Summary:

Radiation Dose Estimates from Hanford Radioactive Material Releases to the Air and the Columbia River

April 21,1994

The Technical Steering Panel of the Hanford Environmental Dose Reconstruction Project

This material was prepared with the support of the U.S. Centers for Disease Control and Prevention (CDC). However, any opinions, findings, conclusions or recommendations expressed herein are those of the Technical Steering Panel of the Hanford Environmental Dose Reconstruction Project, and do not necessarily reflect the view of CDC.

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Preface

For more than 40 years, the U.S. Government made plutonium for nuclear weapons at the Hanford Site in southeastern Washington State. As a result of these operations, radioactive materials were released from Hanford to both the air and the Columbia River. People were exposed to these radioactive materials. Public concern that this exposure could have affected people's health prompted a study into past radioactive material releases from Hanford.

The purpose of the Hanford Environmental Dose Reconstruction Project is to determine how much radioactive material was released from Hanford, how that material may have reached and exposed people, and most importantly, what radiation dose people may have received. An independent Technical Steering Panel (TSP) directs the Project, which is being conducted by Battelle Pacific Northwest Laboratories in Richland, Washington. The Project is funded by the U.S. Centers for Disease Control and Prevention (CDC).

In July 1990, the TSP and Battelle reported *preliminary* dose *estimates* for ten counties surrounding Hanford. These estimates covered periods of the largest releases to air and the Columbia River. After analyzing the preliminary estimates and receiving extensive public comment, scientists revised and improved the dose estimating models. They also continued to search for additional data and expanded the study area. The results in this summary reflect this four year effort.

This report provides a summary of two reports completed by Battelle in the spring of 1994. These reports explain the dose estimates for representative persons from radioactive materials released to the air and to the Columbia River.

These dose estimates are subject to change. Although the TSP considers significant changes unlikely, additional Project work could result in revisions of these dose estimates.

Companion Technical Reports are Available

This Summary Report is directed to readers who want a general understanding of the representative dose estimates. Other reports are for readers who understand the radiation dose assessment process and want to see more technical detail. Some of these reports are listed in Appendix 1. Technical reports are available in the USDOE-Richland Public Reading room or from:

Technical Steering Panel
c/o Nuclear Waste Program
Department of Ecology
PO Box 47651
Olympia, WA 98504-7651

Tribal Dose Estimates Not Included Here

Northwest Native American Tribes are now in the process of collecting demographic and lifestyle data for use in Tribal dose estimates. Tribes included are Coeur d'Alene, Colville, Kalispel, Nez Perce, Spokane, Umatilla, Warm Springs and Yakima. Tribal dose estimates will be included in later reports.

Hanford Thyroid Disease Study

One important user of the new dose estimation process is the Hanford Thyroid Disease Study, which is being conducted for the CDC by researchers at the Fred Hutchinson Cancer Research Center in Seattle. The purpose of the Thyroid Study is to determine whether thyroid disease has increased among persons exposed to air releases of radioactive iodine-131 from Hanford between 1944 and 1957. Participants in the Thyroid Study and their closer relatives or friends are asked to provide information needed to estimate the radiation dose to the participants' thyroid glands. This information is then entered into the computer programs developed in the Dose Reconstruction Project to calculate those estimated doses. For more information about the Hanford Thyroid Disease Study call 1-800-638-4837.

Overview

Hanford History

The federal government chose Hanford in 1942 as one of the sites for the Manhattan Project–the country's secret program to build an atomic bomb. The Hanford area was selected because of its remote location, arid climate, abundant electricity, and access to river water to cool the nuclear reactors.

In 1943, construction began on the first of what would eventually be nine nuclear production reactors at Hanford. All were built along the banks of the Columbia River. Fuel fabrication facilities were built to prepare the uranium fuel for the reactors. The fuel was irradiated in the reactors to create plutonium. Chemical separation plants were used to separate the plutonium from uranium and from fission products created during irradiation.

The first three nuclear reactors—B, D, and F–began operating in 1944 and 1945. Chemical separation plants T and B were started up in December 1944 and April 1945, respectively. After World War II ended in 1945, the Cold War prompted a major expansion at Hanford. From 1949 through 1963, six new reactors–H, DR, C, KW, KE, and N–and several new separation plants were built. In addition to producing plutonium, N Reactor produced steam to generate electricity. This reactor also differed from earlier reactors in that it discharged much smaller amounts of radiation to the river.

During the first few years of operations, large amounts of radioactive materials–primarily iodine-131–were released to the atmosphere from the separation plants. Better filter systems, new knowledge about radiation hazards, and stricter operating procedures all but eliminated these releases by the mid-1950s.

Radioactive material releases to the Columbia River came primarily from the eight single-pass production reactors which discharged cooling water directly to the river. Through much of the 1950s and the mid-1960s, as many as eight production reactors operated at one time. These eight reactors used water from the Columbia River for cooling. During the cooling process, impurities in the water became radioactive.

Beginning in the mid-1960s, the government began to shut down the production reactors at the rate of about one per year. By 1971, all eight reactors that used this once-through cooling system were shut down. N reactor operated until 1987.

Health Concerns Prompt Dose Reconstruction Work

Public concern about past Hanford operations led the U.S. Department of Energy (USDOE) in 1986 to release thousands of pages of documents. These documents detailed some of Hanford's operating history and showed that there were past off-site releases of radioactive material.

Washington, Oregon, and regional Native American Tribes gathered an independent panel of experts–called the Hanford Health Effects Review Panel–to evaluate this information. They found that the releases to the air in the 1940s and early 1950s, and releases to the river up until 1971, exposed people in the region to radioactive materials. Many people in the region fear these releases caused a variety of health problems. In September 1986, the Health Effects Review Panel recommended dose reconstruction and thyroid health effects feasibility studies.

In response, USDOE directed Battelle Pacific Northwest Laboratory to conduct the Hanford Environmental Dose Reconstruction Project. The project was to determine how much radioactive material was released, how that material may have reached and exposed people, and most importantly, what radiation dose people may have received.

Mistrust of USDOE threatened the credibility of the Project results. After decades of

secrecy, some members of the public believed USDOE was to blame for the radioactive material releases, and would be less than forthcoming in investigating them. Some members of the public also lacked confidence in the independence of the Battelle scientists doing the work. As a result, USDOE agreed with the States and Tribes that independent project direction was necessary to provide credible scientific direction. It would also provide a forum for participation and direction by the States, Native American tribes, and the public.

Independent Project Direction

A Technical Steering Panel (TSP) of independent scientists and experts was formed in 1988 to direct the work. The TSP consists of experts in the various technical fields relevant to the Project. The TSP includes experts in environmental pathways, epidemiology, and surface and ground water transport. There is expertise in statistics, demography, agriculture, and meteorology. And, the Panel has experts in nuclear engineering, radiation dosimetry, cultural anthropology, health physics and public policy.

The technical members on the Panel were selected by Deans of Research at major universities in Washington and Oregon. Washington and Oregon State representatives were selected by the respective governments. Two members were selected by involved Indian tribes. One member represents the public and was chosen by the TSP. At the request of their Governor, Idaho gained a representative on the Panel in 1991.

The TSP first met in 1988. USDOE initially asked the TSP to give independent guidance to the project. The Panel concluded that its independence would be credible only if the TSP directed the work. USDOE agreed and committed to distance itself from the study. USDOE has lived up to that promise.

There were still some concerns about the TSP's independence, in large part because USDOE funded the study. The question of the funding source was one which concerned the TSP from the beginning. They recognized that the public perceived a major conflict of interest with USDOE controlling the funding.

Therefore, funding was transferred to the CDC in 1992 through a memorandum of understanding signed by the Secretary of Health and Human Services and the Secretary of Energy in 1990. But, the TSP develops its own budget and sets Project priorities.

Early in the process, the TSP set the tone for strong direction of quality science done in an open public forum. This tone was clearly encouraged and supported by the states, the Northwest Tribes and the public. Public trust and support is an absolute necessity to the success of the Project. If the work is not credible, public questions about exposures from Hanford will remain unanswered. The time and money spent on the study would be wasted.

TSP members verify and evaluate project data and computer models. Five subcommittees and two working groups allow scrutiny and meaningful interactions with project staff. The TSP has access to all documents that relate to the Project. Some TSP members have security clearances and review classified documents.

The TSP believes it is crucial that the public have access to all documents used in the Project. This allows for an independent check of the TSP's work. The TSP strongly advocated that USDOE declassify all Project-related documents. USDOE agreed. However, the declassification process is expensive and slow. It will take some time before all Project-related documents are publicly available.

Washington and Oregon State staff provide logistic and communications support to the TSP. These staff also provide technical support and assure TSP coordination and intra-panel communications. Technical staff provide assistance on quality assurance and special technical reviews.

Dose Reconstruction

Hanford dose reconstruction started by gathering data about the amounts and types of radioactive materials released to the environment from Hanford facilities. This is the Source Term.

The Source Term estimates are based on data found in Hanford records. Battelle and

TSP scientists reviewed thousands of documents in an effort to locate references to past Hanford releases. The records contain extensive information about radioactive releases to the air and the Columbia River from Hanford operations. Although some daily reactor operation information does exist, it does not cover the entire 1944-1971 time period.

The next step is to determine how and where the radioactive materials traveled in the atmosphere, soil, ground water and river water. Although radionuclide release monitoring data are plentiful, the number of radionuclides covered and the time periods addressed are limited. The data in the Hanford literature are generally reported on a monthly basis.

The ways in which people could have been exposed to radioactive materials–such as breathing contaminated air or eating contaminated food–were identified (see Figure 1 below). These routes of radiation exposure are called environmental pathways.

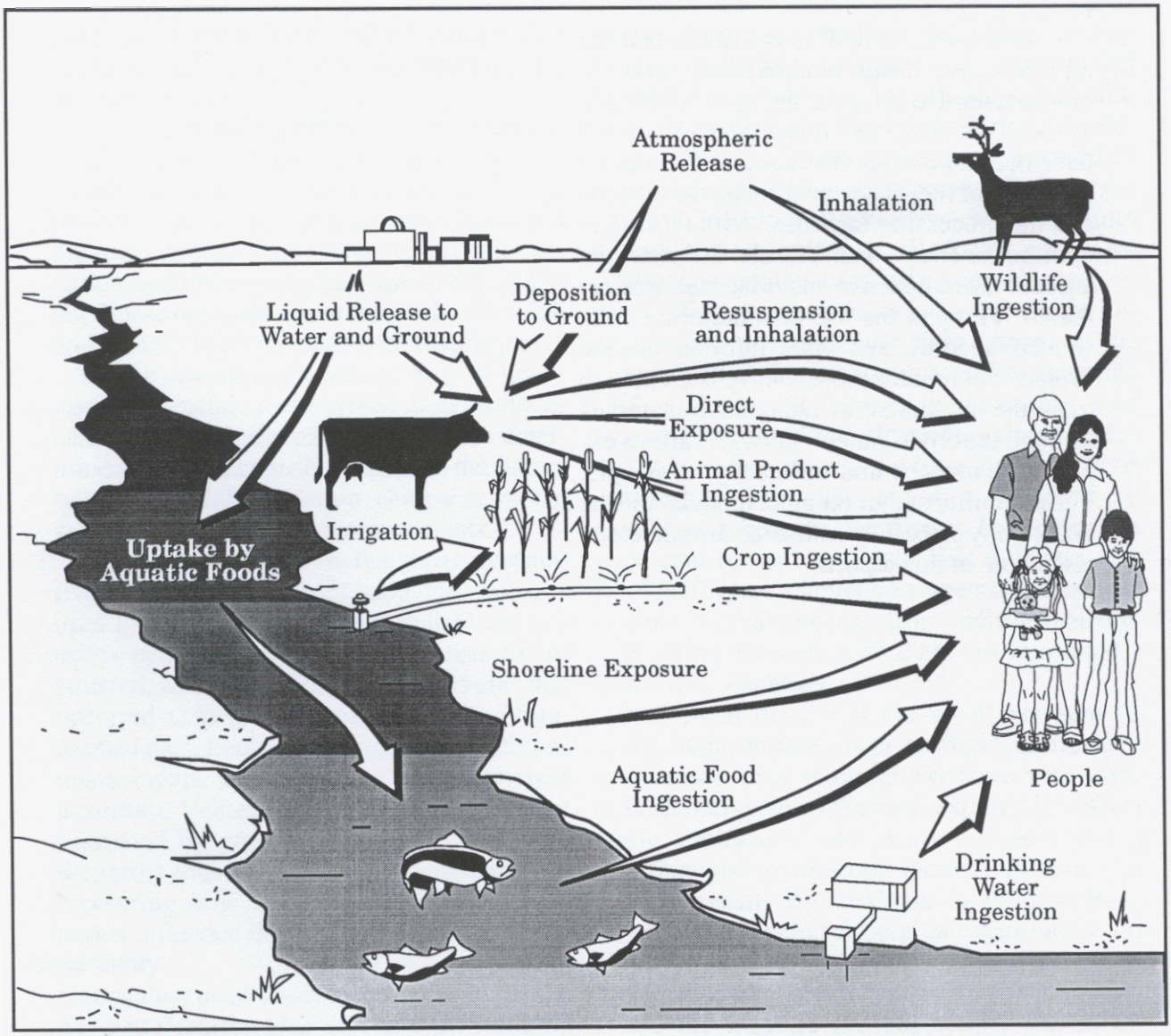


Figure 1. How People Could Have Been Exposed to Radioactive Materials from Hanford

Information is also gathered about the number of people that could have been exposed, and where they lived, their age, sex, eating habits, lifestyles, and any other factors that could influence their exposure. All this information is fed into complex computer programs that calculate the radiation dose estimates.

Much of the historical data that goes into the computer models contains gaps. Some historical records are incomplete, missing, or not sufficiently detailed. Data gaps like these mean that radiation dose estimates can never be totally certain.

However, the TSP is confident that the representative doses reported here, and the methods used to calculate them, are as reliable as today's science can make them. Scientists have been able to reconstruct data that details each load of fuel that went through the reactors and the processing facilities. With this information, scientists can closely estimate the amount of radioactive material that was released. Through the use of monitoring data, weather records, and other information, the Project's computer models have been able to track the movement of radioactive materials through the environment, through various exposure pathways, and ultimately, to people. The reliability of the computer models, and the uncertainty of the dose estimates, are addressed elsewhere in this report.

Model Reliability

The information needed to tell us exactly what dose any one person received simply does not exist. Amounts of radioactive contamination that was in the air, on the ground or on plants, or in water at any given place and time can only be estimated, not calculated. Radiation doses also depend on factors unique to each person. Many of these factors–such as location and diet at specific times–cannot be recalled exactly. As a result, there will be some uncertainty about the true dose that each person actually received.

Doses have been estimated with models in computer programs that were extensively tested for accuracy and for their ability to predict results that compare with historical monitoring data. This was done through validation and uncertainty and sensitivity analyses. These methods were reviewed by the TSP and a CDC/TSP convened peer review panel.

The uncertainty analyses help to determine the precision with which dose estimates can be made. The sensitivity analyses determine what data contribute most to the uncertainties. Model validation compares model predictions with actual measurements.

The TSP is confident that the representative doses reported here, and the methods used to calculate them, are as reliable as science can make them. Project scientists reconstructed, as well as could be done, events that occurred as long as 50 years ago, using fragmented data. Each of the Project's models has many inputs. Most of these are themselves uncertain. Values for many key factors were estimated by generating a large number of scenarios that fit the known facts, and then measuring how the differences in the scenarios influence the dose estimates.

Uncertainty

Uncertainty in the dose estimates can be caused by several factors. One is uncertainty resulting from incomplete information such as not being able to measure all the food people actually ate. Another source is the possibility of errors made in past measurements of radioactivity in emissions, the environment, or people. Natural variations also contribute to uncertainty in much of the input information in the dose model. Examples of these variations include differences among individuals in age, sex, lifestyle and geographic location; differences among dairy cows in the amounts of contaminated pasture grass they ate; and differences in milk production of individual cows during the year.

These different factors were assessed to determine their level of uncertainty. Researchers could then decide how much work should go into each part of the Project. Work that greatly reduced uncertainty received a high priority.

Sometimes, more work to reduce the uncertainty will have very little impact on the precision of the dose estimates. For example, if you look at dose based on the ingestion of resident fish and waterfowl, the salmon ingestion dose is not known with a high degree of certainty. However, the dose received by salmon ingestion contributes less than one percent to the total dose. This indicates that while Project scientists are uncertain about the dose from salmon ingestion, additional efforts to refine the salmon dose are not warranted.

Sensitivity Analyses

Individual dose is made up of the sum of the contributions from multiple radioactive materials over multiple exposure pathways. Different types of persons, exposed by different pathways, will have different doses influenced by different factors. The purpose of a sensitivity analysis is to determine which factors have the greatest influence on the uncertainty.

For all cases, the single factor contributing the most to the uncertainty (30 to 70

percent) is the difference in the way a person's body takes up radioactive material that has been ingested.

For persons consuming milk from family cows fed fresh pasture, the second most important factor (contributing 35 to 40 percent of the overall uncertainty) is the difference in the way a cow transfers the radioactivity in the feed to her milk.

In Richland, the second most influential factor is the difference in the way a person's body takes up radioactive material that has been inhaled. This reflects 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 factors must be considered.

Validation

The general approach of the model validation is to assess accuracy by comparing the computer's predictions with actual measurements obtained from the field or laboratory. Part of testing the model involved comparing its results with independent, but similar, information not calculated by the computer models. This independent information includes actual measurements of radioactive materials in the environment (vegetation, fish, and Columbia River water); measurements of radioactive materials in Hanford workers and school children; and limited, past dose estimates for the public.

It is not possible to validate doses to real persons because they were not measured and no database exists. However, radioactive material concentrations were measured at various times and in various media by environmental monitoring programs operated at Hanford and by the States of Washington and Oregon. Although insufficient for estimating doses directly, these measurements do provide the possibility of validating portions of the models for particular times and/or occurrences. Compilation of a sufficient number of these validations was done to demonstrate the general reliability of the Project's dose estimation methods.

The model validation report provides a comprehensive analysis of the ability of the Project models to accurately simulate radioactive material releases, environmental transport and human exposure. The report states that, in general, the comparisons are good and that most of the calculated results are within acceptable levels of the monitoring data. Some examples of the validation work:

Tens of thousands of whole-body radioactivity measurements were made on Hanford workers employed from 1959 through the present. Almost all of the whole-body counts taken during the period of reactor operation indicate the presence of Hanford-originated zinc-65 and sodium-24. The measured whole body counts and model predictions compare well.

An experiment was conducted by Hanford scientists between January 1962 and late 1963, in which a single investigator voluntarily ingested whitefish containing measured quantities of zinc-65 from the Columbia River at regular intervals. His body burden of zinc-65 was measured weekly. To validate the Project model, this experiment was simulated. Results of the Project models were consistent with the values contained in the 1962-63 study. The results of this comparison indicated that the computer models were working as intended.

For the reactor model, maximum discrepancies between predictions and observations are in the range of 15 percent. Comparisons made for later times are better, in part because the monitoring methods for the later periods were improved.

As a result of the model validation work, no revisions to any of the models were recommended by the TSP.

Air Exposure Pathway

Irradiating uranium fuel rods in a nuclear reactor produces plutonium and a large number of other radioactive materials. Once produced in Hanford's reactors, the plutonium was separated from other radioactive materials in chemical separations plants. Four chemical separations plants–called T, B, REDOX, and PUREX–operated at various times on the Hanford Site from 1944 through 1990. The rods containing the fuel were dissolved in acid and the plutonium was extracted. During the first few years of operations, large amounts of radioactive materials–primarily iodine-13I–were released to the air during this process. Once in the atmosphere, the radioactive materials were dispersed throughout eastern Washington and into neighboring states. The dominant direction of transport is to the northeast.

People who lived in the Columbia Basin and other areas of eastern Washington, northeastern Oregon, and western Idaho may have been exposed to the radioactive materials released from Hanford. The radiation dose to people could have occurred from a variety of pathways. Exposures to radioactive materials released to the air may have come from eating food containing radioactive materials, inhaling contaminated air or by direct exposure to radioactivity in soil or air.

The process for estimating doses from the atmospheric pathway began with estimating the amount of material produced in the reactors and transferred to the separations plants. This allowed for an estimate of the amount of radioactive materials discharged to the air from Hanford's separation plants. The concentrations in the air and deposited on the soil were then calculated. Once this was known, scientists determined the effects of environmental accumulation. Dose estimates were then made using lifestyle information for average or typical groups of people. Much of this work was done using computer models. The computer models were thoroughly tested to confirm they were reliable and valid. These tests are described elsewhere in this summary.

Scientists calculated doses to persons from radioactive releases to the atmosphere from a number of exposure pathways during the years 1944 to 1992. The dose calculations are for representative (or typical) persons in a 75,000 square mile area surrounding Hanford. This area extends from central Oregon to northern Washington, and from the crest of the Cascade Mountains to the eastern edge of northern Idaho. It is about 306 miles from north to south and 246 miles from east to west. The Project study area is shown in Figure 2 (page 10).

The principal radioactive material of interest released to the air is iodine-131. Figure 3 (page 11) shows the iodine-131 release estimates from the separations plants from 1944 through 1951. Iodine-131 releases total nearly 730,000 curies during these years. As filtering systems were added, and then improved, the releases were dramatically reduced. Production processes were also changed to reduce the releases. Rough estimates made early in the Project showed iodine-131 would account for most of the radiation dose people could have received from Hanford.

