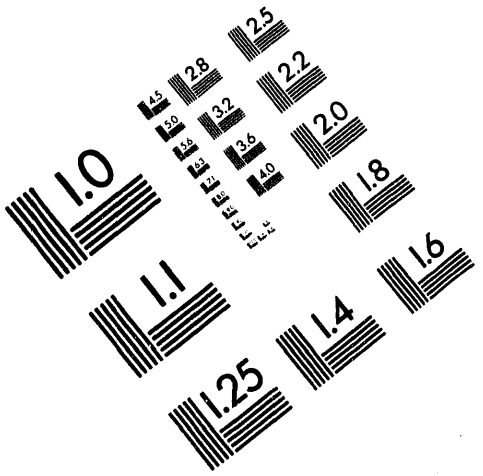

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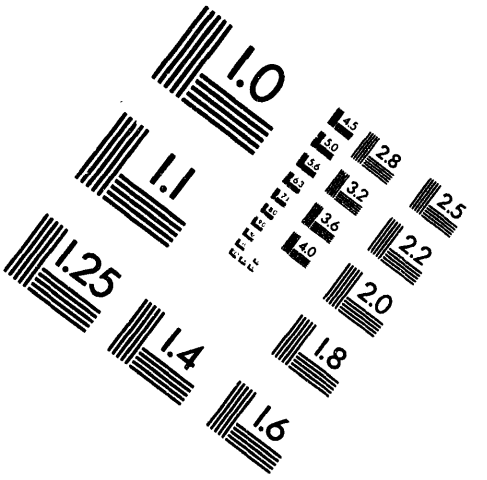

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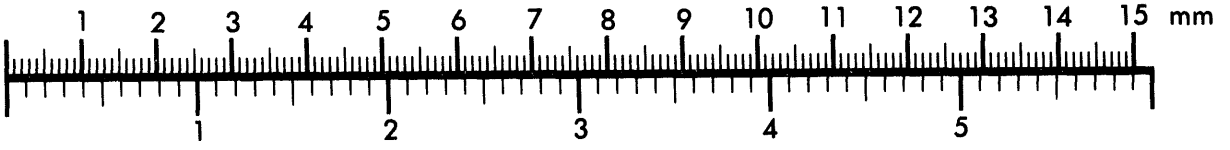

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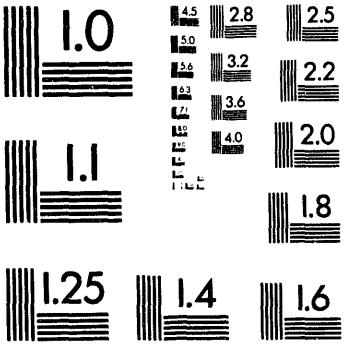

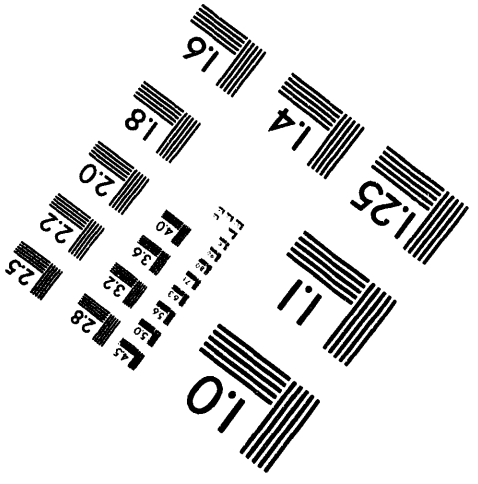

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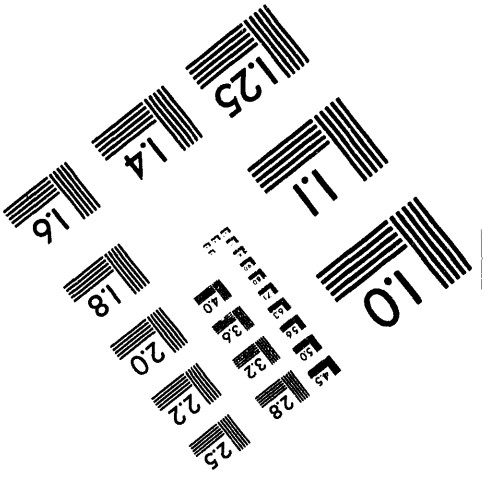

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# RADIATION DOSES FROM HANFORD SITE RELEASES TO THE ATMOSPHERE

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# RADIATION DOSES FROM HANFORD SITE RELEASES TO THE ATMOSPHERE

W. T. Farris, B. A. Napier, T. A. Ikenberry*

*Abstract* - Radiation doses to individuals were estimated for the years 1944-1992. The dose estimates were based on the radioactive releases from the Hanford Site in south central Washington. Conceptual models and computer codes were used to reconstruct doses through the early 1970s. The published Hanford Site annual environmental data were used to complete the dose history through 1992. The most significant exposure pathway was found to be the consumption of cow's milk containing iodine-131. For the atmospheric pathway, median cumulative dose estimates to the thyroid of children ranged from < 0.1 to 235 rad throughout the area studied. The geographic distribution of the dose levels was directly related to the pattern of iodine-131 deposition and was affected by the distribution of commercial milk and leafy vegetables. For the atmospheric pathway, the highest estimated cumulative effective dose equivalent (EDE) to an adult was estimated to be 1 rem at Ringold, Washington for the period 1944-1992. For the Columbia River pathway, cumulative EDE estimates ranged from < 0.5 to 1.5 rem cumulative dose to maximally exposed adults downriver from the Hanford Site for the years 1944-1992. The most significant river exposure pathway was consumption of resident fish containing phosphorus-32 and zinc-65.

Key words: atmosphere, Columbia River, dose reconstruction, Hanford, radiation.

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## INTRODUCTION

The purpose of the Hanford Environmental Dose Reconstruction (HEDR) Project was to estimate radiation doses to individuals. The doses resulted from releases of radionuclides during the period of 1944-1992 from the Hanford Site in south-central Washington State. To estimate radiation doses, the quantity of radioactivity released and transported was estimated, and models to simulate uptake and movement of radionuclides in the environment were developed. The subsequent dose estimates include uncertainties associated with facilities operations, environmental monitoring, demography, food consumption, lifestyles, and the variability of natural phenomena.

Dose were estimated for two exposure pathways: atmospheric and surface water (Columbia River). For the atmospheric pathway, radiation doses were reconstructed for 1944-1972. For the Columbia River pathway, radiation doses were reconstructed for 1944-1971. Dose estimates in Hanford Site annual environmental reports were used to complete the dose history for both pathways through 1992. The primary focus of this paper is the presentation of the results of dose calculations. Detailed discussions of the dose estimation methods used have been documented in the publications referenced in this article.

For 1944-1951, the maximum years of iodine-131 releases (Heeb 1994), absorbed thyroid doses from iodine-131 exposure were estimated using computer models. Dose estimates were made for 12 categories of representative individuals distinguished by age, sex, and lifestyle, for 1102 locations in the study area. The study area was the 200,000-square-kilometer area surrounding the Hanford Site (Fig. 1). For 1944-1972, doses from five additional key radionuclides were estimated for a maximum representative adult at several locations. In addition to iodine-131, the other radionuclides from which doses were estimated were strontium-90, ruthenium-103, ruthenium-106, cerium-144, and plutonium-239.

Phosphorus-32 and zinc-65 exposure from the consumption of fish contributed most to the Columbia River pathway dose. For January 1950 through January 1971, the maximum years of radionuclide releases to the Columbia River (Heeb and Bates 1994), dose equivalents for the red bone marrow and lower large intestine as well as the effective dose equivalent were estimated on a monthly basis using a computer model. For 1944-1949, less detailed annual calculations were used to provide the reconstructed radiation doses. The radionuclides reconstructed for the Columbia River pathway were sodium-24, phosphorus-32, zinc-65, arsenic-76, and neptunium-239. The estimates were calculated for three representative individuals with distinctly different lifestyle patterns.

The study area for the Columbia River pathway began at Priest Rapids Dam just before the river flows through the Hanford Site and ended below Portland, Oregon near the mouth of the river. The concentrations of radionuclides were estimated for 12 locations along the Columbia River. Fig. 2 shows the domain of the Columbia River pathway the Hanford Site, and the locations used for reconstruction of radionuclide concentrations.

## DOSE ESTIMATION APPROACH

The methods used to estimate dose as documented in (Shipler and Napier 1994) have the ability to accept actual life-style information from real individuals. To estimate potential doses to large cross-sections of the affected population, life-style information for representative individuals was used. Representative individuals are not intended to depict any real individual but to share the general life-style characteristics of broad segments of the population.

**Atmospheric Pathway**

The atmospheric pathways modeled were external dose from submersion in contaminated air or exposure to contaminated soils, inhalation, and ingestion of food crops and animal products. The milk pathway included commercial and private milk sources as well as grocery sources, with four possible cow feeding regimes (Farris et al 1994a).

The dose estimation process for the atmospheric pathway began by estimating the source term based on radionuclides released from Hanford plutonium separations plants (Heeb 1994). The air and soil concentrations, depositions, and environmental accumulation that resulted from the releases were then modeled (Ramsdell et al. 1994). Last, the environmental accumulation information along with life style information for representative individuals (Anderson et al. 1993; Deonigi et al. 1994; Marsh et al. 1992) were used to estimate doses.

Fig. 3 shows the monthly estimates of iodine-131 released to the atmosphere (Heeb 1994). The totals (Ci/mo) are the median values of 100 stochastic realizations using monte Carlo techniques. The release amounts depicted in Fig. 3 demonstrate why more detailed reconstruction was undertaken for the earlier periods of Hanford operations. Very fine temporal resolution was used to model the largest releases of radionuclides to the air during the mid-1940s. Decreased dose reconstruction emphasis for later years was justified by lower releases as well as other factors: better historical measurements, more technically defensible dose estimates during 1952-1972, increasing reliability of dose estimates during 1973-1992, and shutdown of the eight single-pass reactors and reprocessing plants by the end of 1972.

**Columbia River Pathway**

The Columbia River pathways modeled were ingestion of drinking water, resident fish, shellfish, waterfowl, and salmon as well as external exposure from along the shoreline, swimming, and boating. The dose estimation process for the Columbia River pathway began by estimating the source term

based on radionuclides released from eight Hanford single-pass production reactors (Heeb and Bates 1994). Computer modeling of flow and transport was used to estimate river concentrations at downstream locations (Walters et al. 1994). Environmental accumulation was estimated in aquatic biota (Thiede et al. 1994) as well as use of the river by humans, including ingestion of Willapa Bay shellfish and Columbia River salmon (Farris et al. 1994b) (Willapa Bay is located on the Washington coast, 20 miles north of the mouth of the Columbia River.) Doses were then estimated using food consumption and lifestyle information for representative individuals.

Fig. 4 shows the annual releases of the five key radionuclides to the Columbia River used for dose estimates (Heeb and Bates 1994). These totals (Ci/yr) are the median values of 100 stochastic realizations (Heeb and Bates 1994). Fig. 5 shows the activity of the five key radionuclides that existed at any time throughout the Columbia River and adjacent area in the Pacific Ocean. This radionuclide burden was calculated as the amount of activity at the end of each calendar year accounting for all previous releases and radioactive decay.

To note when comparing Figs. 4 and 5 is the effect the radionuclide half-lives had on dose. Sodium-24 was the radionuclide with the greatest releases to the Columbia River. Because of its relatively short half-life of approximately 15 hours, however, the activity of sodium-24 in the Columbia River was negligible. In contrast, no more than 56,000 Ci of zinc-65 were ever released in one year. However, because of its long half-life of approximately 244 days, almost 80,000 Ci of zinc-65 attributable to Hanford existed, mostly in the Pacific Ocean, during the highest year of 1962.

