive gas, reactive gas, and particulate components, and deposition is estimated using weighted average deposition rates.

Surface contamination is computed at nodes on the concentration grid; spacing between nodes is 6 miles. The accumulation period for surface contamination ends at midnight each day. Material deposited on the surface is removed from the puffs to maintain a mass balance.

B.2.4 Chemical and Physical Transformation

Iodine exists in three general forms in the atmosphere. It is found attached to aerosol particles, in inorganic (reactive) gases (e.g., I_2), and in organic (slightly reactive) gases (e.g., CH_3I). These forms have significantly different deposition characteristics. For example, Voilleque and Keller (1981) give typical deposition velocities for I_2, CH_3I, and particulates as 0.01, 0.00001, and 0.001 m/s, respectively.

Burger (1991) states that the iodine should evolve from the dissolution process in the elemental form. Ludwick (1964) presents data on the change in the partitioning of iodine with distance following release of elemental iodine (I_2). In the time that it took the iodine to travel 3200 meters (i.e., 3.2 kilometers or about 2 miles), it was found that about two-thirds of the iodine had changed form. Approximately one-third of the iodine was in organic species, and the remaining third was associated with particulate material. The partitioning of iodine at 3200 meters in Ludwick's experiments is consistent with the results of other measurements of iodine in plumes from stacks at Hanford (Ludwick 1967; Perkins 1963, 1964), with the partitioning of iodine released in the plume following the Chernobyl reactor accident (Aoyama et al. 1986; Bondietti and Brantley 1986; Cambray et al. 1987; Mueck 1988), and with the partitioning of natural iodine in the atmosphere (Voilleque 1979). Consequently, RATCHET assumes that the partitioning of iodine is independent of travel time once the plume has travelled more than 3000 meters.

RATCHET models the deposition of each of the three forms individually, and it can model the deposition of a mixture of the forms. Iodine partitioning is specified through three input parameters in the run specification file. The partitioning was changed from one model realization to the next to account for the uncertainty in the iodine partitioning.

B.2.5 RATCHET Model Results

The results of the RATCHET modeling are used as input to the environmental accumulation calculations conducted with the DESCARTES code. The output includes daily estimates of iodine-131 in air and the amount deposited within the HEDR study area. For the purposes of illustration, the total 1945 deposition of iodine-131 across the study area is shown in Figure B.1. Figure 1.1 should be used to identify geographic features such as cities and counties.

This figure depicts the iodine-131 "footprint" or location of deposition. The figure shows where the iodine released from Hanford was deposited. However, it is not intended to give an accurate representation of the iodine-131 concentration in the soil at any given time and cannot be used by itself to estimate doses. The figure shows the cumulative undecayed deposition at each location. Because iodine-131 is constantly decaying with an 8-day half-life, the actual concentrations in surface soils would be much less.

Figure B.1 does show that in general the iodine-131 is deposited to the northeast of the Hanford Site. There is a slight southeastern component to the deposition pattern as well. These findings are

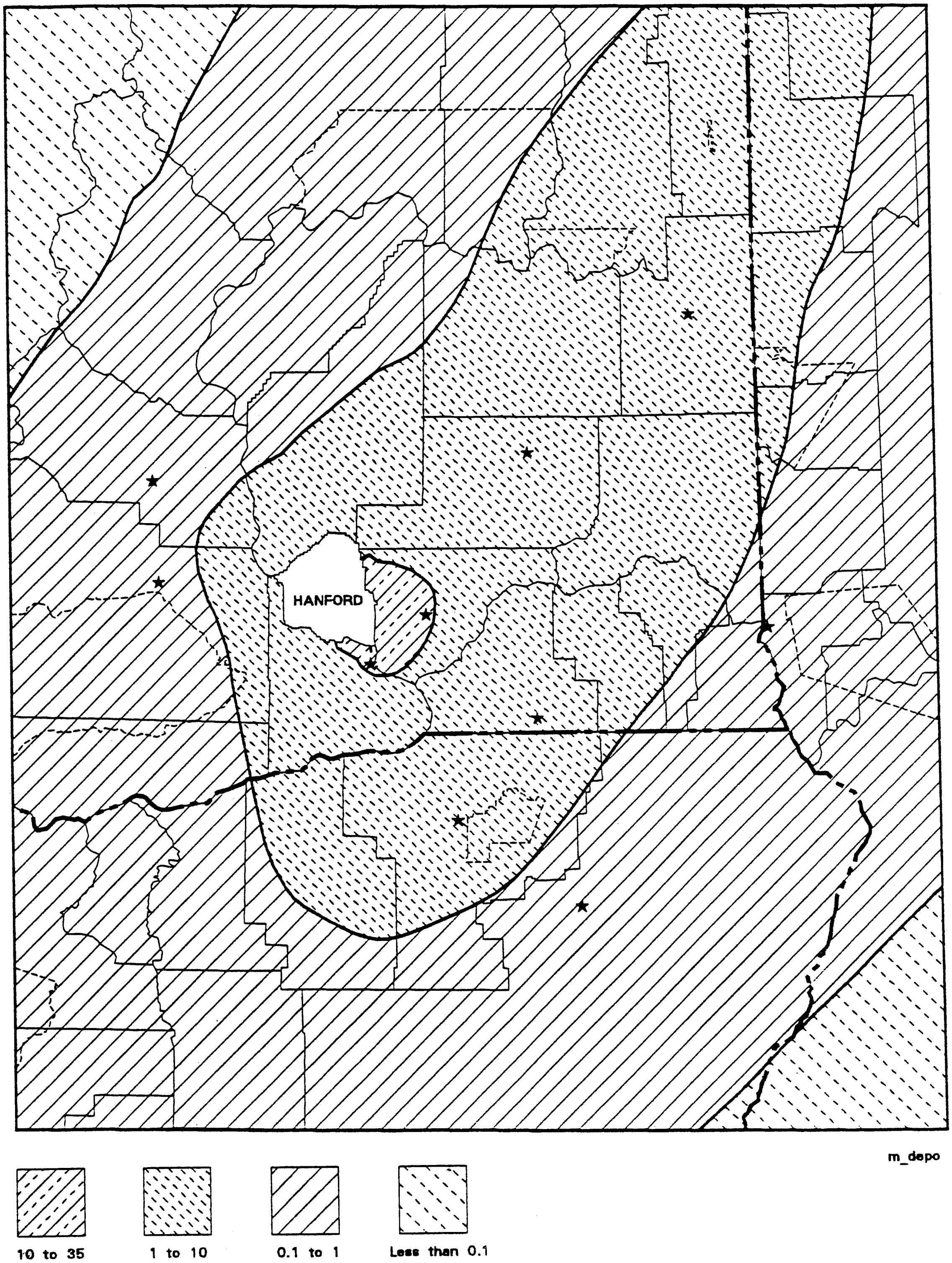


Figure B.1. 1945 Cumulative Iodine-131 Deposition ($\mu Ci/m^2$ undecayed) consistent with the prevailing winds in the region. Material released to the atmosphere at Hanford is generally transported southeasterly toward the Tri-Cities and is then moved to the northeast with the continental winds.

The total amount of iodine-131 deposited in the HEDR study area during 1945, as shown in Figure B.1, is approximately 260,000 curies. This accounts for roughly half of the 560,000 curies estimated to have been released during that year. Therefore, approximately 55 percent of the iodine-131 released from Hanford is estimated to have been deposited within the 75,000-square-mile area under study. Some 10 percent decayed during atmospheric transport within the study area. The remaining 35 percent was either deposited outside the HEDR study area or decayed beyond the study area boundary.

B.3 Environmental Accumulation Model

Radioactive material transported through the atmosphere deposited on soil and plants, providing the possibility for human exposure and dose. The environmental accumulation model tracks and estimates the accumulation and transfer of radionuclides from initial atmospheric deposition and interception through various soil, vegetation, and animal products compartments. This model contains a set of four linked linear differential equations that give the models their dynamic nature, generating daily soil and vegetation concentrations. Other portions of the model use these daily concentration data and equilibrium-type equations to estimate time-dependent radionuclide concentrations in animal products. Figure B.2 illustrates the environmental accumulation model.

The model function may be visualized as a series of sequential operations. The biomass submodel generates daily biomass values (quantities of vegetation) for each plant type modeled. These values are then used in the soil and vegetation submodel to determine the daily concentrations of radionuclides in soil and vegetation. Results are estimated for every location, providing the concentration in vegetables, grains, and fruits directly consumed by people and in plants (grass, alfalfa, silage, grain) used for animal feed. Animal feed concentrations are then used to determine concentrations in animal products (beef, poultry, eggs, milk), also by location. Finally, the radionuclide concentrations in commercially distributed milk are estimated. Values of radionuclide concentrations in soil, vegetation, and animal products are stored for later use by the individual dose model CIDER.

B.3.1 Model Development

Although there are a number of food chain transport models and codes documented in the scientific literature, most are steady-state or quasi-steady-state. Few are dynamic. The primary source used for development of the HEDR environmental accumulation model was PATHWAY, developed by Whicker and Kirchner (1987) for dose reconstruction studies around the Nevada Test Site. A number of other dynamic food chain models have also been developed, including TERMOD (Booth and Kaye 1971), RAGTIME (Pleasant et al. 1980), FOOD-MARC (Simmonds and Linsley 1981; Linsley 1982), RADFOOD (Koch and Tadmor 1986), and ECO-SYS (Proehl et al. 1988). PATHWAY was selected as the basis for development of the HEDR environmental accumulation

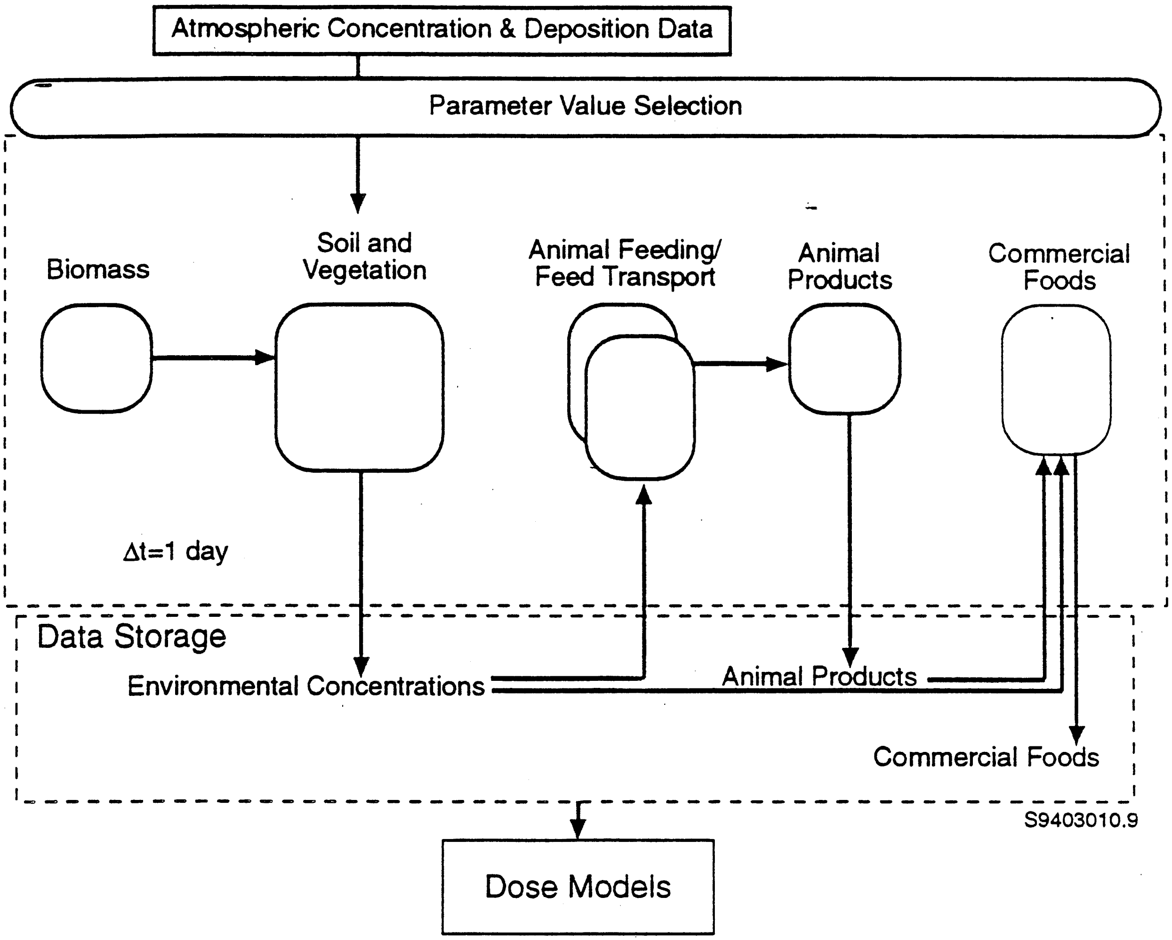


Figure B.2. Environmental Accumulation Model

model because it was recently developed, well documented, and developed for use in a region with geographic and climatic characteristics similar to those of the semi-arid region surrounding the Hanford Site.

The mechanisms for radionuclide transfer in the environmental accumulation model are generally standard processes that are well documented in the open literature (NCRP 1984; Petersen 1983; IAEA 1982). The specific requirements of the DESCARTES computer code were approved by the TSP and are documented in the *Software Requirements Specification for the Hanford Environmental Dose Reconstruction Project Air Pathway Environmental Accumulation and Dose Codes* (Napier 1992c).

The environmental accumulation model is described in terms of its various constituent parts, called submodels, as shown in Figure B.2. Each of these submodels contain equations for modeling specific processes of radionuclide transfer. They address biomass, radionuclide concentrations in soil and vegetation, animal feeding and feed transport, concentrations in animal products, and commercial foods accumulation and distribution.

B.3.2 Biomass Submodel

The biomass submodel performs calculations to generate data required by two pathways for transfer of contaminants from the atmosphere and soil to plants. Foliar interception of depositing atmospheric contamination depends on the above-ground mass of the vegetation. Root uptake also is a function of the rate of growth of the plants. By calculating plant growth rate and integrating the growth to determine total biomass, the biomass submodel provides data to drive both processes.

A plant growth model adapted from that of Whicker and Kirchner (1987) is used for biomass calculations. Daily biomass values are currently estimated for nine plant types. Three plant types are modeled as being consumed exclusively by humans: leafy vegetables, other vegetables, and fruit (Callaway 1992). Animals are modeled as exclusively consuming four categories of feed: pasture grass (irrigated), alfalfa, silage, and grass hay. Both humans and animals are assumed to consume grain or grain products. The final plant category, sagebrush, is consumed by neither. Sagebrush, which was the most commonly monitored vegetation type in the early years of Hanford operations, was used in the validation exercises documented in Napier et al. (1994).

Harvest, which removes plant biomass and associated radionuclide concentration from the submodel, may occur on specific dates, continuously, or not at all, depending upon the plant category. Leafy vegetables, other vegetables, fruit, and pasture grass are assumed to be harvested gradually and continuously, representing the harvesting of fresh produce by humans or grazing by animals. There is currently no biomass loss term for harvesting in these plant categories; i.e., daily concentrations are estimated and stored without concomitant loss of biomass or radionuclide that would occur during actual grazing or harvesting. Grass hay, silage, and grain are modeled as being harvested once per yearly growing season. Alfalfa is modeled as being harvested three times per season. Harvest dates are specific to each plant category (Beck et al. 1992). On the day of harvest, the biomass is reset to the minimum value, and the concentration per unit surface area of radionuclides in the vegetation is reduced by a proportional amount. The final plant category, sagebrush, is not harvested or ingested.

The estimated daily biomass values and rates of change of biomass are internal variables used by the soil and vegetation concentration submodel and are not stored for outside examination or for use by the individual dose model.

B.3.3 Soil and Vegetation Concentration Submodel

This submodel estimates the concentration of radionuclides in soil and vegetation on a daily basis. Daily vegetation concentrations are needed because plants are directly consumed by humans and by animals whose products, such as milk, meat, or eggs, are then consumed by humans. Soil concentrations are estimated because radionuclides deposited on soil can be transferred back to the air by resuspension or to plants through root uptake, rainsplash, or redeposition of resuspended particles. Contaminated soil directly irradiates exposed humans (groundshine dose) and is also directly ingested by animals during grazing. The different mechanisms for transfer between soil and vegetation compartments are shown schematically in Figure B.3.

Conditions on a given day are likely to be different at every node on the atmospheric dispersion grid because of local meteorological differences and variations in the length of time required for released material to be dispersed and transported to the different nodes. Environmental concentrations in soil and vegetation depend on local depositions and, therefore, also vary from point to point and from day to day. The basic model illustrated in Figure B.2 is implemented each day at each location. As shown in Figure B.2, input comes from the biomass submodel and from the atmospheric transport model.

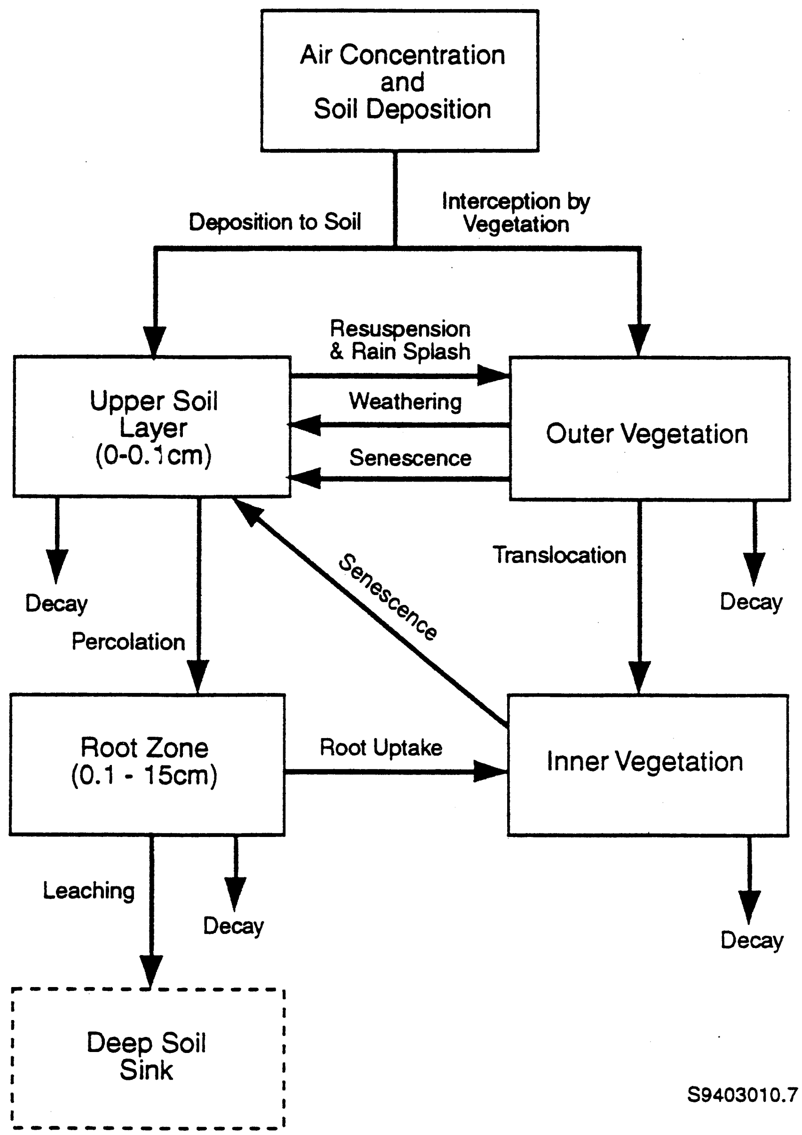


Figure B.3. Dynamic Compartments in the Environmental Accumulation Model

B.3.4 Animal Feeding/Feed Transport Submodel

Output from the soil and vegetation submodel provides the concentration of radionuclides in these environmental media at each location. Currently, animals are assumed to obtain feed and fodder from the grid area where they live. Dairy cows are assumed to have eaten several types of diets, with a diet defined as a sum of fractional feed-type intakes. Five types of feed are available: alfalfa hay, pasture grass, grass hay, silage, and grain. There are currently eight milk cow feeding regimes for the HEDR study area, four for family cows and four for commercial cows.

Beef cattle, goats, and poultry (producing both meat and eggs) are currently considered in the animal feeding submodel in addition to dairy cattle. Beef cattle and goats are assumed to eat pasture grass only and are also assumed to eat different (smaller) total feed quantities than dairy cattle (Beck et al. 1992; Comar 1966). The poultry diet includes grain and fresh forage (Ensminger et al. 1990). All animals are considered to ingest small amounts of soil during the normal feeding process, the quantity of soil varying with the different animals and diets (Darwin 1990).

The definitions of feed include the dates when feed types were harvested or when animals were put on pasture. Thus, each of the three cuttings of alfalfa during the growing season is considered to be a different "type" of feed.

B.3.5 Animal Product Concentration Submodel

There are currently six types of animal products included in the model: cow's milk (both commercial and backyard cow), goat's milk, eggs, poultry, and beef. Preliminary knowledge of agricultural patterns in the study area indicated inclusion of poultry and beef because large quantities of these products were probably consumed in the study area (Callaway 1992).

The concentration of radionuclides in animal products is a function of the time-varying diets of the animals. The animal product submodel addresses animal product radionuclide concentrations in a simple manner, assuming equilibrium conditions and using feed-to-animal-product transfer factors. With such a model, the concentration of a radionuclide in animal products on a given day is directly related to that day's intake of that radionuclide. This method provides the correct integrated concentrations of radionuclides in animal products and, thus, the correct estimate of dose from intake of such products, but the method loses some of the temporal (day-to-day) resolution. Use of this formulation in dynamic pathway codes was suggested by the work of Whicker (1985) and is discussed in greater detail in Napier et al. (1992).

B.3.6 Commercial Foods Submodel

This submodel takes into account the commercial production and distribution of various types of food. Foods produced at various locations may be combined or pooled at collection centers, such as creameries and packing plants. These foods may then be redistributed to grocery stores throughout the region. Thus, foods eaten by people at one location may have come from one or more other locations. The commercial distribution of cows' milk and leafy vegetables is included in the model. The commercial distribution of these commercially grown foods was found to be an important dose contributor (Marsh et al. 1992). The complex distribution of commercial milk within the HEDR study area is presented in Deonigi et al. (1994), a reference that presents the commercial milk operations of 163 known commercial milk producers within the HEDR study area.

B.3.7 Estimated Media Concentrations

Figures B.4 through B.9 show the iodine-131 concentrations in six different environmental media: for air (Figure B.4), surface soil (Figure B.5), pasture grass (Figure B.6), milk from backyard cows (Figure B.7), grocery milk (Figure B.8), and commercial leafy vegetables (Figure B.9). The concentrations are presented for August 1945 because it was one of the months with the highest iodine-131 releases (72,000 curies) and it was within the agricultural growing season. These two factors combined tended to maximize the iodine-131 concentrations in vegetation and milk.