Doses from iodine-131 releases for the maximum release years (1944-1951) are calculated for 12 age, sex, and lifestyle categories at 1,102 different locations. In addition, dose calculations were made for six radionuclides–strontium-90, ruthenium-103, ruthenium-106, iodine-131, cerium-144, and plutonium-239–for eight locations for the years 1944 through 1972. These six radionuclides make up 99

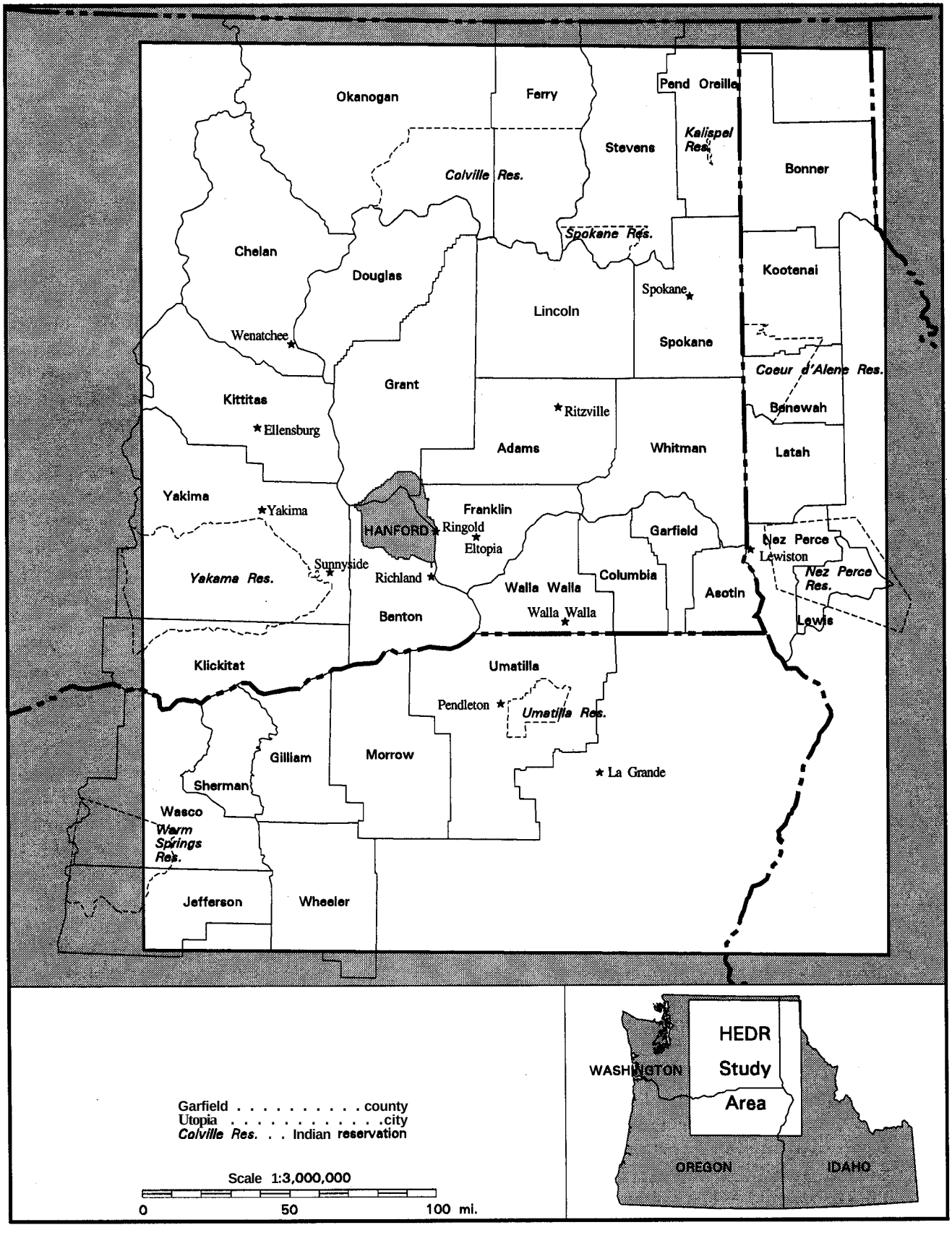


Figure 2. Project Study Area (Air Exposure Pathway)

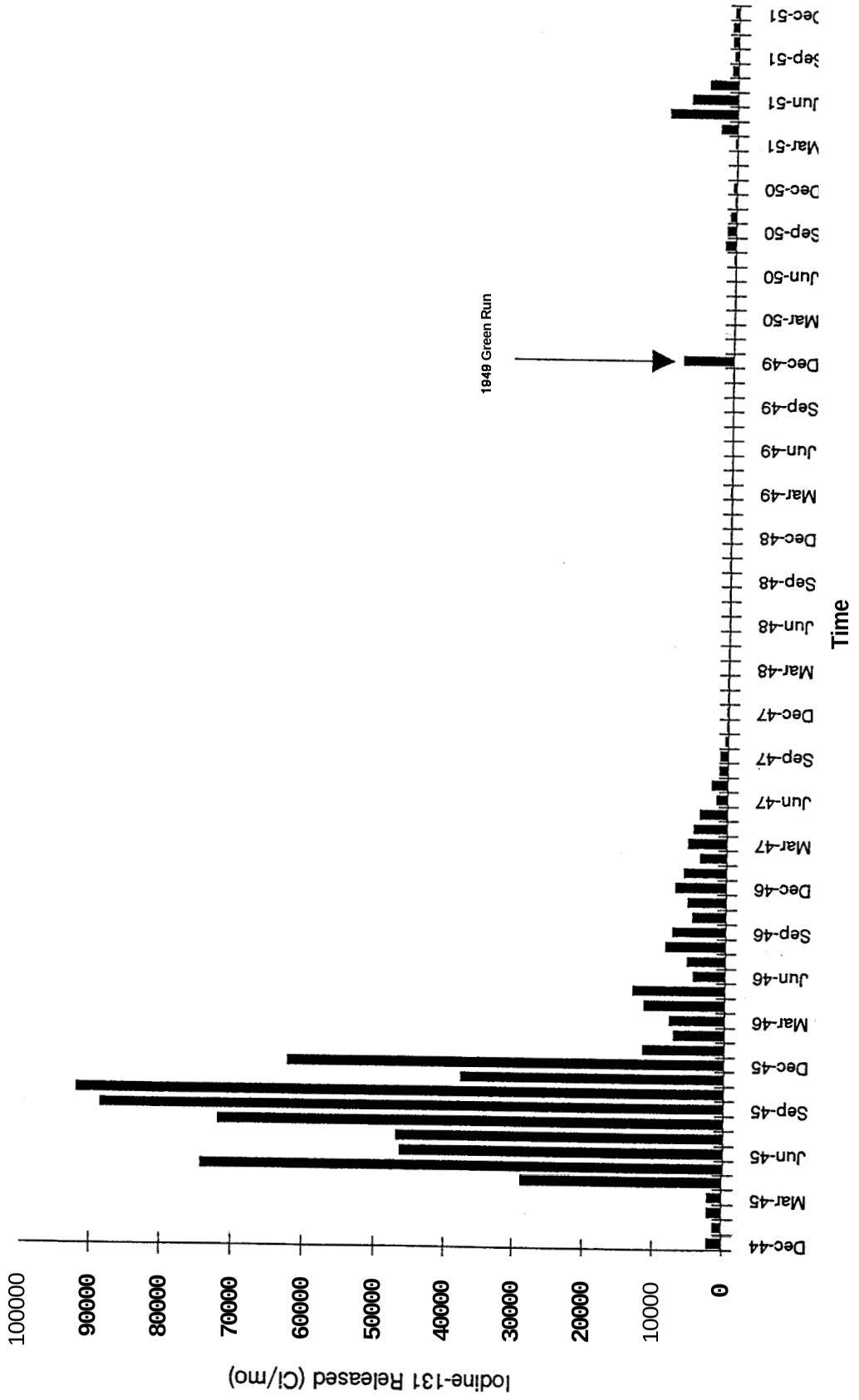


Figure 3. Monthly Iodine-131 Releases, 1944–1951

percent of the potential radiation dose from the atmospheric pathways. Previously published Hanford Annual Report doses were summarized to complete the dose history for the years 1973 through 1992. Releases of tritium, carbon-14, and argon-41 from reactor stack gas systems and from reactor effluent cooling water were found to produce very small doses.

Iodine-131 disappears within a few months of its release. That's because it decays rapidly—half decays every eight days, half of what remains in another eight days, and so on. Because iodine-131 transforms into an element that is not radioactive, within 80 days (10 half-lives) the radioactivity is basically gone.

Once the iodine-131 was released to the air, it traveled with the wind. As the iodine-131 traveled over land, some fell onto vegetation and the ground. During the growing season, iodine deposited on pasture used by dairy cows and goats would have been eaten by the cows and goats. The iodine-131 went to their milk. The radiation dose to a person is, therefore, largely dependent upon the source and the amount of milk consumed by the person.

Much of the radioactive iodine-131 consumed by people would go to the thyroid gland, an organ that needs iodine to function. After six days, about half of the iodine-131 absorbed by the thyroid gland still remains. Part of the loss results from radioactive decay, and part is from biological excretion processes.

Monitoring of Radioactive Materials from Hanford

Scientists studied environmental and emissions monitoring records to find out how much radioactive materials were released, and how and where they were deposited. Emissions monitoring began with the start-up of Hanford facilities in 1944. It consisted of measuring the amounts of radioactive materials vented to the atmosphere and released to soils and to the Columbia River. The technology to accurately measure atmospheric releases evolved for several years before measurements became reliable. Until then, releases to the air were estimated on the basis of production data and estimated filter efficiencies after filters were installed in 1948.

RECONSTRUCTING THE MILK SYSTEM

Pinpointing people's source of milk is an important part of estimating doses from Hanford radioactive material releases. Milk from a cow or goat that ate pasture grass in the downwind area would contain higher levels of iodine-131 than milk from cows pastured in less contaminated areas. Milk from cows that ate stored feed would also contain lower levels of contamination. Family cow and goat milk may yield the highest doses because it was consumed immediately by the owners or their neighbors. In contrast, milk produced commercially might be mixed at the creamery with milk from other, less contaminated areas. It also may not be consumed for several days after milking. This could result in a lower dose to the person who drinks the milk.

To answer some of these questions, it was necessary to reconstruct the milk production and distribution system near the Hanford Site in the late 1940s. Very few records remain from the dairy industry during this time. Scientists consulted dairy farmers, agricultural extension agents, dairy industry specialists from universities and employees of dairies operating during this time. They sought information on where dairies got their milk, where they sold it, and how much dairy farmers relied on pasture to feed their herds. The dairy system from the 1940s was reconstructed by putting together information from all these sources.

Environmental studies started before the Hanford facilities began operating. These consisted of meteorological measurements and observations of atmospheric plume behavior to predict the path of radioactive materials released to the air.

Environmental studies were expanded to include measurements of radioactive materials in the air, ground, vegetation, food, wildlife, Columbia River water, drinking water, sediment, fish, and other aquatic life. It was not until the mid-1950s, however, that the possibility of milk as a pathway for radioactive iodine was recognized. As a result, milk containing iodine-131 was not monitored during the period of highest releases of iodine-131 (1944 through 1947). Drinking contaminated milk resulted in radiation exposures 10 to 100 times greater than from breathing iodine-131.

Air Pathway Computer Models

Each step in the dose estimation process involves the use of conceptual and mathematical computer models. These models are needed because there is not enough data about radioactive material concentrations in air, soil, vegetation, and foodstuffs for necessary locations and time periods.

Project scientists developed several computer programs referred to collectively as HEDRIC (Hanford Environmental Dose Reconstruction Integrated Codes) to estimate radiation doses and their uncertainties. HEDRIC consists of four collections of programs with well-defined interfaces. The programs, which must be executed in sequence, implement:

- a source-term model
- an atmospheric transport model
- an environmental pathways model
- a dose model.

The first part of HEDRIC consists of three programs that calculate the source term. These are the Reactor Model (RM), Do Iodine (DOI), and the Source Term Release Model (STRM). Collectively, these programs use information about the operation of Hanford's reactors and processing plants to estimate hourly releases of radioactive materials from the processing plant stacks to the air. Appendix 2 shows the annual summary of the six radioactive materials released to the air between 1944 and 1972 that is used in the dose calculations.

Unusual release events such as the December 1949 Green Run were included in STRM. This experimental release from the T Plant occurred when a dissolver was loaded with fuel that had been discharged from the reactor after an unusually short cooling time. The Green Run was conducted to measure how airborne radioactive materials spread. Filtering systems were bypassed to be sure that the release carried enough radioactive material to be measured. The Green Run accounts for about 7,000 - 9,000 curies of 1-131 released to the air.

DEFINITIONS

Code–Instructions that tell a computer to do something. A computer program consists of code. When a reference is made to the project software consisting of 60,000 lines of code, it refers to the code contained in all of the programs in the Hanford Environmental Dose Reconstruction Integrated Codes (HEDRIC).

Program–A complete set of code. When you tell a computer to run a program it does something. HEDRIC consists of ten programs plus several data files.

Model–A mathematical formula, algorithm, or combination of them that can be used to predict the behavior of something in the real world. Reactor Model (RM) is a program (consisting of a few lines of code) that contains a model of how a reactor works. Battelle used RM to calculate the amount of iodine produced by the Hanford reactors.

The second part of HEDFUC is the atmospheric transport model. The model in RATCHET (Regional Atmospheric Transport Code for Hanford Emission Tracking) combines the radioactive material release information with observed meteorological data. It then calculates daily air concentrations and surface contamination throughout the Project study region. These estimates are made for over 2,000 locations within the Project study area on a daily basis.

The third part of HEDRIC is the environmental accumulation program, called Dynamic Estimates of Concentrations And Radionuclides in Terrestrial Environments (DESCARTES). DESCARTES is comprised of several environmental models, which together calculate concentrations of radioactive material in the environment and the food chain. Radioactive material transported through the atmosphere deposited on soil and plants, providing the possibility for human exposure and dose. DESCARTES uses the daily inputs from RATCHET to calculate estimates of the concentrations of radioactive materials in several types of vegetation, crops, and animal products. This calculation requires the input of extensive data about the agricultural production and distribution systems during 1944-1951.

Results provide the concentration in vegetables, grains, and fruits eaten 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, venison, poultry, eggs, *milk).* Finally, the radioactive material concentrations in commercially distributed milk are calculated.

The fourth and last part of HEDRIC is a program called CIDER (Calculations of Individual Doses from Environmental Radionuclides) which calculates individual doses. It uses data from the preceding programs to estimate exposure and dose for people living within the Project study area.

The environmental accumulation models establish the concentrations of radioactive materials in environmental media and food products for all locations and times of interest. In the individual dose model, people are introduced into the calculation. The dose model calculates dose by four exposure pathways:

- submersion in contaminated air;
- inhalation of contaminated air,
- irradiation from contaminated surfaces and soils; and
- ingestion of contaminated farm products and vegetation.

The individual dose model is designed to calculate doses to reference individuals and real people. Annual and cumulative doses are reported. These are calculated as a sum of daily exposures from all sources. The person's movements about the study area may be accounted for, as well as his or her probable sources and quantities of food.

Distributions

For this Project, scientists felt it was important to consider differences in radiation doses that would result from differences in age, sex, lifestyle, food habits, geographical location, agricultural production, month, season, year, and other factors. To accomplish this objective, input data to the Project model consists of distributions instead of single-number estimates.

For example, instead of using one number to represent the amount of milk all people in the study area drank per day, the Project uses a distribution of amounts of milk that people–by age and sex–could have drunk. This approach accounts for variability and recognizes that actual milk consumption can range from none to more than a quart a day, and that a person often can't remember exactly how much milk he or she drank 45 years ago. The use of distributions enables the dose. estimates to reflect differences in milk consumption.

Deposition Patterns

The total 1945 deposition of iodine-131 across the study area is shown in Figure 4 (page 15). This figure provides an example of the iodine-131 "footprint" or location of deposition. The figure is not intended to give- an accurate representation of the iodine-131 concentration in the soil at any given time. It cannot be used to estimate doses. The figure shows the cumu-

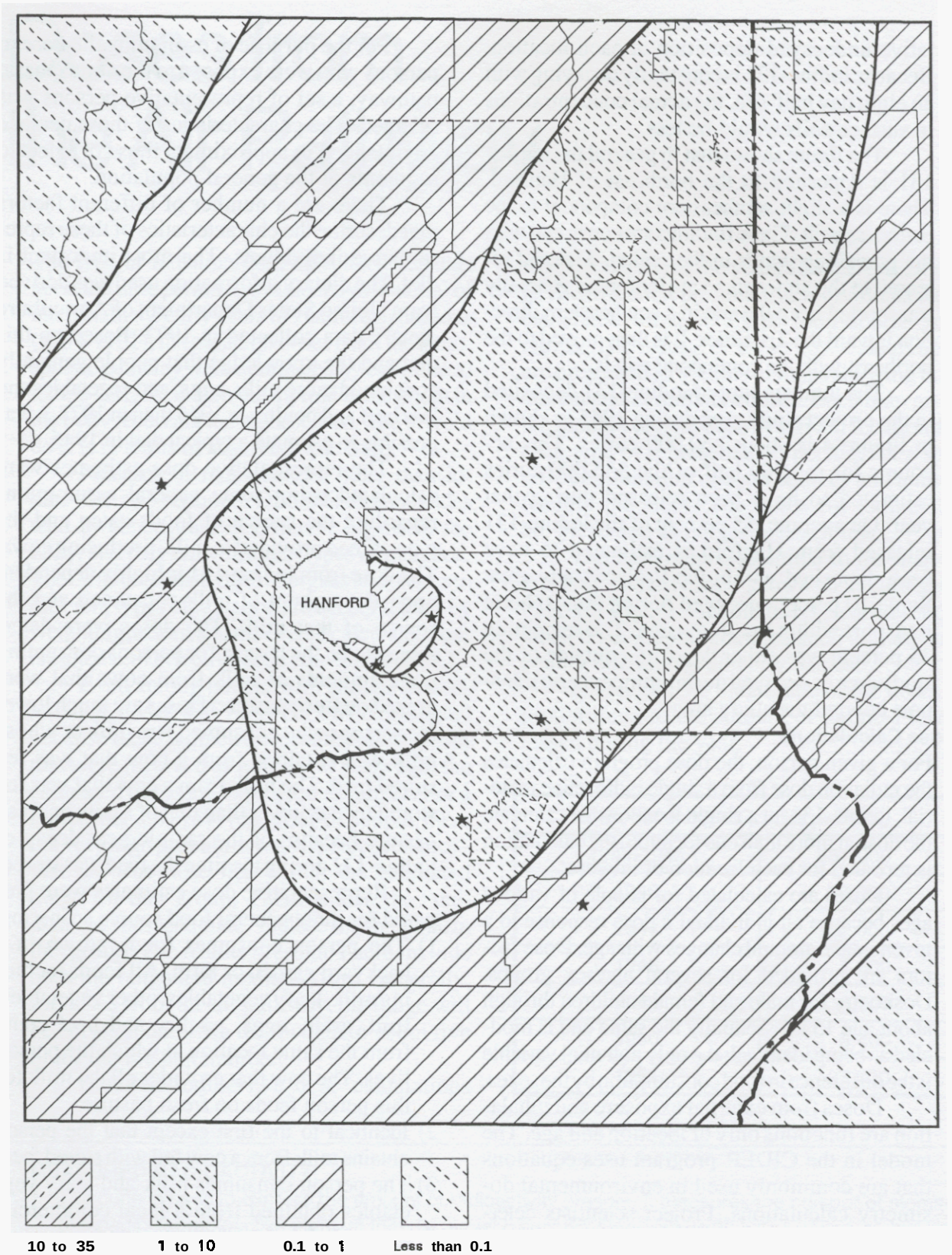


Figure 4. Cumulative Iodine-131 Deposition for 1945 (microcuries per square meter undecayed)

lative undecayed deposition at each location. Because iodine-131 is constantly decaying with an eight day half-life, the actual concentrations in surface soils would be less.

The figure shows that in general the iodine-131 is deposited to the northeast of Hanford. There is a slight southeastern component to the pattern as well. These findings are consistent with the prevailing winds in the region. Material released to the atmosphere at Hanford is generally transported from the site in a southeastern direction toward the Tri-Cities. It is then moved to the northeast with the continental winds.

The total amount of iodine-131 deposited in the project study area during 1945 as shown in Figure 4 is about 260,000 curies. This accounts for roughly half of the 555,000 curies estimated to have been released during that year. On average, 55 percent of the iodine-131 released from Hanford is estimated to have been deposited within the Project study area. Some 10 percent decayed during atmospheric transport within the study area. The remaining 35 percent was either deposited outside of the study area or decayed during atmospheric transport beyond the study area.

Dose Calculations

For a given person, the dose program calculates the radiation dose from a single radioactive material, iodine-131, at a single location. To calculate the dose at more than one location, the calculation is repeated for each location of interest.

Doses are calculated for people of various ages because an individual's dose response to a given intake amount changes with age. 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.

Doses from external exposure and inhalation are functions only of location and age. The model in the CIDER program uses equations that are commonly used in environmental dosimetry calculations. Project scientists determined that air submersion is a minor pathway.

For the purpose of estimating the dose to persons who were exposed to the atmospheric pathway, a set of representative persons was selected. The characteristics of these persons are intended to approximate those of selected segments of the general population.

There are a number of different factors that describe the characteristics of these representative individuals. The most important is diet. The dietary information used was derived from United States Department of Agriculture dietary data collected in 1977. Based on this diet and the knowledge that people generally consumed more milk, eggs, and vegetables and less beef and poultry in 1945 than in 1977, it was possible to estimate a typical diet in 1945.

The representative dose estimates were calculated using some general assumptions regarding the source of foods eaten and the type of feed provided to milk-producing cows. The dose from iodine-131 is highly dependent upon the amount of milk consumed and the source of that milk. The doses were determined to be the largest for persons consuming large amounts of milk from cows that were grazed on fresh pasture. Doses are much lower for persons who consumed less milk or whose milk was obtained from a cow that was fed stored feed. The milk from a cow that was fed stored feed is lower than that of a cow on fresh pasture because of the radiological decay of iodine-131 during the time the feed was stored.

Representative dose estimates were prepared for three general food source scenarios:

1) The person consumes foods grown in a backyard garden or farm. All foods including milk, leafy vegetables, other vegetables, fruit, grain, eggs, poultry and beef come from the same location at which the person lives. The cow that provides all the milk for this person feeds on fresh pasture.
2) Identical to the first except that the person obtains milk from a cow fed with stored feed.
3) The person consumes milk and leafy vegetables obtained from a local commercial source such as a grocery store or other market.

Doses from the Air Pathway

The type of radiation dose calculated depends upon the time period and radioactive material of interest. In the early years of Hanford operations (1944-1951), the radiation doses from the atmospheric pathway were dominated by exposure to iodine-131, for which the thyroid is the organ in the body receiving the highest dose. The thyroid dose is in terms of absorbed dose *(cad).*

Releases of radionuclides other than iodine-131 also occurred. Different radionuclides tend to concentrate in different organs in the body, and they emit different types of radiation. The different sensitivities of organs and tissues to different types of radiation are accounted for by weighting factors, and the overall calculated dose is called rem effective dose equivalent (EDE).

Even among people with similar characteristics, doses will vary. For this reason, and because there is much uncertainty about doses that were received as long as 50 years ago, the estimated doses are expressed as ranges. For a typical person in a given group of people, there is a very high probability--a 90 percent chance--that the true dose lies within the estimated range for that group. There is also the "median" or "best estimate" of dose for someone in this group. The results presented here include both the range and median doses. Generally, for doses from the air pathway, the range will be between one-fifth the median to about five times the median number.

Detailed iodine-131 dose calculations were prepared for the years 1944-1951. Doses to 12 different representative individuals were calculated for a series of food source scenarios. The results of these dose calculations are presented as a series of maps showing both annual and cumulative doses. Each map gives the median annual dose at a given location for each type of representative person, for a specific combination of food sources and animal feeding practices. The doses for iodine-131 are presented as ranges for each map.

The base map is identical to the map of the Project study area shown in Figure 2 on Page 10. Figure 2 should be referenced for the labeled geographic features such as state and county boundaries and city names.

In general, the magnitude of the doses is proportional to the amount of iodine-131 released during the year.

Iodine-131 Releases (curies per year)	
1944-1945	557,000
1946	96.000
1947	32,000
1948	1,800
1949	8,700
1950	5.400
1951	27,000

MEASURED RADIOACTIVITY

The curie is used to express the amount of radioactivity present. It measures the number of atoms of a particular radioactive element that decay each second. One curie is 37 billion atoms undergoing radioactive decay each second.