## RESULTS AND DISCUSSION

The dose estimates resulting from the atmospheric and Columbia River pathways are summarized in this article. The details appear in Farris et al. (1994a; 1994b).

### Atmospheric Pathway

Doses estimated for the atmospheric pathway from 1944-1951 are presented as absorbed dose to the thyroid for iodine-131 and effective dose equivalent for six key radionuclides, including iodine-131, for 1944-1972.

Cumulative thyroid doses over the period beginning December 26, 1944 and ending December 31, 1951 are shown in Figs. 6-8. Fig. 6 depicts cumulative median thyroid doses to a child born December 26, 1944 (the first day plutonium was separated at Hanford) through age seven. The doses are from all exposure pathways including consumption of foodstuffs (milk, fresh fruits, vegetables, eggs, poultry, and beef), inhalation, and external exposure. All food stuffs were assumed to be from a backyard source (i.e., grown at the location of consumption with no distribution of foodstuffs and short hold-up times from harvest to consumption). The milk was produced by a cow that was grazing on fresh pasture. The cumulative absorbed dose to the thyroid of a child at the maximum impact location was estimated to be 235 rad, with the lowest estimated dose at 0.05 rad. The highest impact offsite location was at Ringold, Washington, (see Fig. 1 for location) while the lowest was in the northwest corner of the study area.

Fig. 7 shows cumulative median thyroid dose estimates for an adult who was 18 years old on December 26, 1944, under the same conditions as in Fig. 6. The estimated cumulative absorbed dose to the thyroid of an adult at the maximum impact location was 36 rad; the lowest estimated dose was 0.012 rad. The differences in the doses presented in Fig. 6 and Fig. 7 result from age dependent dose conversion factors and food consumption rates. In general, the doses to children were six times those of adults for this time period.

Fig. 8 shows cumulative median thyroid dose estimates from the consumption of commercially available foods (i.e., those from a grocery store or informal local market) in 1944-1951. The doses are for a child born December 26, 1944. When compared with Fig. 6, Fig. 8 demonstrates that consumption of commercial milk resulted in a lower dose than drinking milk from a backyard cow. The highest dose estimated for a child drinking commercial milk was 112 rad in contrast to 235 rad for consumption of milk from a backyard cow. The lower doses resulting from the consumption of commercial milk were due to the increased delay time between milk production and consumption, the feeding practices for commercial dairy cows, and the impact of the commercial distribution of milk.

In areas of widely differing iodine depositions or where there was movement of milk between two contrasting areas, knowledge of the distribution system was important in determining iodine-131 dose. For instance, in comparing Figs. 6 and 8, it can be seen that the pattern of doses is similar, with the dose decreasing with distance from the Hanford Site and the trend of higher doses to the northeast of the site. Much of the milk that was consumed in Richland during 1945 was produced by the Carnation Dairy in Sunnyside, Washington. As a result, the doses from commercial milk in Richland were lower than they would have been if the milk had been produced by cows in the Richland area. On the other hand, the distribution system also could increase dose: milk that was produced in the Yakima area was consumed in the Ellensburg area, thereby slightly increasing the dose there.

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

Annual EDEs were estimated for 1944-1972 for the six atmospheric pathway radionuclides. Annual EDEs at all locations were the highest in 1945, decreasing by a factor of about 1500 by 1957. Fig. 9 shows the annual total dose and contribution of each of the six radionuclides to an adult at Ringold from 1945-1972. During the 1940s and 1950s, iodine-131 exposure was responsible for 99.8% of the dose to an adult in Ringold, with plutonium-239 and cerium-144 at about 0.1% each. By 1965, cerium-144 accounted for about 81% of the dose to an adult in Richland from the air pathway, with plutonium-239 at 11%.

**Columbia River Pathway**

Figs. 10 and 11 show annual doses estimated for a maximum and a typical representative individual, respectively, at various locations, from 1950-1970. Doses at each successive downriver location below Pasco decrease as a result of radioactive decay and river dilution. The doses were greatest for the maximum individuals and lowest for the typical individual.

Prior to October 1963, the municipal water supply for the City of Richland, Washington, was drawn from the Yakima River water. The Richland municipal water supply after September 1963 was taken from the Columbia River. Fig. 11 shows the impact of the water source on the doses to the typical representative individual at Richland. Before 1963, the doses to a typical individual at Richland were less than those at Pasco and other locations. After 1963, the doses were highest at Richland. The doses for the maximum representative individual (Fig. 10) does not exhibit the effect because those doses were dominated by exposure pathways other than drinking water.

Within the 1950-1971 time period, the doses for all representative individual types were lowest during the periods 1950-1955 and 1965-1971. The doses peak during the late 1950s and early 1960s, the period of greatest radionuclide releases to the Columbia River. The decrease in annual dose in 1959 was a result of slightly lower radionuclide releases and increased river

flow during that year. These two factors combined to produce dose estimates that were 30 to 40% lower for 1959 than for either 1958 or 1960.

## COMPARISON OF ATMOSPHERIC AND RIVER PATHWAY DOSES

The annual effective dose equivalent from both the atmospheric and Columbia River pathways are shown in Fig. 12. The doses are to a maximally exposed adult located at Ringold, Washington. Ringold was the highest impact location for both the atmospheric and Columbia River exposure pathways. The atmospheric pathway doses decrease rapidly from a maximum dose rate of 790 mrem/yr in 1945 to less than 1 mrem/yr for all years after 1958. By contrast, the Columbia River pathway doses were above 10 mrem/yr for the entire operating period of the Hanford single-pass reactors (1944-1971). The river pathway doses reached a maximum of 140 mrem/yr in 1960. The cumulative effective dose equivalent over the period 1944 through 1992 for maximum representative individuals was estimated to be 1 rem and 1.5 rem for the atmospheric and Columbia River pathways, respectively.

## UNCERTAINTY AND SENSITIVITY ANALYSES

The HEDR Project has conducted uncertainty and sensitivity analyses for the atmospheric and Columbia River pathway models. The uncertainty analyses helped to determine the precision with which dose estimates could be made. The sensitivity analyses determine the parameters and pathways that contribute most to the uncertainties. The methods for conducting the uncertainty and sensitivity analyses were documented in Simpson and Ramsdell (1993).

### Uncertainty Analyses

Using Monte Carlo methods, the uncertainty in a dose estimate was defined by its calculated distribution. For example, each stage of the

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

The estimated uncertainty ranges are illustrated through the use of boxplots. The box portion of a boxplot contains the middle 50 percent of the estimated values, between the 25th and 75th percentiles. Within the box, the median (50th percentile) and mean are indicated. The ends of the whiskers are the 5th and 95th percentiles, which are the lower and upper confidence limits of the 90-percent confidence interval. A confidence interval has a specified probability (e.g., 90 percent) of containing a given parameter. The minimum and maximum estimated values are also depicted. The statistics are based on the use of 100 realizations of a Monte Carlo calculation. Using 100 realizations, there is a 99.4-percent probability that the 95th percentile of the true distribution is less than the maximum value estimated.

**Atmospheric Pathway.** Uncertainty analyses were conducted to estimate the range of doses that a representative individual could have received from the atmospheric pathway. Fig. 13 shows estimated uncertainties of thyroid

doses from each milk source at eight locations for a 2-5 year old child. The shape of the boxplots on logarithmic scales indicates that the dose distributions can be described as approximating a lognormal distribution. These plots indicate that the 90-percent confidence interval for thyroid dose to young children drinking milk from individual backyard cows in 1945 ranges over about a factor of 25 (i.e., the 95th percentile is about 25 times higher than the 5th percentile). The 50-percent confidence interval (the middle two quartiles) covers about a factor of 3. The thyroid dose to children drinking milk from cows eating stored feed was lower than the dose to children drinking milk from cows on fresh pasture, and the uncertainties are also slightly less: the 90-percent confidence interval is about a factor of 8 to 10 rather than a factor of 20 or more. The thyroid doses to children drinking milk from the commercial supply were midway between the other two types in magnitude but have the least uncertainty. The 50-percent confidence interval covers about a factor of 2, and the 90-percent confidence interval covers a range of from 5 to 10. Within an individual category, the shapes of the probability distributions are remarkably similar for each location. This is largely because the factors determining the uncertainty are more related to the modeling of environmental transport and dose assessment than to spatially dependent factors.

Median dose estimates and the geometric standard deviation (GSD) for the 12 different representative individuals for three selected locations are shown in Table 1. The GSDs are smallest for adults and slightly greater for teenagers. The GSD was not found to be correlated with location, and the average GSD for each location in Table 1 is in the range of 2.28 to 2.3.

Table 1. Median and Geometric Standard Deviation of Absorbed Thyroid Dose (rad) at Selected Locations[a]

| Sex/Age | | Eltopia | | Richland | | Pendleton | |
|---|---|---|---|---|---|---|---|
| | | Median | GSD | Median | GSD | Median | GSD |
| All | <1 year | 61 | 2.31 | 79 | 2.28 | 7.3 | 2.34 |
| All | 1-4 years | 41 | 2.45 | 40 | 2.39 | 3.7 | 2.39 |
| Male | 5-9 years | 26 | 2.34 | 27 | 2.33 | 2.4 | 2.35 |
| Female | 5-9 years | 22 | 2.27 | 23 | 2.27 | 2.1 | 2.30 |
| Male | 10-14 years | 17 | 2.63 | 19 | 2.58 | 1.8 | 2.57 |
| Female | 10-14 years | 15 | 2.37 | 15 | 2.29 | 1.4 | 2.30 |
| Male | 15-19 years | 10 | 2.36 | 11 | 2.34 | 1.0 | 2.35 |
| Female | 15-19 years | 8.9 | 2.33 | 9.5 | 2.28 | 0.86 | 2.22 |
| Male | 20-34 years | 7.5 | 2.24 | 8.3 | 2.20 | 0.74 | 2.23 |
| Female | 20-34 years | 6.6 | 2.18 | 7.4 | 2.14 | 0.65 | 2.08 |
| Male | >35 years | 6.6 | 2.17 | 7.1 | 2.14 | 0.61 | 2.17 |
| Female | >35 years | 6.7 | 2.11 | 7.3 | 2.12 | 0.63 | 2.05 |

*Columbia River Pathway.* Uncertainty estimates of the dose resulting from the Columbia River pathway were prepared for two types of representative individuals at two locations: adult males with maximum and typical exposure patterns at Richland, Washington, and The Dalles, Oregon. Fig. 14 shows cumulative EDEs for 1950-1971. Doses to maximum representative individuals could have been about 30-50 times those to typical representative individuals. Doses were higher upstream at Richland for both types of individual by a factor of about 2.5. The 90-percent confidence interval for both locations ranges over a factor of 4. The 50-percent confidence interval for both locations is well under a factor of 2.

**Sensitivity Analyses**

Parameters contributing to uncertainty in dose estimates were determined via sensitivity analyses. For the atmospheric pathway, for most combinations of the representative individual category, location, and year, as many as 10 to 12 parameters must be considered to describe 90% of the uncertainty in the thyroid dose estimates. Fig. 15 shows the relative importance of parameters for the iodine-131 thyroid dose to a child in 1945. The dose to this age group

and year were the largest doses found during the HEDR study. In this case, the single parameter contributing the most to uncertainty (30 to 70%) is the ingestion dose conversion factor. For milk from cows on fresh pasture, the second most important parameter (35-40% of uncertainty) is the cow feed-to-milk transfer coefficient.