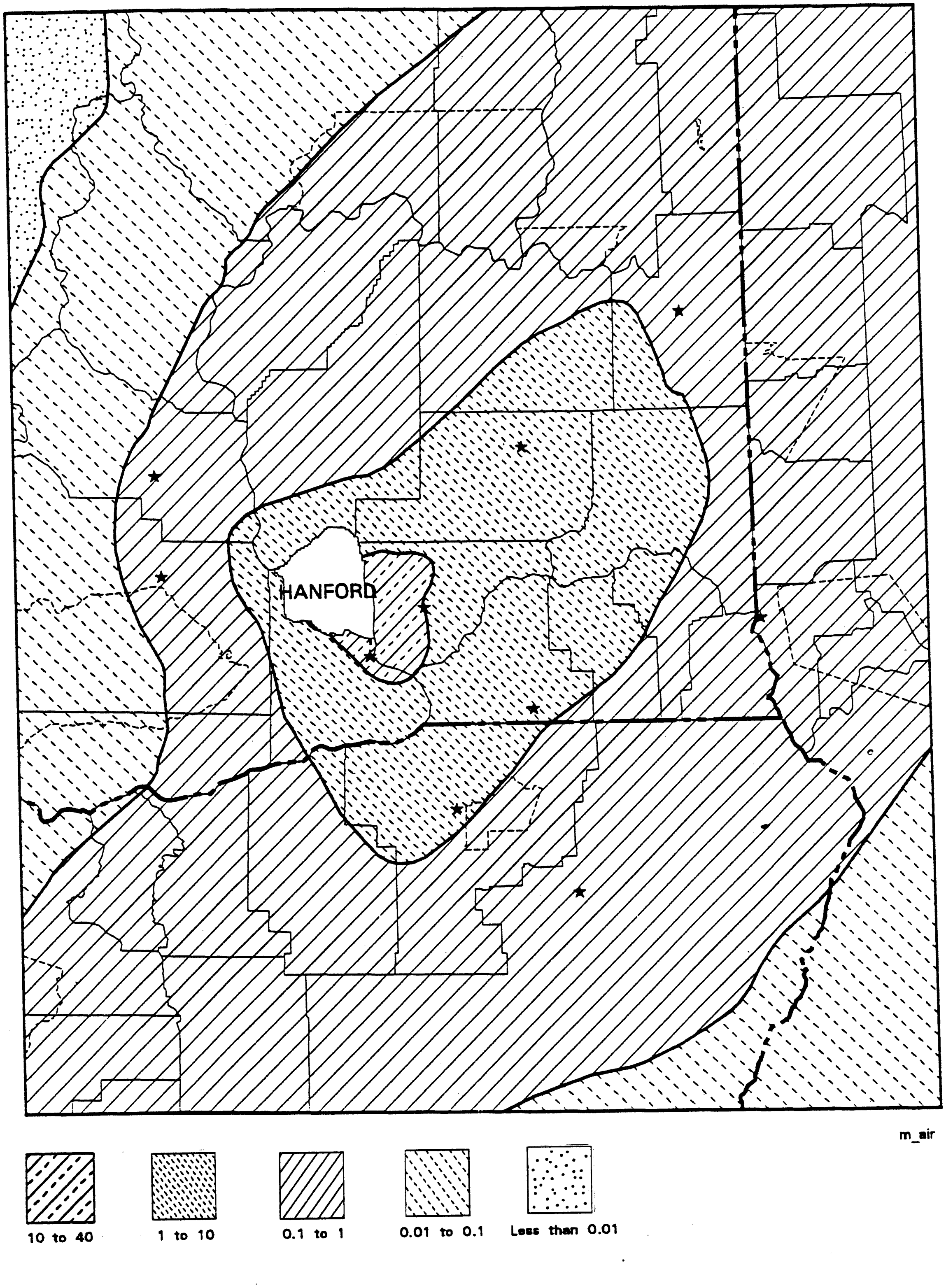
B.4 Dose Assessment

The dose assessment methods described above were used to translate the radionuclide concentrations in key environmental media into the radiation dose received by a representative individual. The environmental accumulation models establish the concentrations of radionuclides in environmental media and food products for all locations and times of interest. In the individual dose model, human receptors are introduced into the calculation. The CIDER dose model estimates dose via four exposure pathways: submersion in contaminated air, inhalation of contaminated air, irradiation from contaminated surfaces and soils, and ingestion of farm products and vegetation. The individual dose model is currently designed for the estimation of doses to representative individuals and real people. For this report, only representative individual doses were estimated. Inputs to this model are the outputs from both the environmental accumulation model (DESCARTES) and the atmospheric transport model (RATCHET), plus generic consumption and exposure rates for each category of representative individual type (age, sex, lifestyle).

Currently, for a given representative individual, the dose model estimates the radiation dose from a single radionuclide, iodine-131, at a single location. To estimate the dose at more than one location, the calculation is repeated for each location of interest and then summed. For the time a representative individual resided at a given location, doses from external exposure and inhalation and most ingestion pathways are dependent solely on the local characteristics. The exception for ingestion is milk and leafy vegetables, for which doses may result from consumption of either local or commercial (grocery store) foods.

B.4.1 Ingestion Dose from Local and Commercially Available Food

With the exception of milk and leafy vegetables, doses from ingestion of locally and commercially produced foods are considered together in CIDER because milk and leafy vegetables are the only commercially produced food products for which distribution data are currently available. Also, the radioactive decay during the storage and production time is handled in CIDER. For leafy vegetables and fruits, the model accounts for radionuclide concentrations for inner and outer vegetation compartments separately. This allows for the consideration of the potential loss of surface contamination during food preparation processes.



10 to 40 | 1 to 10 | 0.1 to 1 | 0.01 to 0.1 | Less than 0.01

Figure B.4. Iodine-131 Concentrations (μCi · s/m^3) in Air, August 1945

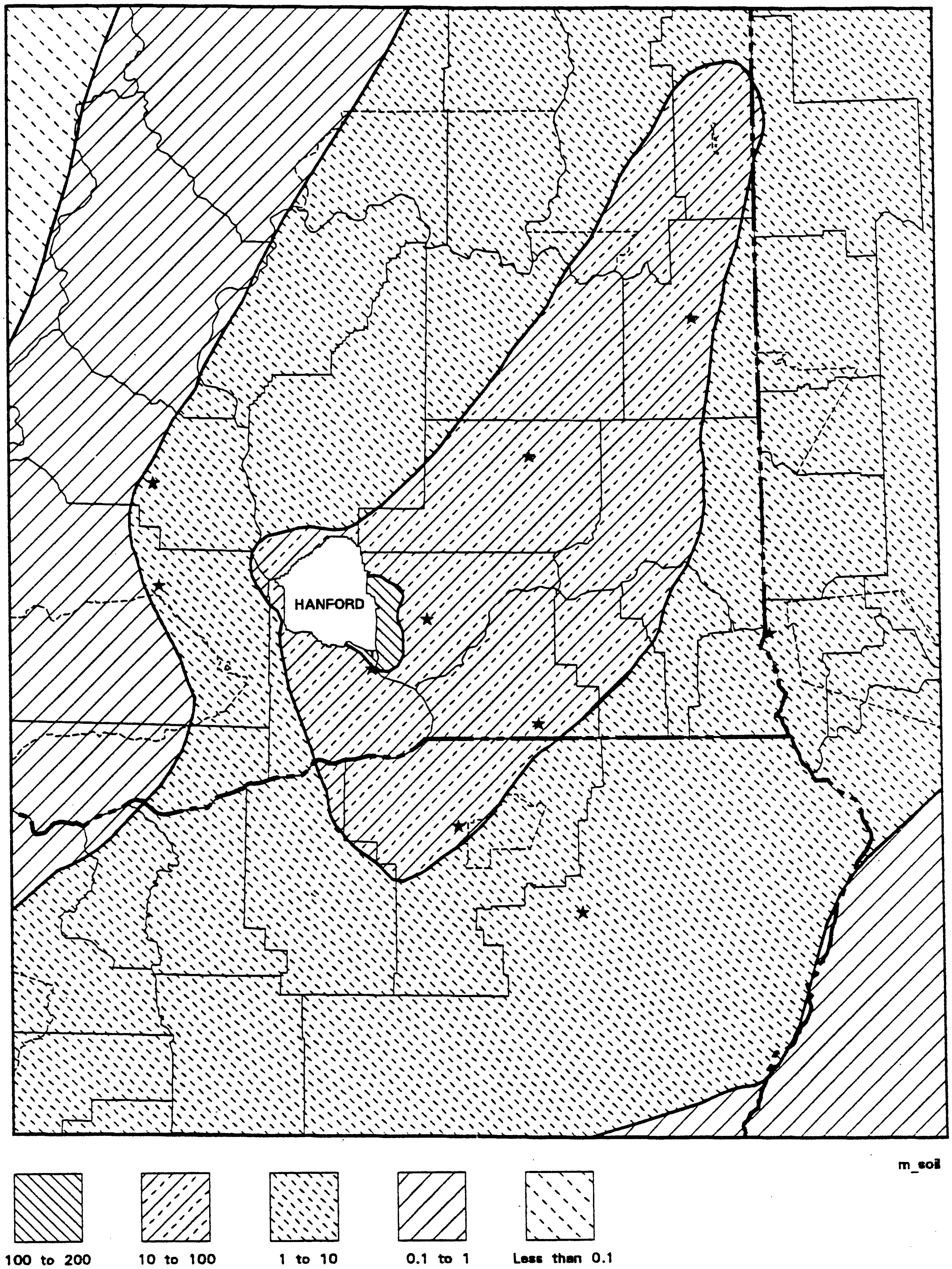


Figure B.5. Iodine-131 Concentrations (nCi/m^2) in Surface Soil, August 1945

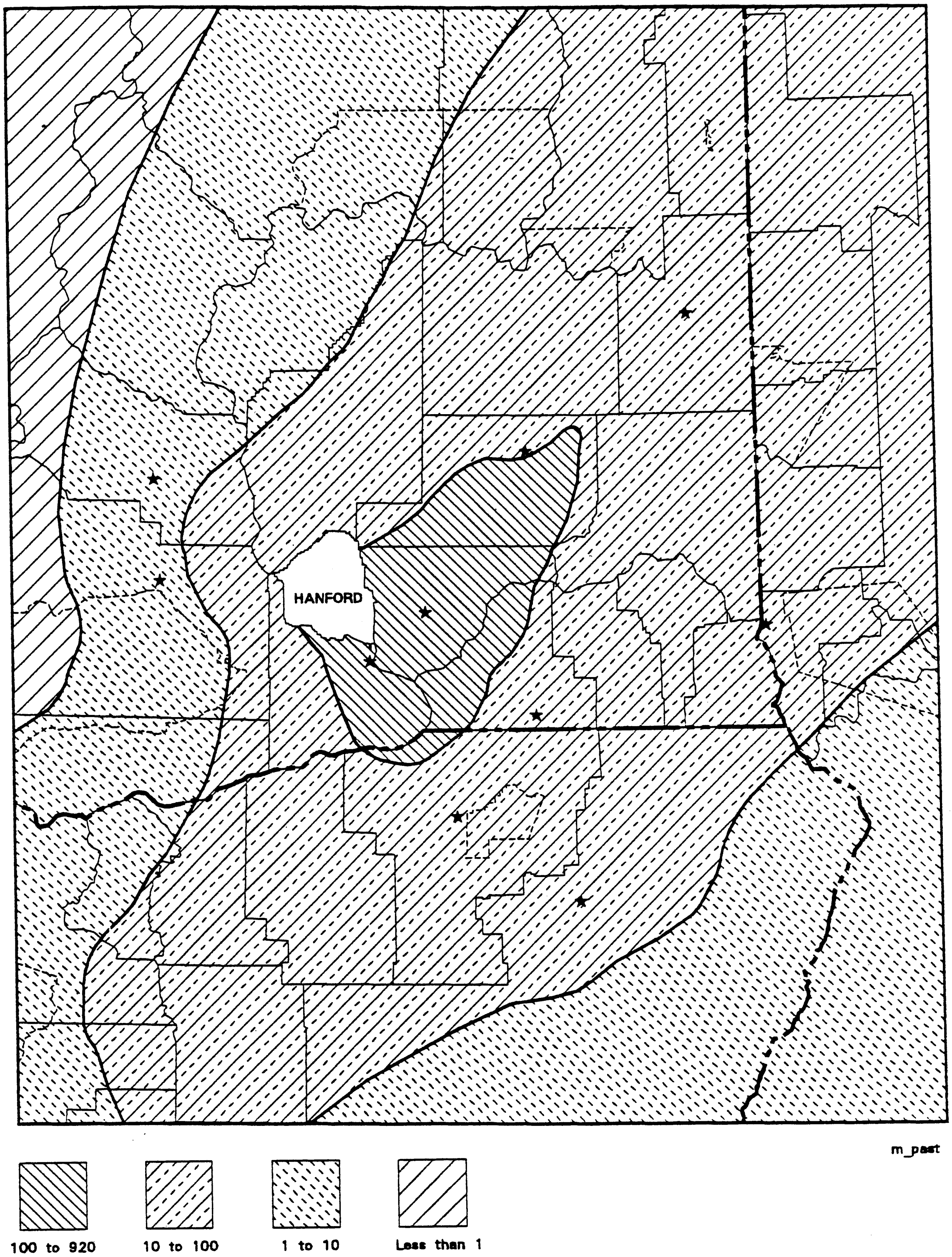


Figure B.6. Iodine-131 Concentrations (nCi/kg) in Pasture Grass, August 1945

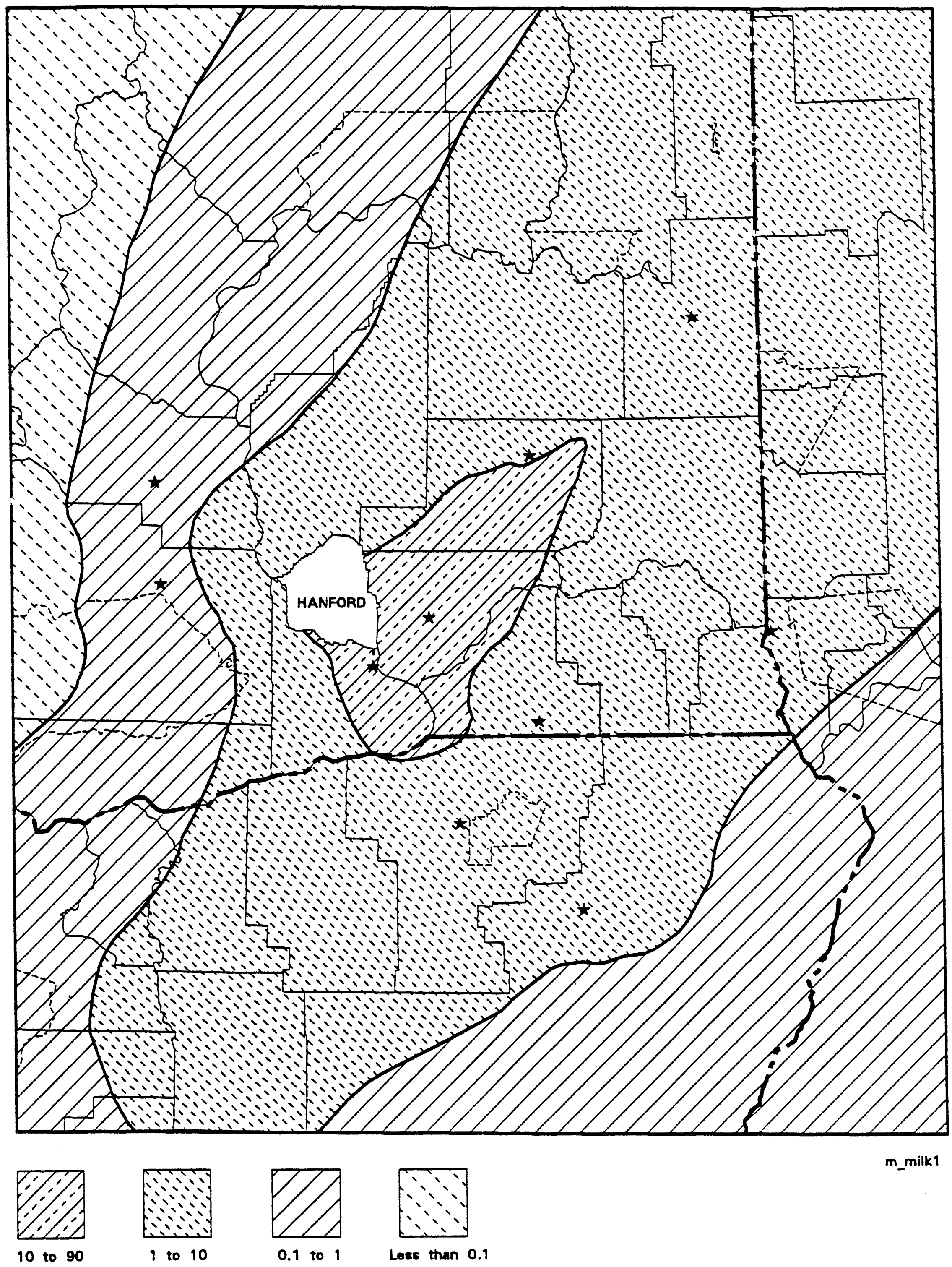


Figure B.7. Iodine-131 Concentrations (nCi/L) in Milk from Backyard Cows on Fresh Pasture, August 1945

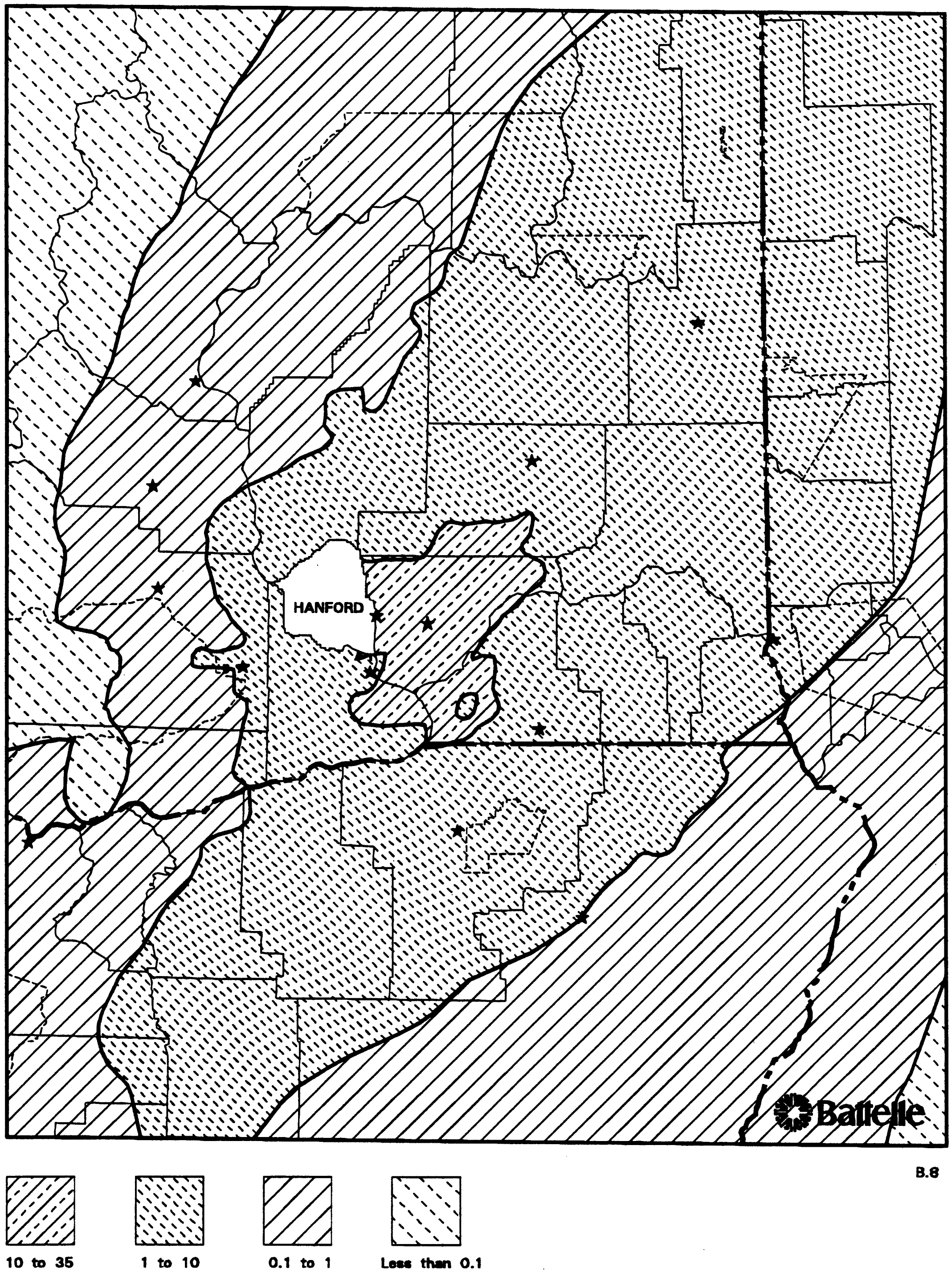


Figure B.8. Iodine-131 Concentrations (nCi/L) in Grocery Milk, August 1945

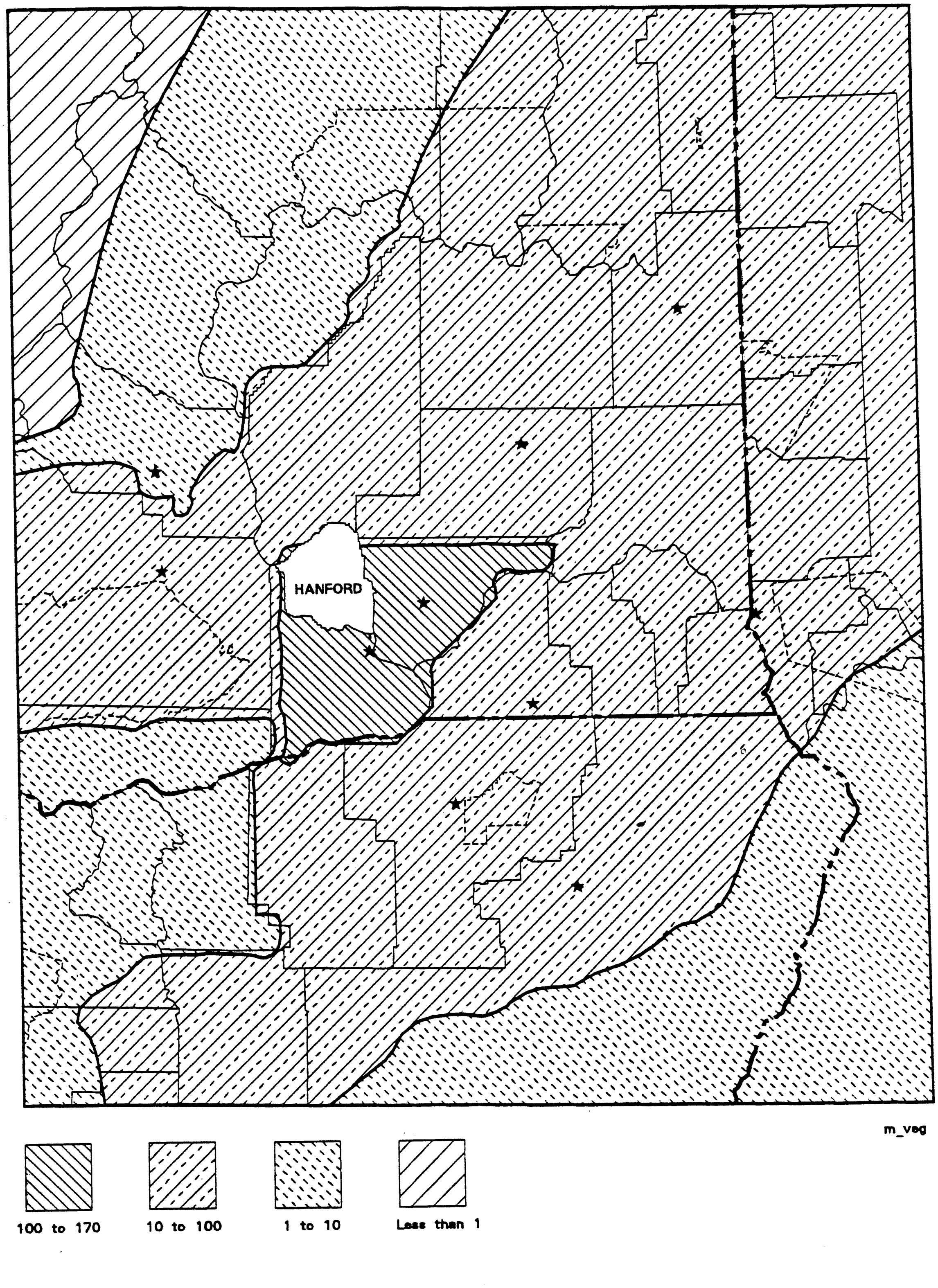


Figure B.9. Iodine-131 Concentrations (nCi/kg) in Commercial Leafy Vegetables, August 1945

Committed dose from ingestion of foodstuffs is estimated by multiplying the foodstuff radionuclide concentration by the amount consumed and the appropriate dose factor and summing over all foodstuffs and radionuclides (Soldat et al. 1974). The levels of radionuclide contamination of local food crops and animal products available in the database were prepared using the environmental accumulation model. Distribution of commercially available foods (milk and leafy vegetables) is handled in the commercial foods submodel. The concentration in commercial milk at local grocery stores is also available from the environmental accumulation database. The model assumes that all commercial milk products consumed are purchased locally. The ingestion dose equation also corrects for the decay of the radionuclides during handling and storage.