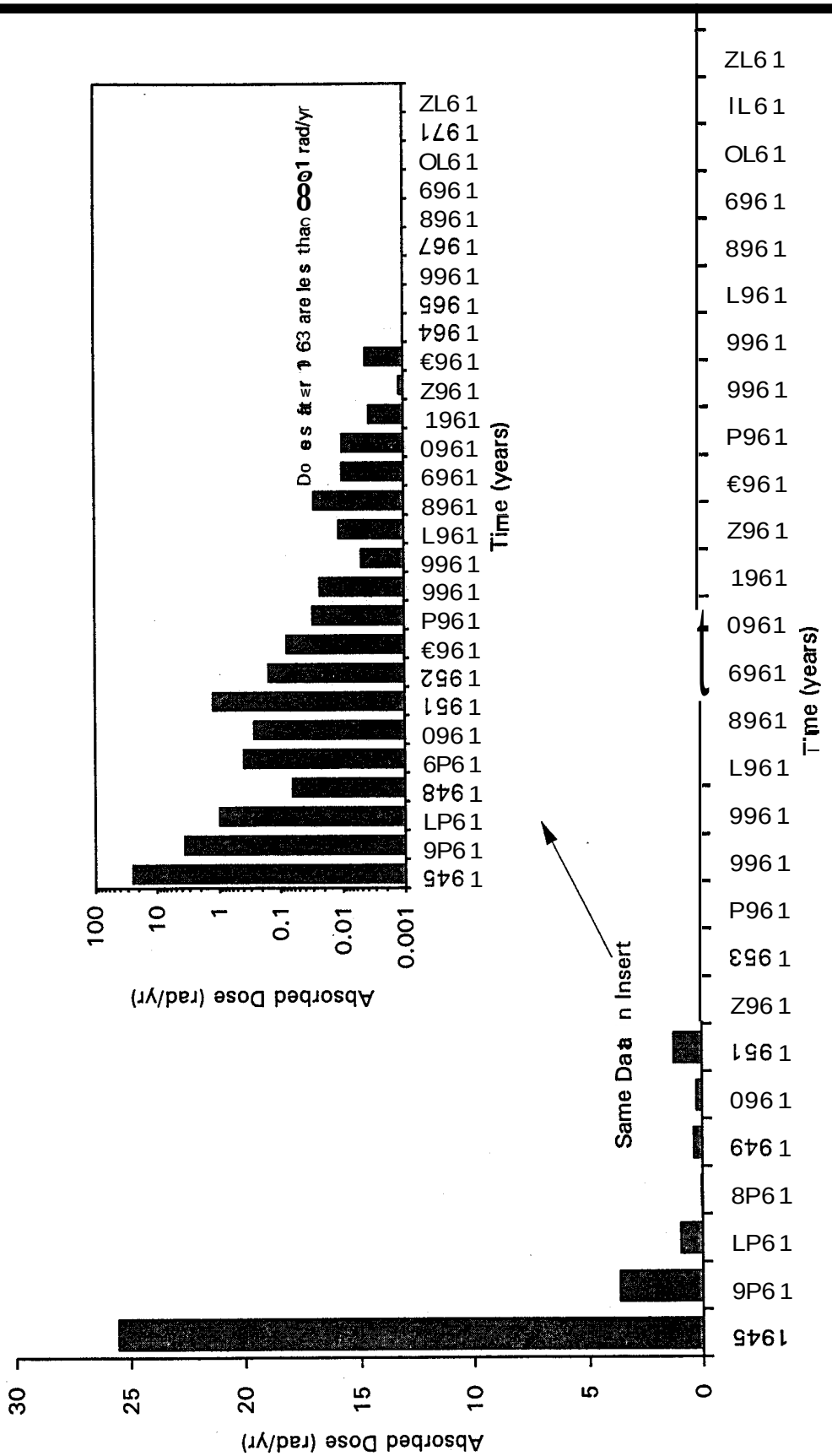


Figure 5. Estimated Thyroid Dose to a Maximally Exposed Adult at the Highest Impact Off-site Location from Iodine-131, 1945–1972

The doses shown in Figure 5 (page 18) reflect this trend, with a dramatic decrease in doses from 1945 to 1948, then an increase from 1948 to 1951. The doses after 1951 drop sharply.

Figures 6 (pages 20/21) and 7 (pages 22/23) show the doses to the thyroids of representative persons who consumed food grown in a backyard garden in 1945 and 1949. Milk, eggs, poultry and beef were also from a backyard source. The dose from inhalation and external exposure were also included. The most important assumption for these two figures is that the milk was produced by a backyard cow that was fed fresh pasture supplemented by alfalfa and grain.

Each figure gives the dose for twelve different age and sex classifications over the entire Project study area. To read the figure, pinpoint the location of interest, note the shading, and then consult the legend on the adjoining page. All doses are in terms of annual dose to the thyroid in units of rad per year.

The median thyroid dose to an infant for the year 1945 is estimated to be as high as 192 rad (range of dose: 45 rad to 824 rad) at the maximum impact location in western Franklin County. By contrast, the dose to an identical infant in the northwest corner of the study area is estimated to be .05 rad (range of dose: .009 rad to .23 rad). The doses in 1945 were larger than in any other year.

Figures 8 (pages 24/25) and 9 (pages 26/27) show the same information as Figures 6 and 7 with the exception of the source of feed for the milk cows. The milk cows represented in these maps 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 decayed to a lower concentration level. In general, the doses from milk from cows fed stored feed were five times less than those from milk produced by a cow that was fed fresh pasture. Milk from cows fed some combination of fresh pasture and stored feed resulted in doses between the two presented here.

Doses in Figures 6 through 9 were estimated 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 Project study area. Information on the commercial distribution of milk and leafy vegetables has been collected by the

DOSE

When radiation enters a person's body, that person receives a radiation dose. Several different terms describe these radiation doses. The rad expresses the amount of energy deposited by radiation in the body. The rad is the most basic unit of radiation dose, but its use is limited because different types of radiation have different effects on the cells in the body. The rem is a unit of radiation dose that takes these differences into account. It puts different types of radiation on an equivalent basis in terms of their potential impact on human cells. A third measure of dose, rem effective dose equivalent or rem EDE, is used to account for the fact that a rem of radiation dose to one part of the body does not have the same potential health impact as a rem of dose to another part. The rem EDE puts radiation doses to different organs on an equivalent basis in terms of the potential health risk.

To help people interpret these preliminary radiation doses, it may help to compare them with other radiation doses people typically receive in daily life. This is called background radiation. Each year the average American receives a dose of about 0.3 rem EDE (300 millirem) from background radiation. This radiation is from naturally occurring sources, such as the sun, air, soil and radon gas. Manmade sources such as medical x rays add about 60 millirem per year to the average person's dose. Radiation doses received from releases at Hanford were in addition to normal background doses.

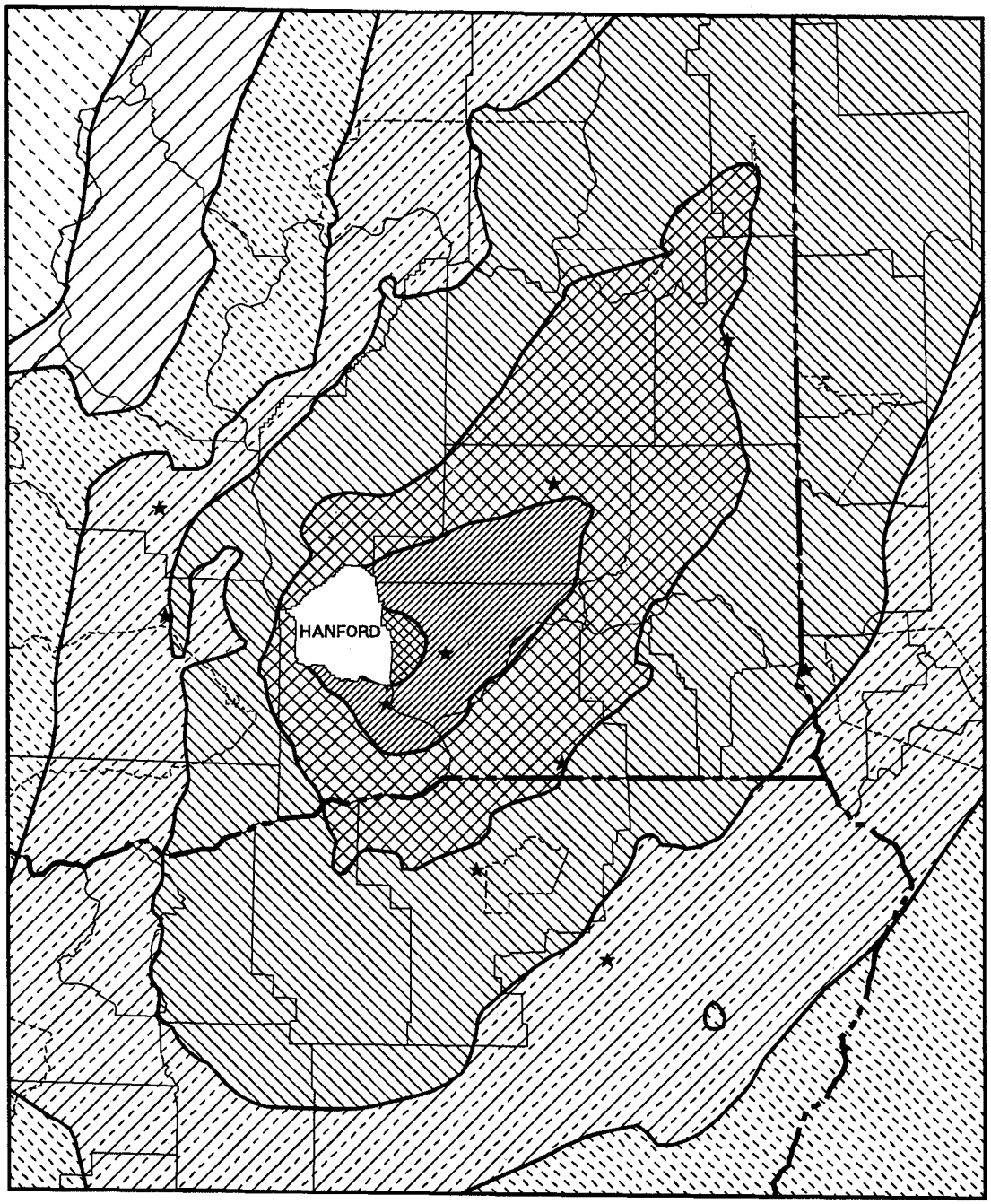
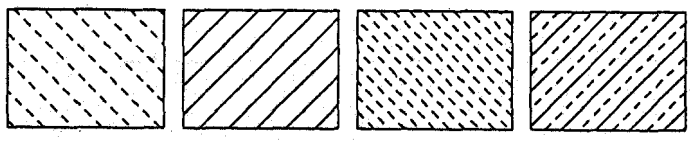
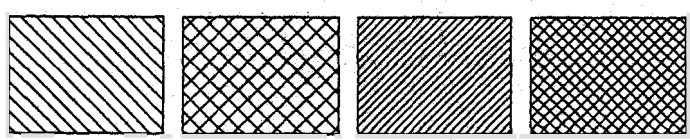


Figure 6. 1945 Iodine-131 Thyroid Dose from All Exposure Pathways (Milk Cows on Fresh Pasture)



Sex/Age Category				
All 0-1 years	0.027 - 0.09	0.09 - 0.27	0.27 - 0.85	0.85 - 2.7
All 1-5 **years**	0.015 - 0.05	0.05 - 0.15	0.15 - 0.49	0.49 - 1.5
Male 5-10 **years**	0.010 - 0.03	0.03 - 0.1	0.1 - 0.32	0.32 - 1
Female 5-10 **years**	0.008 - 0.03	0.03 - 0.08	0.08 - 0.27	0.27 - 0.84
Male 10-15 **years**	0.007 - 0.02	0.02 - 0.07	0.07 - 0.22	0.22 - 0.68
Female 10-15 **years**	0.006 - 0.02	0.02 - 0.06	0.06 - 0.18	0.18 - 0.57
Male 15-20 **years**	0.004 - 0.01	0.01 - 0.04	0.04 - 0.13	0.13 - 0.41
Female 15-20 **years**	0.003 - 0.01	0.01 - 0.03	0.03 - 0.11	0.11 - 0.33
Male 20-35 **years**	0.003 - 0.01	0.01 - 0.03	0.03 - 0.09	0.09 - 0.29
Female 20-35 **years**	0.002 - 0.01	0.01 - 0.02	0.02 - 0.08	0.08 - 0.24
Male >35 years	0.003 - 0.01	0.01 - 0.03	0.03 - 0.08	0.08 - 0.25
Female >35 **years**	0.002 - 0.01	0.01 - 0.02	0.02 - 0.08	0.08 - 0.24



Sex/Age Category				
All 0-1 **years**	2.7 - 8.5	8.5 - 27	27 - a5	85 - 190
All 1-5 **years**	1.5 - 4.9	4.9 - 15	15 - 49	49 - 110
Male 5-10 **years**	1 - 3.2	3.2 - 10	10 - 32	32 - 73
Female 5-10 **years**	0.84 - 2.7	2.7 - 8.4	8.4 - 27	27 - 61
Male 10-15 years	0.68 - 2.2	2.2 - 6.8	6.8 - 22	22 - 49
Female 10-15 **years**	0.57 - 1.8	1.8 - 5.7	5.7 - 18	18 - 42
Male 15-20 **years**	0.41 - 1.3	1.3 - 4.1	4.1 - 13	13 - 30
Female 15-20 **years**	0.33 - 1.1	1.1 - 3.3	3.3 - 11	11 - 24
Male 20-35 **years**	0.29 - 0.93	0.93 - 2.9	2.9 - 9.3	9.3 - 21
Female 20-35 **years**	0.24 - 0.78	0.78 - 2.4	2.4 - 7.8	7.8 - 18
Male >35 **years**	0.25 - 0.8	0.8 - 25	25 - 8	8 - 18
Female >35 **years**	0.24 - 0.77	0.77 - 2.4	2.4 - 7.7	7.7 - 18

Figure 6. Legend (Doses in rad to the thyroid).

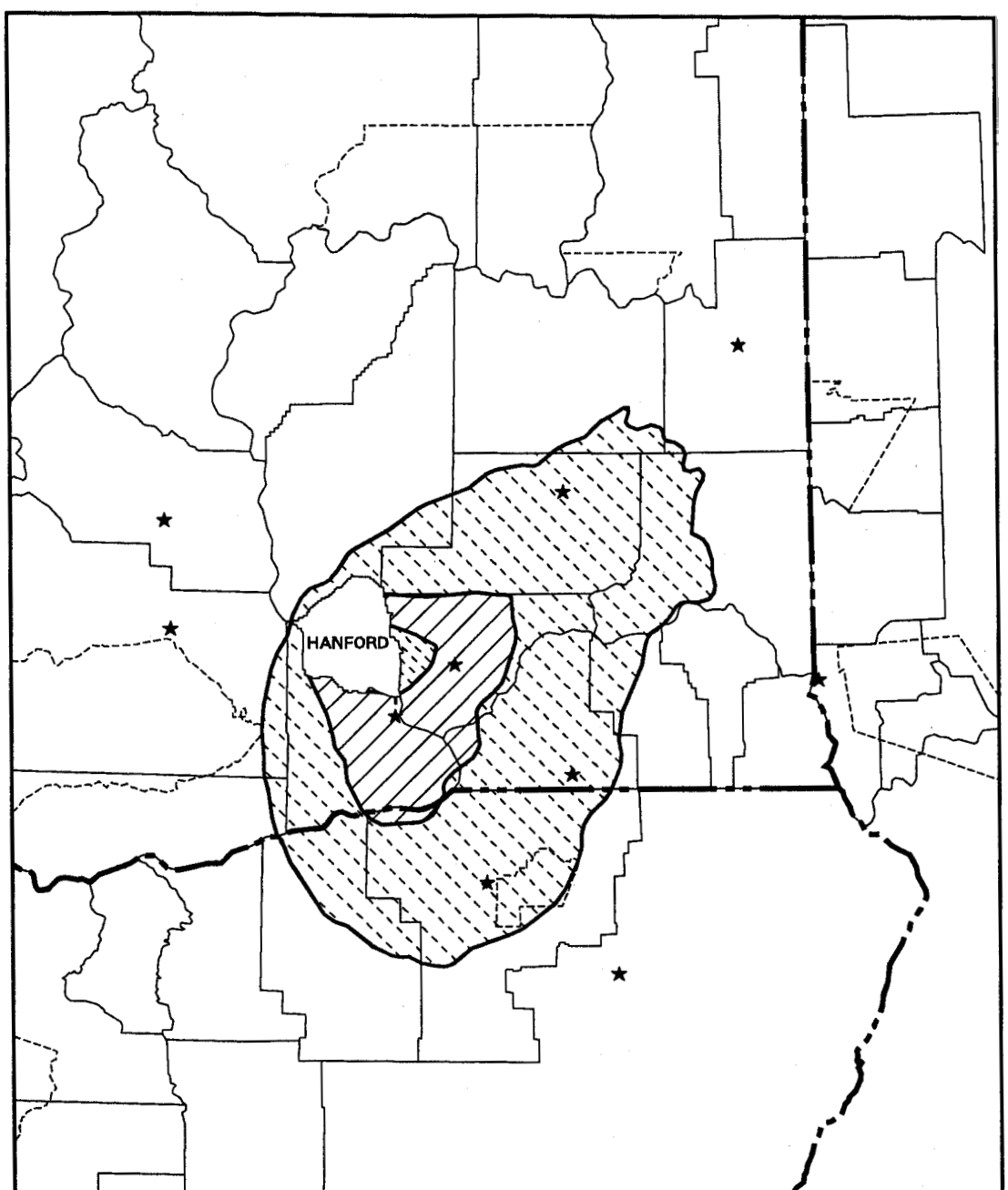
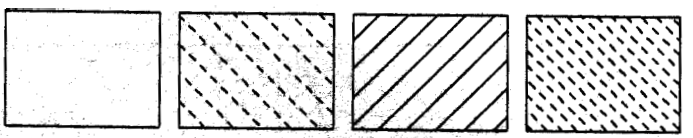


Figure 7. 1949 Iodine-131 Thyroid Dose from All Air Exposure Pathways (Milk Cows on Fresh Pasture)



Sex/Age Category				
All 0-1 years	< 0.025	0.025 - 0.08	0.08 - 0.25	0.25 - 0.61
All 1-5 years	< 0.014	0.014 - 0.05	0.05 - 0.14	0.14 - 0.35
Male 5-10 years	< 0.010	0.010 - 0.03	0.03 - 0.1	0.1 - 0.24
Female 5-10 years	< 0.009	0.009 - 0.03	0.03 - 0.09	0.09 - 0.23
Male 10-15 years	< 0.008	0.008 - 0.03	0.03 - 0.08	0.08 - 0.2
Female 10-15 years	< 0.007	0.007 - 0.02	0.02 - 0.07	0.07 - 0.17
Male 15-20 years	< 0.006	0.006 - 0.02	0.02 - 0.06	0.06 - 0.13
Female 15-20 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.12
Male 20-35 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.12
Female 20-35 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 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 - 0.02	0.02 - 0.05	0.05 - 0.11

Figure 7. Legend (Doses in rad to the thyroid).

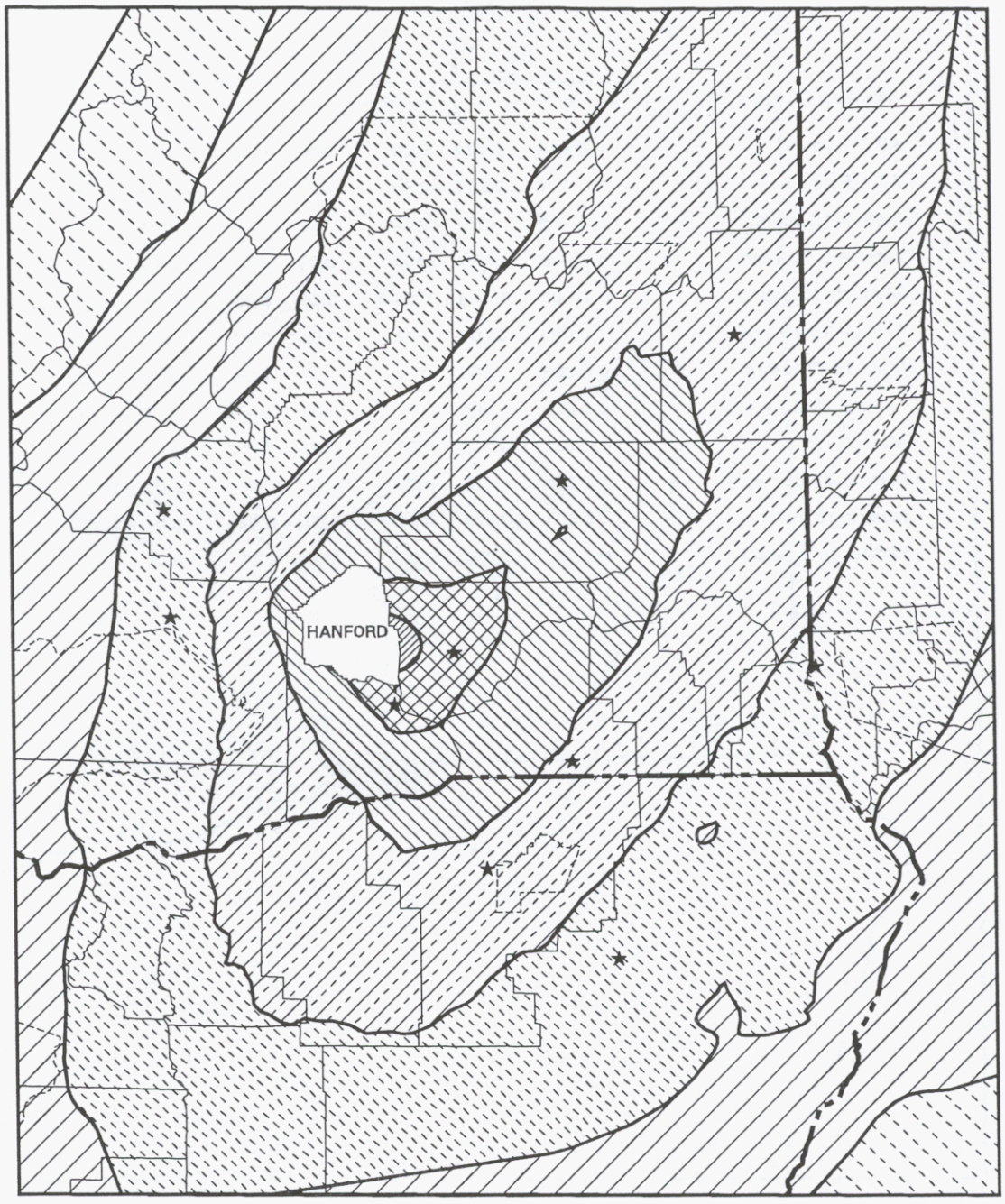
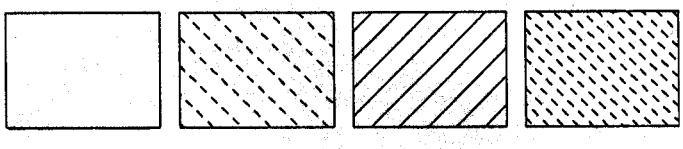
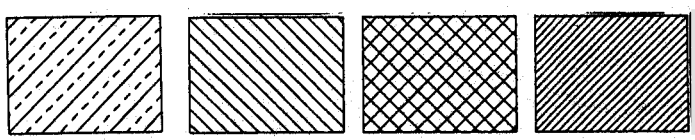


Figure 8. 1945 Iodine-131 Thyroid Dose from All Air Exposure Pathways (Milk Cows on Stored Feed)



Sex/Age Category				
All 0-1 years	< 0.032	0.032 - 0.1	0.1 - 0.32	0.32 - 1
All 1-5 years	< 0.015	0.015 - 0.05	0.05 - 0.15	0.15 - 0.48
Male 5-10 years	< 0.010	0.010 - 0.03	0.03 - 0.1	0.1 - 0.32
Female 5-10 years	< 0.010	0.010 - 0.03	0.03 - 0.1	0.1 - 0.31
Male 10-15 years	< 0.008	0.008 - 0.03	0.03 - 0.08	0.08 - 0.26
Female 10-15 years	< 0.007	0.007 - 0.02	0.02 - 0.07	0.07 - 0.22
Male 15-20 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.17
Female 15-20 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.15
Male 20-35 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.15
Female 20-35 years	< 0.005	0.005 - 0.02	0.02 - 0.05	0.05 - 0.15
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 0-1 years	1 - 3.2	3.2 - 10	10 - 32	32 - 54
All 1-5 years	0.49 - 1.5	1.5 - 4.9	4.9 - 15	15 - 26
Male 5-10 years	0.32 - 1	1 - 3.2	3.2 - 10	10 - 17
Female 5-10 years	0.31 - 0.98	0.98 - 3.1	3.1 - 9.8	9.8 - 17
Male 10-15 years	0.26 - 0.81	0.81 - 2.6	2.6 - 8.1	8.1 - 14
Female 10-15 years	0.22 - 0.7	0.7 - 2.2	2.2 - 7	7 - 12
Male 15-20 years	0.17 - 0.54	0.54 - 1.7	1.7 - 5.4	5.4 - 9.2
Female 15-20 years	0.15 - 0.48	0.48 - 1.5	1.5 - 4.8	4.8 - 8.3
Male 20-35 years	0.15 - 0.47	0.47 - 1.5	1.5 - 4.7	4.7 - 8
Female 20-35 years	0.15 - 0.48	0.48 - 1.5	1.5 - 4.8	4.8 - 8.2
Male >35 years	0.16 - 0.51	0.51 - 1.6	1.6 - 5.1	5.1 - 8.7
Female >35 years	0.17 - 0.54	0.54 - 1.7	1.7 - 5.4	5.4 - 9.3

Figure 8. Legend (Doses in rad to the thyroid).