For the Columbia River pathway, Fig. 16 shows the results of the sensitivity analyses for the total effective dose equivalent. The parameters that contributed most to the uncertainty in the estimated dose depended upon the type of individual and exposure location. Uncertainties in the dose received by a maximum representative individual at Richland and The Dalles were both dominated by contributions to the dose from zinc-65, but the percent contribution was different at the two locations. Zinc-65 also dominated the uncertainty in the dose receive by a typical individual at The Dalles but not at Richland. At Richland, the uncertainty was dominated by the holdup time of drinking water in the municipal water supply. The reason for the holdup time taking precedence for typical representative individuals at Richland was the contribution from short-lived radionuclides such as sodium-24.

## CONCLUSIONS

### Atmospheric Pathway

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

- The most important means of exposure via the atmospheric pathway was consumption of fresh milk. The highest estimated dose was to a child consuming milk produced by cows fed fresh pasture near Ringold, Washington.

- The cumulative effective dose equivalent to an adult for 1944-1992 was 1 rem.

- The maximum cumulative absorbed dose to the thyroid of a child (for the years 1944-1951) was estimated to be 235 rad, with the lowest estimated dose for a child at the maximum location at 0.05 rad.

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

- For any representative individual at any location, the average uncertainty range from the minimum to the maximum is a factor of 50. Ninety percent of the estimates are within a factor of 25.

**Columbia River Pathway**

- The most important contributors to dose were phosphorus-32 and zinc-65 released from the single-pass production reactors.

- The most important means of exposure via the Columbia River pathway was consumption of resident fish.

- The cumulative effective dose equivalent for a maximum representative individual for the years 1944-1992 was estimated to be 1.5 rem.

- The highest estimated median dose (140 mrem EDE for 1960) was to an adult consuming 40 kg of resident fish from the Columbia River at Ringold.

- The most important contributors to uncertainty in the dose estimates were the dose conversion factors, the time between catch and consumption, and the bioconcentration factors.

## REFERENCES


Anderson, D. M., Bates, D. J., T. L. Marsh. Estimation of 1945 to 1957 food consumption. Richland, WA: Battelle, Pacific Northwest Laboratories; PNWD-2113 HEDR; 1993.

Deonigi, D. E., Wilfert, G. L., Anderson, D. M. Commercial milk distribution profiles and production locations. Richland, WA: Battelle, Pacific Northwest Laboratories; PNWD-2218 HEDR; 1994.

Farris, W. T., Napier, B. A., Ikenberry, T. A., Simpson, J. C., Shipler, D. B. Atmospheric pathway dosimetry report, 1944-1992. Richland, WA: Battelle, Pacific Northwest Laboratories; PNWD-2228 HEDR; 1994a.

Farris, W.T.; Napier, B.A.; Simpson, J.C.; Snyder, S.F.; D.B. Shipler. Columbia River pathway dosimetry report, 1944-1992. Richland, WA: Battelle, Pacific Northwest Laboratories; PNWD-2227 HEDR; 1994b.

Heeb, C.M. Iodine-131 releases from the Hanford Site, 1944 through 1947. Richland, WA: Battelle, Pacific Northwest Laboratories; PNWD-2033 HEDR; 1993.

Heeb, C.M. Radionuclide releases to the atmosphere from Hanford operations, 1944-1972. Richland, WA: Battelle, Pacific Northwest Laboratories; PNWD-2222 HEDR; 1994.

Heeb, C.M.; Bates, D.J. Radionuclide Releases to the Columbia River from Hanford operations, 1944-1971. Richland, WA: Battelle, Pacific Northwest Laboratories; PNWD-2223 HEDR; 1994.

Marsh, T. L., Anderson, D. M., Farris, W. T., Ikenberry, T. A., Napier, B. A., Wilfert, G. L. Commercial production and distribution of fresh fruits and vegetables: a scoping study on the importance of produce pathways to dose. Richland, WA: Battelle, Pacific Northwest Laboratories; PNWD-2022 HEDR; 1992.

Ramsdell, J. V., Jr., Simonen, C. A., Burk, K. W. Regional atmospheric transport code for Hanford emission tracking (RATCHET). Richland, WA: Battelle, Pacific Northwest Laboratories; PNWD-2224 HEDR; 1994.

Shipler, D.B.; Napier, B.A. HEDR modeling approach. Richland, WA: Battelle, Pacific Northwest Laboratories; PNWD-1983 HEDR Rev. 1; 1994.

Simpson, J. C., Ramsdell, Jr., J. V. Uncertainty and sensitivity analyses plan. Richland, Wa: Battelle, Pacific Northwest Laboratories; PNWD-2124 HEDR; 1993.

Snyder, S.F.; Farris, W.T.; Napier, B.A.; Ikenberry, T.A.; Gilbert, R.O. Parameters used in the environmental pathways and radiological dose modules (DESCARTES, CIDER, and CRD codes) of the Hanford Environmental Dose Reconstruction Integrated Codes (HEDRIC). Richland, WA: Battelle, Pacific Northwest Laboratories; PNWD-2023 HEDR Rev. 1; 1994.

Thiede, M. E., Bates, D. J., Mart, E. I., Hanf, R. W. A guide to environmental monitoring data, 1945-1972. Richland, WA: Battelle, Pacific Northwest Laboratories; PNWD-2226 HEDR; 1994.

Walters, W.H., Richmond, M. C., Gilmore, B. G. Reconstruction of radionuclide concentrations in the Columbia River from Hanford, Washington to Portland, Oregon January 1950-January 1972. Richland, WA: Battelle, Pacific Northwest Laboratories; PNWD-2225 HEDR; 1994.

Figure Captions

1. Hanford Environmental Dose Reconstruction Project study area.

2. Columbia River pathway model study area.

3. Monthly iodine-131 releases, 1944-1951.

4. Key radionuclides released to the Columbia River, 1944-1971.

5. River/ocean radionuclide burden, 1944-1971.

6. Cumulative iodine-131 thyroid dose (rad) to a child from all air exposure pathways, 1944-1951 - milk cows on fresh pasture.

7. Cumulative iodine-131 thyroid dose (rad) to an adult from all air exposure pathways, 1944-1951 - milk cows on fresh pasture.

8. Cumulative iodine-131 thyroid dose (rad) to a child from consumption of commercial foods, 1944-1951.

9. Annual doses to an adult at Ringold, 1945-1972.

10. Annual doses to a maximum representative individual at selected Columbia River locations.

11. Annual doses to a typical representative individual at selected Columbia River locations.

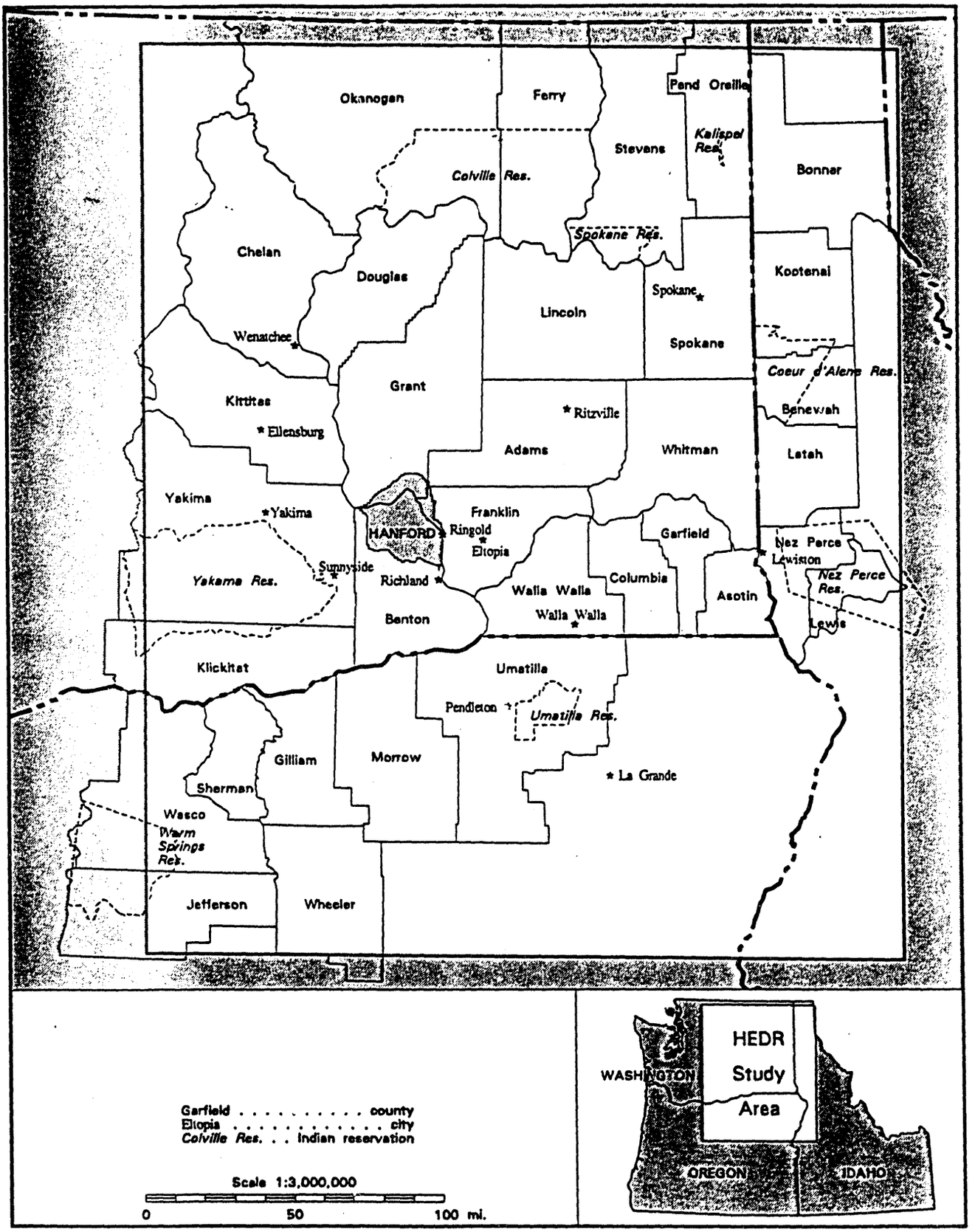
12. Comparison of atmospheric and Columbia River pathway doses.

13. Uncertainty in estimated thyroid doses resulting from radionuclide releases to the atmosphere, 1945.

14. Uncertainty in estimated effective dose equivalent resulting from radionuclide releases to the Columbia River, 1950-1971.