B.4.2 Age-Dependent Dose Factors

Doses are estimated for people of various ages because an individual's dose response to a given intake amount changes with age (ICRP 1989). Dose factors are provided for several age/sex groups. Dosimetry for male and female children through about age 15 is essentially the same and is modeled as being identical. The only potential variable is the difference in food consumption by the sexes. Age-dependent dose factors for iodine-131 are taken from ICRP Publication 56 (ICRP 1989).

B.4.3 Location-Specific Doses

Doses from external exposure and inhalation are functions only of location and age. The CIDER model uses equations that are commonly used in environmental dosimetry calculations. They have been integrated previously into a set of environmental dosimetry computer codes as used here by Napier et al. (1988).

The dose from submersion in contaminated air is estimated using a semi-infinite plume approximation because the equation is computationally simple and is a conservative method for estimating doses from this pathway. It has previously been determined that air submersion is a minor pathway with small dose contribution from radionuclides that were investigated in the HEDR Project (Napier 1991b). Calculation of external air submersion dose is the integrated air concentration multiplied by an air submersion dose factor and a shielding factor (≤ 1.0) to account for building shielding while indoors (Napier et al. 1988). The equation is given for daily exposures but may be integrated to any period through simple summation over time.

A similar equation is used to estimate dose from external exposure to contamination deposited on the ground, called "groundshine." Dose is estimated using an infinite slab approximation and a shielding factor (Napier et al. 1988); i.e., assuming contamination is uniformly spread over a large area surrounding the exposed representative individual.

Radioactive material may be inhaled directly from a passing cloud or from contaminated surface dust suspended back into the local air. The dose from inhalation is not received immediately. The material deposited in the body continues to irradiate the individual, but the dose received over time from a single day's inhalation is credited to that day using the concept of committed dose. This concept allows summation of inhalation exposures over a specified period and assignment of a committed dose to that period (ICRP 1989). For simplicity, internal committed dose is referred to as dose. The concept of committed dose allows internal and external daily doses to be added together even though, strictly speaking, the internal dose has not been fully received. Both internal dose conversion factors and quantity of material inhaled are functions of age.

Appendix C

Annual and Cumulative Dose Estimates for Key Radionuclides

Appendix C

Annual and Cumulative Dose Estimates for Key Radionuclides

Iodine-131 was the dominant radionuclide contributing to dose during all of the 1940s and 1950s. Figure C.1 shows that in 1945 iodine-131 exposure was responsible for 99.83 percent of the dose to an adult in Richland. Plutonium-239 and cerium-144 were the next largest contributors at about 0.08 percent each. By 1961, iodine-131 releases had decreased to the point that cerium-144 became the dominant contributor to dose and was dominant for the remainder of the time period examined. Cerium-144 releases generally increased slightly each year over the period from 1949 to 1961, but were obscured by the large iodine-131 releases. Plutonium-239 releases remained relatively constant from 1949 to 1967, when they decreased sharply. By 1965, cerium-144 accounted for about 83 percent of the dose to an adult in Richland (Figure C.2). Plutonium-239 was the next largest contributor with approximately 9 percent. Each of the other radionuclides contributed less than 4 percent or less. By 1965, the dose received was approximately 3,000 times less than in 1945.

Although by 1965 iodine-131 was no longer the dominant radionuclide, its cumulative effect on dose for the period 1945-1972 contributed 99 percent of the effective dose equivalent potentially received by an adult in Richland. As shown in Figure C.3, iodine-131 was followed by cerium-144 at 0.58 percent and plutonium-239, ruthenium-106, ruthenium-103, and strontium-90 at 0.32 percent, 0.09 percent, 0.02 percent, and 0.01 percent, respectively. To note is that the percentages shown in Figures C.1-C.3 may not total to 100 percent due to rounding.

Annual and cumulative effective dose equivalents are presented in Tables C.1 through C.7. The doses were estimated for six radionuclides and nine specific locations for the years 1945 through 1972. Scientific notation is used in Tables C.1-C.7 to express very large or very small numbers. For example, the number 0.001 is written in scientific notation as 1.0E-03.

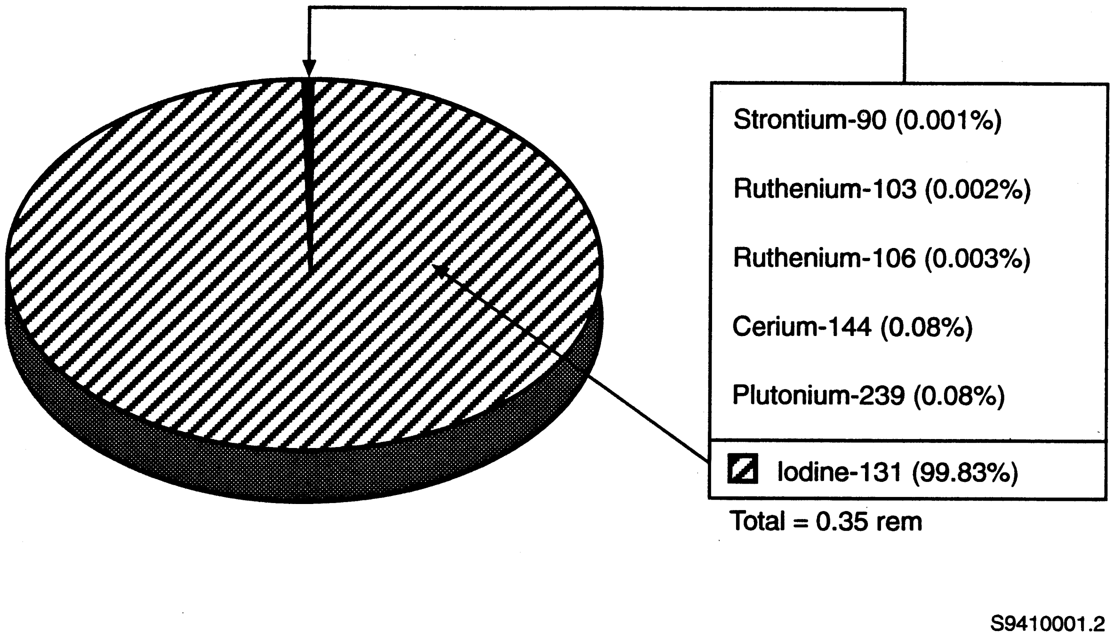


Figure C.1. 1945 Relative Contribution to Dose (EDE) by Radionuclide for an Adult in Richland

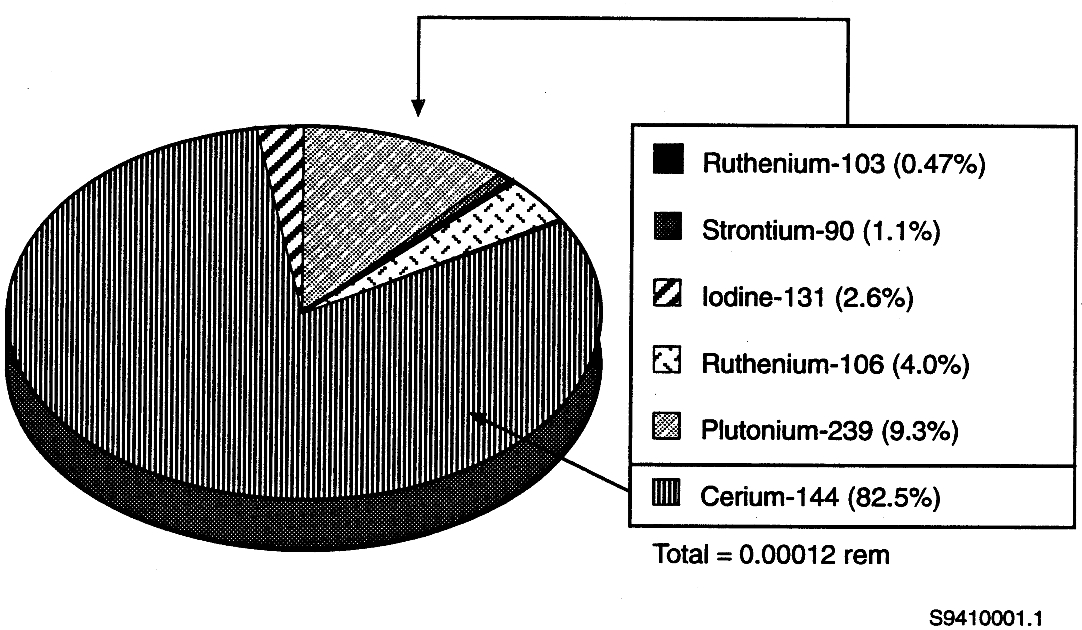


Figure C.2. 1965 Relative Contribution to Dose (EDE) by Radionuclide for an Adult in Richland

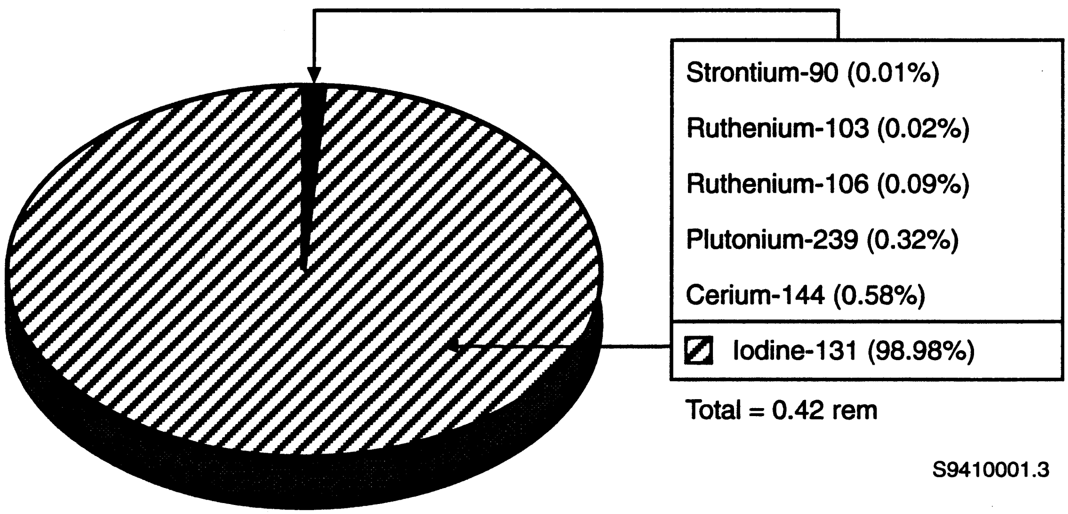


Figure C.3. 1945-1972 Relative Contribution to Cumulative Dose (EDE) by Radionuclide for an Adult in Richland

Table C.1. Effective Dose Equivalent *(rem)* from Key Radionuclides at Selected Locations, 1945-1972[(a)]

Radionuclides include: Sr-90, Ru-103, Ru-106, I-131, Ce-144, Pu-239

Location:	Eltopia	Lewiston	Pendleton	Richland	Ritzville	Spokane	Sunnyside	Wenatchee	Ringold
Cumulative:	4.1E-01	1.9E-02	4.7E-02	4.2E-01	1.4E-01	5.4E-02	3.8E-02	3.0E-03	1.2E+00
1945	3.4E-01	1.6E-02	3.8E-02	3.5E-01	1.2E-01	4.4E-02	3.0E-02	2.2E-03	9.9E-01
1946	4.4E-02	2.1E-03	5.6E-03	4.7E-02	1.4E-02	5.5E-03	4.6E-03	2.8E-04	1.2E-01
1947	8.6E-03	4.9E-04	9.8E-04	7.4E-03	3.2E-03	1.7E-03	1.1E-03	1.8E-04	2.1E-02
1948	5.2E-04	3.5E-05	6.9E-05	7.5E-04	1.5E-04	5.8E-05	8.4E-05	1.2E-05	1.2E-03
1949	9.9E-04	6.1E-05	2.5E-04	1.2E-03	1.8E-04	9.3E-05	1.4E-04	1.1E-05	4.5E-03
1950	1.7E-03	1.0E-04	2.3E-04	2.0E-03	4.7E-04	2.3E-04	2.3E-04	1.8E-05	4.1E-03
1951	1.1E-02	6.1E-04	1.3E-03	9.1E-03	3.4E-03	2.0E-03	1.1E-03	1.4E-04	2.5E-02
1952	1.8E-03	7.1E-05	2.4E-04	2.5E-03	3.3E-04	1.4E-04	2.9E-04	3.6E-05	4.2E-03
1953	1.1E-03	2.9E-05	9.2E-05	9.8E-04	1.6E-04	7.7E-05	1.1E-04	1.2E-05	2.3E-03
1954	5.2E-04	2.1E-05	7.2E-05	7.3E-04	9.6E-05	3.7E-05	9.1E-05	1.1E-05	1.2E-03
1955	3.1E-04	1.1E-05	3.5E-05	3.8E-04	5.2E-05	2.1E-05	4.5E-05	5.0E-06	6.9E-04
1956	1.0E-04	3.3E-06	1.2E-05	1.2E-04	1.7E-05	7.3E-06	1.5E-05	1.8E-06	2.4E-04
1957	1.9E-04	6.4E-06	2.6E-05	2.4E-04	3.2E-05	1.3E-05	3.1E-05	4.0E-06	4.7E-04
1958	4.1E-04	1.4E-05	4.7E-05	5.1E-04	7.1E-05	3.0E-05	5.7E-05	6.9E-06	9.2E-04
1959	2.0E-04	6.3E-06	2.3E-05	2.3E-04	3.3E-05	1.4E-05	2.9E-05	3.3E-06	4.6E-04
1960	2.0E-04	7.2E-06	2.7E-05	2.6E-04	3.5E-05	1.5E-05	3.1E-05	3.9E-06	4.8E-04
1961	1.4E-04	4.9E-06	1.7E-05	1.7E-04	2.4E-05	1.0E-05	2.1E-05	2.6E-06	3.3E-04
1962	1.0E-04	3.5E-06	1.4E-05	1.3E-04	1.7E-05	6.6E-06	1.7E-05	2.2E-06	2.4E-04
1963	1.2E-04	4.1E-06	1.5E-05	1.6E-04	2.1E-05	7.7E-06	2.3E-05	2.4E-06	2.9E-04
1964	1.0E-04	3.3E-06	1.2E-05	1.2E-04	1.7E-05	6.9E-06	1.5E-05	2.0E-06	2.3E-04
1965	9.1E-05	3.1E-06	1.1E-05	1.2E-04	1.6E-05	6.4E-06	1.4E-05	1.8E-06	2.1E-04
1966	8.3E-05	3.5E-06	1.3E-05	1.2E-04	1.6E-05	5.4E-06	1.8E-05	2.4E-06	1.9E-04
1967	5.8E-05	2.1E-06	7.7E-06	7.7E-05	1.0E-05	3.9E-06	1.0E-05	1.3E-06	1.3E-04
1968	5.7E-05	1.9E-06	6.7E-06	6.9E-05	9.7E-06	3.9E-06	8.5E-06	1.1E-06	1.3E-04
1969	4.0E-05	1.4E-06	5.2E-06	5.2E-05	6.9E-06	2.7E-06	6.5E-06	8.3E-07	9.5E-05
1970	8.2E-06	3.5E-07	1.3E-06	1.3E-05	1.6E-06	6.1E-07	1.7E-06	2.4E-07	2.0E-05
1971	1.5E-05	3.8E-07	1.2E-06	1.5E-05	2.3E-06	1.1E-06	1.6E-06	1.3E-07	3.3E-05
1972	1.9E-06	9.1E-08	2.5E-07	3.1E-06	3.6E-07	1.5E-07	2.7E-07	3.7E-08	4.2E-06

(a) Doses shown are the effective dose equivalent (EDE) to an adult male. The doses are from all exposure pathways including consumption of foodstuffs (milk, fresh fruits, vegetables, eggs, poultry, and beef), inhalation, and external exposure. All foodstuffs were assumed to be from a backyard source. The milk was produced by a cow that grazed on fresh pasture.

Table C.2. Effective Dose Equivalent *(rem)* from Strontium-90 at Selected Locations, 1945-1972[(a)]

Location:	Eltopia	Lewiston	Pendleton	Richland	Ritzville	Spokane	Sunnyside	Wenatchee	Ringold
Cumulative:	2.5E-05	8.9E-07	3.2E-06	3.2E-05	4.3E-06	1.7E-06	4.0E-06	5.2E-07	5.7E-05
1945	2.5E-06	7.9E-08	3.3E-07	3.0E-06	4.1E-07	1.6E-07	4.2E-07	5.6E-08	6.1E-06
1946	4.1E-06	1.6E-07	5.3E-07	5.5E-06	7.4E-07	3.0E-07	6.5E-07	8.8E-08	9.5E-06
1947	2.8E-06	1.0E-07	3.6E-07	3.7E-06	5.0E-07	2.0E-07	4.4E-07	5.7E-08	6.6E-06
1948	1.2E-06	5.7E-08	1.8E-07	2.0E-06	2.2E-07	9.3E-08	2.2E-07	3.2E-08	2.8E-06
1949	4.4E-08	1.7E-09	6.3E-09	6.1E-08	7.9E-09	3.0E-09	7.8E-09	1.0E-09	1.1E-07
1950	7.4E-08	2.6E-09	9.4E-09	9.4E-08	1.3E-08	5.1E-09	1.2E-08	1.5E-09	1.7E-07
1951	1.1E-07	3.9E-09	1.4E-08	1.4E-07	1.9E-08	7.4E-09	1.8E-08	2.4E-09	2.5E-07
1952	1.5E-07	5.5E-09	2.0E-08	2.0E-07	2.7E-08	1.1E-08	2.4E-08	3.2E-09	3.6E-07
1953	2.0E-07	6.9E-09	2.6E-08	2.5E-07	3.4E-08	1.4E-08	3.1E-08	3.7E-09	4.7E-07
1954	2.5E-07	9.1E-09	3.4E-08	3.4E-07	4.4E-08	1.7E-08	4.2E-08	5.6E-09	6.0E-07
1955	2.9E-07	9.6E-09	3.5E-08	3.5E-07	5.0E-08	2.0E-08	4.4E-08	5.9E-09	6.8E-07
1956	4.6E-07	1.5E-08	5.7E-08	5.7E-07	7.9E-08	3.1E-08	7.2E-08	9.2E-09	1.1E-06
1957	7.3E-07	2.6E-08	9.3E-08	9.3E-07	1.3E-07	5.1E-08	1.2E-07	1.5E-08	1.7E-06
1958	7.5E-07	2.9E-08	1.0E-07	1.0E-06	1.4E-07	5.3E-08	1.3E-07	1.7E-08	1.8E-06
1959	8.9E-07	3.1E-08	1.1E-07	1.1E-06	1.5E-07	6.2E-08	1.4E-07	1.7E-08	2.1E-06
1960	9.8E-07	3.5E-08	1.3E-07	1.3E-06	1.7E-07	6.8E-08	1.6E-07	2.2E-08	2.3E-06
1961	1.1E-06	3.8E-08	1.4E-07	1.4E-06	1.9E-07	7.7E-08	1.6E-07	2.0E-08	2.5E-06
1962	9.8E-07	3.4E-08	1.3E-07	1.2E-06	1.7E-07	6.6E-08	1.6E-07	2.1E-08	2.3E-06
1963	9.5E-07	3.4E-08	1.1E-07	1.2E-06	1.7E-07	6.6E-08	1.5E-07	2.0E-08	2.1E-06
1964	1.1E-06	3.6E-08	1.2E-07	1.3E-06	1.8E-07	7.5E-08	1.6E-07	2.0E-08	2.4E-06
1965	1.0E-06	3.6E-08	1.2E-07	1.3E-06	1.8E-07	7.4E-08	1.5E-07	1.9E-08	2.3E-06
1966	9.4E-07	4.1E-08	1.5E-07	1.5E-06	1.9E-07	6.2E-08	2.1E-07	2.9E-08	2.2E-06
1967	8.5E-07	2.9E-08	1.0E-07	1.1E-06	1.5E-07	5.9E-08	1.4E-07	1.7E-08	1.9E-06
1968	8.4E-07	3.0E-08	1.0E-07	1.1E-06	1.5E-07	5.9E-08	1.3E-07	1.7E-08	1.9E-06
1969	6.5E-07	2.3E-08	8.5E-08	8.6E-07	1.1E-07	4.5E-08	1.0E-07	1.3E-08	1.6E-06
1970	1.5E-07	6.2E-09	2.3E-08	2.4E-07	3.0E-08	1.1E-08	3.0E-08	4.1E-09	3.7E-07
1971	4.1E-07	1.0E-08	3.3E-08	4.0E-07	6.0E-08	2.9E-08	4.3E-08	3.4E-09	8.7E-07
1972	4.6E-08	2.2E-09	6.2E-09	7.6E-08	8.8E-09	3.5E-09	6.5E-09	9.0E-10	1.0E-07

(a) Doses shown are the effective dose equivalent (EDE) to an adult male. The doses are from all exposure pathways including consumption of foodstuffs (milk, fresh fruits, vegetables, eggs, poultry, and beef), inhalation, and external exposure. All foodstuffs were assumed to be from a backyard source. The milk was produced by a cow that grazed on fresh pasture.