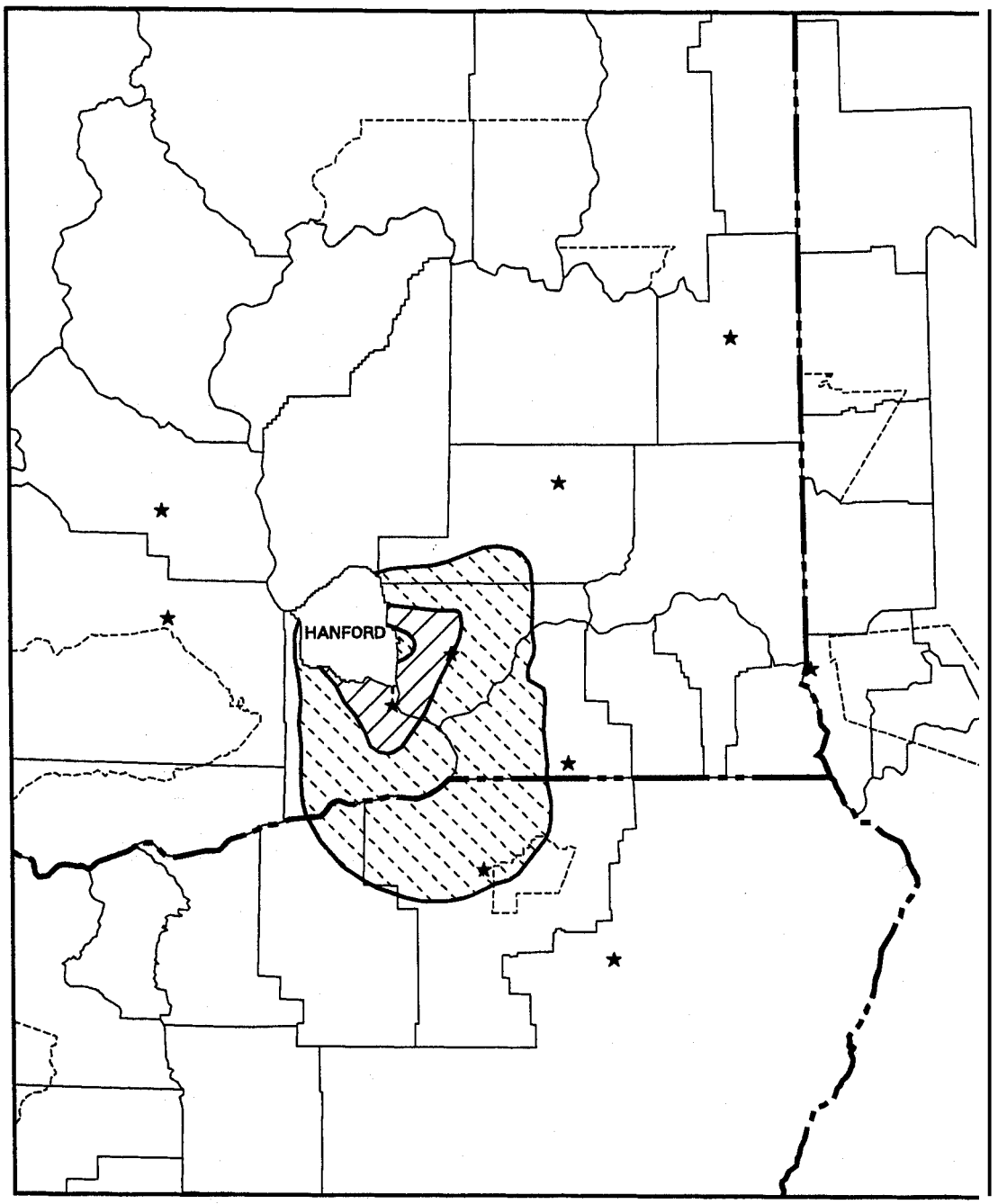
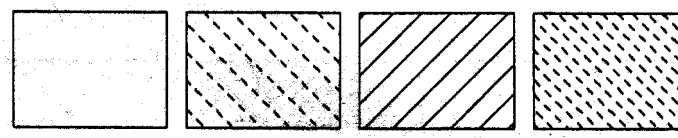


Figure 9. 1949 Iodine-I 31 Thyroid Dose from All Air Exposure Pathways (Milk Cows on Stored Feed)



Sex/Age Category				
All 0-1 years	< 0.027	0.027 - 0.09	0.09 - 0.27	0.27 - 0.45
All 1-5 years	< 0.013	0.013 - 0.04	0.04 - 0.13	0.13 - 0.22
Mate 5-10 years	< 0.010	0.010 - 0.03	0.03 - 0.1	0.1 - 0.17
Female 5-10 years	< 0.010	0.010 - 0.03	0.03 - 0.1	0.1 - 0.16
Male 10-15 years	< 0.009	0.009 - 0.03	0.03 - 0.09	0.09 - 0.15
Female 10-15 years	< 0.008	0.008 - 0.03	0.03 - 0.08	0.08 - 0.13
Male 15-20 years	< 0.006	0.006 - 0.02	0.02 - 0.06	0.06 - 0.1
Fernale 15-20 years	< 0.006	0.006 - 0.02	0.02 - 0.06	0.06 - 0.1
Male 20-35 years	< 0.006	0.006 - 0.02	0.02 - 0.06	0.06 - 0.11
Female 20-35 years	< 0.007	0.007 - 0.02	0.02 - 0.07	0.07 - 0.11
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

Figure 9. Legend (Doses in rad to the thyroid).

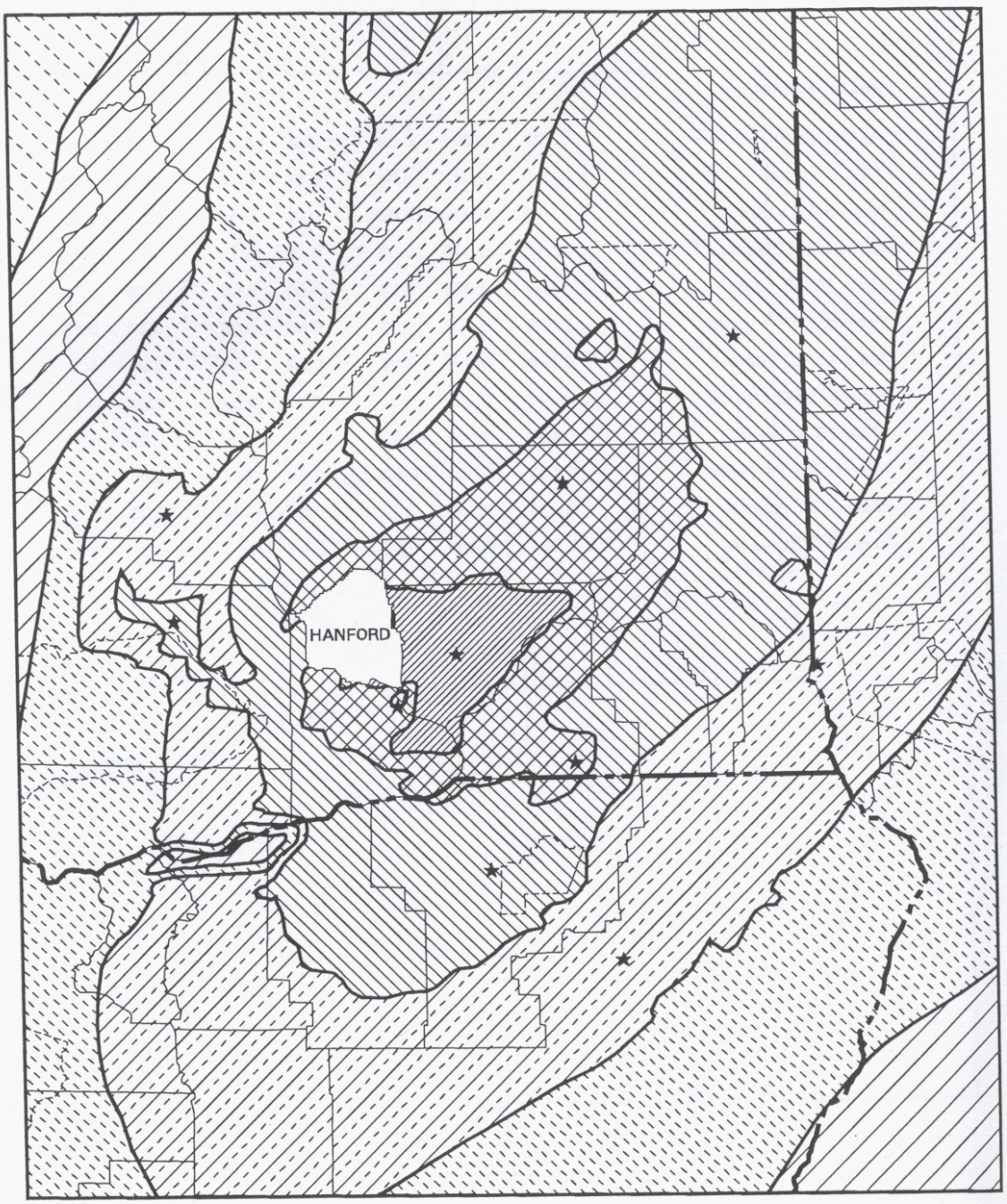
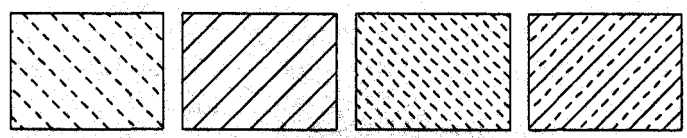
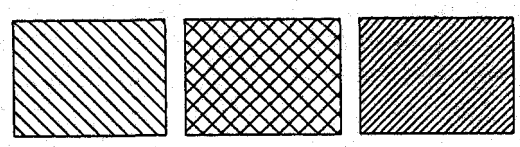


Figure 10. 1945 Iodine-131 Thyroid Dose from Consumption of Commercial Milk



Sex/Age Category				
All 0-1 years	0.024 - 0.08	0.08 - 0.24	0.24 - 0.77	0.77 - 2.4
All 1-5 years	0.015 - 0.05	0.05 - 0.15	0.15 - 0.48	0.48 - 1.5
Male 5-10 years	0.010 - 0.03	0.03 - 0.1	0.1 - 0.32	0.32 - 1
Female 5-10 years	0.008 - 0.02	0.02 - 0.08	0.08 - 0.24	0.24 - 0.76
Male 10-15 years	0.006 - 0.02	0.02 - 0.06	0.06 - 0.2	0.2 - 0.61
Female 10-15 years	0.005 - 0.02	0.02 - 0.05	0.05 - 0.17	0.17 - 0.54
Male 15-20 years	0.004 - 0.01	0.01 - 0.04	0.04 - 0.12	0.12 - 0.37
Female 15-20 years	0.003 - 0.01	0.01 - 0.03	0.03 - 0.09	0.09 - 0.29
Male 20-35 years	0.002 - 0.01	0.01 - 0.02	0.02 - 0.07	0.07 - 0.21
Female 20-35 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 - 0.15
Female >35 years	0.001 - 0.004	0.004 - 0.01	0.01 - 0.04	0.04 - 0.13



Sex/Age Category			
All 0-1 years	2.4 - 7.7	7.7 - 24	24 - 65
All 1-5 years	1.5 - 4.8	4.8 - 15	15 - 41
Male 5-10 years	1 - 3.2	3.2 - 10	10 - 27
Female 5-10 years	0.76 - 2.4	2.4 - 7.6	7.6 - 21
Male 10-15 years	0.61 - 2	2 - 6.1	6.1 - 16
Female 10-15 years	0.54 - 1.7	1.7 - 5.4	5.4 - 15
Male 15-20 years	0.37 - 1.2	1.2 - 3.7	3.7 - 10
Female 15-20 years	0.29 - 0.91	0.91 - 2.9	2.9 - 7.7
Male 20-35 years	0.21 - 0.69	0.69 - 2.1	2.1 - 5.8
Female 20-35 years	0.16 - 0.51	0.51 - 1.6	1.6 - 4.3
Male >35 years	0.15 - 0.49	0.49 - 1.5	1.5 - 4.2
Female >35 years	0.13 - 0.42	0.42 - 1.3	1.3 - 3.5

Figure 10. Legend (Doses in rad to the thyroid).

Project because transport of these products between areas of high and low iodine-131 deposition can alter the pattern of radiation doses across the study area.

Figure 10 (pages 28/29) shows the iodine-131 thyroid doses from commercially produced milk in 1945. This is *milk* obtained from a grocery store.

Cumulative thyroid doses over the eight-year period beginning December 26, 1944 and ending December 31, 1951 are shown in Figures 11 through 13. The doses were estimated for specific combinations of reference individual type, exposure pathways and food sources.

Figure 11 (page 31) shows the cumulative dose to a child who consumed milk from a cow on fresh pasture. The median dose for a child at the maximally exposed location (at Ringold, in northwest Franklin County) is about 235 rad (range of dose: 54 rad to 870 rad). At the lowest exposed location, the estimated dose is 0.07 rad or 70 millirad. A millirad is equal to one/thousandth of a rad. (The range of the lowest estimated dose is 12 millirad to 340 millirad).

The cumulative doses calculated for locations near Hanford were *larger* than those farther from the site and correspond to the iodine-131 deposition at each location. This is evident by looking at doses for a maximally exposed child in other areas:

Median Dose		Range
Richland	93 rad	24 rad to 350 rad
Eltopia	73 rad	19 rad to 300 rad
Ritzville	28 rad	7.4 rad to 120 rad
Spokane	11 rad	2.8 rad to 44 rad
Walla Walla	13 rad	3.7 rad to 44 rad
Pendleton	8.6 rad	2 rad to 30 rad
Lewiston	4 rad	1 rad to 15 rad
Yakima	2.8 rad	.66 rad to 9.6 rad
Ellensburg	2.1 rad	.5 rad to 6.7 rad

The distribution of commercial milk and leafy vegetables also had some impact on the pattern of doses.

Figure 12 (page 32) shows the cumulative dose to an adult who consumed milk from a cow on fresh pasture. The median dose for an adult at the maximally exposed location is about 36 rad (range of dose: 9.8 rad to 150 rad). At the lowest exposed location, the estimated dose is 0.01 rad or 10 millirad (range of dose: 1.5 millirad to 60 millirad).

Figure 13 (page 33) shows cumulative doses to children consuming commercially available foods including milk, vegetables, meat, eggs and fruit. The highest estimated dose to a child in this category is about 110 rad (range of dose: 45 rad to 340 rad. The lowest estimated dose is about *0.09* rad or 90 millirad (range of dose: 22 millirad to 390 millirad).

Comparison to Phase I Results

In July 1990, the TSP announced preliminary iodine-131 dose estimates for the years 1944-47. This "Phase" of the Project was to determine if an assessment of the atmospheric pathway was possible and to determine the magnitude of possible doses. At that time, it was known that further Project work would likely change the results.

The results in this summary differ from the preliminary Phase I results. The doses in this report are usually lower than those presented in 1990. For example, the highest dose reported in 1990 was to an infant near Eltopia, WA. The thyroid dose in 1945 from the consumption of milk from a backyard cow fed fresh pasture was estimated to be about 374 rad (median dose), with a range of from 54 to 2,333 rad. The estimated doses using the updated calculational methods and data indicate a median thyroid dose to the same infant in 1945 to be 143 rad, with the range 29 to 700 rad.

Although work during the past four years resulted in an increase in the source term (increased from 340,000 curies of iodine-131 released in 1945 to 555,000 curies released that same year) improvements in the calculational methods and data from Phase I actually resulted in many lower doses. A better understanding of the atmospheric transport results in estimates of lower deposition of iodine-131 near Hanford, but higher deposi-

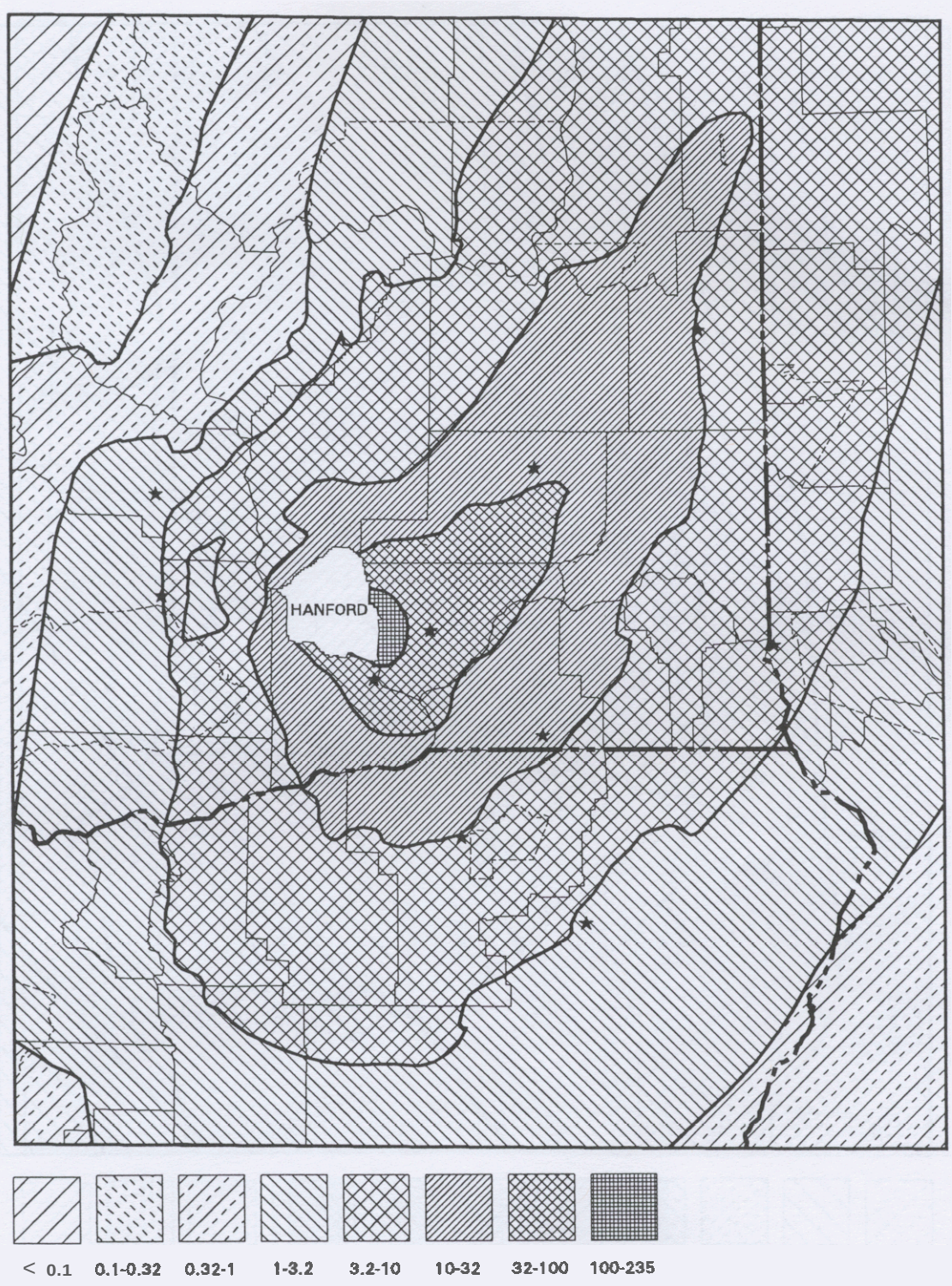


Figure 11. Cumulative Iodine-I31 Thyroid Dose (rad) to a Child from All Air Exposure Pathways for the Years 1944 through 1951 (Milk Cows on Fresh Pasture)