15. Parameters contributing to uncertainty in total iodine-131 dose - child in 1945.

16. Parameters contributing to uncertainty in total effective dose equivalent - maximum and typical representative individuals.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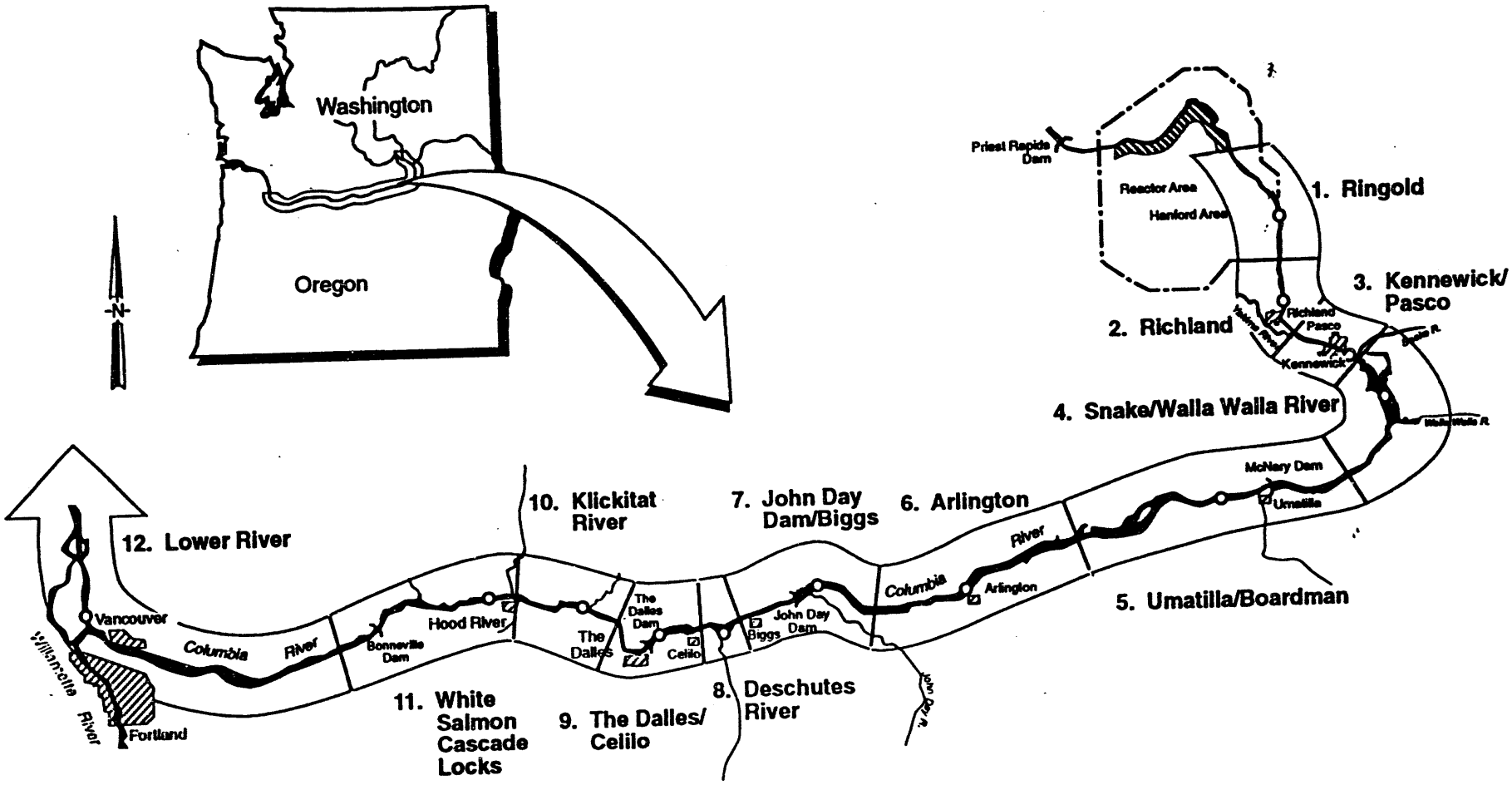
Nez Perce Res.
Asotin
Walla Walla
Benton
Lewis
Klickitat
Umatilla
Pendleton
Umatilla Res.
Gilliam
Morrow
La Grande
Sherman
Wasco
Warm Springs Res.
Jefferson
Wheeler
Garfield . . . . . county
Eltopia . . . . . city
Colville Res. . . Indian reservation
Scale 1:3,000,000
0
50
100 mi.
HEDR
Study
Area
WASHINGTON
OREGON
IDAHO

FIG.1




o Locations of Computed Water Concentrations

S9403005.1

FIG.2

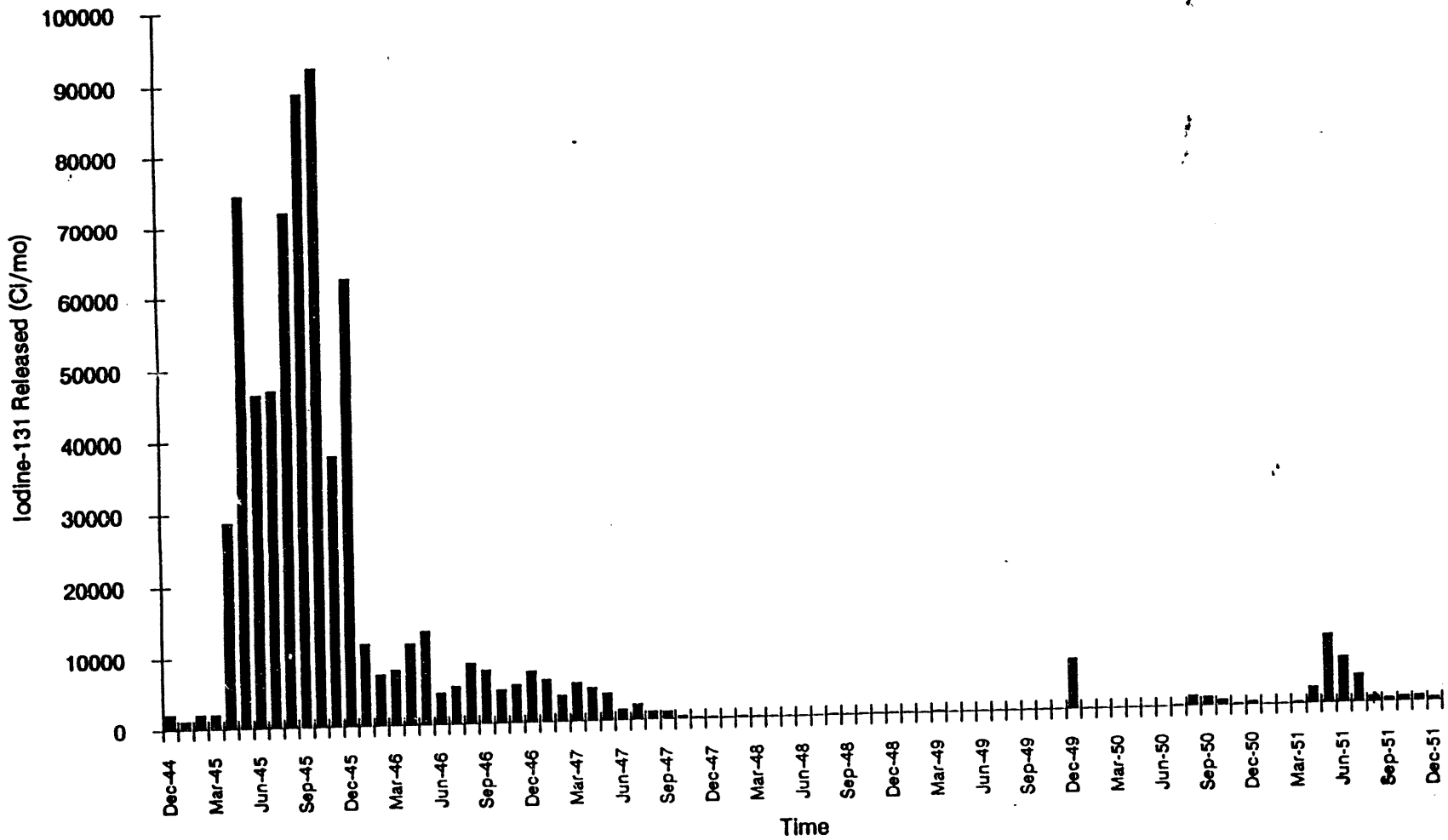

Iodine-131 Released (Ci/mo)
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
Dec-44
Mar-45
Jun-45
Sep-45
Dec-45
Mar-46
Jun-46
Sep-46
Dec-46
Mar-47
Jun-47
Sep-47
Dec-47
Mar-48
Jun-48
Sep-48
Dec-48
Mar-49
Jun-49
Sep-49
Dec-49
Mar-50
Jun-50
Sep-50
Dec-50
Mar-51
Jun-51
Sep-51
Dec-51
Time

FIG.3

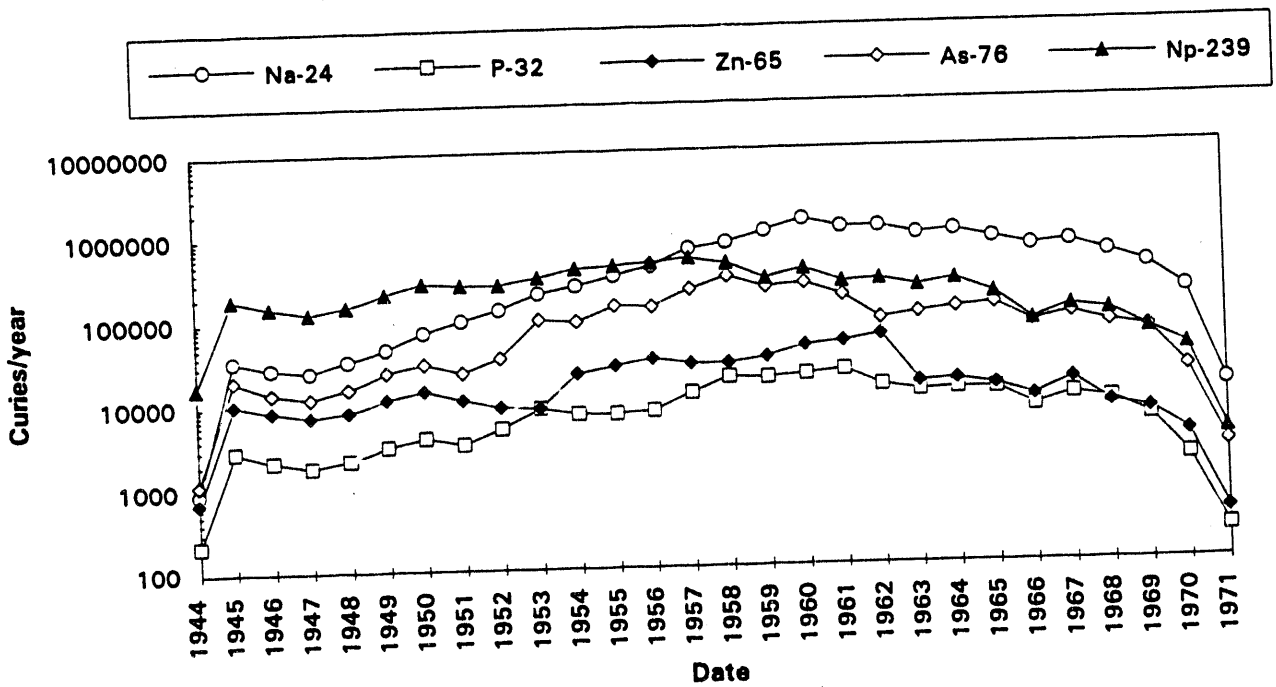

Na-24
P-32
Zn-65
As-76
Np-239
10000000
1000000
100000
10000
1000
100
Curies/year
1944
1945
1946
1947
1948
1949
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
Date