Table C.3. Effective Dose Equivalent *(rem)* from Ruthenium-103 at Selected Locations, 1945-1972[(a)]

Location:	Eltopia	Lewiston	Pendleton	Richland	Ritzville	Spokane	Sunnyside	Wenatchee	Ringold
Cumulative:	6.8E-05	2.8E-06	9.4E-06	9.8E-05	1.3E-05	5.0E-06	1.2E-05	1.5E-06	1.6E-04
1945	4.9E-06	1.5E-07	5.9E-07	5.6E-06	8.3E-07	3.1E-07	7.9E-07	1.0E-07	1.1E-05
1946	5.0E-06	1.8E-07	6.3E-07	6.6E-06	9.2E-07	3.6E-07	7.8E-07	1.0E-07	1.1E-05
1947	3.0E-06	1.1E-07	3.6E-07	3.9E-06	5.5E-07	2.1E-07	4.5E-07	5.9E-08	6.8E-06
1948	6.9E-07	3.4E-08	1.1E-07	1.2E-06	1.5E-07	5.4E-08	1.3E-07	1.9E-08	1.6E-06
1949	2.4E-08	9.5E-10	3.4E-09	3.4E-08	4.6E-09	1.7E-09	4.2E-09	5.6E-10	5.7E-08
1950	4.6E-08	1.6E-09	5.7E-09	5.7E-08	8.2E-09	3.1E-09	7.3E-09	9.1E-10	1.1E-07
1951	1.3E-07	4.7E-09	1.7E-08	1.7E-07	2.4E-08	9.3E-09	2.1E-08	2.8E-09	3.1E-07
1952	1.9E-06	6.0E-08	2.0E-07	2.1E-06	3.2E-07	1.3E-07	2.6E-07	3.1E-08	4.2E-06
1953	1.6E-05	4.3E-07	1.5E-06	1.6E-05	2.5E-06	1.1E-06	1.9E-06	2.0E-07	3.5E-05
1954	2.9E-05	1.6E-06	5.1E-06	5.3E-05	6.5E-06	2.3E-06	6.0E-06	8.4E-07	7.1E-05
1955	4.1E-07	1.9E-08	4.8E-08	6.5E-07	8.5E-08	3.1E-08	7.7E-08	1.0E-08	9.7E-07
1956	3.3E-07	1.1E-08	4.0E-08	4.0E-07	5.9E-08	2.2E-08	5.2E-08	6.7E-09	7.6E-07
1957	7.1E-07	2.5E-08	9.3E-08	8.9E-07	1.3E-07	4.7E-08	1.2E-07	1.7E-08	1.7E-06
1958	9.5E-07	3.7E-08	1.3E-07	1.3E-06	1.8E-07	6.7E-08	1.6E-07	2.1E-08	2.2E-06
1959	8.8E-07	3.0E-08	1.1E-07	1.1E-06	1.6E-07	6.1E-08	1.3E-07	1.7E-08	2.0E-06
1960	9.4E-07	3.5E-08	1.3E-07	1.3E-06	1.8E-07	6.8E-08	1.5E-07	2.0E-08	2.2E-06
1961	8.8E-07	3.1E-08	1.0E-07	1.1E-06	1.6E-07	6.2E-08	1.3E-07	1.6E-08	2.0E-06
1962	5.2E-07	1.9E-08	6.8E-08	6.5E-07	9.4E-08	3.6E-08	8.4E-08	1.1E-08	1.2E-06
1963	4.4E-07	1.5E-08	4.9E-08	5.3E-07	7.8E-08	3.0E-08	6.3E-08	8.4E-09	9.6E-07
1964	5.5E-07	1.7E-08	5.7E-08	6.1E-07	9.4E-08	3.8E-08	7.3E-08	1.0E-08	1.2E-06
1965	4.4E-07	1.5E-08	5.1E-08	5.5E-07	7.7E-08	3.1E-08	6.3E-08	7.9E-09	1.0E-06
1966	3.2E-07	1.4E-08	5.0E-08	4.8E-07	6.5E-08	2.1E-08	6.9E-08	9.3E-09	7.5E-07
1967	2.3E-07	9.5E-09	3.5E-08	3.5E-07	5.1E-08	1.6E-08	4.5E-08	5.7E-09	5.5E-07
1968	1.2E-07	3.5E-09	1.2E-08	1.3E-07	2.0E-08	8.0E-09	1.5E-08	1.8E-09	2.5E-07
1969	4.3E-08	1.4E-09	4.7E-09	5.1E-08	7.5E-09	2.8E-09	6.6E-09	7.7E-10	9.5E-08
1970	1.1E-08	6.3E-10	2.5E-09	2.2E-08	2.6E-09	8.1E-10	3.3E-09	4.6E-10	2.9E-08
1971	7.1E-09	1.5E-10	3.5E-10	4.2E-09	1.1E-09	5.3E-10	4.5E-10	4.1E-11	1.4E-08
1972	3.0E-10	1.4E-11	4.0E-11	4.9E-10	5.8E-11	2.3E-11	4.2E-11	5.9E-12	6.7E-10

(a) Doses shown are the effective dose equivalent (EDE) to an adult male. The doses are from all exposure pathways including consumption of foodstuffs (milk, fresh fruits, vegetables, eggs, poultry, and beef), inhalation, and external exposure. All foodstuffs were assumed to be from a backyard source. The milk was produced by a cow that grazed on fresh pasture.

Table C.4. Effective Dose Equivalent *(rem)* from Ruthenium-106 at Selected Locations, 1945-1972[(a)]

Location:	Eltopia	Lewiston	Pendleton	Richland	Ritzville	Spokane	Sunnyside	Wenatchee	Ringold
Cumulative:	2.7E-04	1.1E-05	3.8E-05	3.9E-04	5.1E-05	2.0E-05	4.7E-05	6.1E-06	6.4E-04
1945	8.8E-06	2.8E-07	1.2E-06	1.1E-05	1.5E-06	5.4E-07	1.5E-06	2.0E-07	2.1E-05
1946	1.2E-05	4.7E-07	1.6E-06	1.7E-05	2.2E-06	8.9E-07	2.0E-06	2.7E-07	2.9E-05
1947	8.4E-06	3.0E-07	1.1E-06	1.1E-05	1.5E-06	5.9E-07	1.3E-06	1.7E-07	2.0E-05
1948	3.1E-06	1.5E-07	4.8E-07	5.3E-06	6.2E-07	2.4E-07	5.8E-07	8.3E-08	7.3E-06
1949	1.3E-07	5.0E-09	1.9E-08	1.8E-07	2.4E-08	8.7E-09	2.4E-08	3.2E-09	3.2E-07
1950	2.4E-07	8.5E-09	3.2E-08	3.1E-07	4.2E-08	1.7E-08	3.9E-08	5.2E-09	5.7E-07
1951	4.1E-07	1.5E-08	5.4E-08	5.3E-07	7.2E-08	2.8E-08	6.8E-08	9.4E-09	9.5E-07
1952	7.8E-06	2.5E-07	9.1E-07	9.0E-06	1.3E-06	5.3E-07	1.1E-06	1.4E-07	1.8E-05
1953	6.2E-05	1.8E-06	6.7E-06	6.6E-05	9.7E-06	4.2E-06	8.6E-06	8.9E-07	1.4E-04
1954	1.2E-04	6.1E-06	2.0E-05	2.1E-04	2.5E-05	9.2E-06	2.3E-05	3.2E-06	2.8E-04
1955	1.4E-06	5.4E-08	1.9E-07	1.9E-06	2.5E-07	9.8E-08	2.4E-07	3.3E-08	3.2E-06
1956	1.9E-06	6.1E-08	2.4E-07	2.3E-06	3.1E-07	1.2E-07	3.0E-07	3.9E-08	4.4E-06
1957	3.2E-06	1.2E-07	4.4E-07	4.2E-06	5.8E-07	2.2E-07	5.5E-07	7.8E-08	7.6E-06
1958	3.1E-06	1.2E-07	4.3E-07	4.2E-06	5.6E-07	2.1E-07	5.3E-07	7.1E-08	7.4E-06
1959	3.7E-06	1.3E-07	4.7E-07	4.6E-06	6.4E-07	2.5E-07	5.7E-07	7.4E-08	8.8E-06
1960	4.1E-06	1.5E-07	5.5E-07	5.3E-06	7.2E-07	2.8E-07	6.8E-07	9.2E-08	9.7E-06
1961	4.3E-06	1.5E-07	5.5E-07	5.4E-06	7.3E-07	3.0E-07	6.6E-07	8.1E-08	1.0E-05
1962	3.8E-06	1.3E-07	5.0E-07	4.7E-06	6.5E-07	2.5E-07	6.3E-07	8.4E-08	9.0E-06
1963	3.5E-06	1.3E-07	4.2E-07	4.5E-06	6.3E-07	2.4E-07	5.6E-07	7.9E-08	7.8E-06
1964	4.0E-06	1.3E-07	4.5E-07	4.7E-06	6.7E-07	2.7E-07	5.8E-07	7.6E-08	9.0E-06
1965	3.7E-06	1.3E-07	4.4E-07	4.6E-06	6.3E-07	2.6E-07	5.4E-07	7.0E-08	8.4E-06
1966	3.3E-06	1.4E-07	5.3E-07	5.1E-06	6.5E-07	2.1E-07	7.4E-07	1.0E-07	7.8E-06
1967	3.0E-06	1.0E-07	3.8E-07	3.8E-06	5.2E-07	2.0E-07	5.0E-07	6.5E-08	6.8E-06
1968	3.3E-06	1.2E-07	4.0E-07	4.2E-06	5.7E-07	2.3E-07	5.1E-07	6.7E-08	7.5E-06
1969	2.5E-06	8.9E-08	3.3E-07	3.3E-06	4.4E-07	1.7E-07	4.1E-07	5.3E-08	6.0E-06
1970	5.4E-07	2.1E-08	8.0E-08	8.2E-07	1.0E-07	4.0E-08	1.0E-07	1.4E-08	1.3E-06
1971	7.4E-07	1.8E-08	5.9E-08	7.1E-07	1.1E-07	5.3E-08	7.9E-08	6.4E-09	1.6E-06
1972	8.3E-08	4.0E-09	1.1E-08	1.4E-07	1.6E-08	6.3E-09	1.2E-08	1.6E-09	1.8E-07

(a) Doses shown are the effective dose equivalent (EDE) to an adult male. The doses are from all exposure pathways including consumption of foodstuffs (milk, fresh fruits, vegetables, eggs, poultry, and beef), inhalation, and external exposure. All foodstuffs were assumed to be from a backyard source. The milk was produced by a cow that grazed on fresh pasture.

Table C.5. Effective Dose Equivalent *(rem)* from Iodine-131 at Selected Locations, 1945-1972[(a)]

Location:	Eltopia	Lewiston	Pendleton	Richland	Ritzville	Spokane	Sunnyside	Wenatchee	Ringold
Cumulative:	4.1E-01	1.9E-02	4.6E-02	4.2E-01	1.4E-01	5.4E-02	3.7E-02	2.9E-03	1.2E+00
1945	3.4E-01	1.6E-02	3.8E-02	3.5E-01	1.2E-01	4.4E-02	3.0E-02	2.2E-03	9.9E-01
1946	4.4E-02	2.1E-03	5.5E-03	4.6E-02	1.4E-02	5.5E-03	4.5E-03	2.7E-04	1.1E-01
1947	8.1E-03	4.7E-04	9.2E-04	6.8E-03	3.1E-03	1.6E-03	1.0E-03	1.7E-04	2.0E-02
1948	3.5E-04	2.6E-05	4.2E-05	4.6E-04	1.1E-04	4.5E-05	5.2E-05	7.7E-06	8.2E-04
1949	9.9E-04	6.1E-05	2.5E-04	1.2E-03	1.8E-04	9.3E-05	1.3E-04	1.1E-05	4.5E-03
1950	1.6E-03	1.0E-04	2.2E-04	2.0E-03	4.7E-04	2.3E-04	2.2E-04	1.8E-05	4.1E-03
1951	1.1E-02	6.1E-04	1.3E-03	9.1E-03	3.4E-03	2.0E-03	1.1E-03	1.4E-04	2.5E-02
1952	1.8E-03	7.0E-05	2.3E-04	2.5E-03	3.3E-04	1.4E-04	2.8E-04	3.6E-05	4.2E-03
1953	9.6E-04	2.6E-05	8.1E-05	8.6E-04	1.5E-04	7.0E-05	9.7E-05	1.0E-05	2.1E-03
1954	3.4E-04	1.2E-05	4.2E-05	4.2E-04	5.8E-05	2.4E-05	5.6E-05	6.5E-06	7.9E-04
1955	2.7E-04	9.4E-06	3.0E-05	3.4E-04	4.6E-05	1.9E-05	3.9E-05	4.2E-06	6.0E-04
1956	5.7E-05	1.7E-06	5.9E-06	5.9E-05	9.3E-06	4.1E-06	6.9E-06	8.1E-07	1.3E-04
1957	1.2E-04	3.8E-06	1.7E-05	1.4E-04	1.9E-05	7.5E-06	1.9E-05	2.4E-06	3.0E-04
1958	3.3E-04	1.2E-05	3.6E-05	4.1E-04	5.7E-05	2.5E-05	4.4E-05	5.2E-06	7.4E-04
1959	1.1E-04	3.4E-06	1.2E-05	1.2E-04	1.8E-05	7.8E-06	1.6E-05	1.6E-06	2.6E-04
1960	1.1E-04	3.9E-06	1.4E-05	1.4E-04	1.9E-05	8.4E-06	1.6E-05	1.8E-06	2.6E-04
1961	4.5E-05	1.4E-06	4.4E-06	4.8E-05	7.3E-06	3.3E-06	5.6E-06	6.6E-07	9.7E-05
1962	1.2E-05	4.6E-07	1.9E-06	1.8E-05	2.2E-06	7.8E-07	2.6E-06	2.5E-07	3.1E-05
1963	4.3E-05	1.2E-06	5.4E-06	5.9E-05	6.8E-06	2.1E-06	1.0E-05	6.2E-07	1.0E-04
1964	5.5E-06	1.5E-07	4.9E-07	5.3E-06	8.1E-07	3.9E-07	6.0E-07	8.1E-08	1.1E-05
1965	2.6E-06	7.5E-08	3.1E-07	3.0E-06	3.9E-07	1.8E-07	3.6E-07	3.9E-08	6.2E-06
1966	4.6E-06	1.4E-07	3.7E-07	4.1E-06	7.8E-07	3.4E-07	5.1E-07	6.3E-08	9.6E-06
1967	4.1E-07	1.7E-08	5.9E-08	6.3E-07	7.3E-08	3.1E-08	7.0E-08	8.8E-09	9.5E-07
1968	8.5E-09	2.2E-10	7.0E-10	8.5E-09	1.3E-09	6.1E-10	8.9E-10	1.0E-10	1.8E-08
1969	8.6E-10	2.3E-11	6.8E-11	7.7E-10	1.3E-10	5.7E-11	1.0E-10	7.8E-12	1.8E-09
1970	2.9E-10	1.9E-11	7.7E-11	6.3E-10	7.3E-11	2.1E-11	1.0E-10	1.4E-11	8.1E-10
1971	5.5E-11	1.1E-12	2.1E-12	2.6E-11	8.1E-12	4.1E-12	2.7E-12	2.4E-13	1.0E-10
1972	1.7E-17	8.7E-19	2.4E-18	3.0E-17	3.5E-18	1.4E-18	2.6E-18	3.6E-19	3.9E-17

(a) Doses shown are the effective dose equivalent (EDE) to an adult male. The doses are from all exposure pathways including consumption of foodstuffs (milk, fresh fruits, vegetables, eggs, poultry, and beef), inhalation, and external exposure. All foodstuffs were assumed to be from a backyard source. The milk was produced by a cow that grazed on fresh pasture.

Table C.6. Effective Dose Equivalent *(rem)* from Cerium-144 at Selected Locations, 1945-1972[(a)]

Location:	Eltopia	Lewiston	Pendleton	Richland	Ritzville	Spokane	Sunnyside	Wenatchee	Ringold
Cumulative:	1.9E-03	6.8E-05	2.5E-04	2.5E-03	3.3E-04	1.3E-04	3.1E-04	4.2E-05	4.5E-03
1945	2.5E-04	7.8E-06	3.3E-05	2.9E-04	4.1E-05	1.5E-05	4.3E-05	5.8E-06	6.0E-04
1946	3.2E-04	1.2E-05	4.2E-05	4.3E-04	5.8E-05	2.3E-05	5.2E-05	7.0E-06	7.6E-04
1947	2.3E-04	8.1E-06	2.9E-05	2.9E-04	4.0E-05	1.6E-05	3.6E-05	4.7E-06	5.3E-04
1948	7.8E-05	3.8E-06	1.2E-05	1.3E-04	1.7E-05	6.1E-06	1.5E-05	2.1E-06	1.9E-04
1949	3.1E-06	1.2E-07	4.5E-07	4.3E-06	5.6E-07	2.1E-07	5.6E-07	7.5E-08	7.6E-06
1950	5.3E-06	1.9E-07	7.0E-07	6.7E-06	9.2E-07	3.6E-07	8.7E-07	1.1E-07	1.3E-05
1951	8.6E-06	3.1E-07	1.1E-06	1.1E-05	1.5E-06	5.8E-07	1.4E-06	2.0E-07	2.0E-05
1952	1.2E-05	4.3E-07	1.6E-06	1.5E-05	2.1E-06	8.2E-07	1.9E-06	2.6E-07	2.8E-05
1953	1.6E-05	5.4E-07	2.1E-06	2.0E-05	2.7E-06	1.1E-06	2.6E-06	3.1E-07	3.9E-05
1954	2.1E-05	7.4E-07	2.9E-06	2.7E-05	3.6E-06	1.4E-06	3.6E-06	4.7E-07	5.0E-05
1955	2.2E-05	7.5E-07	2.8E-06	2.7E-05	3.8E-06	1.5E-06	3.5E-06	4.7E-07	5.2E-05
1956	3.7E-05	1.2E-06	4.8E-06	4.6E-05	6.4E-06	2.5E-06	6.0E-06	7.9E-07	8.9E-05
1957	6.1E-05	2.1E-06	7.9E-06	7.7E-05	1.1E-05	4.1E-06	9.9E-06	1.3E-06	1.4E-04
1958	6.6E-05	2.5E-06	9.2E-06	9.0E-05	1.2E-05	4.5E-06	1.1E-05	1.5E-06	1.6E-04
1959	7.4E-05	2.5E-06	9.5E-06	9.1E-05	1.3E-05	5.0E-06	1.2E-05	1.5E-06	1.8E-04
1960	8.2E-05	2.9E-06	1.1E-05	1.1E-04	1.5E-05	5.6E-06	1.4E-05	1.9E-06	2.0E-04
1961	8.7E-05	3.0E-06	1.1E-05	1.1E-04	1.5E-05	6.0E-06	1.3E-05	1.6E-06	2.1E-04
1962	7.7E-05	2.7E-06	1.0E-05	9.6E-05	1.3E-05	5.1E-06	1.3E-05	1.7E-06	1.8E-04
1963	7.0E-05	2.5E-06	8.4E-06	8.9E-05	1.2E-05	4.8E-06	1.1E-05	1.6E-06	1.6E-04
1964	8.2E-05	2.7E-06	9.3E-06	9.5E-05	1.4E-05	5.5E-06	1.2E-05	1.6E-06	1.8E-04
1965	7.6E-05	2.6E-06	9.0E-06	9.6E-05	1.3E-05	5.3E-06	1.1E-05	1.5E-06	1.7E-04
1966	6.4E-05	2.7E-06	1.0E-05	9.6E-05	1.2E-05	4.1E-06	1.4E-05	1.9E-06	1.5E-04
1967	5.3E-05	1.9E-06	7.0E-06	7.0E-05	9.4E-06	3.6E-06	9.4E-06	1.2E-06	1.2E-04
1968	5.2E-05	1.8E-06	6.2E-06	6.4E-05	8.9E-06	3.6E-06	7.8E-06	1.0E-06	1.2E-04
1969	3.7E-05	1.3E-06	4.7E-06	4.7E-05	6.3E-06	2.5E-06	5.9E-06	7.6E-07	8.7E-05
1970	7.5E-06	3.2E-07	1.2E-06	1.2E-05	1.5E-06	5.5E-07	1.6E-06	2.2E-07	1.8E-05
1971	1.4E-05	3.5E-07	1.1E-06	1.4E-05	2.1E-06	1.0E-06	1.5E-06	1.2E-07	3.0E-05
1972	1.8E-06	8.4E-08	2.3E-07	2.9E-06	3.3E-07	1.4E-07	2.5E-07	3.4E-08	3.9E-06

(a) Doses shown are the effective dose equivalent (EDE) to an adult male. The doses are from all exposure pathways including consumption of foodstuffs (milk, fresh fruits, vegetables, eggs, poultry, and beef), inhalation, and external exposure. All foodstuffs were assumed to be from a backyard source. The milk was produced by a cow that grazed on fresh pasture.

Table C.7. Effective Dose Equivalent *(rem)* from Plutonium-239 at Selected Locations, 1945-1972[(a)]

Location:	Eltopia	Lewiston	Pendleton	Richland	Ritzville	Spokane	Sunnyside	Wenatchee	Ringold
Cumulative:	1.0E-03	3.8E-05	1.4E-04	1.4E-03	1.8E-04	7.1E-05	1.7E-04	2.3E-05	2.5E-03
1945	2.4E-04	7.7E-06	3.3E-05	2.9E-04	4.0E-05	1.5E-05	4.2E-05	5.7E-06	5.8E-04
1946	3.3E-04	1.2E-05	4.4E-05	4.4E-04	6.0E-05	2.4E-05	5.4E-05	7.3E-06	7.8E-04
1947	2.4E-04	8.5E-06	3.0E-05	3.0E-04	4.2E-05	1.6E-05	3.8E-05	4.9E-06	5.6E-04
1948	8.7E-05	4.2E-06	1.4E-05	1.5E-04	1.8E-05	6.8E-06	1.6E-05	2.3E-06	2.1E-04
1949	3.7E-06	1.4E-07	5.4E-07	5.0E-06	6.6E-07	2.4E-07	6.7E-07	8.9E-08	9.0E-06
1950	6.1E-06	2.1E-07	7.9E-07	7.7E-06	1.1E-06	4.1E-07	9.9E-07	1.3E-07	1.4E-05
1951	8.5E-06	3.1E-07	1.1E-06	1.1E-05	1.5E-06	5.8E-07	1.4E-06	2.0E-07	2.0E-05
1952	7.8E-06	3.0E-07	1.1E-06	1.1E-05	1.4E-06	5.5E-07	1.3E-06	1.8E-07	1.9E-05
1953	8.8E-06	3.0E-07	1.2E-06	1.1E-05	1.5E-06	5.9E-07	1.4E-06	1.7E-07	2.2E-05
1954	1.3E-05	4.4E-07	1.7E-06	1.6E-05	2.2E-06	8.2E-07	2.2E-06	2.9E-07	3.0E-05
1955	1.5E-05	4.9E-07	1.8E-06	1.8E-05	2.5E-06	9.9E-07	2.3E-06	3.0E-07	3.4E-05
1956	7.9E-06	2.7E-07	9.7E-07	1.0E-05	1.4E-06	5.4E-07	1.2E-06	1.7E-07	1.8E-05
1957	8.6E-06	3.0E-07	1.1E-06	1.1E-05	1.5E-06	5.7E-07	1.4E-06	1.9E-07	2.1E-05
1958	6.3E-06	2.1E-07	7.1E-07	7.5E-06	1.1E-06	4.7E-07	8.5E-07	9.4E-08	1.5E-05
1959	5.0E-06	1.7E-07	6.8E-07	6.3E-06	8.7E-07	3.3E-07	8.2E-07	1.1E-07	1.2E-05
1960	4.3E-06	1.4E-07	5.0E-07	4.9E-06	7.4E-07	3.0E-07	6.1E-07	8.8E-08	9.9E-06
1961	6.7E-06	2.2E-07	7.7E-07	7.8E-06	1.1E-06	4.7E-07	9.5E-07	1.3E-07	1.5E-05
1962	5.4E-06	2.1E-07	7.4E-07	7.3E-06	9.7E-07	3.7E-07	9.6E-07	1.2E-07	1.3E-05
1963	6.3E-06	2.3E-07	8.0E-07	8.0E-06	1.1E-06	4.6E-07	9.9E-07	1.2E-07	1.5E-05
1964	8.9E-06	3.3E-07	1.4E-06	1.2E-05	1.6E-06	6.2E-07	1.6E-06	2.0E-07	2.3E-05
1965	7.8E-06	3.0E-07	1.0E-06	1.1E-05	1.4E-06	5.6E-07	1.3E-06	2.0E-07	1.8E-05
1966	1.0E-05	4.3E-07	1.6E-06	1.5E-05	2.0E-06	6.8E-07	2.2E-06	2.9E-07	2.4E-05
1967	2.9E-07	1.0E-08	3.8E-08	3.8E-07	5.1E-08	1.9E-08	5.0E-08	6.7E-09	6.6E-07
1968	3.0E-07	1.0E-08	3.6E-08	3.7E-07	5.1E-08	2.0E-08	4.5E-08	6.2E-09	6.7E-07
1969	2.3E-07	7.9E-09	3.0E-08	3.0E-07	3.9E-08	1.6E-08	3.7E-08	4.8E-09	5.5E-07
1970	4.6E-08	1.9E-09	7.0E-09	7.1E-08	9.0E-09	3.4E-09	9.0E-09	1.3E-09	1.1E-07
1971	1.4E-07	3.4E-09	1.1E-08	1.3E-07	2.0E-08	9.9E-09	1.4E-08	1.2E-09	2.9E-07
1972	1.8E-08	8.6E-10	2.4E-09	3.0E-08	3.4E-09	1.4E-09	2.5E-09	3.5E-10	4.0E-08

(a) Doses shown are the effective dose equivalent (EDE) to an adult male. The doses are from all exposure pathways including consumption of foodstuffs (milk, fresh fruits, vegetables, eggs, poultry, and beef), inhalation, and external exposure. All foodstuffs were assumed to be from a backyard source. The milk was produced by a cow that grazed on fresh pasture.