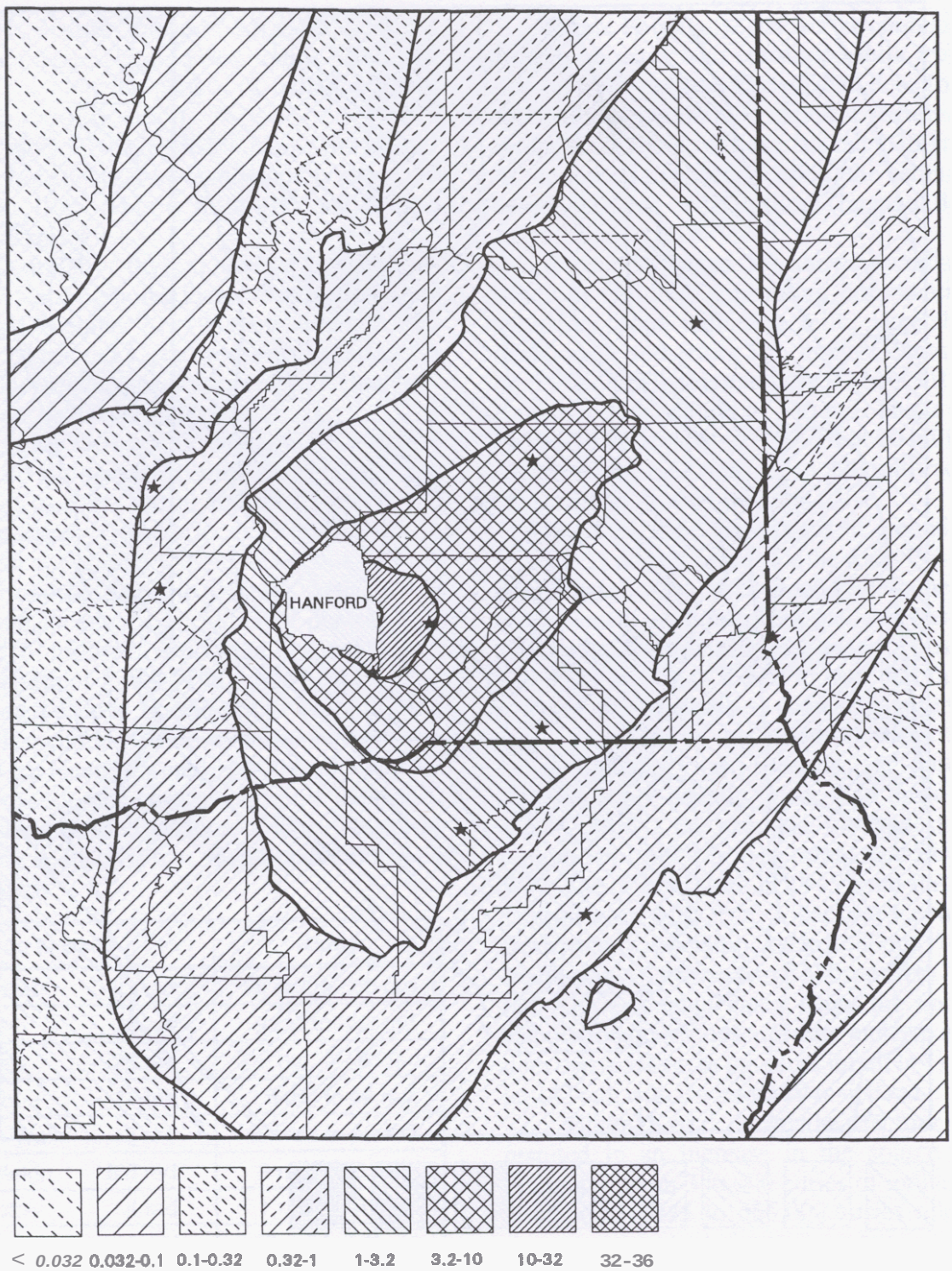


Figure 12. Cumulative Iodine-131 Thyroid Dose (rad) to an Adult from All Air Exposure Pathways for the Years 1944 through 1951 (Milk Cows on Fresh Pasture)

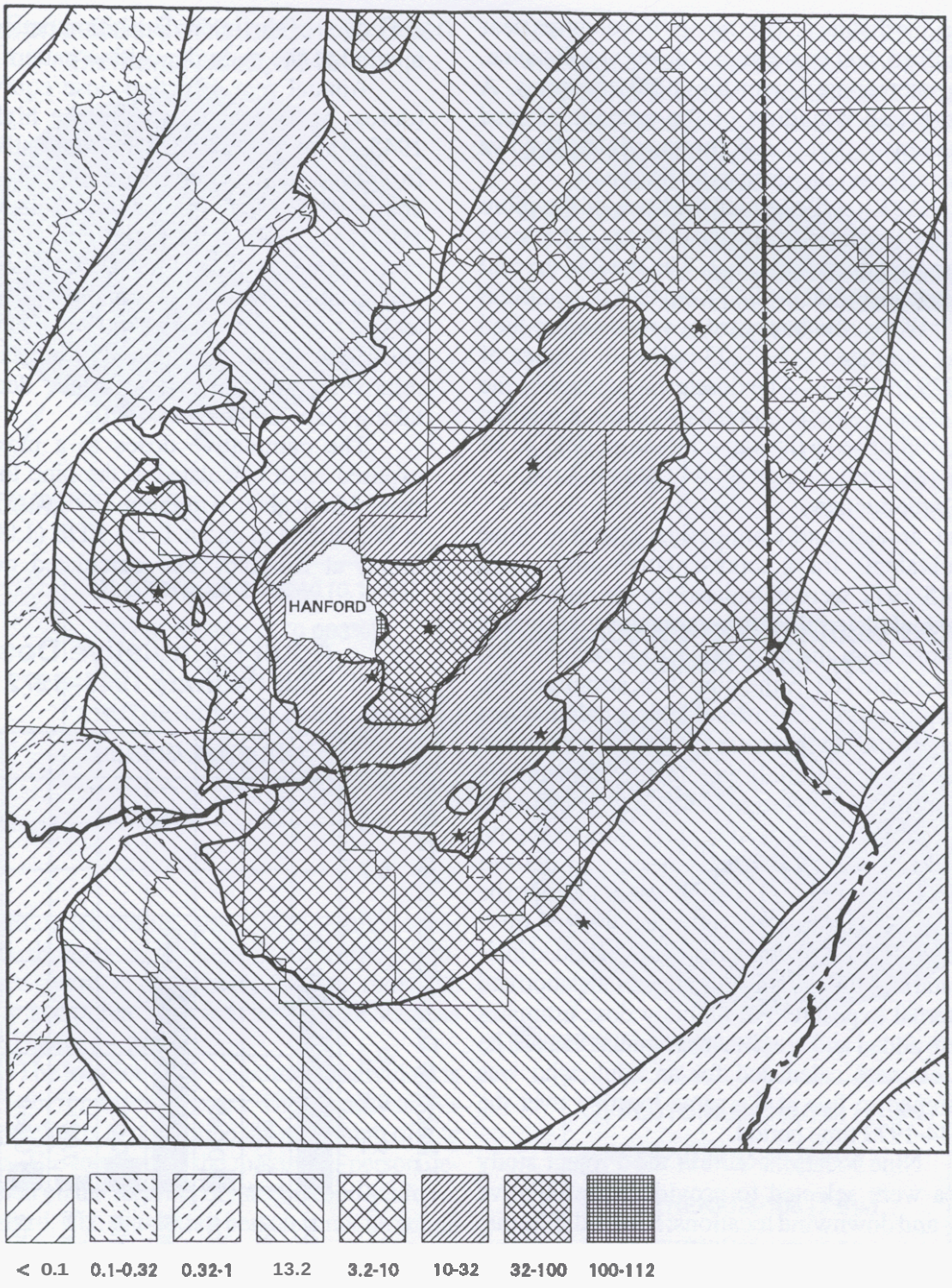


Figure 13. Cumulative Iodine-I31 Thyroid Dose (rad) to a Child from Consumption of Commercial Foods for the Years 1944 through 1951

tion at a distance. This means lower doses near Hanford, and some higher doses at a distance, when compared with the 1990 estimates. A better understanding of the amount of feed eaten by backyard and commercial milk cows also affected the dose calculations.

At Ritzville, which was one of the more distant locations estimated in Phase I, the doses are now generally higher. The median 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, with a range of 0.029 to 1.7 rad. The dose estimates using the updated methods and data indicate a median thyroid dose to the same infant in 1945 to he 1.8 rad, with a range of .34 rad to 8.3 rad.

Key Radionuclides

The annual and cumulative effective dose equivalents for a representative adult from 1945-1972 were calculated for six radioactive materials determined to be the major contributors to dose from the air: iodine-131, cerium-144, ruthenium-103, ruthenium-106, strontium-90, and plutonium-239. Monthly dose calculations were based on environmental accumulation of radioactive materials and human exposure by 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. Other exposure pathways included incidental ingestion of soil by humans, inhalation and external exposure. All monthly dose estimates were added and are shown as annual totals. The doses were calculated for an adult who was assumed to live at the same location over the 1944-1972 time period.

Nine locations within the Project study area were selected to provide representative up- and downwind locations: Ringold, Eltopia, Richland, Ritzville, Spokane, Sunnyside and Wenatchee in 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.

Annual rem effective dose equivalents (doses) at all locations were the highest in 1945. About 75 percent of the cumulative dose from 1944-1972 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 was about 1,400 times less than the dose received in 1945. During the late 1950s and 1960s, annual doses remained relatively constant, with further decreases taking place in the early 1970s.

The cumulative doses to a maximally exposed adult calculated at the nine locations ranged from about 6 millirem EDE (0.006 rem) at Wenatchee to about 1 rem EDE (1,000 millirem) at Ringold. The calculated doses at

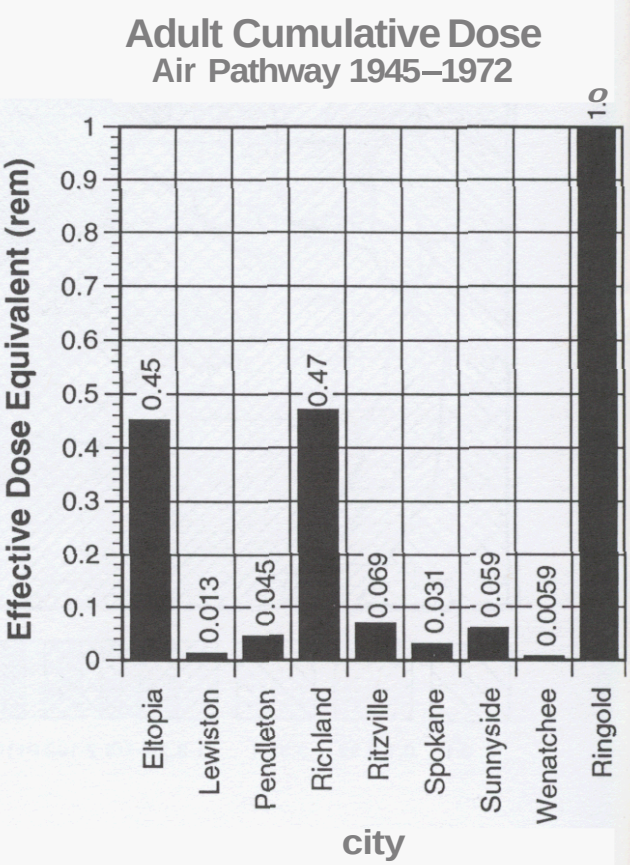


Figure 14. Adult Cumulative Doses at Selected Locations

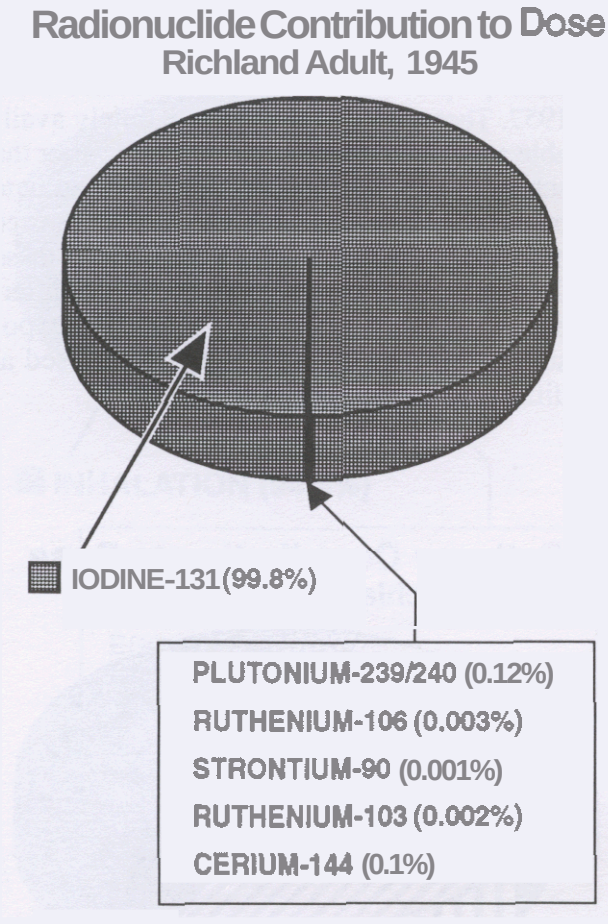


Figure 15.

Ringold, Richland, and Eltopia—three locations directly downwind from Hanford releases—were significantly higher than the other six cities included in the calculations (see Figure 14 page 34).

The location of the maximum individual is different for different years. The purpose of this calculation is to determine the maximum offsite dose. The location of the maximum person depended on the location of the emission source at Hanford. The maximum person is not an actual person: the food consumption habits and lifestyle patterns are assumed to be greater than for any known person. As a result, the doses should be higher than those received by any real person.

Iodine-131 was the dominant radioactive material 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 Richland. Plutonium-239 and cerium-144 were the next largest contributors at about 0.1 percent each (see figure 15 at left).

By 1965, 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. Plutonium-239 releases remained relatively constant from 1949 to 1967, when they decreased sharply. By 1965, cerium-144 accounted for about 81 percent of the dose to an adult in Richland from airborne radioactive materials from Hanford. Plutonium-239 was the next largest contributor at 11 percent. All other radionuclides each contributed four percent or less (see figure 16 below).

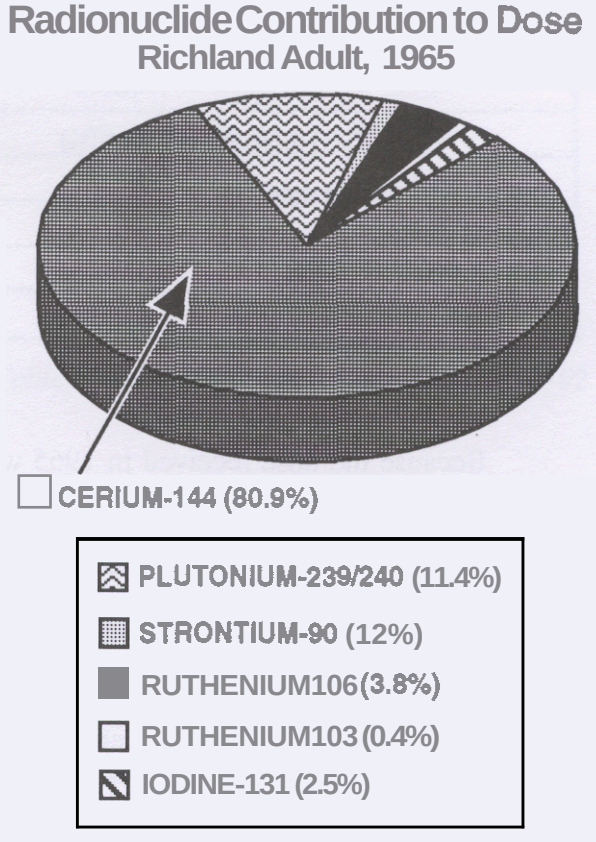


Figure 16.

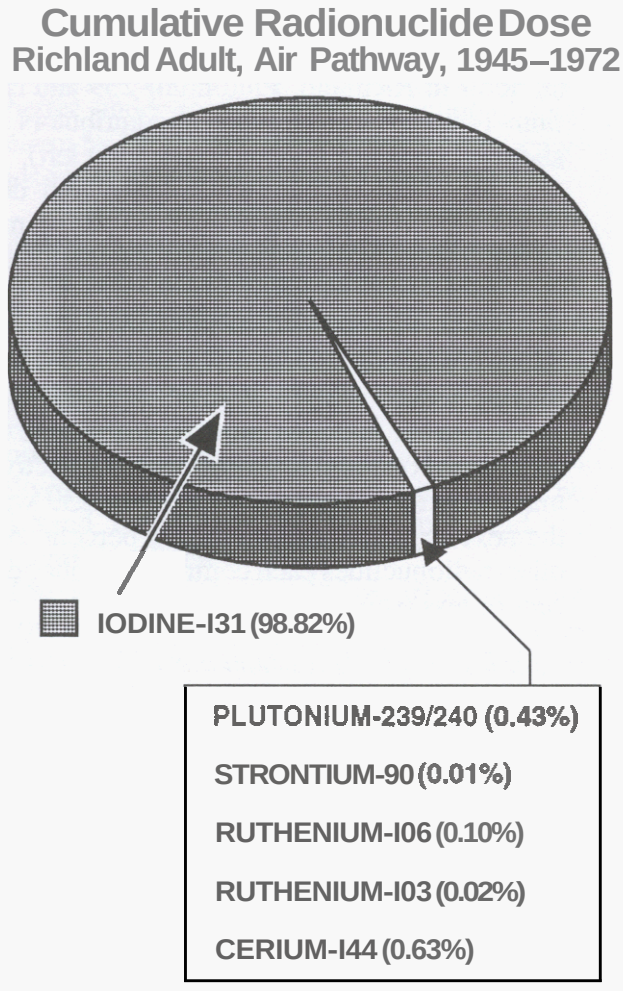


Figure 17.

Because the dose received in 1965 was only about 0.03 percent of that in 1945, iodine-131 was still by far the dominant radioactive material contributing to dose for the entire period of 1945 to 1972 (see figure 17 above).

Figures 18 (at right) and 19 (page 37) show how the exposure pathways reflect some of these changes from 1945 to 1965. In 1945, when iodine-131 was the dominant radioactive material, ingestion of contaminated milk, eggs and meat were the dominant pathways for an adult in Richland. By 1965, when the iodine-131 releases had dropped significantly, inhalation then became the dominant exposure pathway.

Annual reports summarizing environmental monitoring and offsite radiation impacts were prepared by Hanford contractors since 1957. These reports have been publicly available and are prepared one to two years after the subject year. Each report contains an estimate of the radiation dose to a maximally exposed individual. The methods for estimating these doses were evolving during this time and different assumptions regarding dosimetry, exposure parameters, and modeling were used at different times.

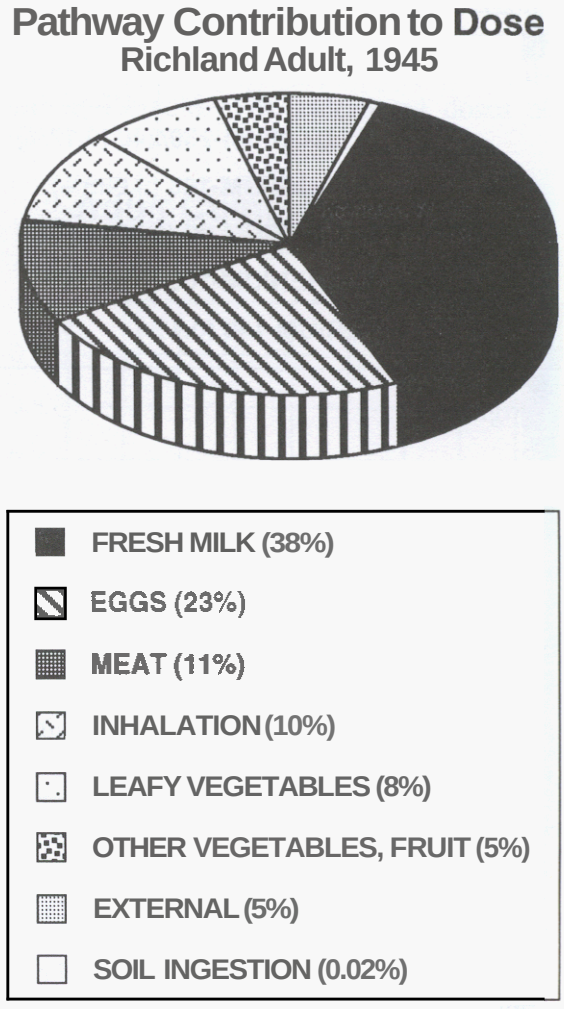


Figure 18.

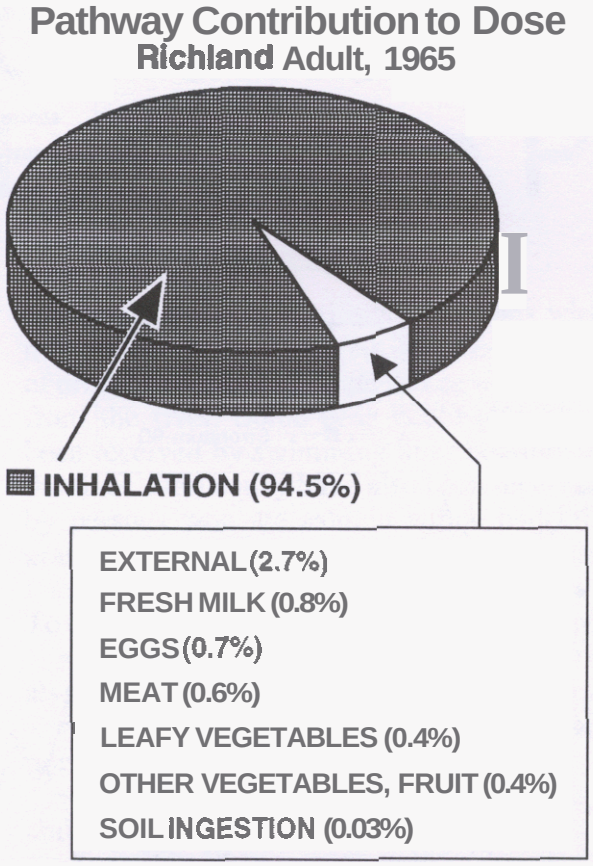


Figure 19.

Year	Maximum Individual Total Body or EDE (mrem)
1973	< 0.1
1974	0.02
	0.003
1976	
1977	0.03
1978	0.08
1979	0.05
1980	c 0.06
1981	0.3
1982	0.06
1983	0.014
1984	0.025
1985	0.04
1986	0.04
1987	0.02
1988	0.065
1989	0.011
1990	0.01
1991	0.007
1992	0.0049

Table 1. Hanford Annual Report Doses 1973–92

The annual doses from the air are presented in Table 1 for the years 1973 through 1992. This is the most recent year for which a Hanford annual environmental monitoring report is available. The report for 1993 will be available in late 1994. The annual report doses were calculated for releases of all radionuclides from all known sources at Hanford. The doses presented in Table 1 (at right) are for the air pathway.