FIG.4

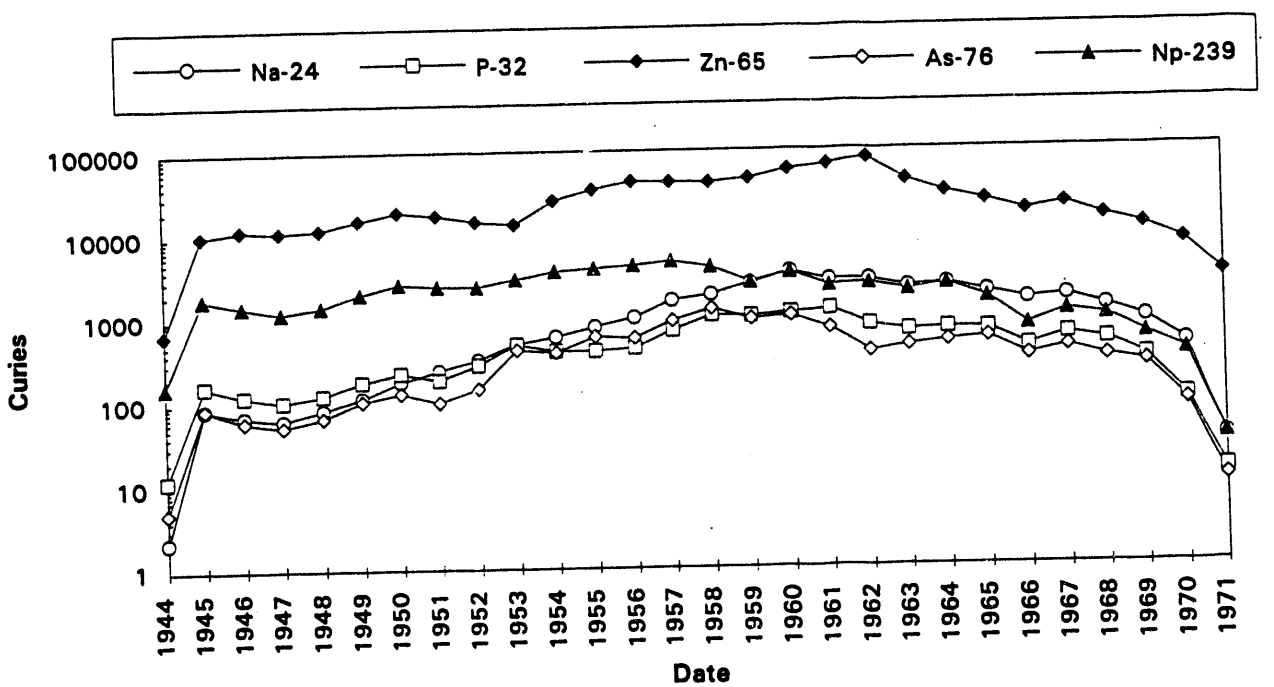

Na-24
P-32
Zn-65
As-76
Np-239
100000
10000
1000
100
10
1
Curies
1944
1945
1946
1947
1948
1949
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
Date

FIG.5

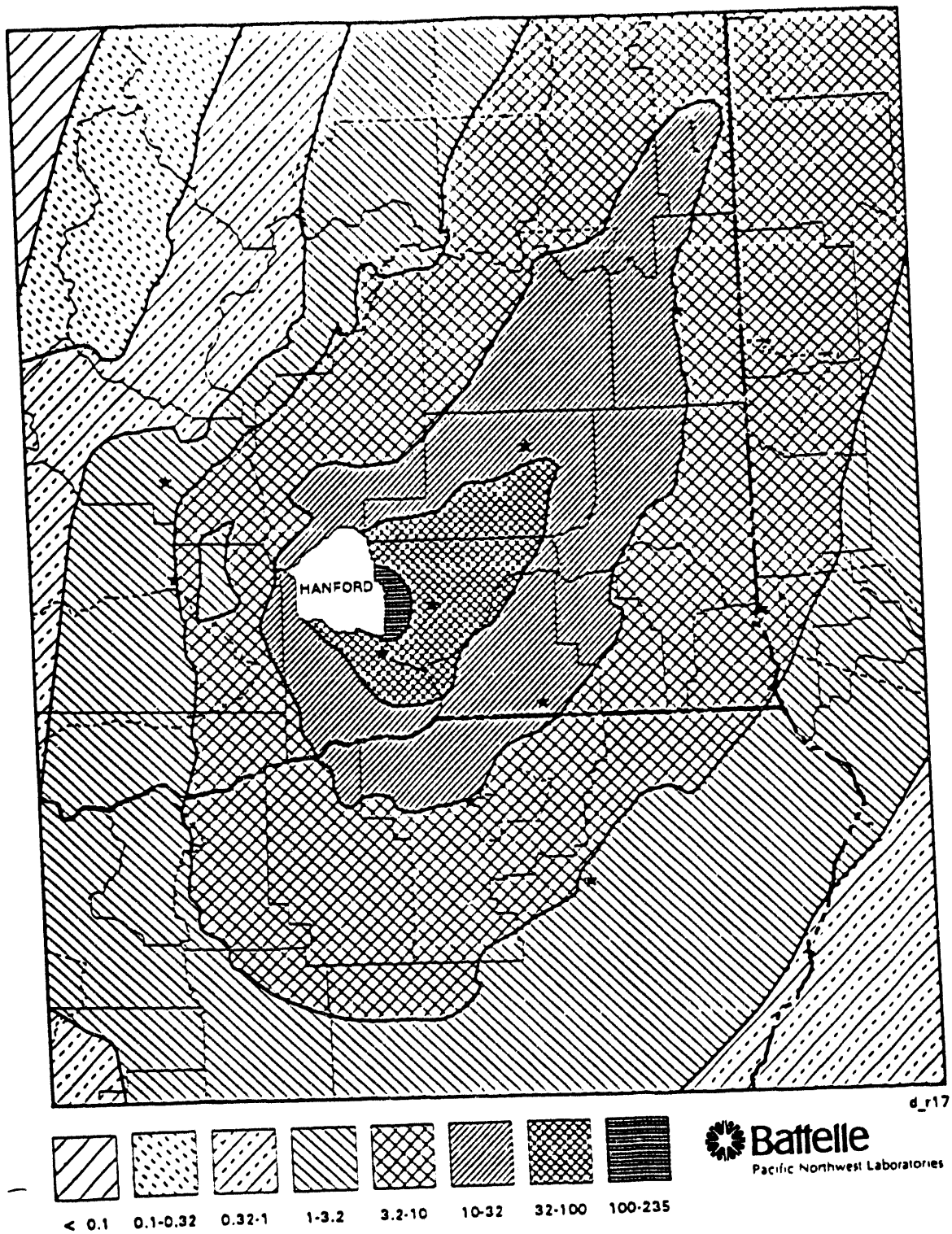

HANFORD
d_r17
Battelle
Pacific Northwest Laboratories
< 0.1
0.1-0.32
0.32-1
1-3.2
3.2-10
10-32
32-100
100-235

FIG. 6

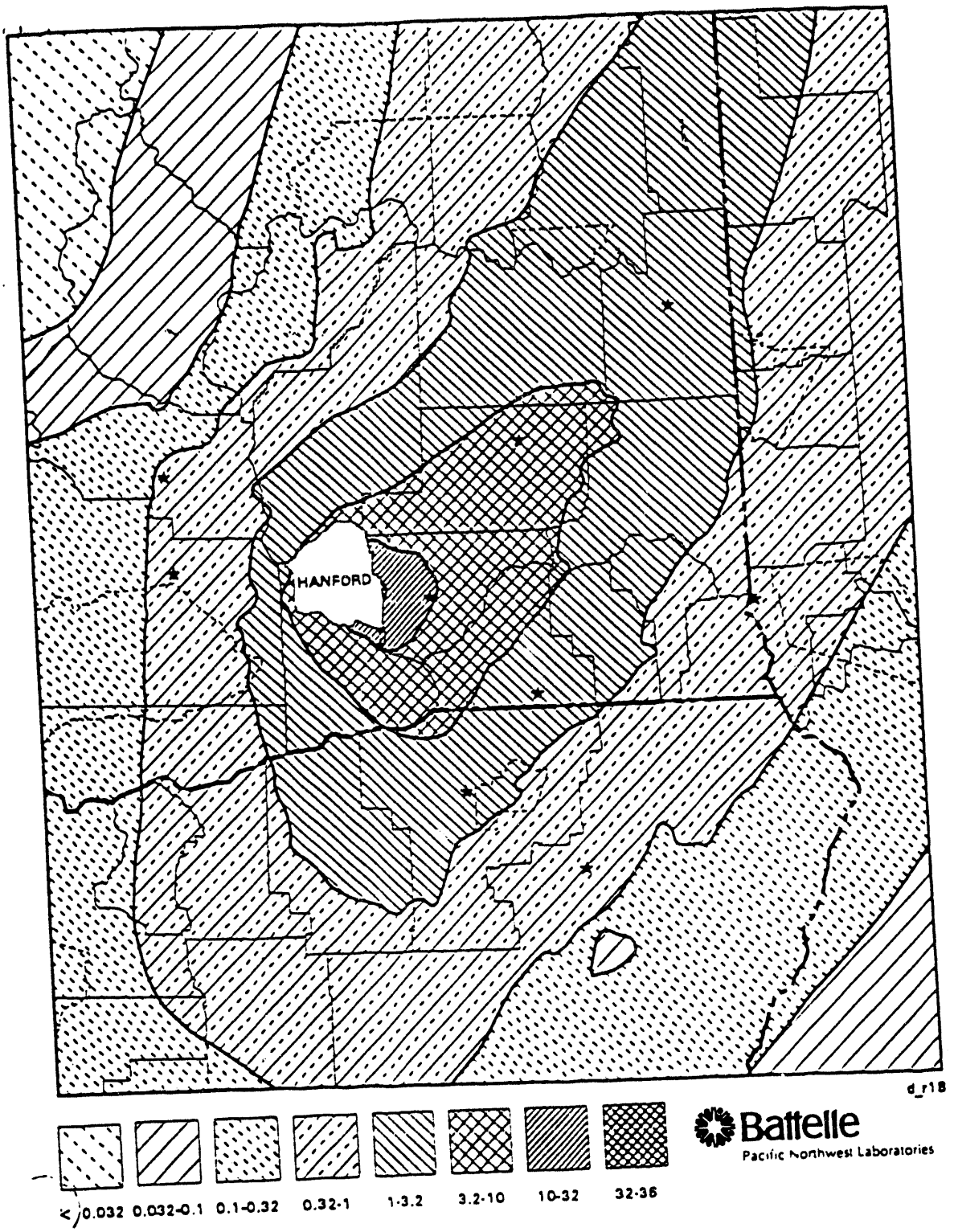

HANFORD
d_r18
Battelle
Pacific Northwest Laboratories
<0.032
0.032-0.1
0.1-0.32
0.32-1
1-3.2
3.2-10
10-32
32-36