Appendix D

Details of Sensitivity Analysis

Appendix D

Details of Sensitivity Analysis

Numerous input parameters are required for the atmospheric pathway models to provide dose estimates. These include parameters that describe the relationships between release rate and concentration of iodine-131 in air; between concentrations of iodine-131 in air and concentrations in crops, animal feed, milk, eggs, and other pathways by which humans might be exposed; and between other parameters that directly describe the habits and activities of a representative individual. For the HEDR Project, these parameters were developed from the available literature (Snyder et al. 1994). Each parameter was developed as a probability distribution function to specify its statistical uncertainty. The computer simulation of dose consisted of repeating calculations of the models 100 times to generate 100 estimates of dose for each representative individual. Each time the dose calculations were repeated, a new value for each uncertain input parameter was randomly generated from its specified probability distribution function, which expresses the uncertainty of the parameter. Thus, the parameter uncertainties have a direct impact on the variability (spread or uncertainty) exhibited by the 100 estimates of dose computed with using the atmospheric pathway models.

The 100 estimates of dose for the various types of representative individuals, along with the 100 sets of input parameters used to estimate them, served as the starting point for the sensitivity analyses. A stepwise multiple linear regression was performed on the results of the 100 calculations and also on the ranks of the estimates and parameters. In explaining the uncertainty in the dose, the increase in the coefficient of determination at each step was used as a measure of the marginal contribution of the input parameters that entered the regression at that step.

D.1 Hierarchical Approach to Determining Parameters Contributing the Most to Uncertainty in Dose Estimates

Individual dose is made up of the sum of the contributions over multiple exposure pathways. Different types of representative individuals, exposed via different pathways, will have different doses influenced by different parameters. The purpose of a sensitivity analysis is to determine which parameters have the greatest influence on the uncertainty. Thus, each class of individual at each location required a separate sensitivity analysis to precisely determine the key parameters.

The atmospheric pathway models are complex and contain many parameters. In many instances, the inputs to a given equation or model are themselves the outputs of earlier equations or models. To best understand the results of the sensitivity analysis, a hierarchical approach was taken to the analysis (Simpson and Ramsdell 1993, p. 4.6). In this approach, the first tier of analysis considered the major contributing inputs to the dose-estimation equation. If the uncertainty in the dose was sensitive to one or more of the derived (previously modeled) parameters going into the equation, then the sensitivity analysis followed up those derived parameters that contributed to uncertainty in the dose calculation. This was the second tier of sensitivity analysis. If dose calculations were determined to be sensitive to any of these additional parameters, they too were followed up through a third or more tiers of analysis. This approach was followed as long as necessary to determine the "key" parameters controlling the overall uncertainty in the dose estimates.

D.2 Key Model Parameters

The results of the sensitivity analysis for the individual classes are presented in this section.

The first tier of the sensitivity analysis addressed the equation

$$D = C_{ing}\,D_{ing} + C_{inh}\,D_{inh} + E \tag{D.1}$$

where
- D = dose, rad
- C_{ing} = total number of curies ingested
- D_{ing} = dose conversion factor for ingestion, rad/Ci
- C_{inh} = total number of curies inhaled
- D_{inh} = dose conversion factor for inhalation, rad/Ci
- E = dose from external sources, rad.

The results of the stepwise multiple regression of the ranks of these five parameters contributing to dose are illustrated for the year 1945 in Figures D.1 for children and D.2 for adults. Although similar figures were prepared for the year 1946, they were essentially indistinguishable from those for 1945. Thus, only the 1945 pair are presented here. Each figure provides results for each milk source at each location. These figures illustrate the contribution of each of the parameters in Equation D.1 to the overall uncertainty in the estimated doses for the 48 categories of representative individuals.

The pie charts in Figures D.1 and D.2 show that the uncertainties in the doses estimated for children and adults consuming milk from cows fed fresh pasture (either privately or commercially) are dominated by two major factors: the uncertainty in the total number of curies ingested and the uncertainty in the dose factor for ingestion. Those two factors are the largest portions of most of the pie charts. Adults and children consuming milk from cows fed stored feed had a smaller fraction of the uncertainty determined from these two parameters, and the uncertainty in the inhalation dose factor and amount inhaled could also contribute up to about 20 percent of the uncertainty for these groups. Note that each pie chart has an open portion. This represents residual uncertainty not explained by a stepwise multiple regression of the five parameters in the Equation (D.1); i.e., the fraction of uncertainty not described by the parameters chosen as most significant. The unnumbered portions of the pie charts account for one or more of the five parameters whose contribution to the total uncertainty was not statistically significant.

Of the two major contributors to uncertainty, the ingestion dose factor is a parameter directly input to the calculations, but the number of curies ingested is a derived value, that is, it depends on

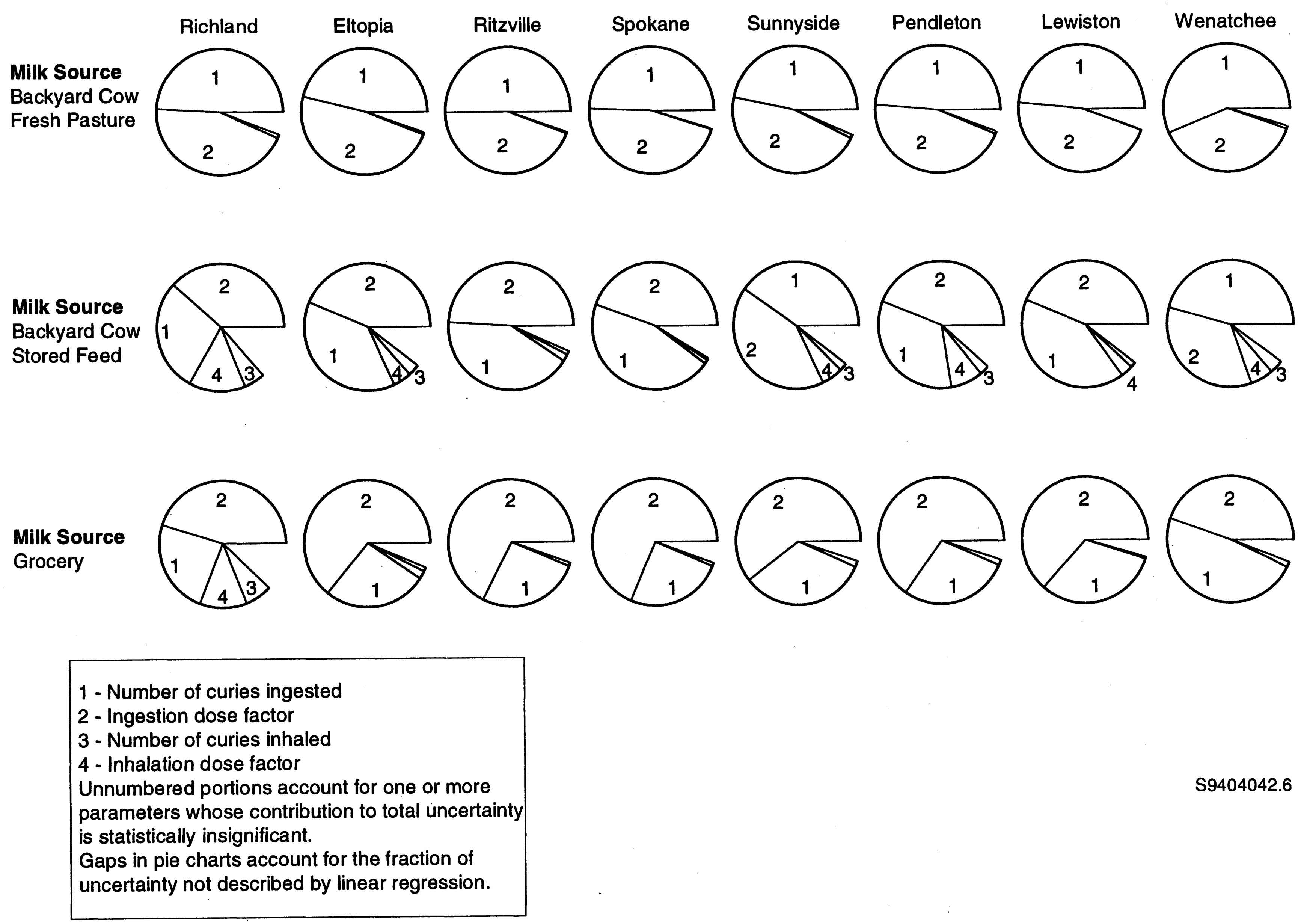
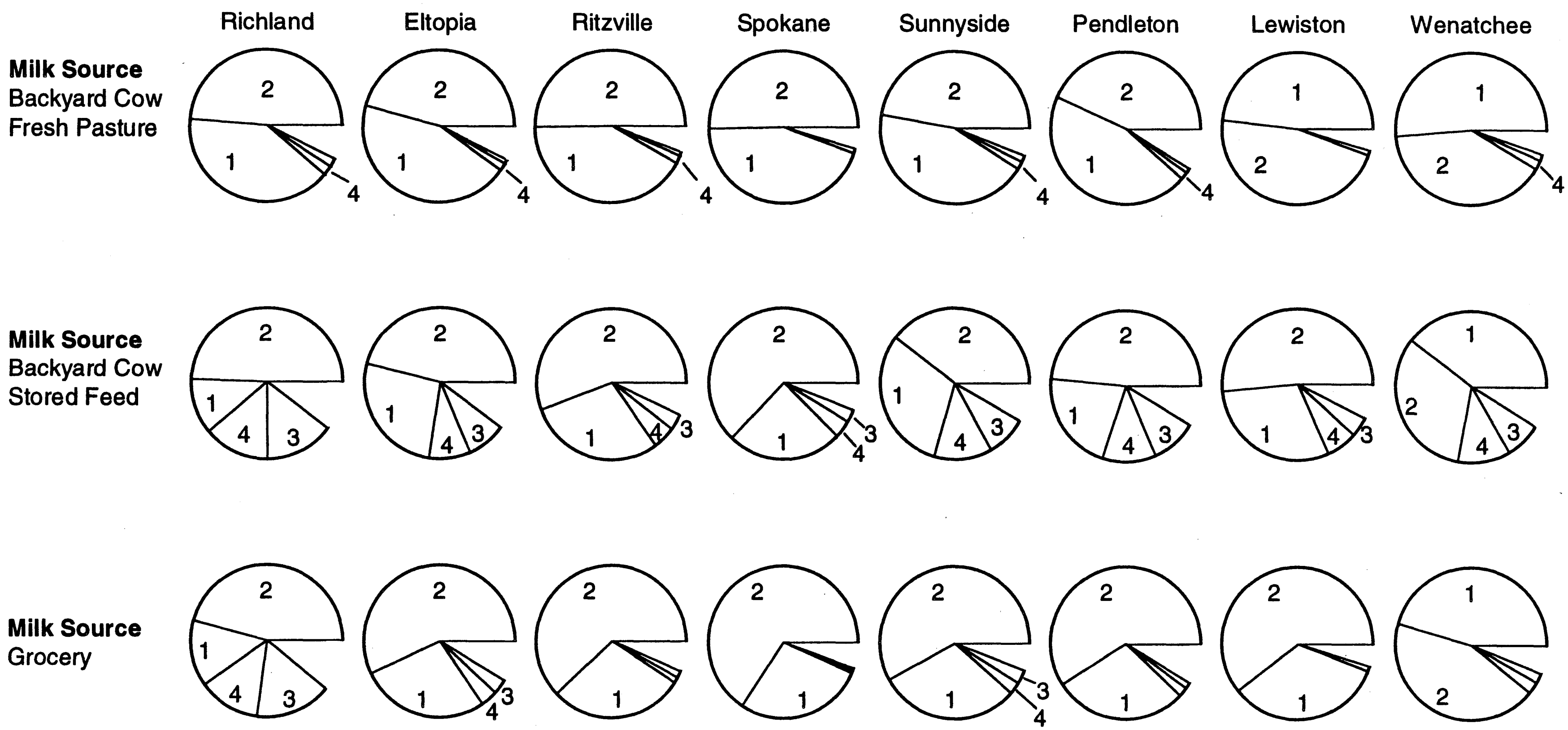


Figure D.1. Relative Importance of Parameters Contributing to the Uncertainty of Total Dose for a Child in 1945



1 - Number of curies ingested
2 - Ingestion dose factor
3 - Number of curies inhaled
4 - Inhalation dose factor
Unnumbered portions account for one or more parameters whose contribution to total uncertainty is statistically insignificant.
Gaps in pie charts account for the fraction of uncertainty not described by linear regression.

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Figure D.2. Relative Importance of Parameters Contributing to the Uncertainty of Total Dose for an Adult in 1945 the results of one or more models. The number of curies ingested is the sum of the curies ingested over each exposure pathway. Thus, for children and adults with family cows fed fresh pasture, the equation for C_{ing} is

$$C_{ing} = M + F + B + E + L + O + G + P \tag{D.2}$$

where M = curies ingested with milk
F = curies ingested with fruit
B = curies ingested with beef
E = curies ingested with eggs
L = curies ingested with leafy vegetables
O = curies ingested with other vegetables
G = curies ingested with grains
P = curies ingested with poultry.

Slightly simpler versions of Equation (D.2) are used for people with family cows fed stored feed or using commercial milk sources. For persons consuming milk from cows fed stored feed, the beef pathway was not included because the model assumption of fresh pasture feed for beef cattle is not logically compatible with stored feed for dairy cows. For persons consuming commercial milk, only commercial leafy vegetables, other vegetables, and fruit were also included so that this type of representative individual could represent an urban dweller without access to free-range poultry and eggs.

The results of the stepwise multiple regression on the ranks of these inputs are shown in Figure D.3 for children and Figure D.4 for adults, both in 1945. Again, very similar results were produced for 1946 and are, therefore, not reproduced here. For representative individuals consuming milk from cows fed fresh pasture, either family cows or commercial dairy herds, the dominant contributor to the uncertainty is the curies ingested via the milk pathway. This single pathway contributed over 95 percent of the total uncertainty to the C_{ing} parameter for these types of representative individuals for all locations but one.

The situation that differed from the others was Richland for commercial milk, for which fruit consumption added a relatively large contribution to the uncertainty (22 percent for children and 33 percent for adults). Richland is unique among these locations in that the commercial milk source was an area distinctly different from the Richland area. Deposition of iodine-131 is much lower in the Richland commercial milk shed than it is in Richland itself. The atmospheric pathway models conservatively assume that all fruit consumed is locally produced. This shifts the relative proportion of the uncertainty in the dose in Richland resulting from fruits and milk such that the uncertainty in the fruit dose has a noticeable impact on the uncertainty in the total dose estimated. For adults and children consuming milk from cows fed stored feed, the uncertainty in total dose resulting from uncertainty in dose from milk was also much lower, allowing contributions from fruit and locally produced eggs also to add to the uncertainty. Like fruit, eggs are assumed to be provided from local sources. In addition, the laying hens are assumed to forage in weeds and grasses contaminated with continuing fresh iodine-131 deposition. However, even in these cases, the uncertainty in intake via milk contributes the most to the uncertainty in curies ingested.

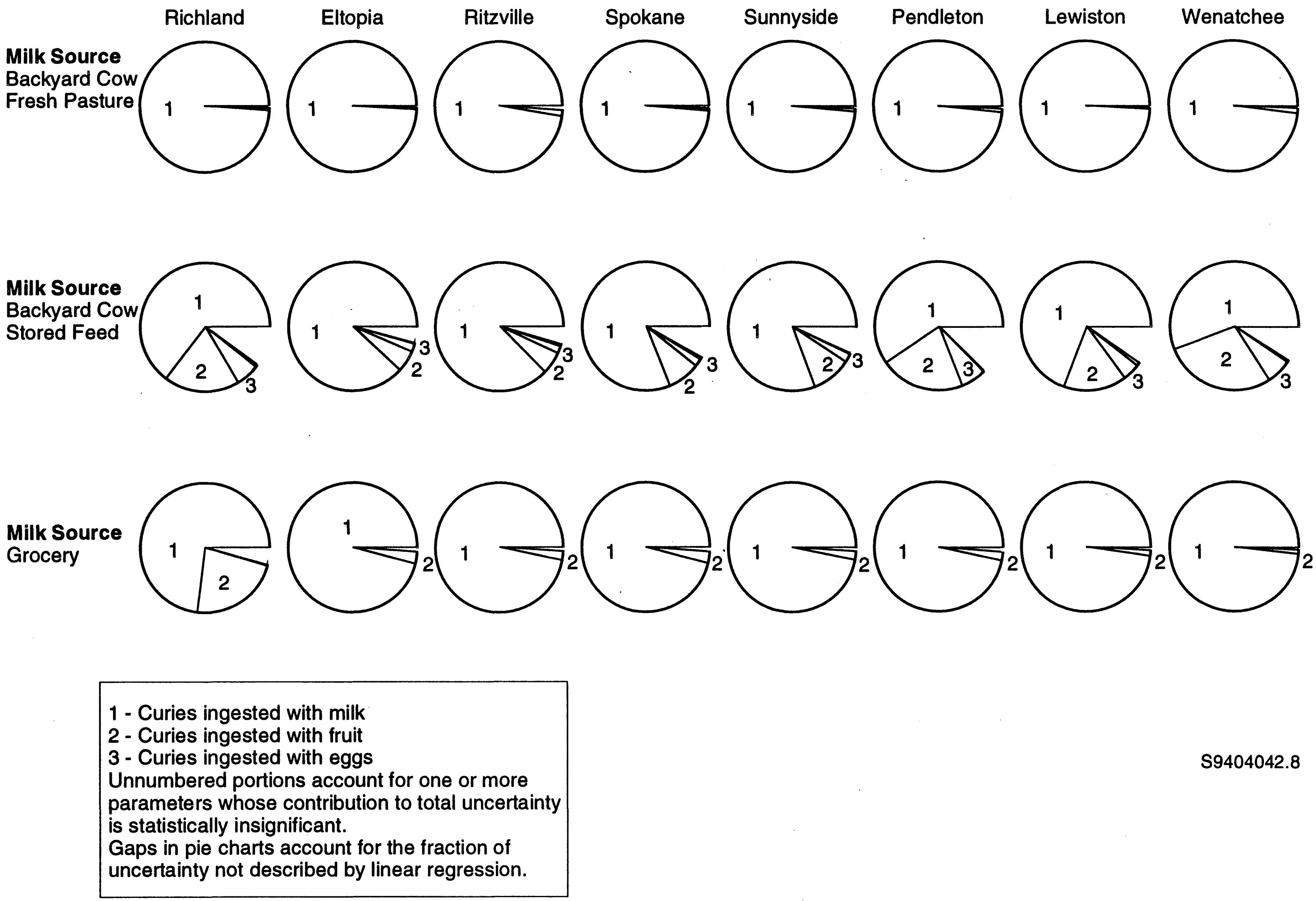


Figure D.3. Relative Importance of Parameters Contributing to the Uncertainty of Total Ingested Iodine-131 Activity for a Child in 1945

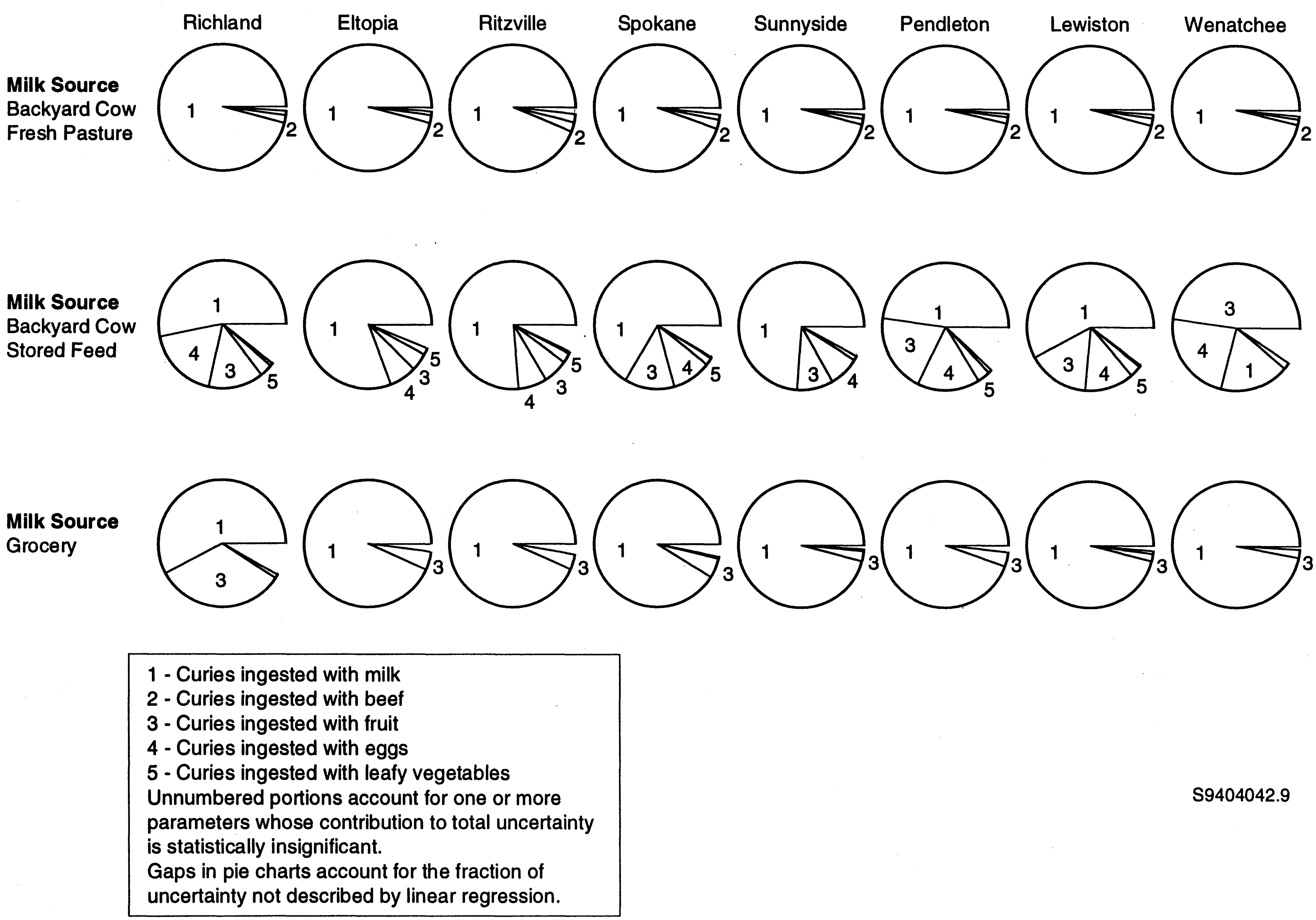


Figure D.4. Relative Importance of Parameters Contributing to the Uncertainty of Total Ingested Iodine-131 Activity for an Adult in 1945

Thus, the uncertainty in the curies a representative individual ingested via cows milk is the third tier of the sensitivity analysis. This quantity can be described for an individual cow or a herd of cows, in the hierarchical sense, as either

$$C = C_{ind-cow}\ TF_{ind-cow}[I_f\ e^{(-\lambda\ T_f)} + I_s\ e^{(-\lambda\ T_s)}] \qquad (D.3)$$

or

$$C = C_{herd-cow}\ TF_{herd-cow}[I_f\ e^{(-\lambda\ T_f)} + I_s\ e^{(-\lambda\ T_s)}] \qquad (D.4)$$

76 where $C_{ind-cow}$ = curies ingested by an individual (single) cow
$C_{herd-cow}$ = average curies ingested by a member of a herd of cows
$TF_{ind-cow}$ = feed-to-milk transfer factor for a single cow, days/liter
$TF_{herd-cow}$ = average feed-to-milk transfer factor for a herd of cows, days/liter
I_f = consumption of fresh milk by representative individuals, liters/day
λ = radiological decay constant, 1/days
T_f = holdup from milking to consumption of fresh milk, days
I_s = consumption of stored milk and milk products by representative individuals, liters (effective)/day
T_s = holdup from milking to consumption of stored milk, days.