Dose History

Dose results from the key radionuclide and annual report were combined in Figure 20 (page 38). The doses are presented for a maximally exposed adult located directly adjacent to the Hanford Site in western Franklin County, WA. The doses at all other locations within the Project study area would be lower. 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 dose over this time period is estimated to be slightly over 1 rem (1,000 millirem). The doses by decade are .96 rem-960 millirem (1944-1949), .06 rem–60 millirem (1950-1959), .003 rem-3 millirem (1960-1969), 0.4 millirem (1970-1979), 0.4 millirem (1980-1989), and 0.02 millirem (1990-1992). Over 92 percent of the total effective dose equivalent is estimated to have been received during the 1945-1947 time period.

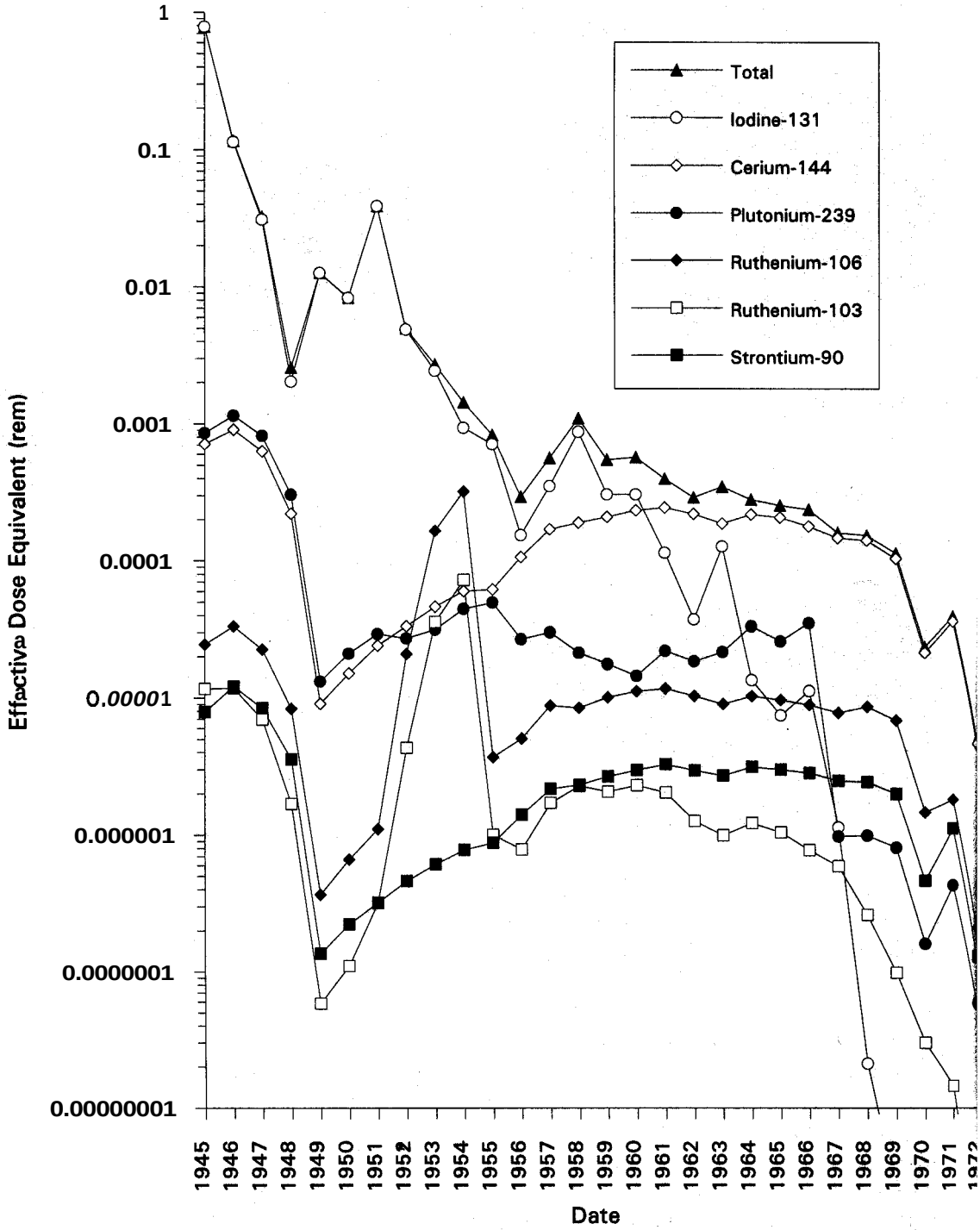


Figure 20. Annual Doses to an Adult at Ringold, 1945–1972

Columbia River Exposure Pathway

The Project estimated doses to persons who may have used the Columbia River as a source of drinking water or who ate fish or waterfowl from the river. Some dose could also have been received by swimming in or boating on the river. Doses may have also been received by persons who ate salmon which had migrated up the river or by eating shellfish from Pacific ocean estuaries.

To calculate doses, scientists needed to know:

- the type and amount of radioactive materials released to the river from Hanford reactors;
- how radioactive materials were transported in Columbia River water;
- the accumulation of radioactivity in fish and waterfowl; and,
- people's diets and lifestyle.

TSP and Battelle scientists estimated the historic releases of 11 radioactive materials to the Columbia River during the operation of Hanford's eight original reactors. These reactors operated at Hanford from 1944–1971. N Reactor, the ninth and last operating production reactor, recirculated water within its core and did not discharge directly to the river. N Reactor continued operation until 1987.

The use of river water to cool the reactors resulted in the release of radioactive materials to the Columbia River. Releases of radioactive materials to the ground resulted in smaller releases to the river.

Nineteen radioactive materials were initially examined to determine their significance to dose. Of these, five (sodium-24, phosphorus-32, zinc-65, arsenic-76, and neptunium-239) are included in the dose calculations because they contributed about 94 percent of the estimated dose to people (see Appendix 2). Six others (scandium-46, chromium-51, manganese-56, yttrium-90, iodine-131, and gallium-72) were included in the source term estimates either because they were needed to validate the river transport model or they were of particular interest to the TSP. The other eight were considered not to have any significant impact on doses.

SOIL AND GROUND WATER

From the time Hanford facilities first began operating, highly radioactive liquids were routed to underground storage tanks, and slightly less radioactive liquids were discharged directly to the ground in ponds, ditches, and engineered structures called cribs. Some of the radioactive liquids moved through the soils into ground water. Some, such as tritium, traveled in the ground water and reached the Columbia River. These radioactive liquids contributed very little to the much larger amounts of radioactive liquids that were routinely discharged into the Columbia River as part of the cooling water from the original reactors.

Columbia River water for use in cooling the reactors was pumped into a treatment plant. Chemicals were added to purify the water and help prevent corrosion of the piping and reactor tubes. The processed river water was then filtered and pumped into large holding tanks. From the tanks it was pumped to the reactor.

Radioactive materials were created when neutrons in the reactor core activated elements present in the cooling water and elements added during water treatment processes. Reactor neutrons also produced radioactive materials by activating elements in the metals used for process tubes and fuel cladding. The resulting radioactive materials

were released in the cooling water discharged to the Columbia River.

During its brief passage through the reactor core (1 to 2 seconds), the water was heated to over 212°F in the highest-powered tubes. The hot effluent water was discharged from the reactor into holding ponds near the Columbia River. After cooling and allowing time for the shortest-lived radioactive materials to decay, the water was discharged to the river.

As the reactors operated, film deposits built up on both the tubing and the fuel elements. Plant operators periodically removed or "purged" the film buildup. Because the film contained radioactive materials, purges resulted in increased radioactive discharges to the river. But these releases were minor compared to routine operational releases and fuel-element failures.

Nearly 2,000 fuel-element failures occurred in the eight original Hanford reactors. A failure is a crack in the aluminum rod that contained the uranium fuel, allowing coolant water direct access to the fuel. Each failure resulted in the release of fission products to the water in the reactor. The reactor was shut down when a rupture occurred. Scientists found many records of ruptures in Hanford reports. The data was included in the source term, but contributed only a small amount to the total released.

River Monitoring Information

Extensive monitoring data are available to help scientists in their research. Discharges from each reactor were measured daily in 1964-1966. Weekly measurements were taken of river water at several locations. Drinking water was sampled at Richland, Pasco, and to a lesser extent, Kennewick. Several kinds of fish were sampled — especially whitefish — which could be caught year-round. Whitefish had among the higher concentrations of important radioactive materials, such as phosphorus-32. External radiation along the river bank from sediments containing radioactive materials was also measured.

However, even with these extensive records, it is not possible to make dose calculations for the river pathway based entirely upon historical monitoring data. That's because sampling was not done at every location along the river on a constant basis for radioactive materials of interest. Therefore, computer modeling was needed to fill in these gaps.

Columbia River Computer Modeling

The process of estimating doses to persons from the river pathway starts with estimating the amount of radioactive materials discharged to the Columbia River. This is the Source Term. The Source Term data provided monthly average releases from each of the eight reactors from January 1950 through January 1971. This was done by using reactor operating history and measurements of radioactive material concentrations, where the latter were available. The radioactive material releases were corrected for decay from the time of release from the reactors to the time of discharge to the Columbia River.

A distinct seasonal cycle is evident in the data. During late spring and summer the melting snow in the Cascades and Rocky Mountains increased the river flow, causing increased dilution of radioactive materials. Reduced Columbia River flow in the winter resulted in the maximum concentrations occurring at this time of the year.

Figure 21 (page 41) shows the annual releases of the five key radioactive materials used for dose calculations.

Using the source term estimates, scientists calculated the concentrations of key radioactive materials in the Columbia River water at several downstream locations (see Figure 22 page 42). This was done by simulating radioactive material flow and transport in the river.

A computer program called CHARIMA, which contains a river model, was used to simulate transport of specific radionuclides from the Hanford reactors to Portland, Oregon. The length of river considered extended from Priest Rapids Dam near Hanford to river mile 100, just downstream of the Willamette

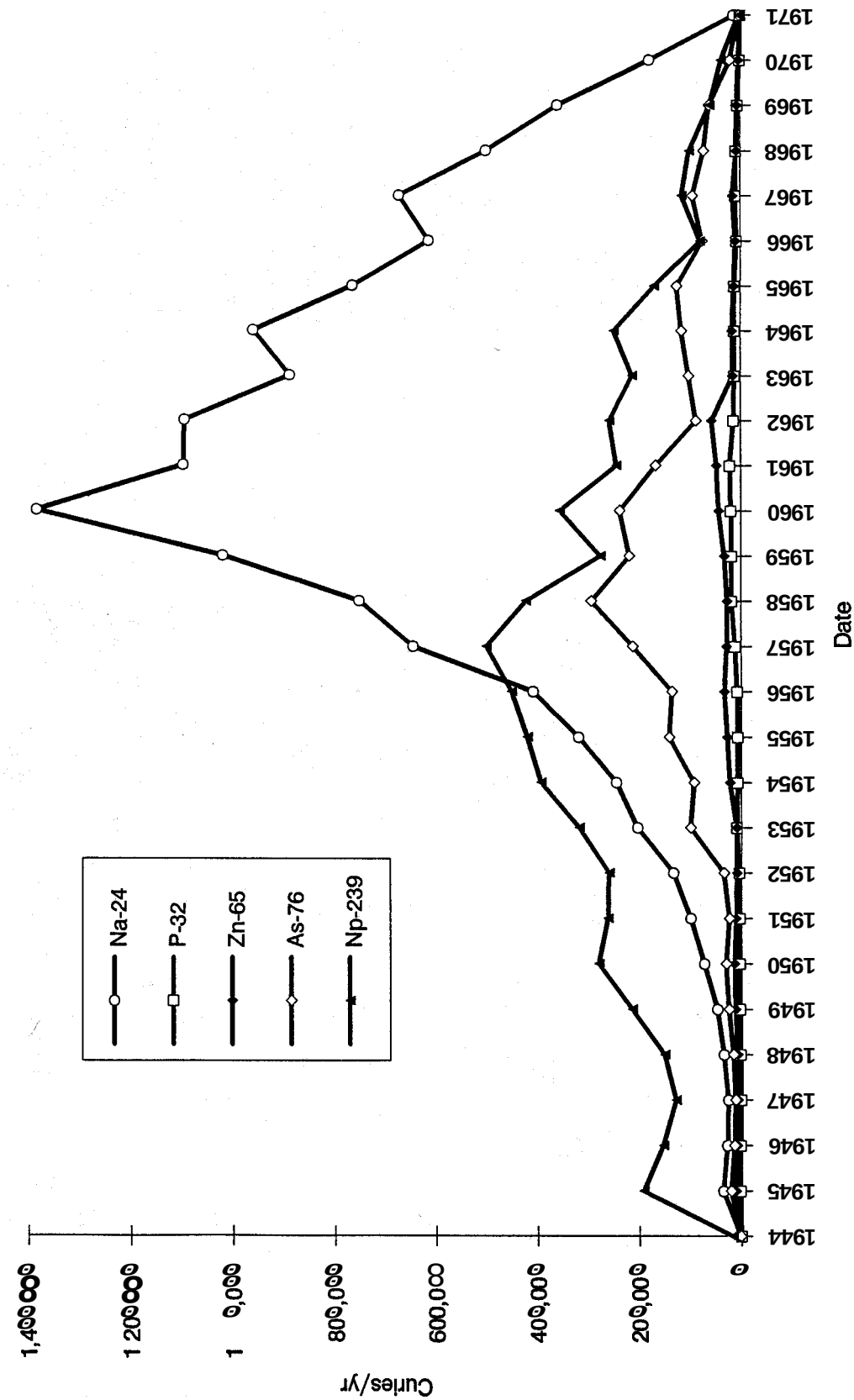


Figure 21. Key Radionuclides Released to the Columbia River by Year, 1944–1971

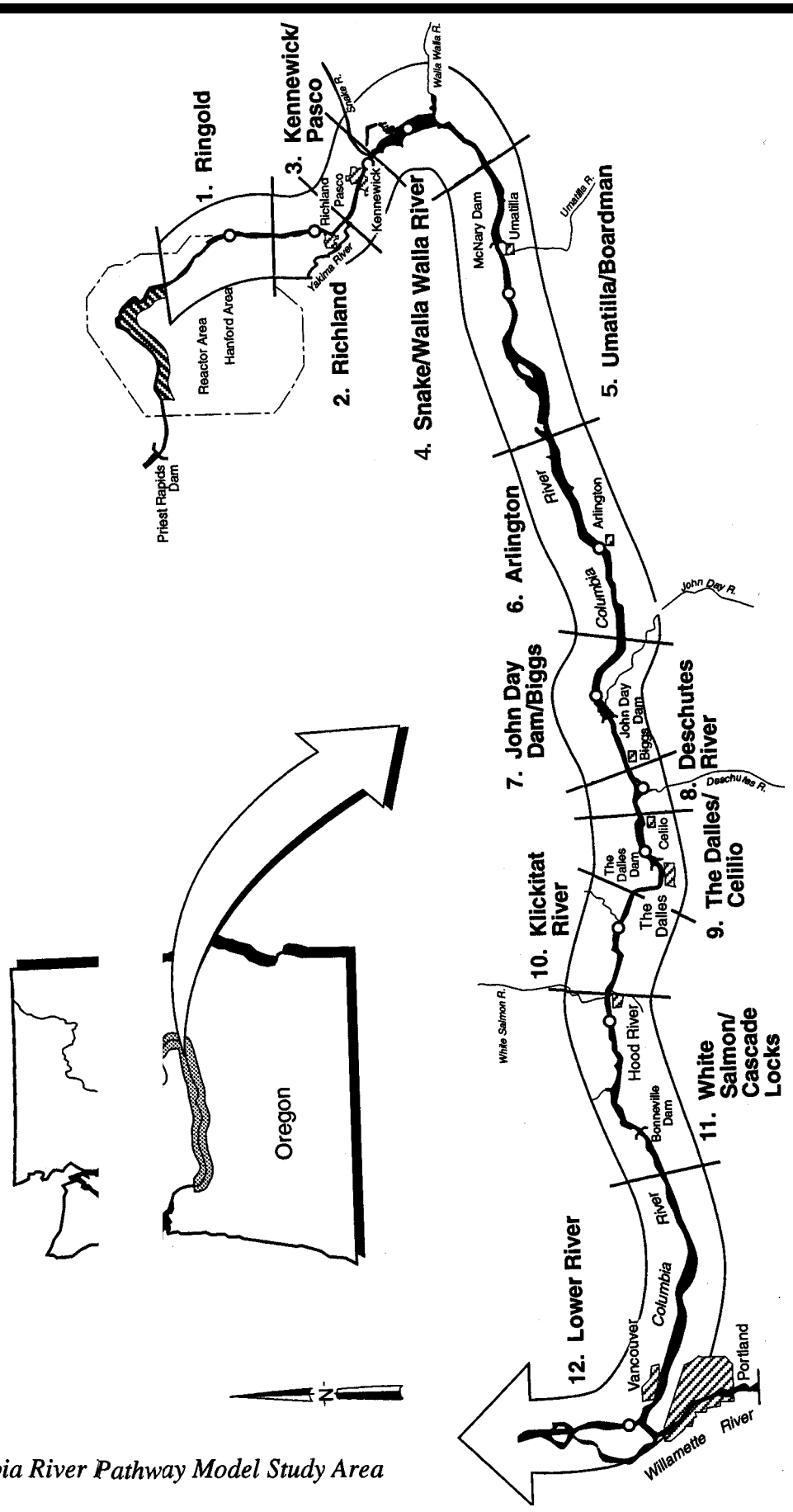


Figure 22. Columbia River Pathway Model Study Area

River confluence at Portland. The time frame spans a 21-year period from January 1950 through January 1971.

Monthly average water concentrations were reconstructed at 12 locations for sodium-24, phosphorus-32, Zinc-65, arsenic-76, and neptunium-239. Concentrations for chromium-51 were computed to help validate the transport model, but were not considered significant for use in dose estimates. Where actual monitoring data were limited, concentrations were calculated by using measurements of releases from the reactors along with information about dilution in the river.

These water concentrations were then used to calculate dose estimates. Historical river monitoring data was used to validate computed water concentrations.

The CHARIMA program can account for tributary inflows, multiple channels within a river and the presence of dams and reservoirs. It also has the capability to route contaminants to any specified location.

The results of the modeling indicated that the five key radioactive materials can be separated into two groups, based on their transport characteristics in the Columbia River. The first group, radioactive materials with relatively short half-lives — sodium-24, arsenic-76, and neptunium-239 — was sensitive to downstream travel time. After dams were constructed below the Snake River, transport speeds were significantly reduced. The reduced flow increased the travel time and allowed more radioactive decay to occur. Downstream travel times were significantly increased after 1953 when the operation of McNary Dam began. The raising of the reservoir behind The Dalles Dam in March 1957 did not have as great an effect as McNary Dam, probably because of its proximity to the Bonneville Dam and reservoir. John Day Dam began operating in April 1968, and a reduction in concentrations was evident. Because of the dams, water concentrations for the three radioactive materials at downstream locations were much lower than they would have been under open channel conditions.

The second group — consisting of phosphorus-32 and zinc-65 — was not as much affected by dam construction because of their longer half-lives. Phosphorus-32 has a half-life of 14.3 days. Zinc-65 has a half-life of 245 days. These are long enough to greatly reduce the effects of travel time.

Major gaps in the information base were due to the lack of specific radioactive material concentration measurements before 1951 and the absence of monitoring data during some months. Missing data were reconstructed using statistical analysis of existing data coupled with modeling techniques.

Radioactive Materiel Concentrations in Aquatic Organisms

In order to estimate doses to individuals who ate fish or waterfowl taken from the Columbia River, scientists needed to estimate the radioactive material concentrations in those organisms. Several different approaches were used. Each approach relied heavily on historical monitoring data collected by Hanford researchers and by other State and Federal government agencies and universities.

The concentration of radioactive material in fish and waterfowl can be related to the radioactive material concentration in the water in which they live and feed. A large historical database of measured radioactive material concentrations in Columbia River fish, waterfowl, and water was assembled. This was used to develop bioconcentration factors specific for the Columbia River. These factors directly relate the radioactive material concentration in the organism to the concentration in the Columbia River water.

Waterfowl

Two types of ducks were included in this study — diver ducks that eat small fish and invertebrates, and puddle ducks that eat near-surface water plants and grain crops. Geese, which feed in a similar manner to puddle ducks, were included in this summary because historical

data were available for them. No seasonal dependence was found in the historical sampling data. Therefore, the bioconcentration factors are for all seasons.

Shellfish

Zinc-65 and phosphorus-32 concentrations in shellfish near the mouth of the Columbia River were first detected in the 1950s. Information was compiled on phosphorus-32 and zinc-65 in shellfish for locations such as Willapa Bay, Astoria, Cannon Beach, Coos Bay, Seaside Beach, Tillamook Bay, and Agate Beach. Oysters generally contained higher concentrations of zinc-65 than did other marine organisms.

Salmon and Steelhead

Anadromous species (fish that live part of their lives in freshwater and part in salt water) such as chinook salmon, sockeye salmon, coho salmon, and steelhead trout travel up the Columbia River to spawn. Sockeye and other Pacific salmon species do not feed once they enter fresh water and head upstream to their spawning area. The fish rely on reserves of fat and protein stored up during their ocean residence to reach their spawning area.

Juvenile salmon and steelhead feed during their river migration downstream to the ocean. However, it is thought that anadromous species such as salmon and steelhead in the Columbia River took in radioactive materials primarily while feeding in the ocean. Fish in the ocean may have accumulated radioactive materials from both Hanford discharge and fallout from atmospheric testing of nuclear weapons. Information on 47 historical samples of salmon caught in the Columbia River show that 37 samples were below the minimum detection limit (0.1 picocuries per gram — pCi/g) for zinc-65. The rest of the samples varied from just above the detection limit to a maximum of 13 pCi/g. The median value for zinc-65 was 0.6 pCi/g.

The TSP determined that doses from salmon and steelhead should he calculated using two approaches. The first approach would be to use available monitoring data. The second approach assumed that the salmon spend their entire lives in the Columbia River and accumulate radioactive materials as do resident species. The second approach provided an upper limit for doses from ingestion of salmon and steelhead. It was used to estimate the uncertainty in salmon and steelhead doses. It yielded zinc-65 concentrations in salmon ranging from about 1 pCi/g to 100 pCi/g.

Standard dose assessment methods were used to translate the radioactive material concentrations in environmental media into the radiation dose that could have been received by a person. The environmental media of concern for the Columbia River pathway include treated and untreated drinking water, resident fish, waterfowl, salmon, and shellfish. The Columbia River Dosimetry code (CRD) calculates doses for 12 specific river segments. The segment names and approximate locations are as follows:

1. Ringold (from below reactor areas to north of Richland)
2. Richland (from north of Richland to above the Yakima River)
3. Kennewick/Pasco (from below the Yakima River to above the Snake River)
4. Snake/Walla Walla River (from below the Snake River to McNary Dam)
5. Umatilla/Boardman (from below McNary Dam to near Arlington, Oregon)
6. Arlington (Arlington, Oregon area)
7. John Day Dam/Biggs (from John Day River to Deschutes River)
8. Deschutes River (Deschutes River mouth area)
9. The Dalles/Celilo (The Dalles/Celilo area)
10. Klickitat River (Klickitat River mouth area)
11. White Salmon/Cascade Locks (from White Salmon River to Bonneville Dam)
12. Lower River (from Bonneville Dam to Columbia River mouth)

Doses resulting from eating shellfish from Willapa Bay and from salmon and steelhead caught at any location in the Columbia River were also calculated.