FIG.7

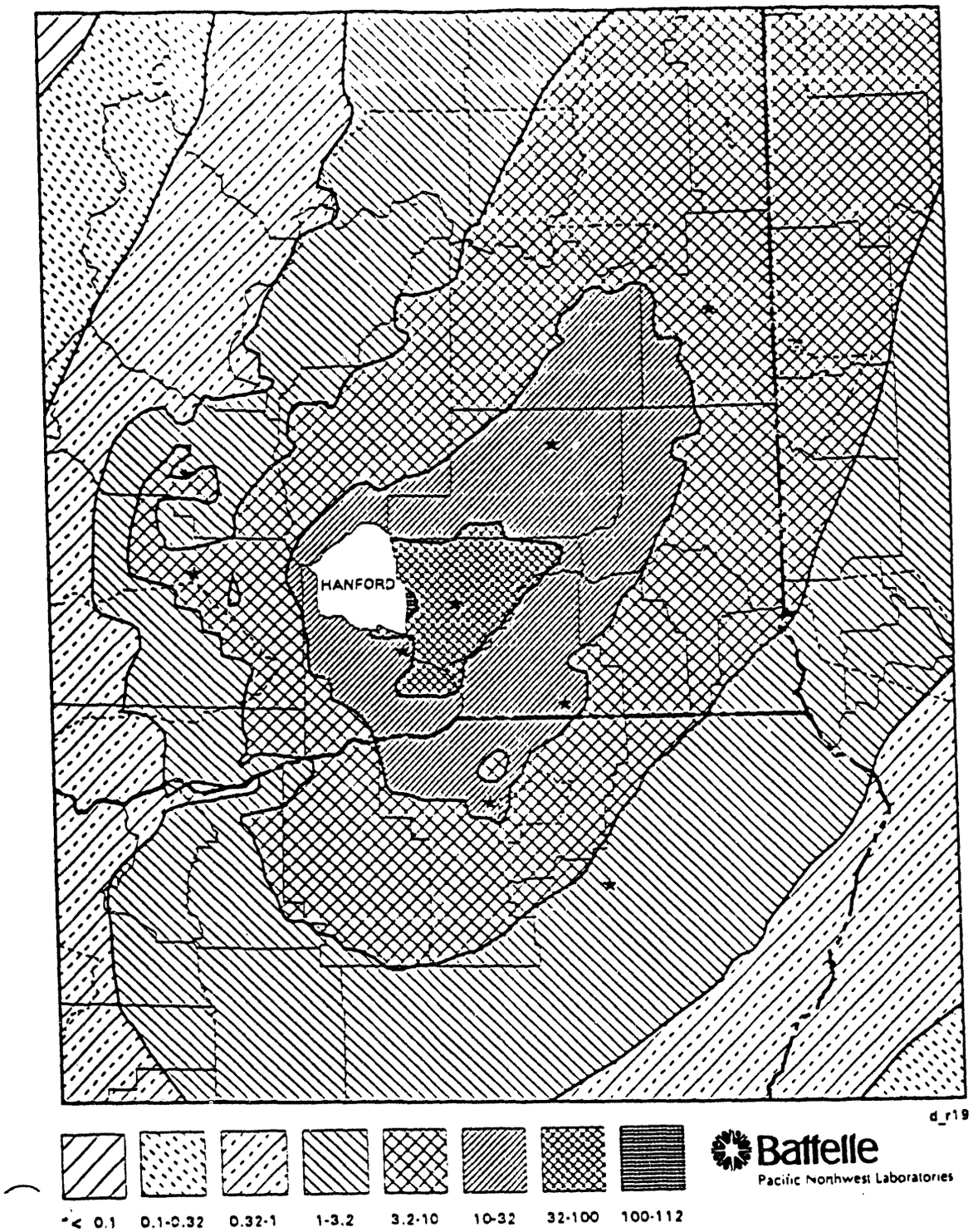

HANFORD
d_r19
Battelle
Pacific Northwest Laboratories
< 0.1
0.1-0.32
0.32-1
1-3.2
3.2-10
10-32
32-100
100-112

FIG.8

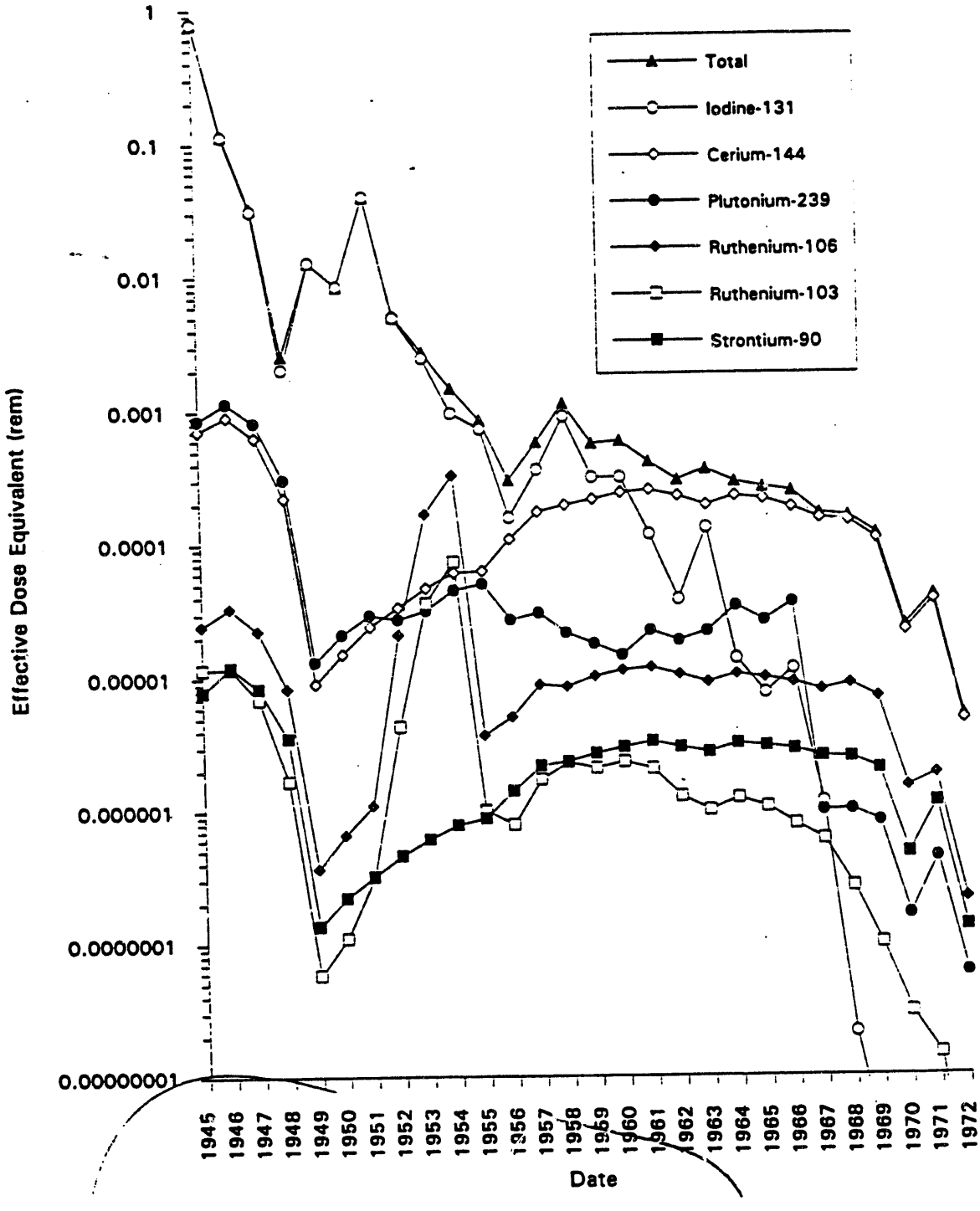

Total
Iodine-131
Cerium-144
Plutonium-239
Ruthenium-106
Ruthenium-103
Strontium-90
Effective Dose Equivalent (rem)
1
0.1
0.01
0.001
0.0001
0.00001
0.000001
0.0000001
0.00000001
1945
1946
1947
1948
1949
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
Date

FIG.9

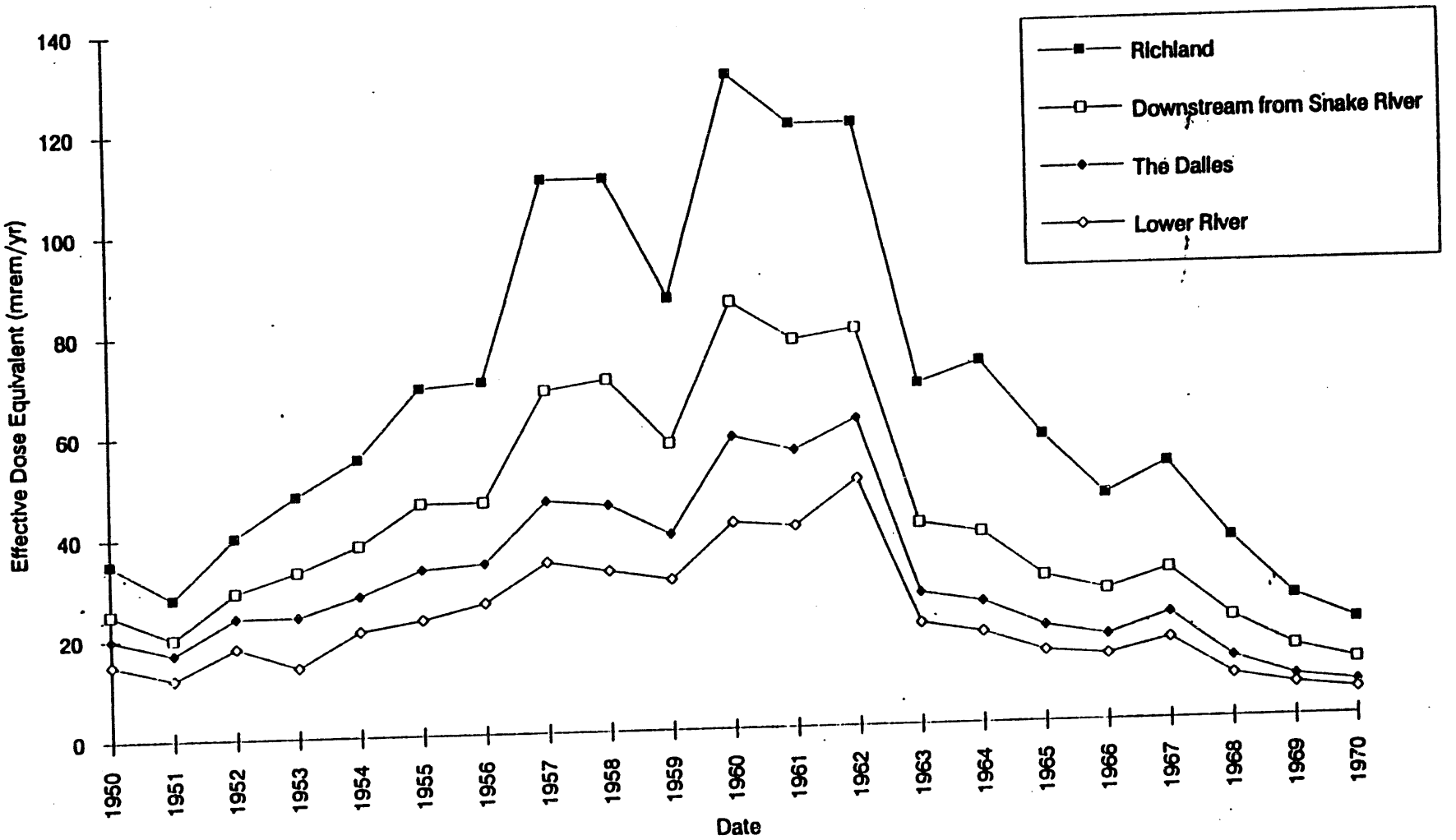

Richland
Downstream from Snake River
The Dalles
Lower River
Effective Dose Equivalent (mrem/yr)
140
120
100
80
60
40
20
0
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
Date