The results of the linear regression on the ranks of the parameters going into Equations D.3 and D.4 are shown in Figure D.5. For individual cows on pasture, about 75 percent of the uncertainty in the curies in milk is from the uncertainty in the transfer factor from feed to milk. For individual cows fed stored feed, about two-thirds of the uncertainty in concentration in milk is caused by uncertainty in the transfer factor. For milk blended from multiple cows in herds, the feed-to-milk transfer factor (option 3 in Figure D.5, third row) accounts for about 20 percent of the uncertainty. It can be much better pinpointed on the average over many cows than it can be for any one individual cow. The second most important parameter for individual cows is the number of curies that they ingest. For the herd cows, this is the most important parameter. For cows fed stored feed, the uncertainty in the curies ingested is strongly influenced by location. Following in third and fourth positions of importance are the quantity of fresh milk consumed by the representative individual and the holdup time from milking to consumption. These four parameters account for well over 90 percent of the uncertainty in the curies ingested by a representative individual via the milk pathway.

In considering the number of curies consumed by a representative individual via the milk pathway, the feed-to-milk transfer factors, individual ingestion rates, and holdup times are input parameters, but the curies ingested by the cow are again the result of a prior computation. Continuing a fourth level down the sensitivity hierarchy, the input parameters to the calculation of the number of curies ingested by cows on either fresh pasture or stored feed were evaluated for both 1945 and 1946. Because cows supplying the commercial milk system are essentially just variants of fresh-pasture cows, they were omitted from this step of the sensitivity analysis. Intake by the cows on fresh pasture is a complex function of the season. Each season accounts for the total deposition provided

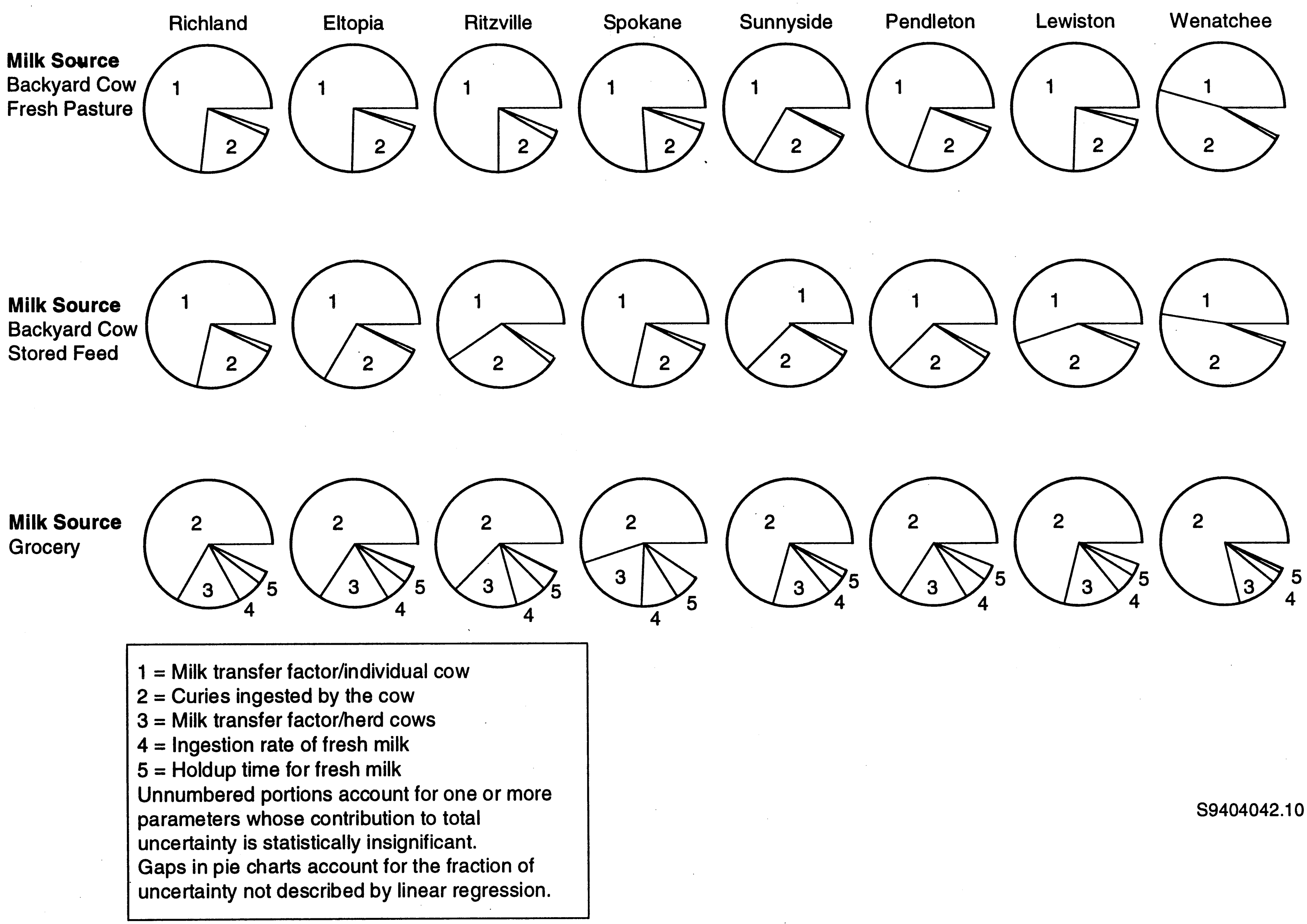


Figure D.5. Relative Importance of Parameters Contributing to the Uncertainty of Total Ingested Iodine-131 Activity for a Child - Milk Cows in 1945 by the RATCHET model, the integral of daily iodine-131 concentration on pasture, the dates at which the cows were put on or taken off pasture, the concentration of iodine-131 in each cutting of alfalfa hay and grain, and the amounts of iodine-131 taken in as a result of soil ingestion, fallout on stored feed, and fallout in water sources. For cows on fresh pasture, the results of the linear regression on the ranks of the input variables are summarized in Figure D.6.

As Figure D.6 shows for the cows fed fresh pasture, the dominant parameter is the integral of the daily concentration estimated for the pasture. In 1945, the date on which the cow on fresh pasture was taken off pasture accounts for up to 20 percent of the uncertainty in the amount of iodine-131 ingested, depending on location. In 1946, it was not a significant variable at most locations. However, in 1946, the date on which cows *began* consuming fresh pasture is significant at several locations although it was not in 1945. These differences are likely the result of differing temporal patterns of iodine-131 deposition in each year. A fairly large spike of deposition occurred late in 1945, and it would be important whether or not the cows remained on pasture through it, but in 1946 the deposition rate was highest at the beginning of the year and declined throughout the year. For 1945, the next six parameters in importance collectively contribute only 2 percent more to the explanation of uncertainty. For 1946, the next six collectively account for about 4 percent. None of these groups is particularly significant, nor does any parameter stand out as worthy of further investigation.

Figure D.7 shows the results of the linear regression for curies ingested by cows fed stored feed for 1945 and 1946, analogous to Figure D.6. Generally, for this feeding regime, the uncertainty in the concentration of iodine-131 in the first cutting of alfalfa is the largest contributor to the uncertainty in amount taken in by the cows. For some locations, the uncertainty in the concentrations in the second or third cutting of alfalfa contributes more uncertainty. The concentration in the alfalfa at harvest is very dependent on the most recent deposition prior to harvest, which has increased uncertainty for areas outside of the main deposition footprint, such as Wenatchee or Pendleton.

For certain groups, the inhalation dose was a noticeable contributor to the total dose. Sensitivity analysis of this portion of the dose is really a second branch of the second tier of the sensitivity analysis as a whole. The inhalation dose is a function of the breathing rate, the time-integrated air concentration of iodine-131, the ratio of time spent indoors and outdoors, total deposition, and resuspension. Results of the stepwise multiple regression on the ranks of the parameters input to the inhalation dose are shown in Figure D.8. Results for adults and children, rural and urban, for both 1945 and 1946 are essentially equivalent. Thus, only the 1945 results for rural children are presented. The uncertainty in the representative individual breathing rate accounts for 50 to 75 percent of the overall uncertainty. For most areas, the uncertainty in integrated air concentration (resulting from uncertainties in the modeling of source term and atmospheric transport) accounts for 10 to 15 percent of the total uncertainty. Only for areas such as Wenatchee, located within the steep gradients along the edges of the main deposition pattern, does this parameter become important. The uncertainty in the ratio of iodine-131 concentration in indoor versus outdoor air always accounts for 10 to 15 percent of the uncertainty. The remaining parameters basically contribute little to the overall uncertainty.

A third branch down the second tier of the sensitivity analysis involves the uncertainty in the representative individual intake of iodine-131 via the consumption of eggs. This calculation is analogous to that for milk. The individual intake of iodine-131 is a function of the feed-to-egg

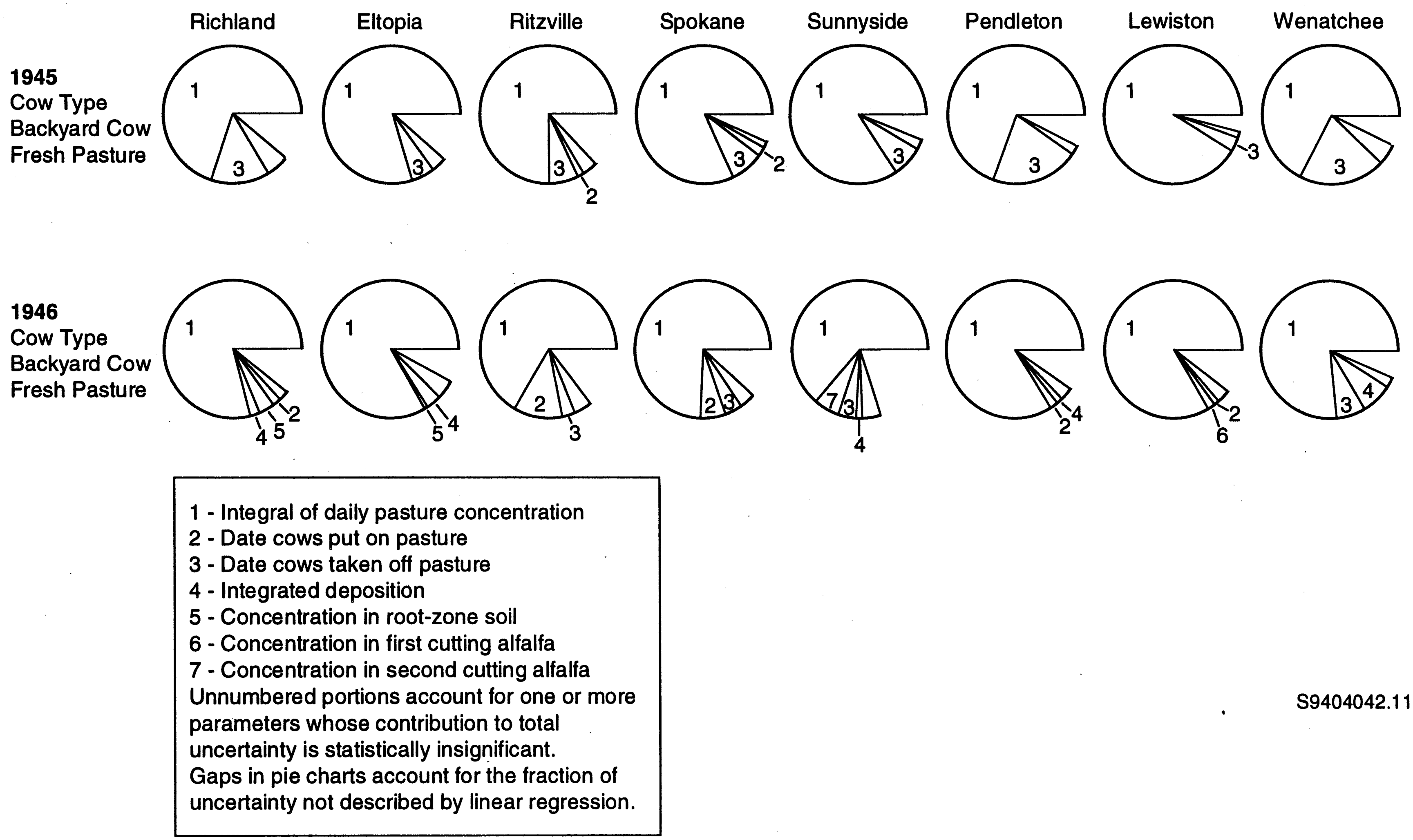
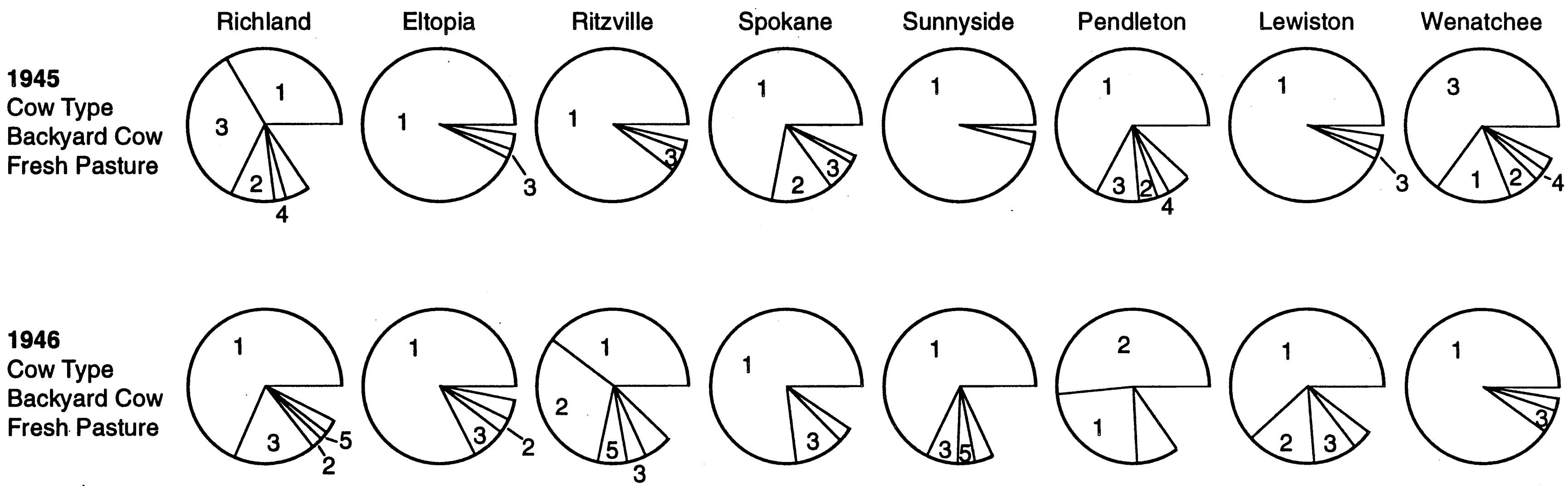


Figure D.6. Relative Importance of Parameters Contributing to the Uncertainty of Total Ingested Iodine-131 Activity for Milk Cows on Fresh Pasture in 1945 and 1946



1 - Concentration in first cutting alfalfa
2 - Concentration in second cutting alfalfa
3 - Concentration in third cutting alfalfa
4 - Concentration in upper soil
5 - Integrated deposition
Unnumbered portions account for one or more parameters whose contribution to total uncertainty is statistically insignificant.
Gaps in pie charts account for the fraction of uncertainty not described by linear regression.

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Figure D.7. Relative Importance of Parameters Contributing to the Uncertainty of Total Ingested Iodine-131 Activity for Milk Cows on Stored Feed in 1945 and 1946

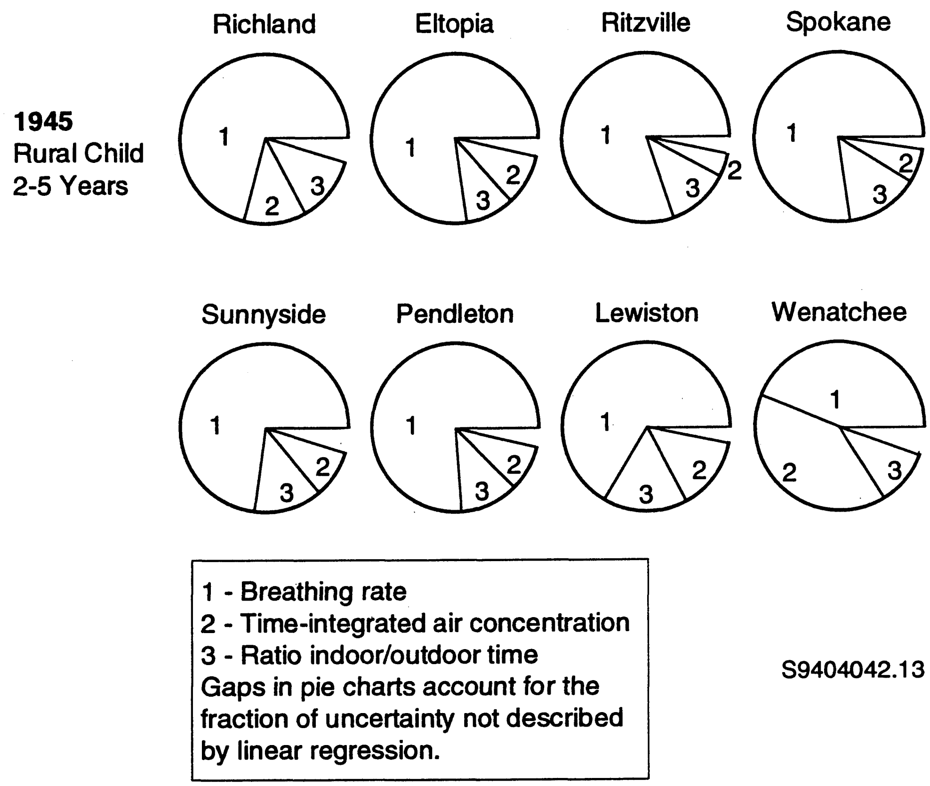


Figure D.8. Relative Importance of Parameters Contributing to the Uncertainty of Inhaled Iodine-131 Activity for a Child in 1945

transfer factor, the number of curies ingested by the laying hen, the holdup from laying to consumption, and the quantity of eggs eaten by the representative individual. The results of the stepwise multiple regression of the ranks of these input parameters are presented in Figure D.9 for 1945. There was no noticeable difference in the results for 1946. Roughly equal portions of the uncertainty in this value are contributed by the feed-to-egg transfer factor, the holdup time from laying to consumption, and the curies ingested by the chicken, with a small percentage contributed by the uncertainty in the representative individual's intake rate. All of these except the curies ingested by the chicken are input parameters. Following down to the third tier for the quantity ingested by the chicken would be analogous to the evaluation performed above for cows, but it would be simpler because the feeding regimes assumed for chickens are much simpler than those for cows.