Specific information relating to exposure must be supplied by each person for whom a radiation dose is to be calculated. The information to be supplied for use in the CRD program includes:

a. river use: swimming (hours/month)
b. river use: boating (hours/month)
c. untreated drinking water ingestion (Literdmonth)
d. treated drinking water ingestion (Liters/month)
e. resident fish (omnivore) ingestion (kilogram/month — a kilogram is about 2.2 pounds)
f. resident fish (first-order predator) ingestion (kg/month)
g. resident fish (second-order predator) ingestion (kg/month)
h. waterfowl ingestion (kg/month)
i. Willapa Bay shellfish ingestion (kg/month)
j. Columbia River anadromous fish (salmon/steelhead) ingestion (kg/month)

Doses from Radioactive Materials Released to the Columbia River

Detailed dose estimates for the time period of largest releases (1950-1971) were calculated on a monthly basis for three types of individuals at 12 distinct locations along the Columbia River. The doses during this time period were found to be the largest because of radioactive material releases during those years. These doses are estimated with the greatest detail. Doses were calculated for two specific organs — red bone marrow and the lower large intestine — and for the effective dose equivalent (whole body dose). Doses are calculated for five radioactive materials: sodium-24, phosphorus-32, zinc-65, arsenic-76, and neptunium-239. In order to show relative dose, this report provides annual doses for a maximally exposed individual at the highest impact location during these years.

Radiation doses were much lower during 1944-1949 and 1972-1992. Screening calculations (a dose calculated using the least favorable assumptions) were performed for 1944 through 1949. Previously published Hanford annual reports were consulted to complete the dose history for the years 1972 through 1992. The screening calculations and doses obtained from the annual reports were performed for a single maximum impact location.

For 1950-71, the Project estimated doses that could have been received by three types of representative persons as a result of radioactive material releases to the Columbia River from Hanford. The first (or maximum) representative person is assumed to have been a significant user of the river. This person had maximum or near maximum ingestion rates for resident fish and spent time in or on the river. The second (typical) representative person is characteristic of the average person residing near the Columbia River. No resident fish were eaten by this type of person. Doses for persons of this second type who did eat fish can be inferred from the doses calculated for the first representative person.

The third (occupationally exposed) representative person is one who is assumed to have been exposed by the nature of his or her work. This person could have been a ferry or barge worker or someone who spent a lot of time on the river, but who ate little to no fish or waterfowl. Dose estimate calculations for the three types of representative persons include doses contributed by six different exposure pathways:

- drinking water ingestion
- resident fish ingestion
- shellfish ingestion
- waterfowl ingestion
- salmon ingestion
- external exposure (swimming and shoreline)

There was a moderate reduction in radioactive materials in drinking water after treatment in a municipal treatment system. This factor was considered in the dose estimates. An untreated drinking water pathway is also included where no such reduction is assumed. Four separate Columbia River dose assessments all indicate that annual doses to most individuals from river pathways are less than a few millirem in all years and for all locations. Only those individuals who ingested large quan-

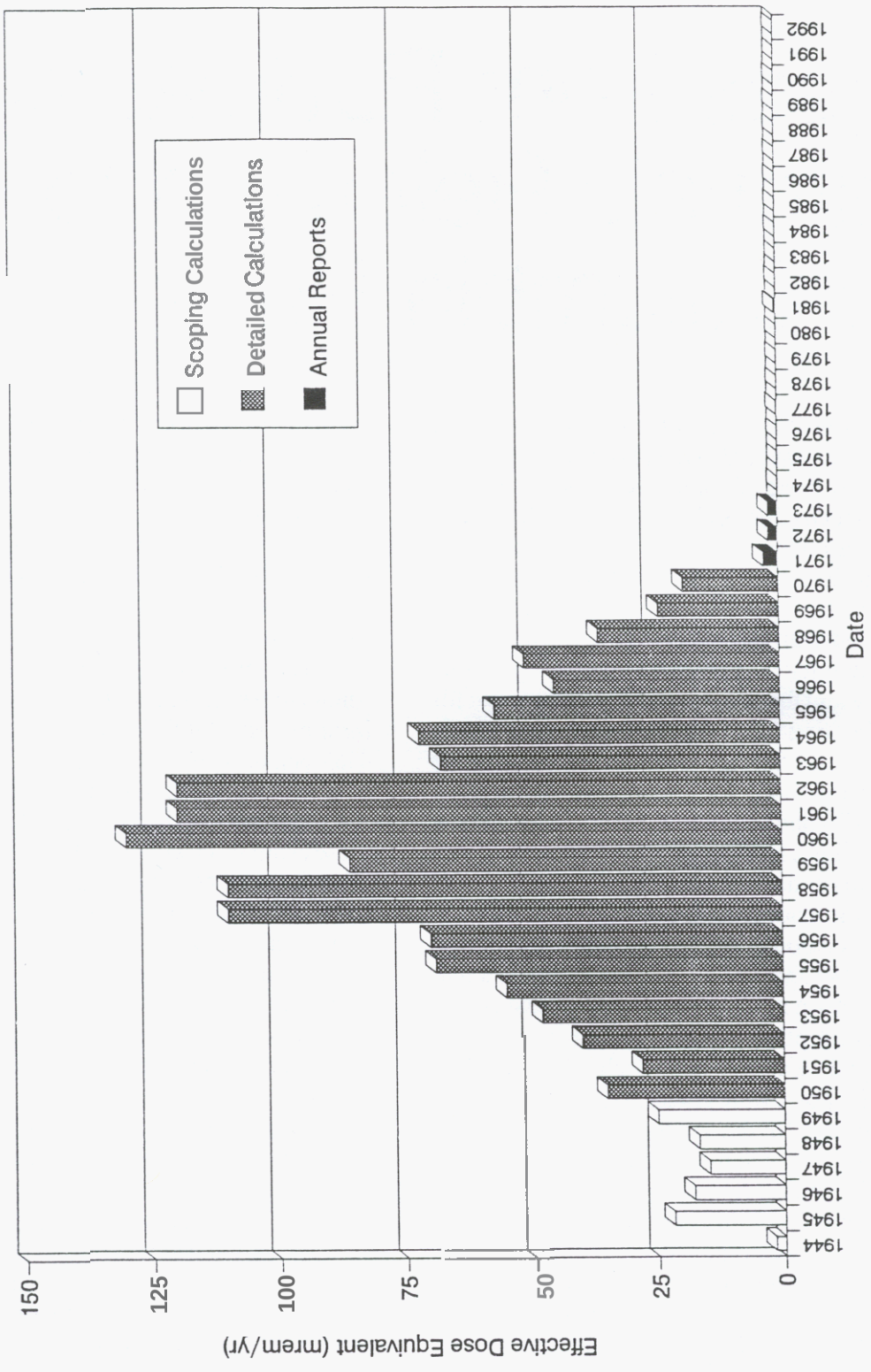


Figure 23. Dose History for a Maximum Representative Individual at Richland, Washington, 1944–1992

tities of resident fish could have received annual doses in excess of a few hundred millirem.

A complete dose history for a maximally exposed person at Richland, Washington, is shown in Figure 23 (page 48). The cumulative dose for this representative person for the years 1944-92 is estimated to be about 1,500 millirem (1.5 rem). A single ten-year period (1956-65) accounted for most of this cumulative dose. The effective dose equivalent during these ten years is about 1,400 millirem (1.4 rem). The dose to this person from this source for all other years combined is about 100 millirem.

The doses calculated for locations near Hanford are larger than those farther downriver by as much as two to ten times higher, depending on the month and type of exposed individual. The decrease in dose to downriver individuals is due to increased dilution and to radiological decay of key radionuclides during transport. The predicted doses for the Tri-Cities area in Washington match well with actual whole body radioactivity measurements collected during the 1960s.

Figure 24 (at left) shows the contribution to the total effective dose equivalent from the 11 radionuclides for 1944–1971. These percentage contributions were determined from the final dose calculations. The top five radionuclides contributed 94 percent of the total dose and were used in the detailed dose calculations.

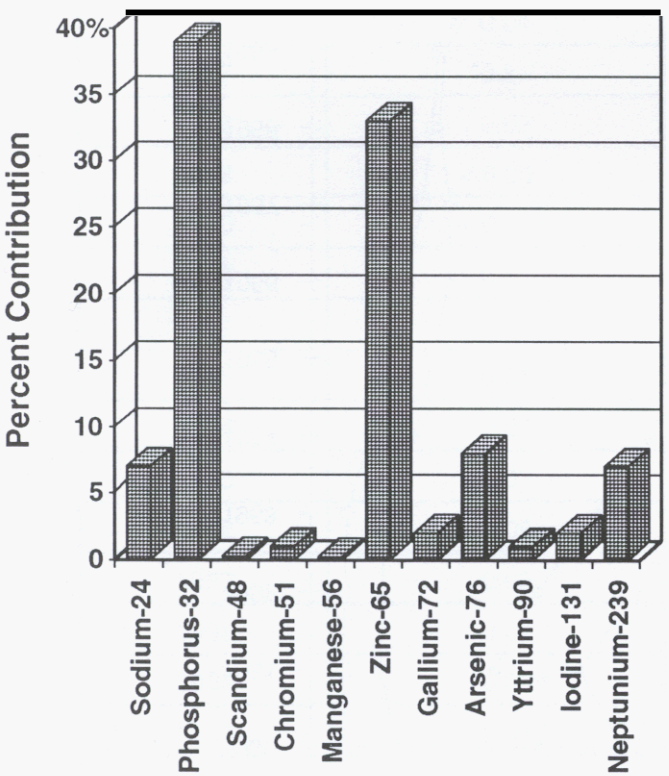


Figure 24. Contribution to Total Effective Dose Equivalent for a Maximum Representative Individual at Richland, Washington, 1944–1971

Doses from 1944-49

Year	EDE (mrem/yr)	Key Pathway	Radionuclide
1944	2	fish	zinc-65, phosphorus-32
1945	22	fish	zinc-65, phosphorus-32
1946	18	fish	zinc-65, phosphorus-32
1947	15	fish	zinc-65, phosphorus-32
1948	17	fish	zinc-65, phosphorus-32
1949	25	fish	zinc-65, phosphorus-32

Table 2 (above) presents the doses to a maximum representative person at Richland for the years 1944-49. Doses to all representative persons at all locations were dominated by the ingestion of fish containing zinc-65 and phosphorus-32. Table 2 shows that the effective dose equivalent ranged from 2 mrem/yr in 1944 to 25 mrem/yr in 1949.

Doses from 1950-71

The doses calculated for 1950 through January 1971 are the most detailed. They were performed on a monthly basis using detailed estimates of source term, river transport, and human exposure. The dose estimates were performed on a monthly basis in order to maximize the detail included in the dose calculations and to account for the seasonal changes. Radioactive material concentrations in the river, bioconcentration factors, and human in-

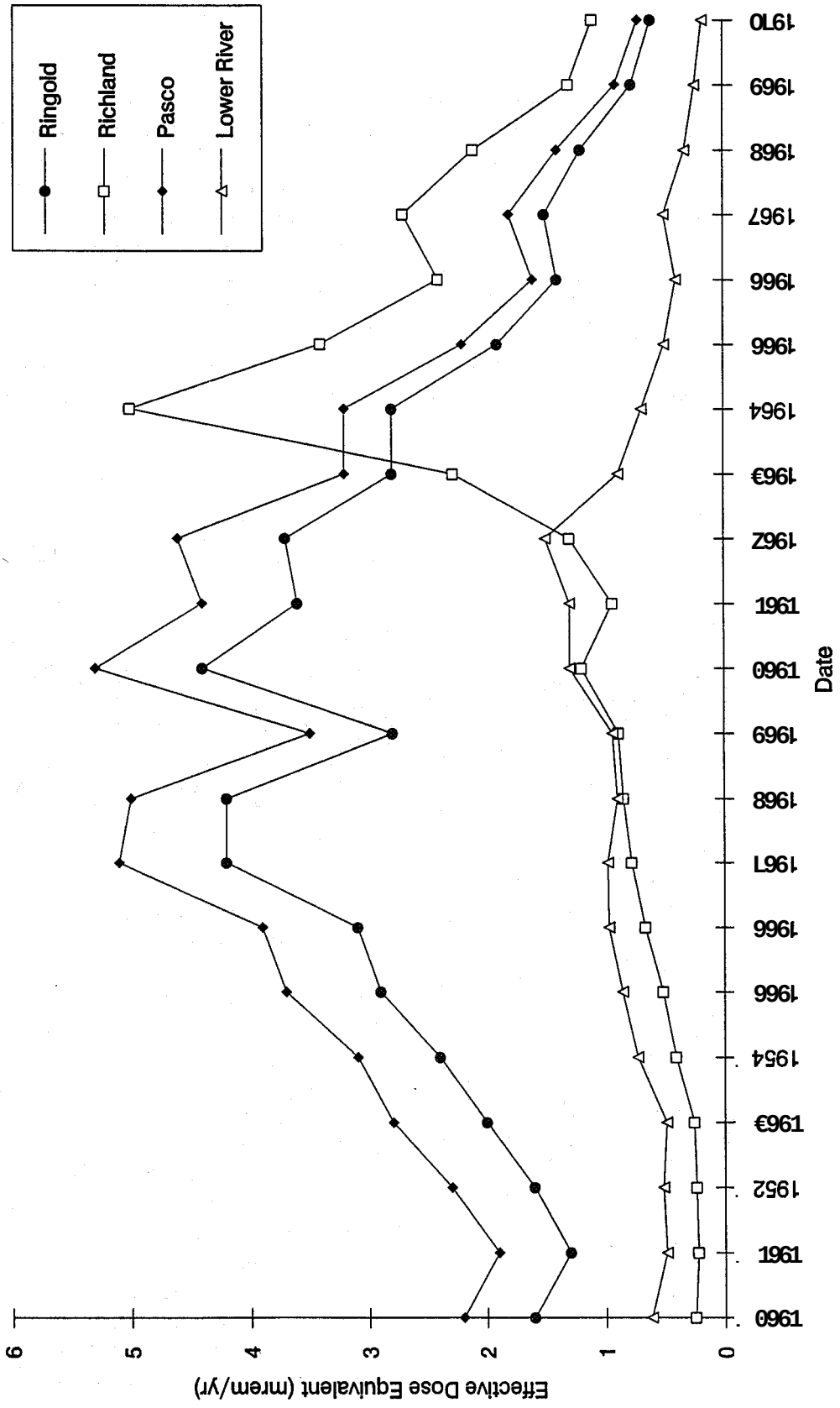


Figure 25. Annual Doses to a Typical Representative Individual at Selected Columbia River Locations, 1950–1970

gestion and exposure characteristics are all highly dependent on the month of the year.

Figures 25 (page 50), 26 (page 52), and 27 (page 53) show estimated doses for the three representative person types at selected locations. Doses at each successive downriver location decrease as radioactive decay and river dilution decrease the local radioactive material concentrations. Doses are greatest for the maximum person and lowest for the typical person. The doses peak during the late 1950s and early 1960s, the period of greatest radioactive material releases to the Columbia River. The decrease in annual dose in 1959 was a result of slightly lower radioactive material releases and increased river flow during that year. These two factors combined to produce dose estimates that were 50 percent lower for 1959 than for either 1958 or 1960.

Doses for a typical person at Richland took a sharp increase in late 1963 when the city changed its municipal water source from the Snake River to the Columbia River. prior to that time, river doses in Richland had been among the lowest for a typical person. From 1963 on, doses in Richland were higher than for any other location.

The doses shown in Figures 25 through 27 are the total doses summed over a number of pathways and radioactive materials and given as effective dose equivalents.

Year	Maximum Individual Total Body or EDE (mrem)
1971	c 3
1972	< 2
1973	2
1974	0.03
1975	0.012
1976	0.04
1977	*0.2*
1978	*0.03*
1979	< 0.09
1980	< 0.1
1981	0.4
1982	0.1
1983	0.01
1984	0.057
1985	0.07
1986	0.05
1987	*0.03*
1989	0.039
1990	0.016
1991	0.009
1992	*0.02*

Doses from 1971-1992

Annual, publicly available reports summarizing environmental monitoring and off-site radiation impacts have been prepared by Hanford contractors every year since 1957. Each report contains an estimate of the radiation dose to a maximum exposed person for the year.

Doses for 1971 through 1992 are presented in Table 3 (at left). The most recent Hanford annual environmental monitoring report available is for 1992. The report for 1993 will be available in 1994. Dose estimates after 1972 are significantly lower than estimates made for the peak dose years of 1955-1965. Doses dropped significantly after the shut-down of the last single-pass production reactor in January 1971. N-Reactor releases during the mid-1980s resulted in doses of a few millirem per year.

Complete Dose History

Dose results from the three. dose estimation approaches (scoping calculations, detailed dose calculations, and doses obtained from annual reports) are combined and presented in table form below (summarized by period). Over 93 percent of the total dose occurred

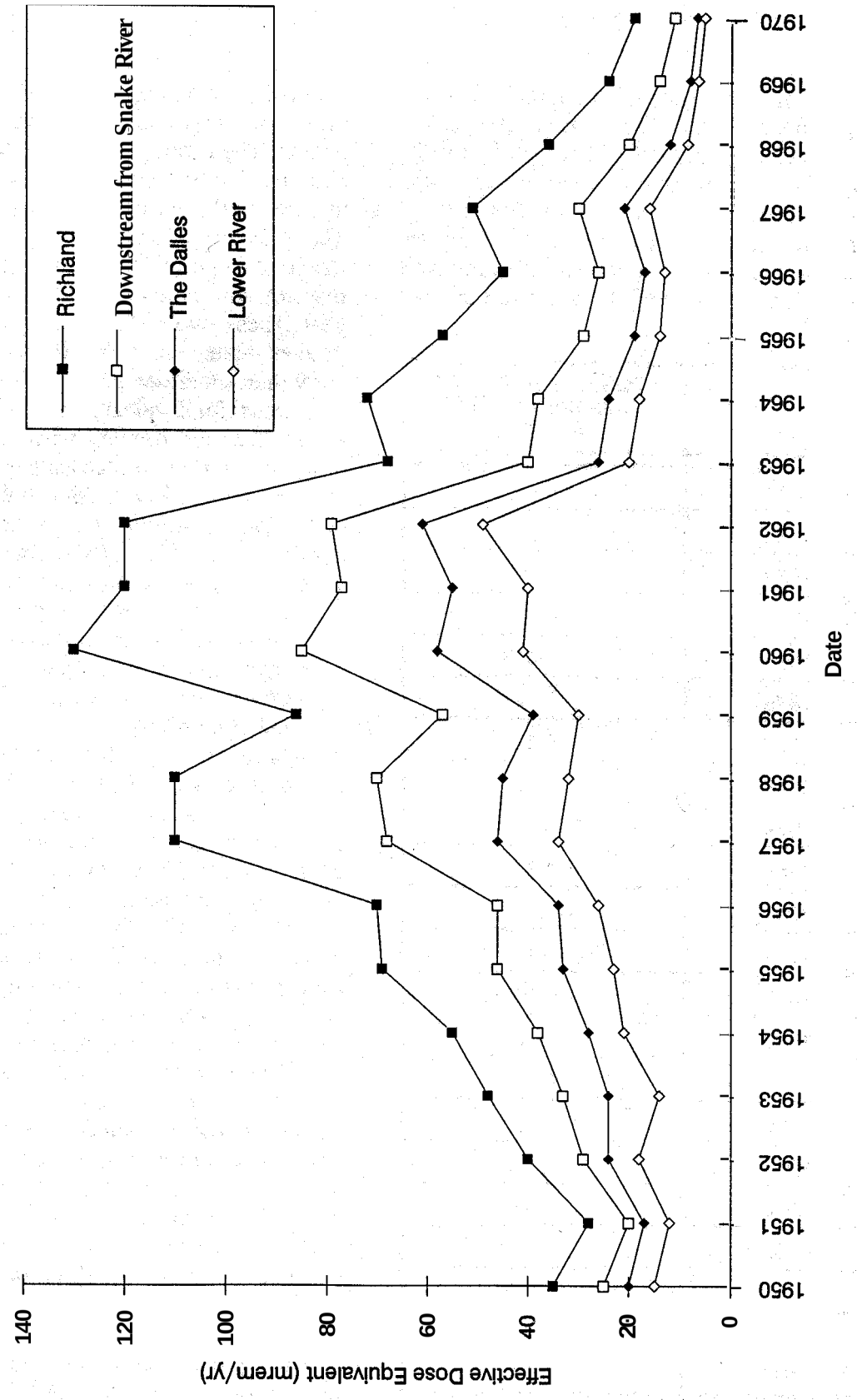


Figure 26. Annual Doses to a Maximum Representative Individual at Selected Columbia River Locations, 1950–1970

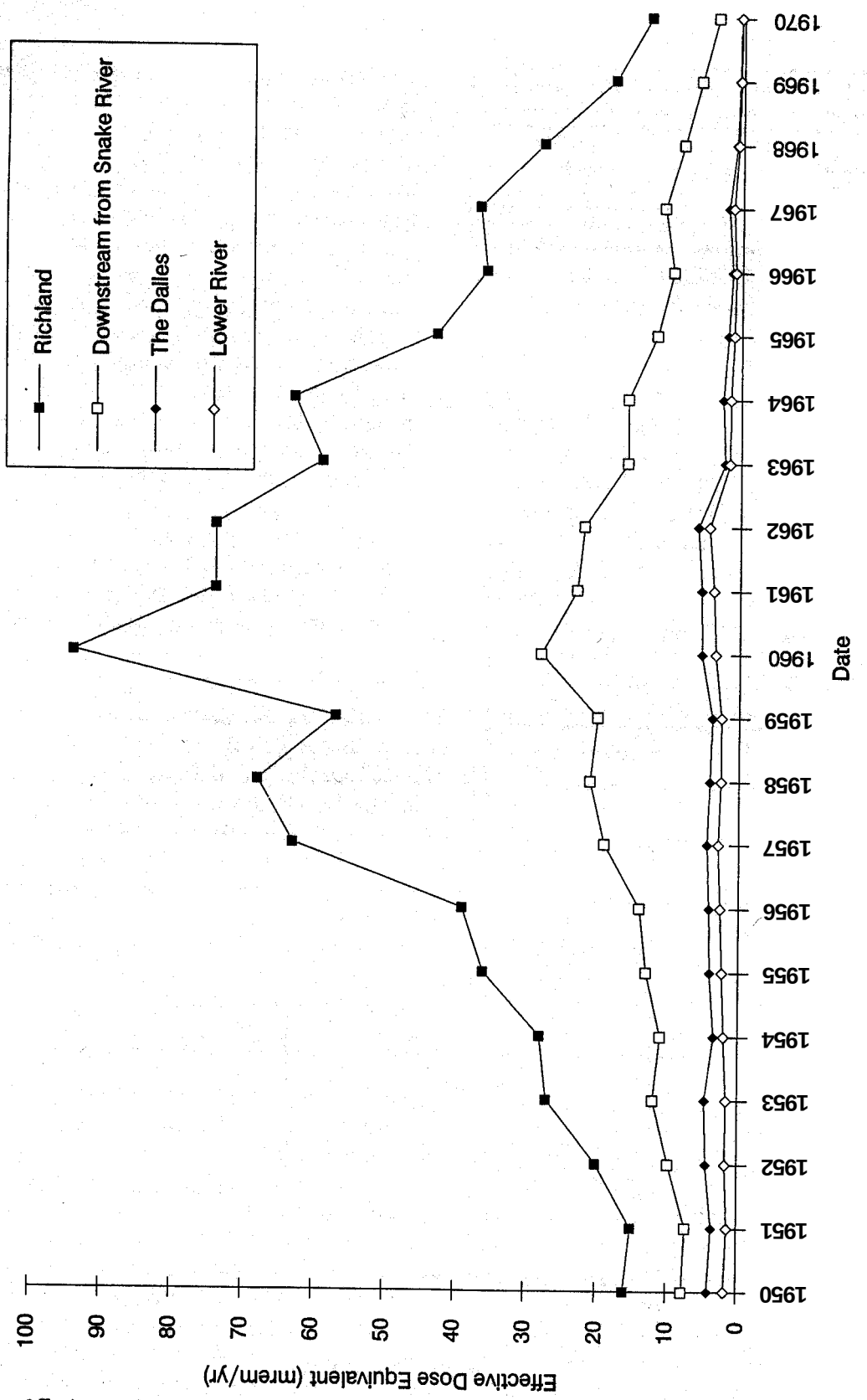


Figure 27. Annual Doses to an Occupational Representative Individual at Selected Columbia River Locations, 1950-1970

Period	Estimated Dose (mrem)
1944-1949	99
1950-1971	1,400

tive person would be about 10- to 40-times lower than those received by a maximum representative person. Doses for an occupationally exposed representative person would be about three times lower than those received by a maximum representative person.