FIG.10

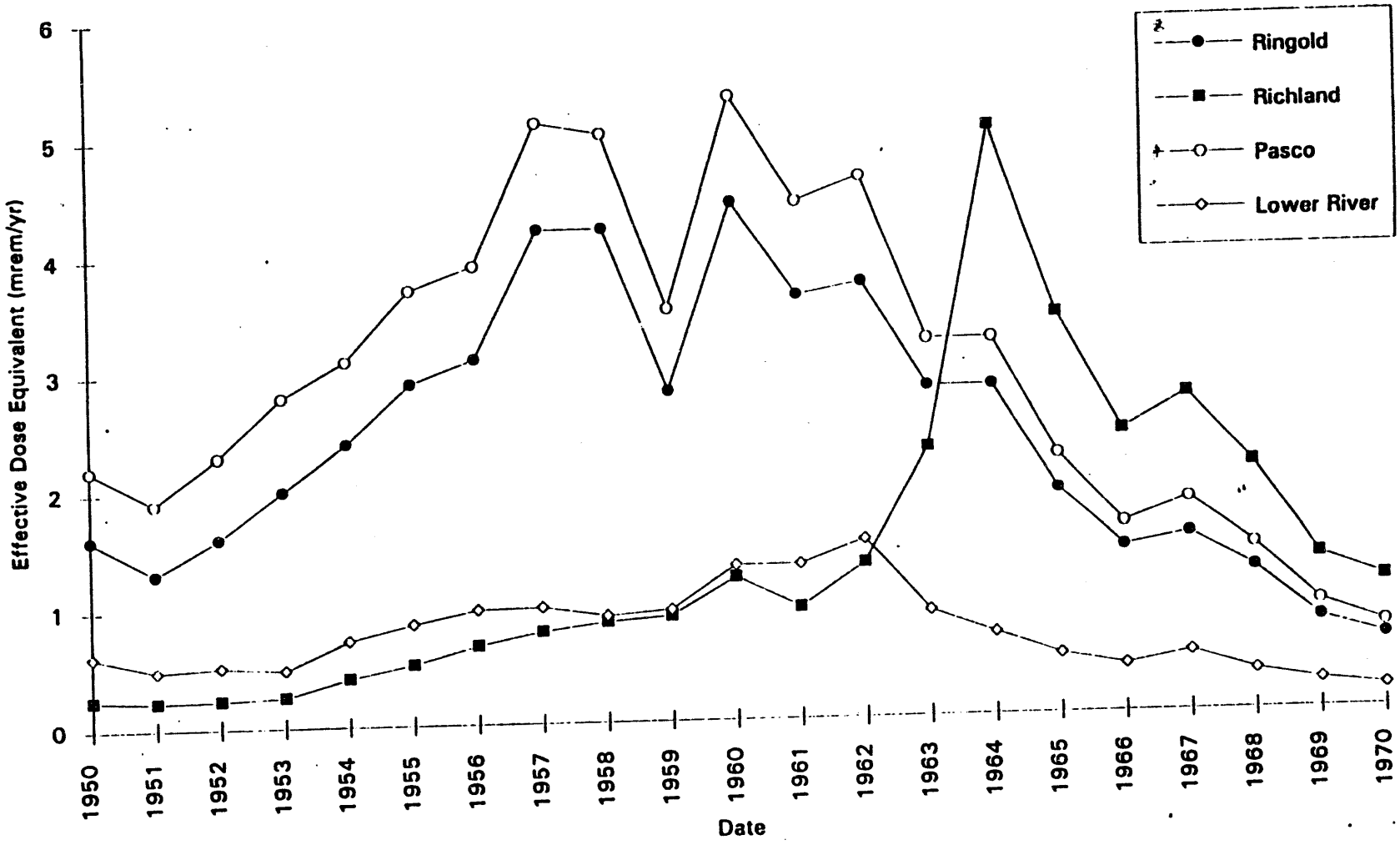

Ringold
Richland
Pasco
Lower River
Effective Dose Equivalent (mrem/yr)
0
1
2
3
4
5
6
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
Date

FIG.11

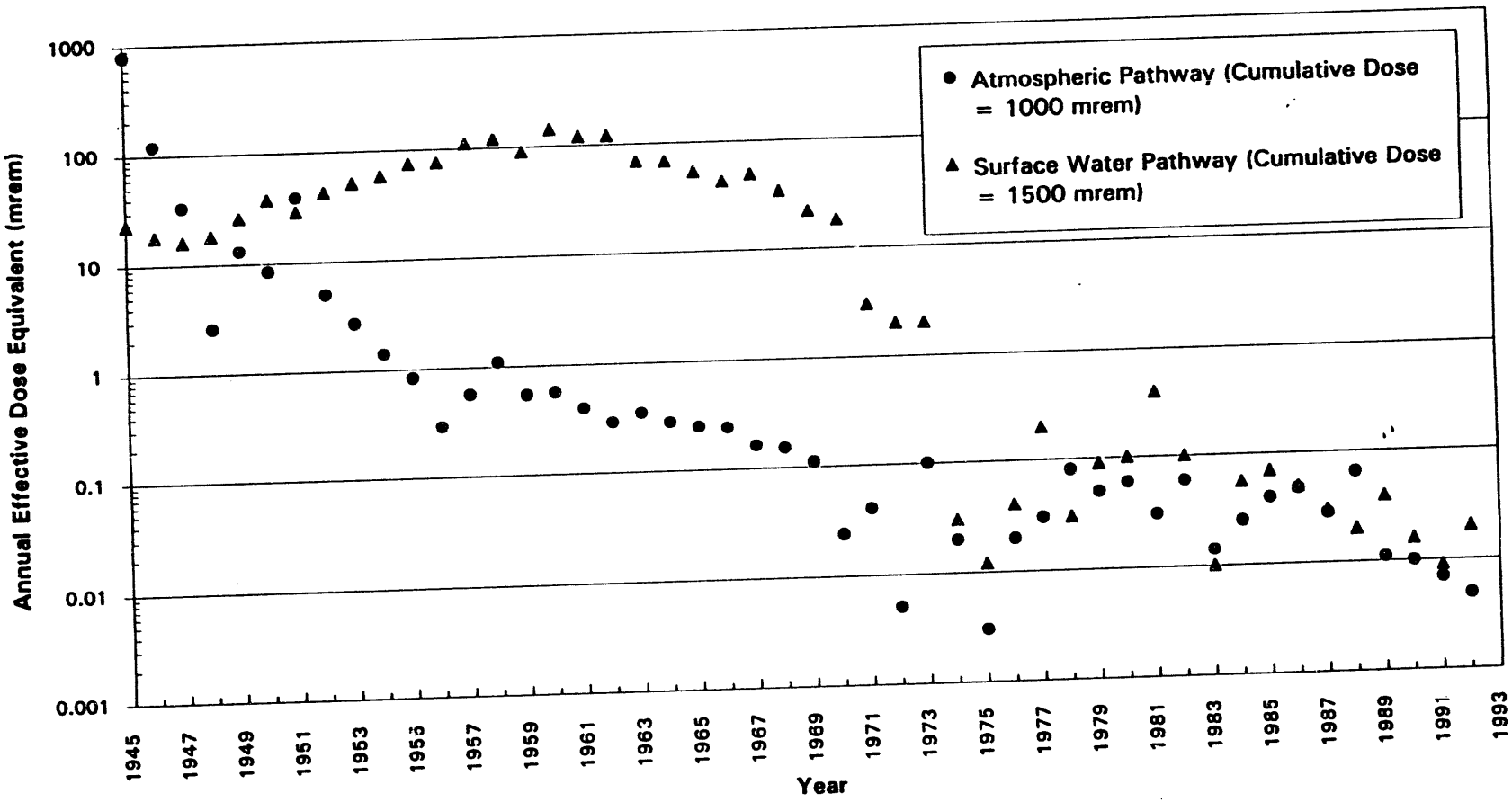

Atmospheric Pathway (Cumulative Dose = 1000 mrem)
Surface Water Pathway (Cumulative Dose = 1500 mrem)
Annual Effective Dose Equivalent (mrem)
1000
100
10
1
0.1
0.01
0.001
1945
1947
1949
1951
1953
1955
1957
1959
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
Year

FIG.12

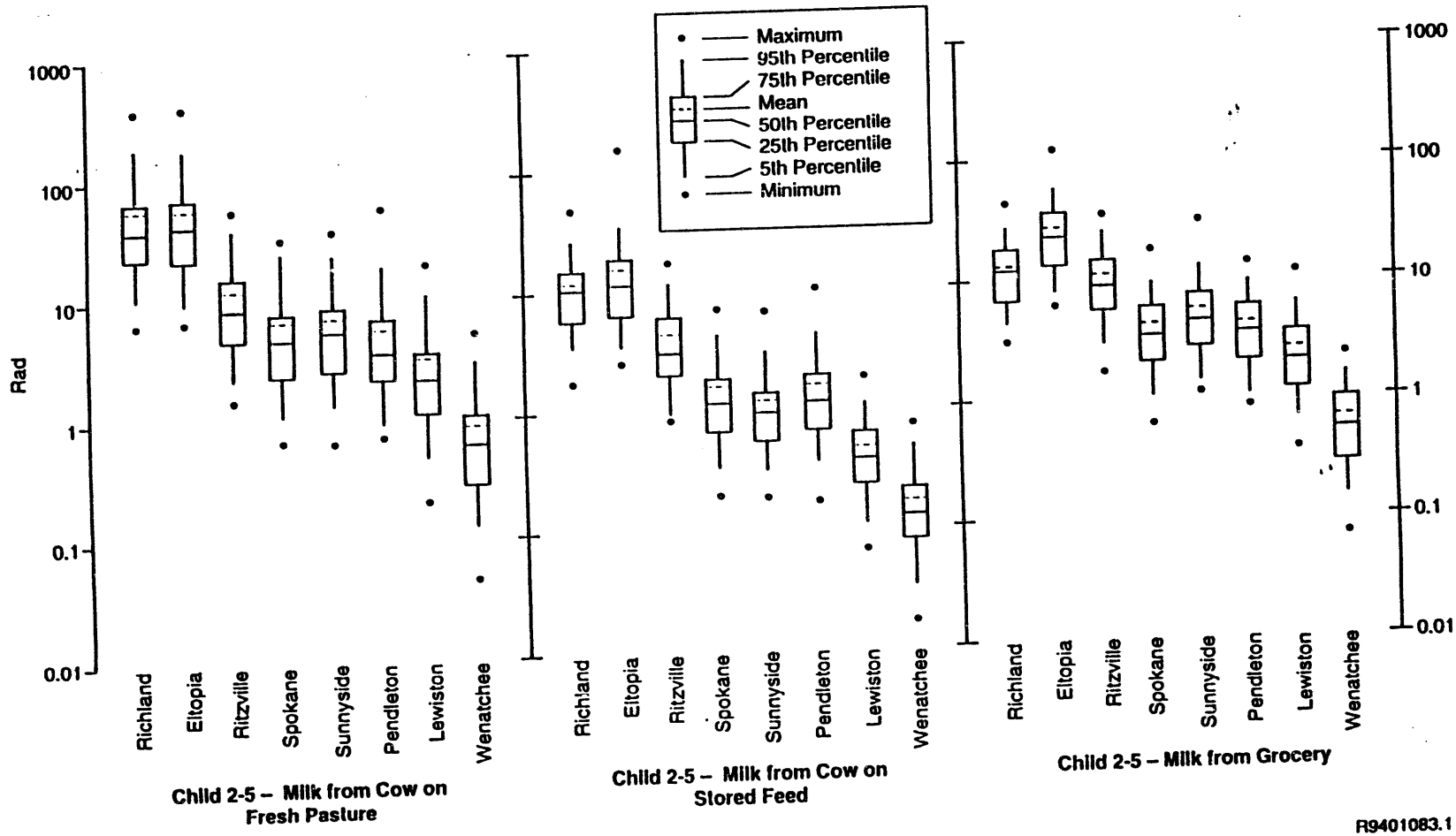

Rad
1000
100
10
1
0.1
0.01
Richland
Eltopia
Ritzville
Spokane
Sunnyside
Pendleton
Lewiston
Wenatchee
Maximum
95th Percentile
75th Percentile
Mean
50th Percentile
25th Percentile
5th Percentile
Minimum
Child 2-5 – Milk from Cow on Fresh Pasture
Child 2-5 – Milk from Cow on Stored Feed
Child 2-5 – Milk from Grocery
R9401083.1