A fourth branch down the sensitivity hierarchy was followed for the uncertainty in the dose resulting from consumption of locally produced fruit, in part because this was a branch that led directly to the models for iodine-131 concentrations in plant products. The atmospheric pathway models for uptake and retention of iodine-131 in vegetation are complex and have many variables, and the dose is further complicated by harvest and storage times, food preparation techniques, and other factors. An example of the results is presented in Figure D.10. Six parameters describe about 90 percent of the overall uncertainty in the amount ingested via the fruit pathway. Contributing about

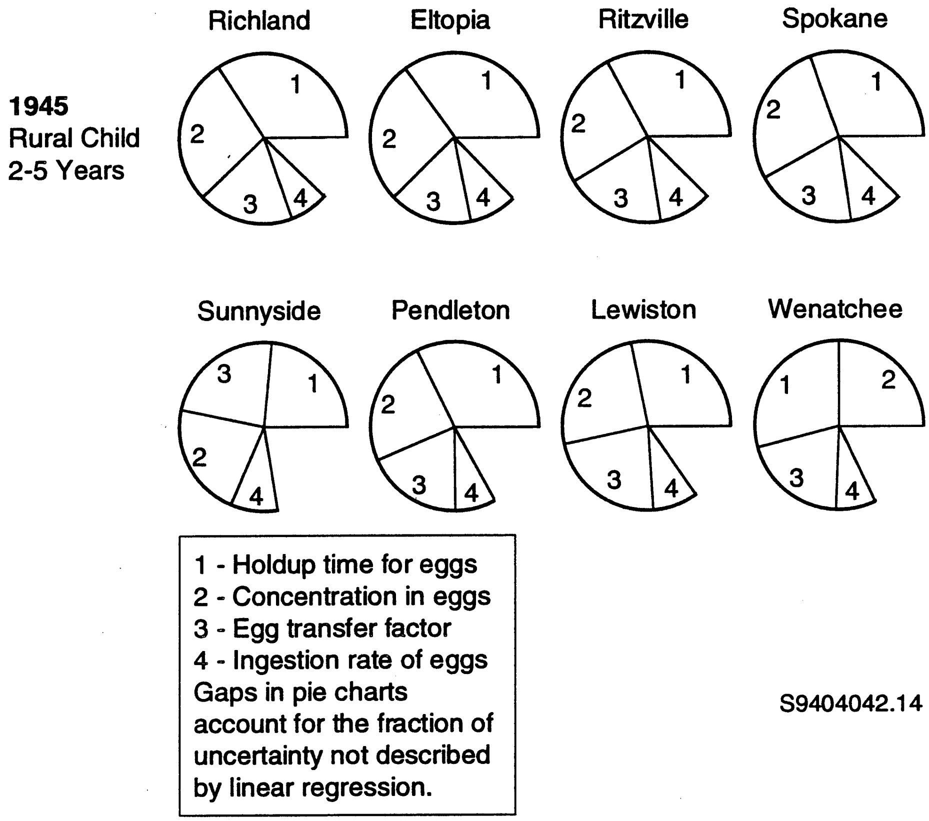


Figure D.9. Relative Importance of Parameters Contributing to the Uncertainty of Ingested Iodine-131 Activity for a Child Consuming Fresh Eggs in 1945

25 to 30 percent of the overall uncertainty is the uncertainty in concentration of iodine-131 on the fruit at harvest. Another 20 to 25 percent is described by the uncertainty in the losses during food preparation (peeling, cooking, processing, etc.). About 10 percent each is accounted for in the variability in holdup time from picking to consumption and the wet-to-dry conversion factor (a parameter used within the code to compensate for changes in plants caused by heat, drought, etc.). The consumption of fruit is modeled as having two components: consumption of fresh fruit during the growing season and consumption of stored fruit after the last harvest. The uncertainty contributed by these two inputs depends on location. For areas with large deposition during the fresh fruit season, the uncertainty introduced by consumption of fresh fruit is more important. For areas that experienced large deposition just prior to the last harvest, the uncertainty introduced by the consumption of stored fruit is more important.

The next tier of the hierarchical sensitivity analysis is the investigation of the parameters important to iodine-131 concentration in vegetation. Sample results for fruit are shown in the upper portion of Figure D.11. Variability in three parameters dominates the uncertainty in iodine-131 concentration in fruit. These are the biomass, the total iodine-131 deposition, and the constant

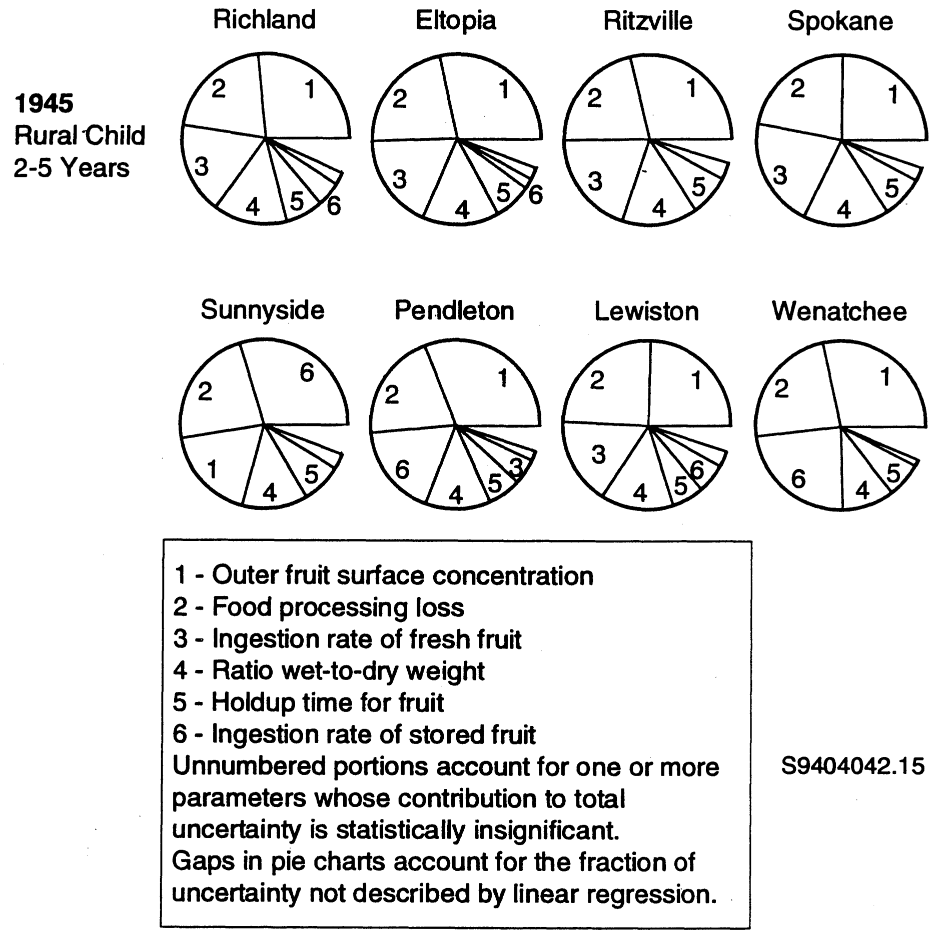


Figure D.10. Relative Importance of Parameters Contributing to the Uncertainty of Ingested Iodine-131 Activity for a Child Consuming Fresh Fruit in 1945

describing foliar interception of fallout. These three parameters describe about 90 percent of the uncertainty in fruit and pasture grass and, by analogy, other vegetation types. Results for pasture grass are shown in the lower half of Figure D.11. These are noticeably different from the results for fruit. For pasture, the dominant uncertainty results from the air-to-vegetation interception parameter. The uncertainty in the interception parameter for pasture contributes 50 to 70 percent of the uncertainty in the pasture concentration at most locations. Because different values of the input parameters with different distributions were used for each type of vegetation, this type of difference between vegetation types is to be expected.

To further follow the sensitivity hierarchy, it would be necessary to fully evaluate the atmospheric transport and deposition models of the HEDRIC suite.

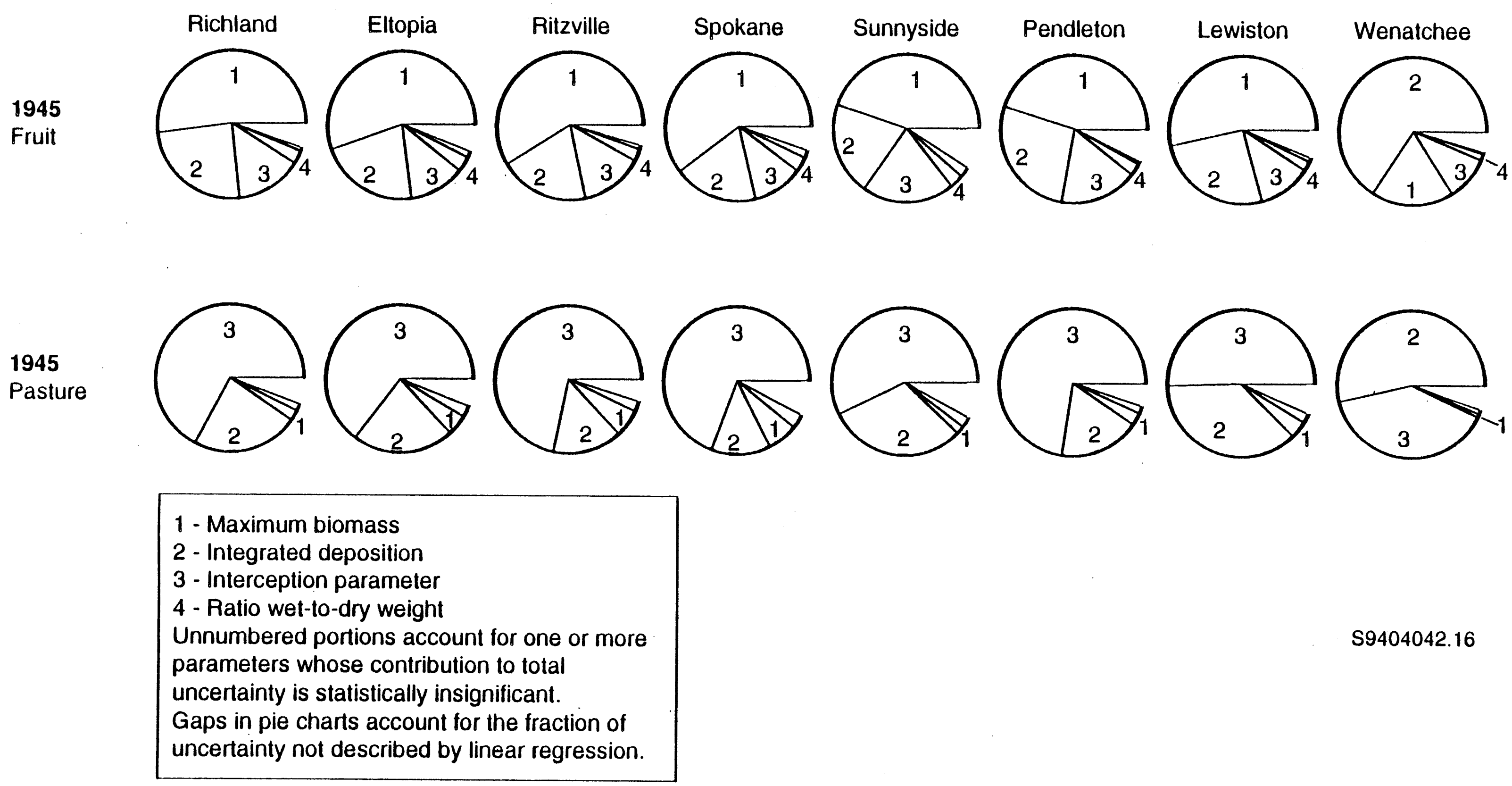
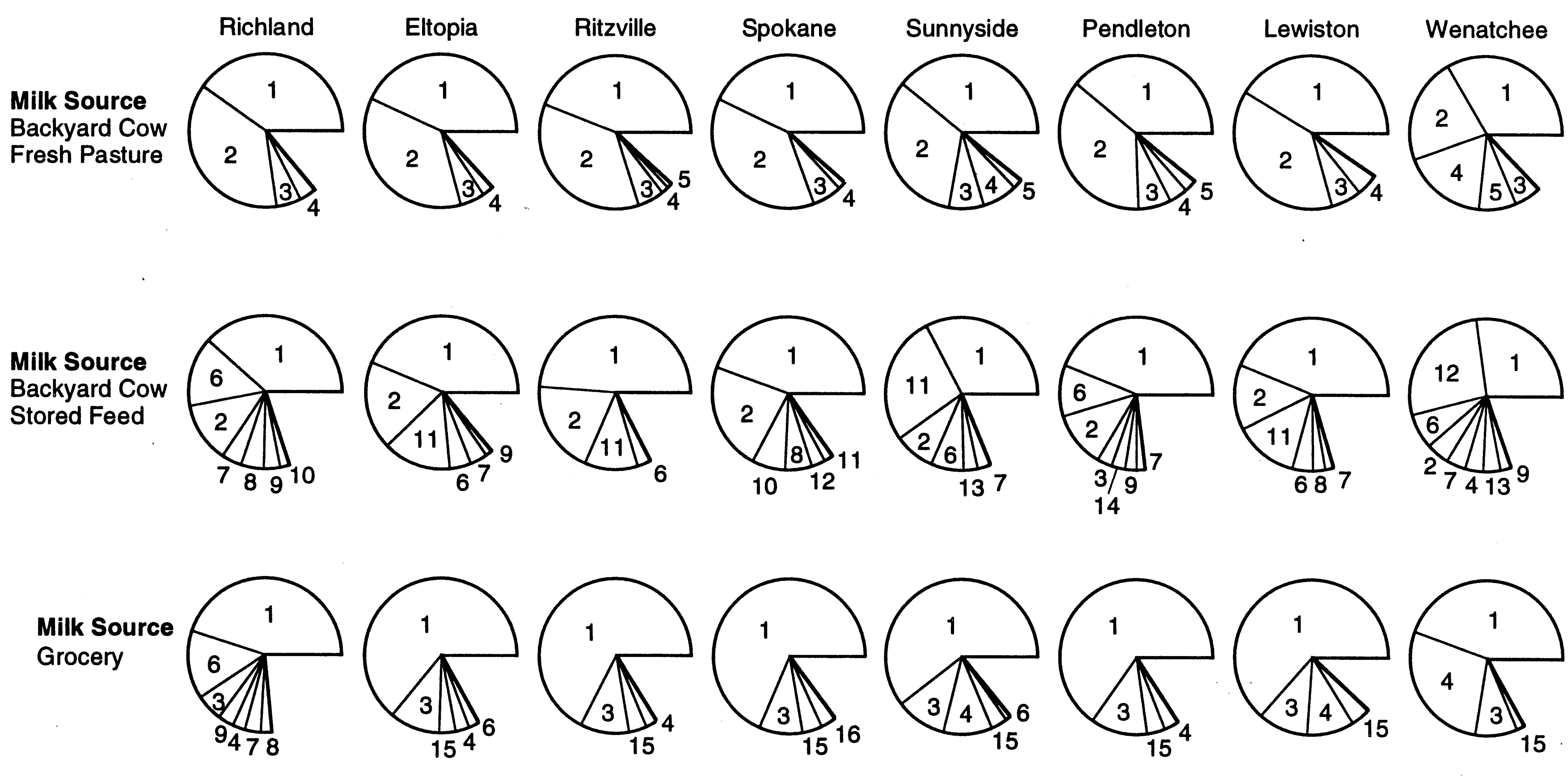


Figure D.11. Relative Importance of Parameters Contributing to the Uncertainty of Iodine-131 Activity in Fruit and Pasture in 1945

At every level of the sensitivity hierarchy, it is possible to define the parameters that are important to the various intermediate results within the dose calculation. To summarize the total sensitivity analysis, the various levels of the analysis are combined and presented in Figure D.12 for children and Figure D.13 for adults. These figures are reproduced as Figures 5.5 and 5.6 in the main text of this report. This summary is prepared by performing a regression on all the parameters identified as important in the hierarchical analysis. For all cases, the single parameter contributing the most to the uncertainty (30 to 70 percent) is the representative individual ingestion dose conversion factor. For representative individuals consuming milk from individual family cows fed fresh pasture, the second most important parameter (contributing 35 to 40 percent of the overall uncertainty) is the individual cow feed-to-milk transfer coefficient. Representative individuals feeding their family cows stored feed had a slightly different breakdown, reflecting the decreased importance of milk to dose and the relative increase in proportion of inhalation. For representative individuals consuming milk from the commercial distribution system, the emphasis changes somewhat. The parameters relating total deposition of iodine-131 and the interception of deposition by plants both tend to rise in importance. However, this trend is not followed at the Richland location, where the dose from commercial milk is much lower because of its upwind source. In Richland, the second most influential parameter is the representative individual inhalation dose conversion factor or the breathing rate, reflecting the relative importance of the inhalation pathway in that location. For most combinations of individual category, location, and year, as many as 10 to 12 parameters must be considered to describe 90 percent of the uncertainty in the representative individual dose calculations.

The hierarchical approach to sensitivity analysis allows the understanding of the relative importance of the various parameters to the uncertainty in the dose estimates. A relative handful of parameters determines the general distribution of the dose results. Interestingly, the most important of these parameters concerns characteristics of the representative individual (the ingestion and inhalation dose conversion factors) rather than the source term, environmental transport, or environmental accumulation portions of the atmospheric pathway model.



1 - Ingestion dose factor
2 - Milk transfer factor/individual cow
3 - Interception parameter
4 - Integrated deposition
5 - Date cows taken off pasture
6 - Inhalation dose factor
7 - Breathing rate
8 - Ingestion rate of fresh fruit
9 - Holdup time for fresh milk
10 - Concentration in 2nd-cutting alfalfa
11 - Concentration in 1st-cutting alfalfa
12 - Concentration in 3rd-cutting alfalfa
13 - Ingestion rate of stored fruit
14 - Food processing loss
15 - Milk transfer factor/herd cows
16 - Maximum biomass

Gaps in pie charts account for the fraction of uncertainty not described by linear regression.

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Figure D.12. Relative Importance of Parameters Contributing to the Uncertainty of Total Iodine-131 Dose for a Child in 1945

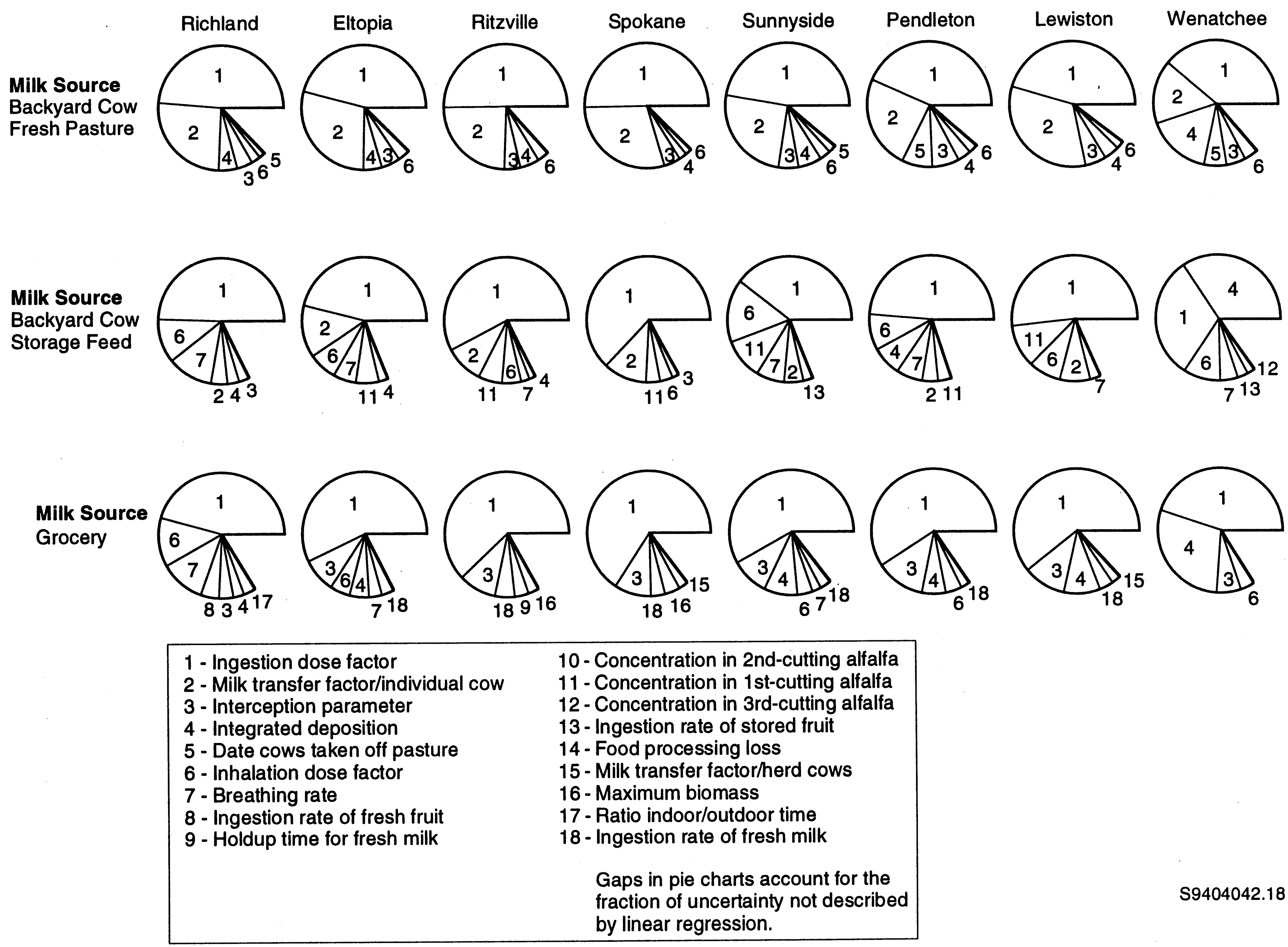

Figure D.13. Relative Importance of Parameters Contributing to the Uncertainty of Total Iodine-131 Dose for an Adult in 1945

Appendix E

User's Guide

Appendix E

User's Guide

The estimated thyroid doses presented in this report were developed to determine the potential doses hypothetical individuals could have received. The doses for such representative individuals were based on theoretical lifestyle information. The computer model used to estimate the doses will next be used for the Hanford Thyroid Disease Study to estimate potential doses to specific individuals. Those doses will be based on lifestyle information specific to each individual. A reader could, however, use the estimates in this report to give an indication of potential doses received.

The thyroid doses are presented for 12 different age and sex categories. To estimate the thyroid dose from iodine-131 in any year between 1944 and 1951 four aspects must be known:

1. the year of interest
2. the type of feed provided for the backyard cow
3. the age and sex of the individual
4. the location of interest

E.1 How to Find Annual Thyroid Doses Estimated for Individuals Who Drank Milk from Backyard Cows

Estimated thyroid doses are shown in a series of maps with accompanying legends. Figures 4.1 through 4.7 depict estimated doses for individuals who drank milk from cows fed fresh pasture. Figures 4.8 through 4.14 depict estimated doses for individuals who drank milk from cows fed stored feed. In addition, these estimated doses assume the individuals consumed all other foods from a backyard garden or small farm.

Year	Milk Cow Fed Fresh Pasture	Milk Cow Fed Stored Feed
1945	Figure 4.1	Figure 4.8
1946	Figure 4.2	Figure 4.9
1947	Figure 4.3	Figure 4.10
1948	Figure 4.4	Figure 4.11
1949	Figure 4.5	Figure 4.12
1950	Figure 4.6	Figure 4.13
1951	Figure 4.7	Figure 4.14

Sample Dose Estimate for a Representative Individual (Estimated Annual Thyroid Dose from Iodine-131)

Question:

What was the annual thyroid dose estimated for a 7-year-old girl living in Lewiston, Idaho, in 1945, who consumed foods from a backyard garden and milk from a backyard cow fed fresh pasture?

Answer:

Using Figure 4.1 and the adjoining legend, the thyroid dose is estimated to have been between 0.8 and 2.6 rad. Lewiston is located near the lower end of this dose range. The estimated dose at Lewiston for a 7-year-old girl in 1945 is approximately 1.1 rad.

E.2 How to Find Annual Thyroid Doses Estimated for Individuals Exposed from Pathways Other than Milk from Backyard Cows

Thyroid doses for other specific exposure pathways have been estimated. The thyroid doses estimated from the consumption of commercial milk, commercially distributed leafy vegetables, or from inhalation are presented in four separate figures.

Exposure Pathway	Year	Figure
Commercial milk only	1945	Figure 4.15
Commercial milk only	1951	Figure 4.16
Commercial leafy vegetables only	1945	Figure 4.17
Inhalation only	1945	Figure 4.18

E.3 Estimated Cumulative Thyroid Doses to Representative Individuals

Cumulative thyroid doses have been estimated for specific types of individuals and exposure conditions. These doses are expected to bound the doses for the majority of individuals who may have been exposed in the study area. Estimated doses are presented over a 7-year time span for a child born on December 26, 1944. For this estimate, the child was assumed to consume foods from a backyard garden or small farm and milk from a backyard cow fed fresh pasture. Doses to all other representative individuals as distinguished by age, sex, and source of milk are estimated to be lower. Estimated cumulative doses to an adult male (18 years old on December 26, 1944) are also presented for the same exposure conditions as the child. The estimated cumulative dose (1944-1951) to a child who consumed only commercial foods is presented as well.