Pathways Contributing to Dose

The pathways contributing to river dose varied depending on the representative person types and location. For example, at Pasco, the largest contribution to maximum person dose came from eating resident fish containing zinc-65 and phosphoms-32. The largest contribution to typical person dose came from the ingestion of treated drinking water containing neptunium-239, zinc-65, sodium-24, and arsenic-76. The largest contribution to occupationally exposed person dose came from external exposure to sodium-24.

Similar pathways dominated the doses calculated for persons located downstream. Contributions from fish ingestion dominated the dose received by maximum persons. Contributions from drinking water dominated the dose re-

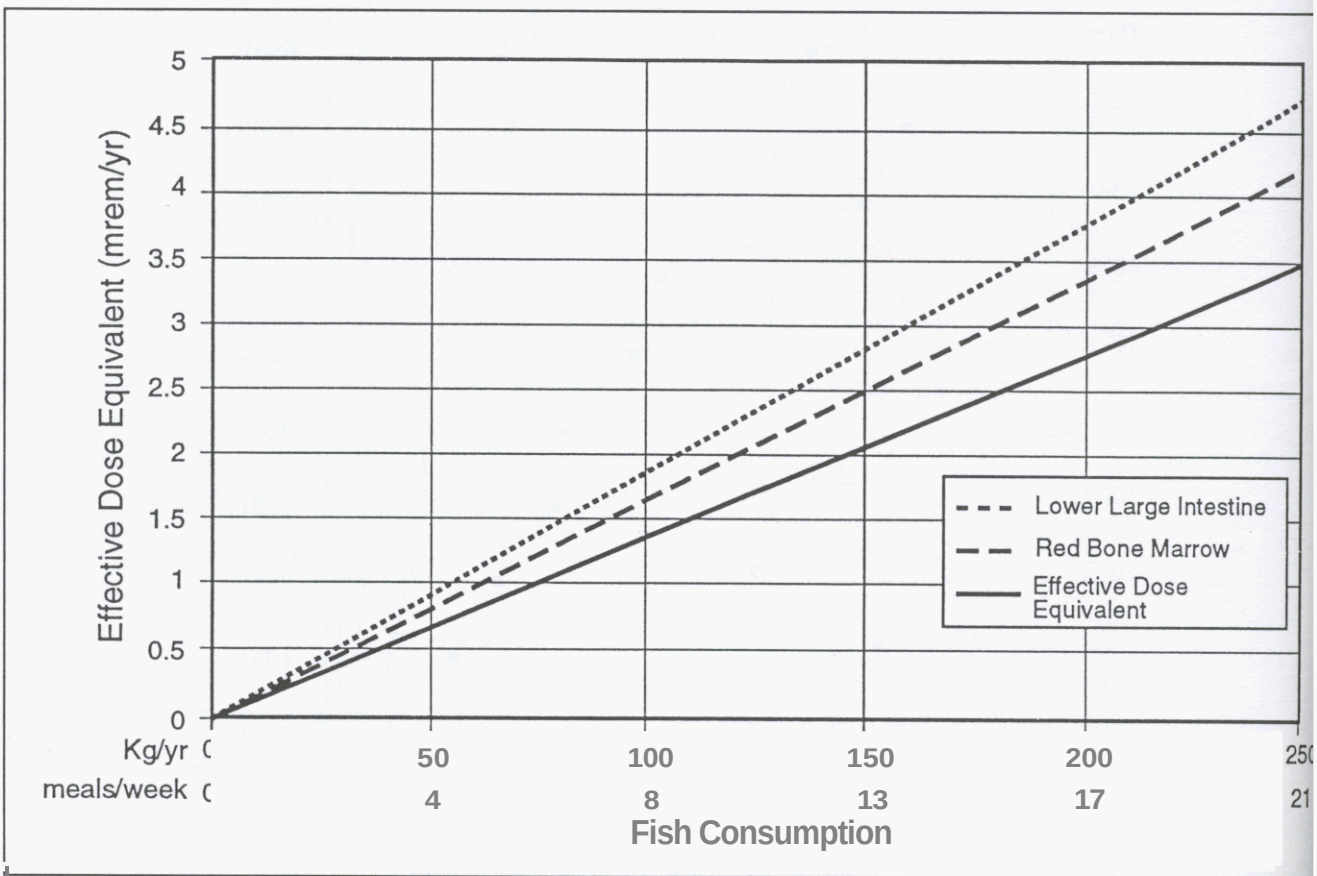


Figure 28. Dose from Consumption of Salmon or Steelhead Using Historical Monitoring Data

ceived by typical and occupationally exposed persons. Eating shellfish from Willapa Bay accounted for 40 percent of the effective dose equivalent to a typical person below the Bonneville Dam. However, a 10-year total effective dose equivalent (1956-65) for such a person was only about 4 millirem (0.4 millirem per year).

Different radioactive materials dominated the effective dose equivalent at different locations. For example, river doses calculated for Pasco show a higher contribution from sodium-24 and arsenic-76 than those calculated for downriver locations. This is due to the short half-life of sodium-24 and arsenic-76. Radioactive decay resulted in lower concentrations of these two radioactive materials in the river downstream of Pasco. Zinc-65 and phosphorus-32 contribute the most to doses at locations downriver from Pasco.

Doses from Salmon and Steelhead

The TSP determined that not enough monitoring data exists on radioactive material concentrations in Columbia River salmon and steelhead to calculate doses resulting from ingestion of these fish over the 1944–1971 time period. Therefore, doses have been calculated using two methods. The first approach relies on the monitoring data collected in the 1960s through 1970. The second approach assumes that salmon and steelhead spend their entire lives in the Columbia River and accumulate radioactive materials as do resident species. This second approach provided an upper limit for doses from ingestion of salmon and steelhead.

Figure 28 (page 54) shows the rem effective dose equivalents resulting from salmon or steelhead ingestion calculated using the first method. For example, the dose to the red bone marrow from ingestion of 330 lb/yr (150 kg/yr) would have been about 2.5 millirem per year.

The rem effective dose equivalent was less than 3.5 mrem/yr for ingestion of up to 550 pounds of fresh salmon per year. The doses were calculated with the assumption that all fish were ingested fresh. If the fish were dried and stored for several months, the doses would have been lower by about 5 percent per month.

Doses calculated using the second method were considerably higher. These dose estimates are shown in Table 5 (below). For

Units	Consumption Rate					
Kg/yr	10	50	100	150	200	250
lb/yr	22	110	220	330	440	550
lb/month	2	9	18	28	37	46
Meals/wk	1	4	8	13	17	21

Year	Effective Dose Equivalent (millirem per year)					
1950	7	35	70	110	140	180
1951	6	32	63	95	130	160
1952	10	50	100	150	200	250
1953	10	50	100	150	200	250
1954	11	55	110	170	220	280
1955	17	85	170	260	340	430
1956	13	65	130	200	260	330
1957	23	115	230	350	460	580
1958	25	125	250	380	500	630
1959	15	75	150	230	300	380
1960	23	115	230	350	460	580
1961	19	95	190	290	380	480
1962	23	115	230	350	460	580
1963	14	70	140	210	280	350
1964	12	60	120	180	240	300
1965	14	70	140	210	280	350
1966	11	55	110	170	220	280
1967	11	55	110	170	220	280
1968	7	36	72	110	140	180
1969	5	26	51	77	100	130
1970	5	26	51	77	100	130

Table 5. Annual Dose from Consumption of Salmon or Steelhead at Ringold. (One meal is 1/2 pound.)

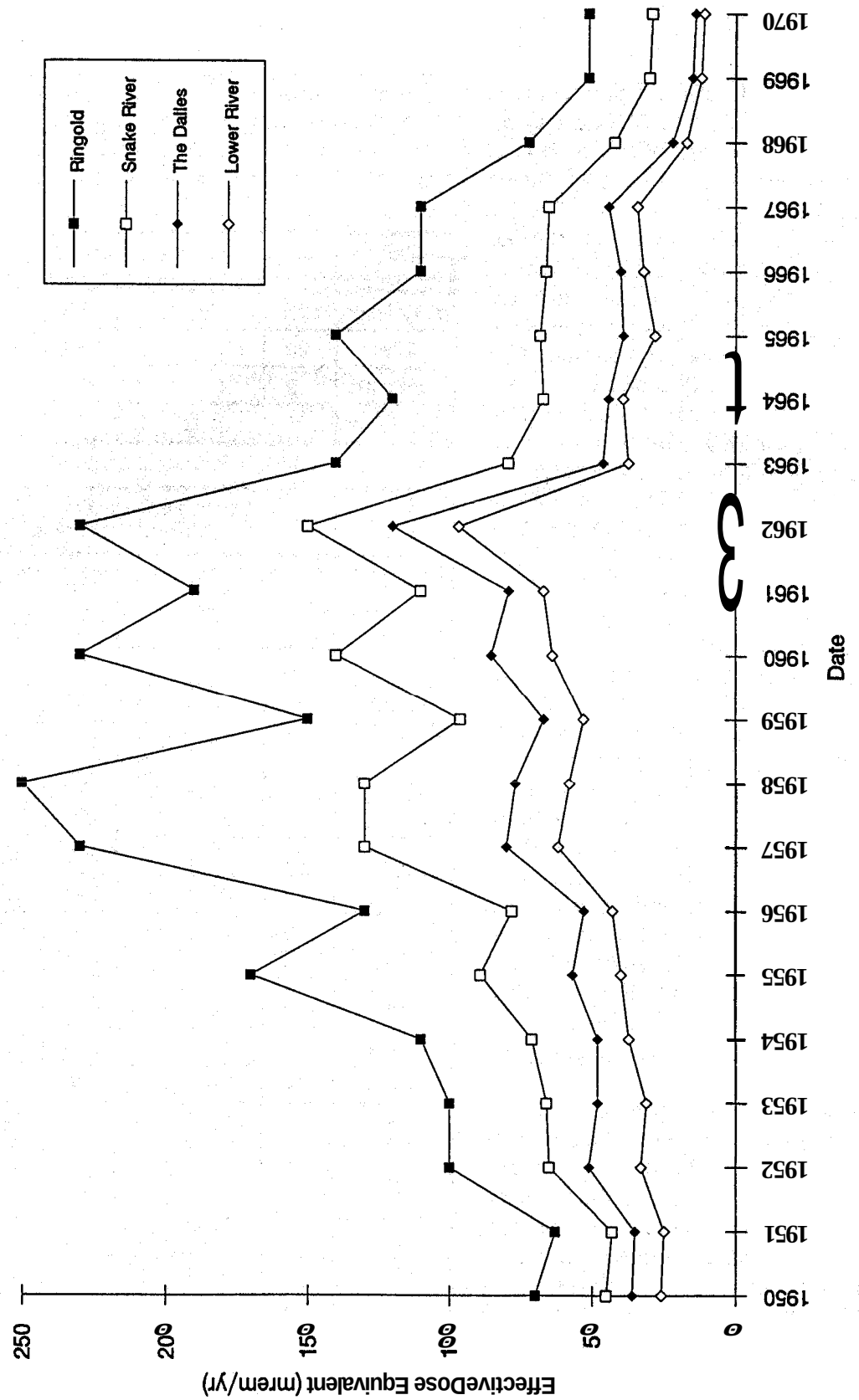


Figure 29. Dose from Consumption of 220 pounds/yr of Salmon or Steelhead at Selected Locations, 1950–1970

example, the rem effective dose equivalent from the ingestion of 220 pounds (100 kg) of salmon or steelhead in 1961 would be about 190 mrem/yr. Because this approach is location- and time-dependent, Table 5 shows the dose at a specific location (Ringold) for all years (1950-1970). The table shows that the largest dose from this pathway occurred in 1958. It could have been as high as 630 mrem/yr from the ingestion of over 500 pounds of salmon or steelhead.

Figure 29 (page 56) shows the doses that persons may have received from ingestion of fish from other locations. Doses are shown for several locations for the years 1950 through 1970. These doses were calculated using the second method (assumption that salmon and steelhead accumulate radioactive materials in a manner similar to that of resident fish). Doses were highest at Ringold and lowest in the lower river, where they were about 20 to 30 percent of those at Ringold. All doses were calculated assuming an ingestion rate of 220 pounds of salmon/steelhead per year.

The doses shown in Figure 29 can be considered representative of doses from salmon ingestion in tributaries of the Columbia River. For instance, salmon that migrate to the upper reaches of the Snake River can be conservatively assumed to have given the same dose as those at the mouth of the Snake River. The doses from ingestion of salmon from other tributaries can be determined using the dose for the location nearest the tributary confluence. Salmon caught above Ringold would not have concentrations of radioactive materials higher than at Ringold.

Shellfish

The dose from eating oysters from Willapa Bay on the coast of Washington State is shown in Table 6 (at right). For example, the rem effective dose equivalent from eating 22 pounds of oysters in 1954 would be about 6 millirem per year. The largest dose occurred in 1962 and could have been as high as 26 mrem/yr from eating over 44 pounds of oysters.

Units	Consumption Rate			
Kg/yr	5	10	12	20
lb/yr	11	22	33	44
Ounces/week	3	7	10	14

Year	Effective Dose Equivalent (mrem/yr)			
1950	2	4	6	8
1951	1	3	4	6
1952	1	2	4	5
1953	1	2	3	5
1954	3	6	9	12
1955	4	7	11	14
1956	4	8	13	17
1957	4	7	11	15
1958	4	7	11	14
1959	4	9	13	17
1960	6	11	17	23
1961	5	10	15	20
1962	6	13	19	26
1963	6	12	18	24
1964	4	7	11	15
1965	3	5	8	10
1966	2	4	6	8
1967	2	4	6	6
1968	2	3	5	7
1969	1	3	4	5
1970	1	2	3	3

Table 6. Annual Dose from Consumption of Willapa Bay Oysters (Residents of other costal areas should use Willapa Bay doses).

Appendix 1

Sources of Additional Information

A Guide to Environmental Monitoring Data, 1944 through 1971. 1994. PNWD-2226.

Air Pathway Report: Phase I of the Hanford Environmental Dose Reconstruction Project. 1991. PNL-7412, Rev.1.

Atmospheric Pathway Dosimetry Report, 1944-1992. 1994. PNWD-2228.

Columbia River Pathway Dosimetry Report 1944-1992. 1994. PNWD-2227.

Columbia River Pathway Report - Phase I of the Hanford Environmental Dose Reconstruction Project, 1991. PNL-7411, Rev. 1.

Commercial Milk Distribution Profiles and Production Locations. 1993. PNWD-2218.

Commercial Production and Distribution of Fresh Fruits and Vegetables: A Scoping Study on the Importance of Produce Pathways to Dose. 1992. PNWD-2022.

Conversion and Correction Factors for Historical Measurements of Iodine-131 in Hanford-Area Vegetation, 194547.1993. PNWD-2133.

Conversion and Correction Factors for Historical Measurements of Iodine-131 in Hanford-Area Vegetation, 1948-51.1993. PNWD-2176.

Determination of Key Radionuclides and Parameters Related to Dose from the Columbia River Pathway. 1993. BN-SA-3768.
1994. PNWD-2221.

Determination of Radionuclides and Pathways Contributing to Cumulative Dose. 1992. BN-SA-3773.

Determination of Radionuclides and Pathways Contributing to Dose in 1945.1992. BN-SA-3774.

Dose Modeling Approach. 1994. PNWD-1983.

Estimation of 1945 to 1957 Food Consumption. 1993. PNWD-2113.

HEDR Modeling Approach. 1994. PNWD-1983, Rev.1.

Iodine–131 in Vegetation Collected Near the Hanfod Site: Concentration and Count Data for 1948-1951. 1993. PNWD-2177.

Iodine–131 Releases from the Hanfod Site, 1944 through 1947.1993. PNWD-2033.

Literature and Data Review for the Surface-Water Pathway: Columbia River and Adjacent Coastal Areas. 1992. PNWD-2034.

Parameters Used in the Environmental Pathways and Radiological Dose Modules (DESCARTES, CIDER, and CRD Codes) of the Hanford Environmental Dose Reconstruction Integrated *codes* (HEDRIC). 1994. PNWD-2023 Rev. 1.

Phase I Summaries of Radionuclide Concentration Data for Vegetation. River Water, Drinking Water, and Fish. 1993. PNWD-2145.

Radionuclide Releases to the Atmosphere from Hanford Operations, 1944-72. 1994. PNWD-2222.

Radionuclide Releases to the Columbia River from Hanford Operations, 1944-1971. 1994. PNWD-2223.

Reconstruction of Radionuclide Concentrations in the Columbia River from Hanford, Washington to Portland, Oregon, January 1950-January 1971. 1994. PNWD-2225.

Regional Atmospheric Transport *Code* for Hanford Emission Tracking (RATCHET). 1994. PNWD-2224.

Selection of Dominant Radionuclides for Phase I of the Hanford Environmental Dose Reconstruction Project. 1991. PNL-7231.

Uncertainty and Sensitivity Analyses Plan. 1993. PNWD-2124.

Uncertainty and Sensitivity Analysis of Historical Measurements of Iodine-131 for Vegetation in 1945-47. 1994. PNWD-1978.

Validation of HEDR Models. Integrated Task Plans for the Hanford Environmental Dose Reconstruction Project, June 1992 through May 1994.1993. PNWD-2187.

Appendix 2

Year	Iodine-131	Ruthenium-103	Ruthenium-106	Strontium-90	Plutonium-239	Cerium-144
1944	2,140	.485	.0351	.0208	.00120	1.57
1945	555,000	87.4	12.2	6.94	.385	460
1946	96,300	87.2	17.9	10.5	.581	650
1947	31,900	51.3	12.2	7.38	.410	451
1948	1,840	11.8	4.61	2.94	.164	167
1949	8,690	.424	.186	.115	.00626	6.15
1950	5,380	.811	.347	.195	.0103	10.4
1951	27,400	2.37	.580	.281	.0145	16.9
1952	5,110	32.2	11.1	.400	.0133	23.3
1953	1,750	266.	88.9	.517	.0148	31.0
1954	827	485.	168.	.672	.0211	40.7
1955	671	6.87	2.00	.784	.0252	43.3
1956	118	5.76	2.63	1.24	.0139	72.9
1957	274	12.6	4.58	1.90	.0147	119
1958	822	16.6	4.38	1.98	.0112	130
1959	227	15.2	5.27	2.30	.00836	144
1960	232	16.6	5.84	2.58	.00717	162
1961	92.4	15.0	6.16	2.81	.113	172
1962	28.7	9.13	5.39	2.59	.00908	151
1963	77.5	7.53	5.10	2.47	.0112	140
1964	11.2	9.26	5.77	2.85	.0151	161
1965	6.08	7.84	5.40	2.71	.0141	154
1966	9.10	5.41	4.75	2.45	.0183	128
1967	1.28	3.82	4.35	2.12	.000509	107
1968	.0213	1.97	4.78	2.18	.000508	103
1969	.00133	.731	3.61	1.74	.000395	72.8
1970	.00110	.195	.887	.416	.0000924	17.2
1971	.0000632	.112	1.14	1.09	.000252	30.3
1972	.0000000000625	.00485	1.17	.108	.0000319	3.55
SUM	739,000.	1,160.	388.	64.3	1.78	3,770

Annual Summary of Five Radioactive Materials Released to the Columbia River from Hanford 1944-71 (in curies)

Year	Sodium-24	Phosphorus-32	Zinc-65	Arsenic-76	Neptunium-239
1944	900	200	700	1,200	17,100
1945	35,000	2,900	10,500	20,300	192,100
1946	28,000	2,200	8,700	14,200	153,400
1947	25,000	1,900	7,500	12,300	127,800
1948	34,000	2,200	8,400	15,800	151,100
1949	47,000	3,200	11,700	24,700	214,600
1950	73,000	4,000	14,500	30,500	279,900
1951	99,000	3,300	11,200	23,700	261,700
1952	133,000	5,000	9,000	34,700	259,000
1953	203,000	8,700	8,700	98,900	316,200
1954	243,000	7,300	21,900	91,400	391,600
1955	318,000	7,200	26,700	139,500	419,400
1956	408,000	7,700	32,000	134,300	450,300
1957	645,000	12,300	27,600	212,100	500,100
1958	751,000	18,500	27,200	293,300	422,300
1959	1,019,000	18,000	32,000	218,400	275,100
1960	1,383,000	19,500	42,700	236,900	354,800
1961	1,096,000	21,500	47,100	166,900	243,900
1962	1,094,000	13,800	56,000	86,700	257,100
1963	888,000	11,700	14,900	100,600	211,800
1964	960,000	12,300	15,700	114,500	247,500
1965	765,000	12,100	13,400	124,600	168,400
1966	613,000	7,400	9,700	74,600	79,000
1967	672,000	10,100	15,400	94,000	115,000
1968	500,000	8,600	7,800	71,700	99,800
1969	359,000	5,500	6,500	61,300	59,800
1970	178,000	1,800	3,400	20,300	36,900
1971	13,000	235	386	2,400	3,500
SUM	12,600,000	230,000	491,000	2,520,000	6,310,000

Appendix 3

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