FIG.13

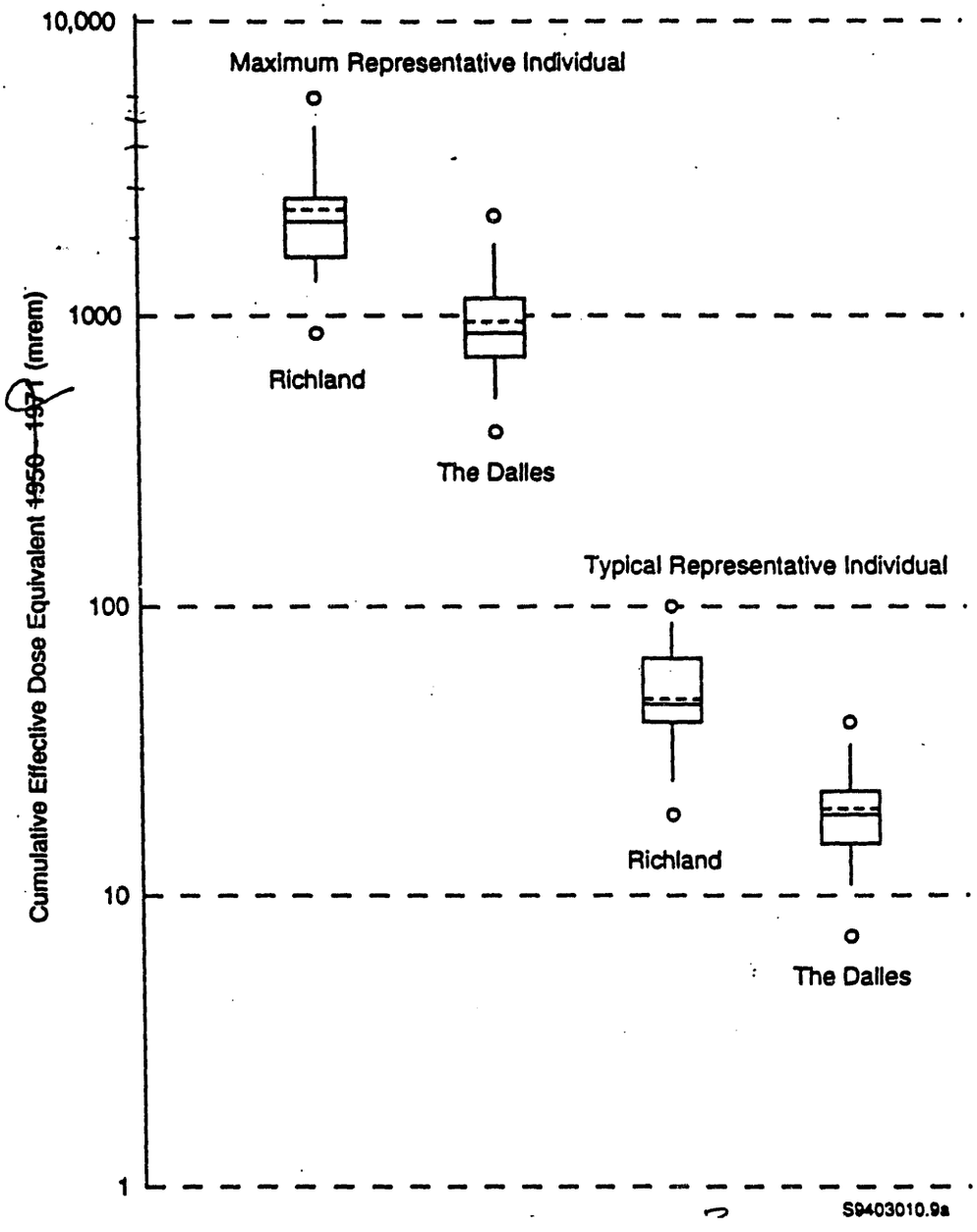
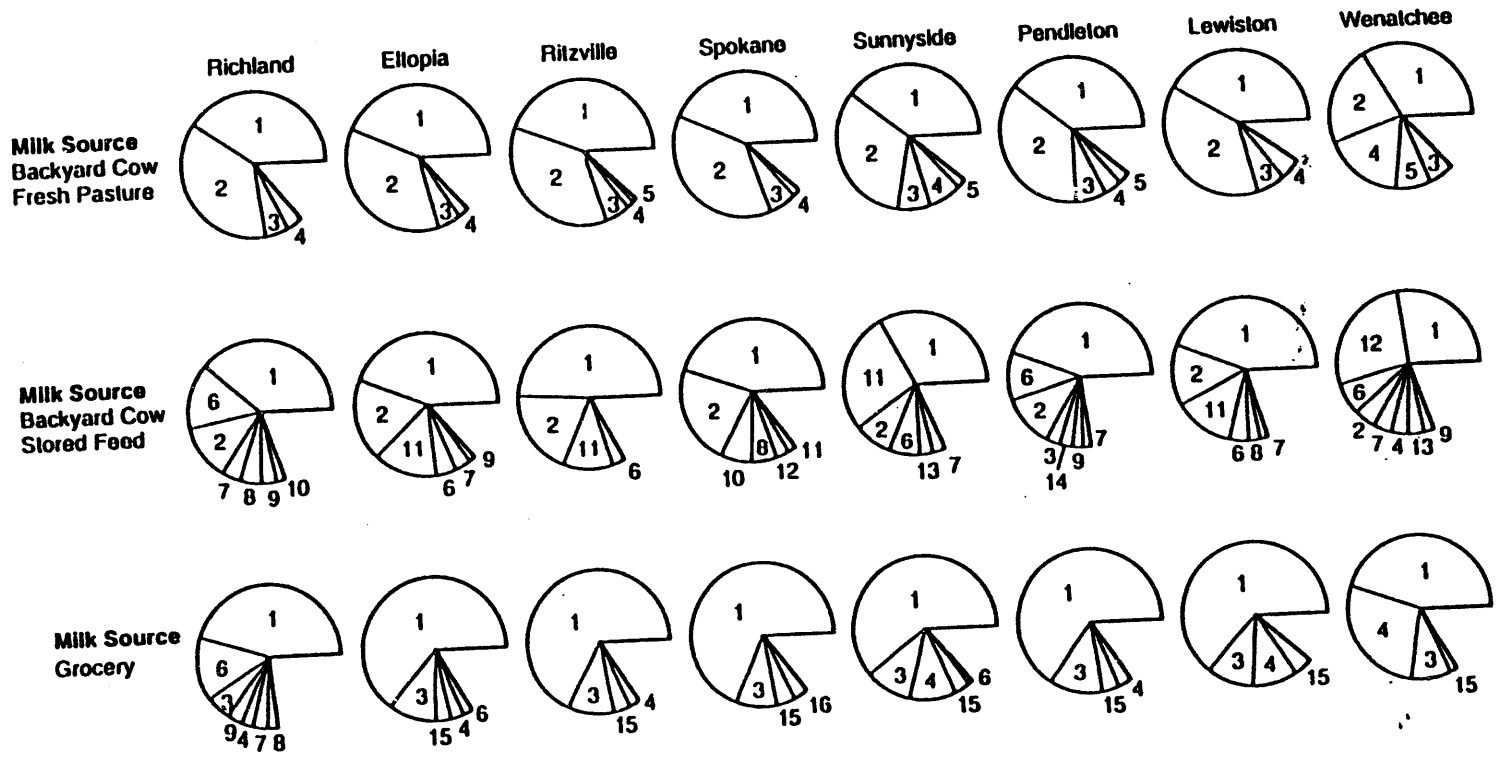

10,000
1000
100
10
1
Cumulative Effective Dose Equivalent ~~1950 - 1971~~ (mrem)
Maximum Representative Individual
Richland
The Dalles
Typical Representative Individual
Richland
The Dalles
S9403010.9a

FIG.14

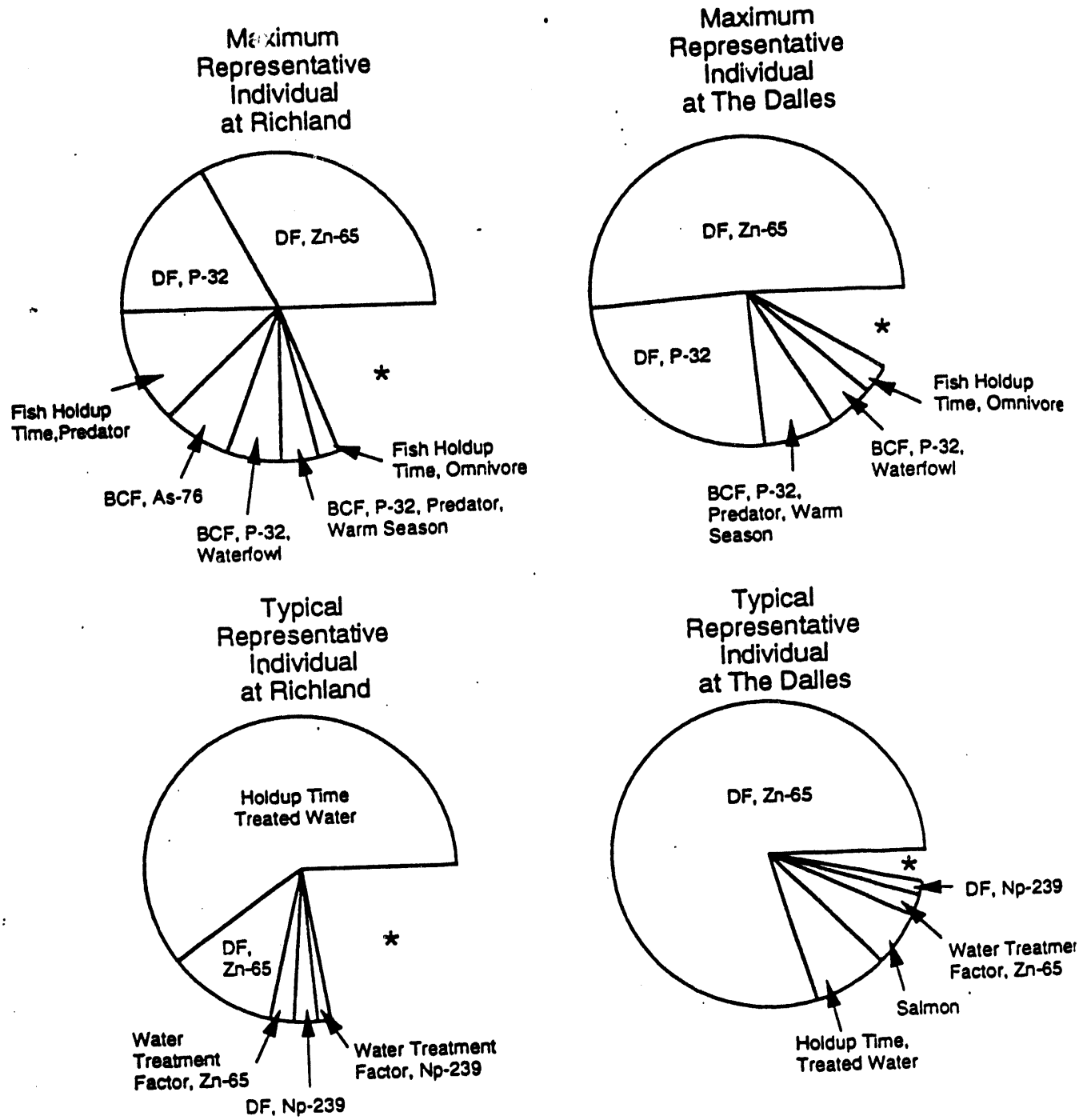



1 - Ingestion dose factor
2 - Milk transfer factor/individual cow
3 - Interception parameter
4 - Integrated deposition
5 - Date cows taken off pasture
6 - Inhalation dose factor
7 - Breathing rate
8 - Ingestion rate of fresh fruit
9 - Holdup time for fresh milk
10 - Concentration in 2nd-cutting alfalfa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

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

S9404042.17

FIG.15




BCF = Bioconcentration Factor
DF = Ingestion Dose Conversion Factor
* = Blank areas are uncertainty contribution from all other parameters and the uncertainty that is not explained by the multiple linear regression.

S9403010.4

FIG.16

DATE
FILMED
10/5/94

END