E.4 How to Find the Estimated Cumulative Thyroid Dose

Type of Individual	Exposure Conditions	Figure
Child	Backyard foods (cows on fresh pasture)	4.19
Adult	Backyard foods (cows on fresh pasture)	4.20
Child	Commercial foods	4.21

Sample Dose Estimate for a Representative Individual (Estimated Annual Thyroid Dose from Iodine-131)

Questions:

What was the estimated cumulative thyroid dose to a child at the maximum impact location for the years 1944-1951?

What was the estimated cumulative dose to a child at Spokane, Washington for the years 1944-1951?

Answers:

Using Figure 4.19, the highest estimated cumulative thyroid dose was in the range of 100 to 230 rad. The highest dose estimated is just east of the Hanford Site and is 230 rad.

The estimated dose to a child at Spokane is at the lower end of the 10 to 32 rad range. The estimated dose is then very near to 10 rad.

E.5 Estimated Doses from Other Key Radionuclides

Estimated doses from other radionuclides are presented for nine locations within the HEDR study area. Doses have been estimated for strontium-90, ruthenium-103, ruthenium-106, iodine-131, cerium-144, and plutonium-239 for all years from 1944 through 1972. Appendix C shows the doses estimated for each location and year. Estimated cumulative doses by radionuclide and location are included. Both the total dose from all radionuclides and individual radionuclide doses are presented. All estimated doses are provided as effective dose equivalent (EDE) to an adult. The doses were estimated using the assumption that all foods were from a backyard garden or small farm.

Sample Dose Estimate for a Representative Individual (Estimated Cumulative Dose from Key Radionuclides)

Question:

What was the total cumulative dose estimated from all radionuclides to an adult living in Eltopia, Washington for the years 1945 through 1972?

Answer:

The estimated dose can be found in Table C.1 (doses for key radionuclides). First, look at the location column labeled Eltopia and then the row labeled "cumulative" dose. The dose is estimated to be 4.1E-01 or 0.41 rem EDE.

Appendix F

Summary of Technical Steering Panel Comments and Battelle, Pacific Northwest Laboratories Responses

Appendix F

Summary of Technical Steering Panel Comments and Battelle, Pacific Northwest Laboratories Responses

Document Title: Atmospheric Pathway Dosimetry Report, 1944-1992

Document Number: PNWD-2228 HEDR   Summary Comments by: D.S. Barth

The comments received from various members of the TSP are all included as an attachment to this summary. Many of the comments are essentially editorial in nature, in that they recommend changes which will improve the clarity of the report. These should be carefully considered and responded to by making appropriate changes or by rebutting the comments. Response: Specific responses addressed in following table.

There are several substantive comments which are believed to be of greater importance. Of these, the ones believed to be of highest priority are summarized below.

It is very important that all statements made in the Summary be precisely in agreement with the contents of the full report and that the Summary statement be clearly understandable by themselves without reference to the full report. Response: Text has been modified for consistency and clarity.

Some estimates should be made of the possible contribution to doses of exposure pathways not included in this report. The most important one here is probably the goat milk pathway. The same comment applies to possible doses to embryos or nursing infants. The relative importance of other radionuclides, including H-3, C-14, and Ar-41, needs to be estimated. Response: See Comment Nos. 4, 8, and 60.

It is important to make clear how the doses reported from Phase I in 1990 compare with the present estimates. Additional explanations and justifications should be added. Response: See Comment Nos. 5, 67, and 77.

Some additional discussion of why the major sources of uncertainty in dose estimations are ingestion dose factors and milk transfer factors would be helpful. Is it possible that gathering additional information or performing a modest experimental program could reduce the present uncertainties? Response: See Comment No. 64.

Questions concerning the sources of commercial milk in north Franklin County need to be resolved. Response: See Comment No. 55.

Summary of Technical Steering Panel Comments and Battelle, Pacific Northwest Laboratories Responses

Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
TSP Comments:				
1	W. Bishop NJ Germond	Full Report	Reviewed -- no specific comments.	NA.
2	J. Till	Full Report	The User's Guide prepared as a separate document should be included in the report.	Agree. The User's Guide has been included as Appendix E.
3	B. Shleien	Full Report	I have previously had an opportunity to review this document during a visit to the Hanford site and relayed my comments verbally to the Battelle staff. There are some additional areas of concern requiring recognition or at least brief discussion.	NA.
4	D. Price	Full Report	This report suffers from numerous omissions. The most serious is the failure to adequately explain what a representative dose means and does not mean.	The term "representative dose" was used once in the report on p. 4.2. It has been deleted.
			The most serious is the failure to mention doses from goat's milk.	Doses from goat's milk have been added. However, there is no basis for assuming how much goat's milk a person might have consumed. Should a real person indicate how much goat's milk s/he drank, a more realistic estimate of the resulting dose could be calculated.
			The report gives the impression that maximum possible doses have been estimated whereas they have not. Factors such as milk consumption and consumption of goat's milk may result in doses to actual individuals being higher than the ones presented in the report.	NA - You are correct. However, the report provides clear indication of the range of doses that were estimated for representative individuals. There is currently no basis for higher or lower doses.

NA = No action.

Summary of Technical Steering Panel Comments and Battelle, Pacific Northwest Laboratories Responses

Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
5	J. Till	General Comment	It is important to make clear how the doses reported in 1990 compare with this dosimetry. More needs to be added, perhaps a table, comparing specifically the doses reported in 1990 and here. For example, the public was most interested in how the 2,900 rad dose reported in 1990 compares with the new dosimetry. We should go back and extract as many specific examples as possible and include them.	A table has been added (see Table A.2). This report has provided estimates of many doses that were not made in 1990 and, therefore, cannot be compared.
6	D. Barth	General Comment	It would be desirable to include in the report the dose estimates with uncertainties at the node nearest the Canadian border and at the most NE node which is near the Montana border. This information should also be included in the Summary.	These doses were included in the body of the report but not in the summary.
7	G. Roessler	General Comment	It took me a long time to go through this document. However, it reminded me of the huge amount of work and the up-to-date science that went into the Project.	NA - Thank you.
8	B. Shleien	General Comment	(1) Reference needs to be made to potential doses to the embryo and/or fetus and to nursing infants. I believe that these groups were considered during the course of investigations for the "scoping" studies. Some mention should be made of the fact that these groups of specific representative individuals were not overlooked. Give an idea of the magnitude of their doses.	NA - The codes will estimate embryo and/or fetus doses, as well as doses for pregnant women and nursing infants based on real information. Such doses have been estimated for individuals in the Hanford Thyroid Disease Study. They were not estimated for the HEDR Project because the doses are dependent on such specific exposure conditions.

NA = No action.

Summary of Technical Steering Panel Comments and Battelle, Pacific Northwest Laboratories Responses

Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
			(2) Other pathways that required elucidation are cisterns, skin absorption, and adsorption through the broken skin. I believe that investigation of these pathways has been suggested for the follow-up period. The goat milk pathway was included in the present exercise, but I did not find a reference to the magnitude of the dose from an individual ingesting goat's milk.	NA - A scoping study of doses from use of water collected in cisterns was initiated. However, it was determined that parametric data related to size, design, and use of cisterns in the mid-Columbia basin necessary to estimate doses were not available. Scoping studies for doses resulting from skin contamination or from adsorption through broken skin were not performed. For goat's milk, see response to Comment No. 4.
			(3) What does "subjective" mean in the 50-percent subjective confidence level?	Agree that the term "subjective" can be confusing. Text modified.
			(4) It is true that the range of the 5th to 95th percentile is a factor of 25. A better feel for the range is presented to the reader, in my opinion, if it is expressed as a factor of 5 above and below the "best estimate."	Text modified.
9	G. Caldwell	Pg vii, Para 1, Lines 5-7	Some radioactivity could have come from exposure to water and drinking water, albeit very limited.	Text modified.
10	G. Roessler	Pg vii, Para 2, Line 1	Sentence not parallel. Suggest: "To estimate doses, it is necessary to estimate the quantity of radioactivity released to the atmosphere, to calculate the atmospheric transport, and to develop models to simulate . . ."	Agree. Sentence rewritten.
11	G. Roessler	Pg vii, Para 4, Line 2	Shouldn't it be <u>central and</u> eastern Washington?	NA - Regionally, eastern Washington is considered to be the area east of the Cascades.

NA = No action.

Summary of Technical Steering Panel Comments and Battelle, Pacific Northwest Laboratories Responses

Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
12	G. Roessler	Pg vii, Para 4, Line 3	Twelve should be 12	NA - To avoid numerical confusion with the immediately preceding number, 131, and because "twelve" is one word, it was determined to be more reader friendly to write the number out.
13	G. Roessler	Pg viii	I suggest that you put ranges in addition to medians in the Results section.	Ranges have been added where stochastic estimates have been prepared.
14	G. Roessler	Pg vii, Para 2, Line 4	Just what is the highest impact location? You say 11 miles west of Eltopia. Is this Ringold? Where is Ringold? (Actually I did find it on a map.) Ringold should be on the map, page 1.2, since it is referred to so much. Persons not from your area might not know where it is.	Ringold is the highest impact location 11 miles west of Eltopia. Ringold has been identified as such in the text. Key locations described in the text have been added to the maps for clarity: Ringold, Sunnyside, and Wenatchee.
15	G. Caldwell	Pg viii, Para 3	Is the maximum representative child also at Eltopia? If not, please indicate location.	Maximum exposure occurred at the same location for adults and children. Text clarified.
16	G. Roessler	Pg viii, Para 6, Line 5	Insert: the milk transfer factor (the amount of . . . milk).	Added.
17	G. Roessler	Pg x, xi	The Y axes should be in rem only, not rem/year. The X axes are in years.	NA - The graphs present average dose rates in a given year.
18	G. Caldwell	Pg ix, Conclusion 4	Indicate size of highest dose.	NA - The highest doses are provided in the Results Section. The Conclusions Section provides qualitative statements not results.
19	G. Caldwell	Pg ix, Conclusion 5	Vague, why not specify what the impact was?	NA - The Conclusions Section provides qualitative statements. For specific information, see Section 4.2.1.2.

NA = No action.

Summary of Technical Steering Panel Comments and Battelle, Pacific Northwest Laboratories Responses

Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
20	G. Roessler	Pg xiv	Suggest the effective equivalent to be: value used to account for the fact that a rem of radiation to one part of the body does not have the same potential health impact as a rem of dose to another part. It is the sum of the dose to all parts of the body from internal deposition of radionuclides and the dose from external radiation exposure. Measurement is denoted as EDE.	Definition clarified.
			Gross beta: I do not understand what the last part **did not include beta-emitting radionuclides** means.	Agree. Corrected.
			Neutron flux: rate of neutron bombardment per unit cross-sectional area.	Definition clarified.
21	G. Roessler	Pg xv	For rad and rem, I would take out the words radiation absorbed dose and roentgen equivalent man.	NA - Such explanations are appropriate for the public.
22	G. Roessler	Pg 1.1, Para 1, Line 4	central and eastern Washington	NA - See response to Comment No. 11.
23	G. Roessler	Pg 1.1, Para 5, Line 7	Should the word By be Until?	Sentence deleted.
24	G. Caldwell	Pg 1.1, Para 5, Lines 8-9	"By 1983 ...". This sentence is unclear and redundant.	Sentence deleted.
25	G. Caldwell	Pg 1.3, Para 1, Lines 3-4	Should drinking water be included for completeness?	NA - See response to Comment No. 9.
26	G. Caldwell	Pg 1.3, Para 1, Line 5	Shouldn't "food" be more specifically "milk" consumed?	NA - All foods are being referred to on line 5. The effects of milk are discussed further on in the paragraph.
27	G. Caldwell	Pg 1.3, Para 1, Line 7, 10	Omit "readily."	Text modified.
28	G. Caldwell	Pg 1.3, Para 1, Line 11	Omit "largely."	Text modified.

NA = No action.

Summary of Technical Steering Panel Comments and Battelle, Pacific Northwest Laboratories Responses

Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
29	G. Caldwell	Pg 1.3, Para 2, Line 2	"were" should be "was."	Text modified.
30	G. Roessler	Pg 2.2, Para 2, Line 1	Delete has been made.	Text modified.
31	G. Roessler	Pg 3.1, Para 4, Line 3	Change would be to was.	Text modified.
32	G. Roessler	Pg 3.2	Y axis should be Ci not Ci/mo.	NA - "Month" needed to indicate that values are a monthly total rather than an average.
33	G. Roessler	Pg 3.5, under RATCHET	2091 locations versus 1102 on page vii and 4.1.	Text modified.
34	D. Price	Pg 3.6, Para 4	Food "preferences" is a misleading term. It should be food "consumption."	Text modified.
35	M. Robkin	Pg 4.1	The reference to ICRP 26 leads one to infer that ICRP 30 parameters were used. If weighting factors from ICRP 60 were actually used, then it should be so stated. If they were not used, then justification for not doing so is required. Since there is nearly a factor of 2 in the tissue weighting factor for thyroid between these, as well as other changes in this factor for other tissues, more clarification is needed.	Text modified. ICRP 56 methodology used.
36	G. Roessler	Pg 4.1, Para 2, Line 5	Delete the first "other."	Deleted.
37	G. Caldwell	Pg 4.1, Para 4, Line 1	Insert "other" between "models" and "than."	Inserted.
38	G. Caldwell	Pg 4.1, Para 4, Line 2	Omit "other."	Deleted.
39	M.L. Blazek	Pg 4.4, Fig 4.1	The *locations should be named on all maps. These maps are difficult for people to use even when they are familiar with the area. Clearly we should attempt to aid those who are not from the Northwest who will use this data.	Key locations added.

NA = No action.

Summary of Technical Steering Panel Comments and Battelle, Pacific Northwest Laboratories Responses

Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
40	G. Roessler	Pg 4.40	It would be easier to handle the map if this page were put before page 4.4.	Information on how to use the maps placed before the maps appear in the report.
			Table 4.2: needs a sum. Here you have 557,000 Ci for 1945; A.2 has 555,000; B.4 has 560,000 and B.9 has 555,000.	Sum provided for Table 4.2. All numbers are correct. Totals appear different because of rounding. Releases for 1944-1945 in Table 4.2 now rounded as well.
41	M. Robkin	Pg 4.41, Table 4.3	The column headings are labeled Regime 1: Regime X. The numbers as given seem to be the ratio of Regime x:Regime 1; i.e., Regime 1 seems to be the denominator of the ratio not the numerator as the ratio is written in the column heading.	Column headings changed.
42	G. Caldwell	Pg 4.2, Para 2, Lines 8-10	Was deposition of iodine on stored hay fed by spreading it on the ground taken into account?	NA - Yes.
43	D. Price	Pg 4.2	The table should be converted to pounds for ease of understanding. Fresh milk should be converted to pints. The fruit consumption for the child less than one year of age appears too high. This should be checked.	Units are consistent with code files and data values. Conversion given in footnote. Consumption rates updated in Table 4.1.
44	D. Price	Pg 4.3, Para 1	Fresh pasture should be defined. The definition should include the type of pasture (irrigated, non-irrigated), the length of the pasture season for each geographic area, and the percent of dry matter intake from pasture while on pasture. The same should be done for the commercial feeding regimes. They should also include the percents for the type of pasture for each geographic area.	NA - The definition of the various feeding regimes is included in Section 4.2.1.1. Additional details are available in referenced documents. Adding details of all calculations would make reading difficult and add considerable bulk to the document.
45	G. Caldwell	Pg 4.3, Para 4.2	This paragraph should indicate that these are medians.	Text modified.

NA = No action.

Summary of Technical Steering Panel Comments and Battelle, Pacific Northwest Laboratories Responses

Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
46	G. Caldwell	Pg 4.3, Para 4.1.1.1	Can we justify that food was not distributed from a high to a low deposition area? How? Using what data?	NA - It was in some cases and is described in Section 4.2.1.2. This phenomenon is also evident in some dose maps. For instance, compare Figure 4.1 with Figure 4.15.
47	D. Price	Pg 4.3	There is no mention of the season in which fruits and vegetables come from the backyard garden. In addition, there is no discussion of the upward seasonal adjustment in consumption for these products when they are in season.	Text modified.
48	D. Barth	Pg 4.32, Figure 4.15	For comparison purposes, it would be desirable to introduce two more figures giving appropriate information on commercial milk for the years 1946 and 1947.	NA - Because the milk distribution did not change significantly in 1946 or 1947 (Deonigi et al. 1994), maps were not created.
49	G. Roessler	Pg 4.44	For the male, 0-1 years old, fruit comes up high for all but especially those on Regimes other than 1. Did those babies actually eat fresh fruit in 1945?	NA - Yes.
50	G. Caldwell	Pg 4.4, Fig 4.1	It would be better if the towns could be identified on all maps.	Key locations added.
51	G. Caldwell	Pg 4.5, Legend	Need to clarify that the ranges are of medians, not uncertainty on all figure legends.	Clarified.
52	G. Caldwell	Pg 4.40, Para 2, Lines 8-9	Do we need to indicate why there are peaks in Dec-49, Aug-Dec-50, Mar-Dec-51, after long periods without releases? Same comment for page 3.2, figure 3.1.	NA - Because the focus of this report is on doses, the details concerning radionuclide releases are not provided. See Heeb (1994) for such explanations.
53	G. Caldwell	Pg 4.40, Para 3	Same comment as above on page 4.2	NA - See response to Comment No. 42.

NA = No action.

Summary of Technical Steering Panel Comments and Battelle, Pacific Northwest Laboratories Responses

Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
54	G. Caldwell	Pg 4.2-4.41, Para 4.2.1.1	No information is included about goat's milk, how was this handled? Will it be accepted and handled when individual data becomes available for personal dose calculation?	See response to Comment No. 4.
55	D. Price	Pg 4.42, Para 4	The statement "The commercial milk in north Franklin County in 1951 was from a single location, Connell," does not agree with the report cited. The Connell dairy went out of business in 1947 (Deonigi, Page B.3). The source of milk for north Franklin County cannot be verified from the Deonigi report since that report is in error for the year 1951. This was pointed out in the review of that report. This suggests that there may be a problem in quality assurance of the data used to estimate these doses.	All data were reverified and in some cases corrected. Text modified.
56	D. Price	Pg 4.44, Table 4.4	Milk regime 1 and Milk regime 4 should be defined at the bottom of the table.	Definition added.
57	G. Roessler	Pg 4.49, Para 3, Line 8	Change <u>effective dose equivalent values</u> to EDEs.	Text modified.
58	G. Roessler	Pg 4.5	Just curious to know what they did in 1967 to reduce the Pu levels released so much.	NA - Operations were curtailed due to a strike.
59	D. Barth	Pg 4.51, Para 2, Line 2	Fruit was greater than eggs for children and almost equal for adults.	NA - True for iodine-131. However, this sentence refers to all key radionuclides. See Figure C.4.
60	J. Till	Pg 4.53	Our handling of H-3, C-14, and Ar-41 is very weak. Since we are not addressing these radionuclides in the main dose code, and yet they are on our list of key radionuclides, there should be a more thorough analysis of these materials. This can easily be done with other dose codes available off the shelf.	Doses presented in the text were estimated using the GENII code. Text is clarified.

NA = No action.

Summary of Technical Steering Panel Comments and Battelle, Pacific Northwest Laboratories Responses

Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
61	G. Roessler	Pg 5.3, Para 5, Line 1	Suggest you put GSD in the glossary along with the equation for calculating it.	Definition added.
62	G. Roessler	Pg 5.11, Fig. 5.5	This figure title and others in Appendix D should be: Relative Importance of Parameters Contributing to the Uncertainty for Total Iodine-131 Dose - Child in 1945.	Titles modified.
63	J. Till	Pg 5.9, Fig 5.4	Maps need better labeling. For example, the key towns cited in the text need to be identified.	Key locations added.
64	D. Price	Pg 5.10	The major sources of uncertainty are the ingestion dose factors and the milk transfer factor for the individual cow. Since these are major components in understanding dose uncertainty, this report should include a discussion of why these transfer factors exhibit this amount of uncertainty. Appropriate references should be included.	Information added.
65	J. Till	Pg 6.1, Last Bullet	The factor of 50 uncertainty is confusing and should be clarified. This is the total range and can lead the reader to believe this is variation from the median. This information is also stated in the conclusions on page ix.	It is the range throughout the domain. Text modified.
66	G. Roessler	Pg A.2	Under Atmospheric Transport: specification should be speciation.	Corrected.
67	G. Roessler	Pg A.3, Para 3, Line 1	As the figures show, the doses in this report nearest the Hanford Site are generally lower than those presented in the feasibility study; however the doses farther out are higher.	Text modified.
68	G. Roessler	Pg B.2, Para 5, Line 6	You can't create a new element by adding a neutron! First you create ^{239}U and it decays by ß- to ^{239}Np.	Text modified.

NA = No action.

Summary of Technical Steering Panel Comments and Battelle, Pacific Northwest Laboratories Responses

Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
69	G. Caldwell	Pg B.4	Shouldn't the columns be right justified and with whole numbers for clarity?	NA - Because of the wide range in the numbers, right justification is not practical.
70	G. Caldwell	Pg B.4, Para 3, Line 4-7	If there is no loss of biomass or radionuclides, will this over-estimate the resulting dose? Is decay included? What effect does this assumption have on uncertainty?	NA - Assuming p. B.11 is meant, the fact that biomass loss during grazing or harvesting is not included in the model is likely to result in minutely higher dose estimates. Decay is included. Because the loss of biomass is such a minor contributor, its exclusion will have little impact on uncertainty.
71	G. Caldwell	Pg C.1,C.2, C.3	It would be helpful if the absolute amounts of these radionuclides were indicated along with the percentages.	Totals are included.
72	G. Roessler	Pg C.2	Put an e in Ruthium-106.	Corrected.
73	G. Roessler	Pg C.5	In the subhead, take out SR-90.	Deleted.
74	M. Robkin	Pg C.5	There are no units given for the Table. Are these rem, person-rem, Sv, person-Sv or what? Are these for the representative average adult, the representative maximum adult, or?	Table labels clarified.
75	G. Caldwell	Pg C.5, Line 3	Omit "SR-90."	Deleted.
76	G. Roessler	Pg D.8	Are the units in D.3 Ci d? It seems like it should be just Ci.	Curies is correct. Text modified.

NA = No action.

Summary of Technical Steering Panel Comments and Battelle, Pacific Northwest Laboratories Responses

Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
77	D. Barth	Summary, PVIII, Results	It should be made clear that the maximum doses being cited for adults and children are maximum median doses and do not include uncertainties.	Clarified.
			The average uncertainty range is cited as a factor of 25. For what type of exposure to what type of individual does this factor apply?	NA - Summary does not provide detail. See Section 5.1 for details.
			What is the principal reason for differences between Phase I and this report doses? For example, it is not clear why the differences between the two studies are substantially different for stored feed and commercial milk from those for fresh pasture.	Information added.
			The second most important parameter contributing to uncertainty in estimated dose is not individual cow feed-to-milk transfer coefficients at all locations for all feeding regimes.	Statement modified.
			Why do the EDEs shown in Figure S.1 not exhibit a reasonably constant ratio to the thyroid doses shown in Figure S.2 for the year 1945-1947?	The doses were not estimated using the same methods. Therefore, the parameter values varied.

Public

None.

NA = No action.

Distribution

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