AEC
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BNWL-439

EVALUATION OF RADIOLOGICAL CONDITIONS IN THE VICINITY OF HANFORD FOR 1966

THE ENVIRONMENTAL STUDIES SECTION STAFF

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JUNE 1967

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BATTELLE MEMORIAL INSTITUTE

for the

UNITED STATES ATOMIC ENERGY COMMISSION UNDER CONTRACT AT(45-1)-1830

PRINTED BY/FOR THE U. S. ATOMIC ENERGY COMMISSION

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Page 8

Figure 4. The dashed lines at 70, 20, 10, 6 and 5 pCi/ℓ are Analytical Limits.

Page 11

Figure 6. ^{32}P - 3.9%

Page 25

Figure 19. Kilometer scale 0 6 12

BNWL-439

UC-41, Health and Safety

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By

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June 1967

PACIFIC NORTHWEST LABORATORY
RICHLAND, WASHINGTON

Printed in the United States of America
Available from
Clearinghouse for Federal Scientific and Technical Information
National Bureau of Standards, U.S. Department of Commerce
Springfield, Virginia 22151
Price: Printed Copy $3.00; Microfiche $0.65

EVALUATION OF RADIOLOGICAL CONDITIONS IN THE VICINITY OF HANFORD FOR 1966

SUMMARY

Surveillance of the Hanford environs during 1966 showed that both the concentrations of radioactive materials in the vicinity and the environmental radiation doses were well within appropriate limits.

Results obtained from the Hanford environmental surveillance program for 1966 indicated that most of the environmental radiation dose for the majority of persons living in the Hanford environs was due to natural sources and world-wide fallout rather than to Hanford operations. The major source of low-level wastes released to the environment from Hanford plants was reactor cooling water, which was discharged to the Columbia River.

Two events occurred during 1966 which significantly influenced radiation levels in the Hanford environs. The first of these was an abnormal release of radioiodines from a production reactor to the Columbia River on February 11, 1966. The net effect of this release was to increase the thyroid dose to the Typical Richland Child from 6% of the limit (1965) to 9% of the limit (1966).

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

The highly unlikely but plausible combination of living habits that would result in an individual's receiving the largest radiation dose from Hanford-effluent radionuclides is postulated as:

- Consumption of 200 meals per year of fish caught down river from the reactors
- Spending 500 hours per year on the riverbank to catch the above quantity of fish
- Consumption of meat, milk, fruit, and vegetables from irrigated farms in the Riverview district
- Consumption of drinking water from the Pasco system.

A person with such habits is called the Maximum Individual. During 1966, the Maximum Individual could have conceivably ingested enough radioactive materials of Hanford origin (mostly ^{32}P) to provide an intake of 10% of the MPRI (Maximum Permissible Rate of Intake) specified by the AEC-ICRP (International Commission on Radiological Protection) for individuals in the general population (with bone as the critical organ). This same intake would have resulted in annual doses for 1966 that were 5 and 7% of the appropriate AEC-FRC (Federal

Radiation Council) limits for the GI tract and whole body, respectively.

The Typical Richland Resident received most of his radiation dose from natural background and world-wide fallout. The radiation dose from Hanford sources received by this population group originates, for the most part, from drinking water obtained from the Columbia River. Normally, the radiation dose received by the GI tract is the largest percentage of appropriate limits for the mixture of radionuclides present in drinking water. During 1966, however, the unusual release of radioiodines mentioned above resulted in an estimated maximum thyroid dose of 40 mrem. The dose to the 2 g thyroid of a Typical Richland Child as a result of the radioiodine release was 20 mrem. Including the latter increment, the thyroid dose to a Typical Richland Child for 1966 was only 9% of the limit.

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

Tabulated below is the composite level of compliance of Hanford Contractors with the appropriate radiation dose standards for individuals and population groups in uncontrolled areas.

SUMMARY OF RADIATION DOSES IN THE HANFORD ENVIRONS-1966

Organ	Annual Dose, mrem	Limit, mrem	% of Limit
Maximum Individual			
GI Tract	70	1500	5%
Thyroid (infant)*	86	1500	6%
Whole Body	33	500	7%
Bone	--(a)	--(b)	10%
Typical Richland Resident			
GI Tract	33	500	7%
Thyroid (infant)	44	500	9%
Whole Body	4	170	2%
Bone	--(a)	--(c)	0.8%

(a) *Not calculated - see introduction*

(b) *AEC-ICRP MPRI for Maximum Individual - 16 μCi ^{32}P/yr and 800 μCi ^{65}Zn/yr*

(c) *AEC-ICRP MPRI for Typical Richland Resident - 5.3 μCi ^{32}P/yr and 270 μCi ^{65}Zn/yr*

* *As a result of the radioiodine release during February, the maximum thyroid dose during 1966 was not received by a Riverview (Pasco) infant as in past years. A Richland child with similar dietary habits received an annual thyroid dose of 86 mrem, while the Riverview child received a thyroid dose of 61 mrem for 1966.*

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EVALUATION OF RADIOLOGICAL CONDITIONS IN THE VICINITY OF HANFORD FOR 1966

INTRODUCTION

The Hanford plant* is located in a semiarid region of southeastern Washington State (Figure 1) where the average rainfall is about 16 cm (6 in.). This section of the state has a sparse covering of natural vegetation primarily suited for grazing, although large areas near the project have gradually been put under irrigation during the past few years. The plant site (Figure 2) covers an area of about 1300 km^2 (500 mi^2). The Columbia River flows through the northern edge of the project and forms part of the eastern boundary. Near the plant production sites, prevailing winds are from the northwest with strong drainage and cross winds causing distorted flow patterns. The meteorology of the region is typical of desert areas with frequent strong inversions occurring at night and breaking during the day to provide unstable and turbulent conditions.

The populated area of primary interest is the Tri-Cities (Richland, Pasco, and Kennewick) situated on the Columbia River directly downstream from the plant. Smaller communities in the vicinity are Benton City, West Richland, Mesa, and Othello. The population of these communities near the plant, together with the surrounding agricultural area, is about 80,000 people.

During the course of operation, various radioactive wastes are generated by the several plant facilities. High level wastes are concentrated and retained in storage within the project boundaries. Controlled releases of low-level wastes, for which concentration and storage is not feasible, are made to the ground. The Hanford practices governing radioactive waste disposal are described in the Hearings on Industrial Radioactive Waste Disposal held by the Joint Congressional Committee on Atomic Energy in 1959.[1]

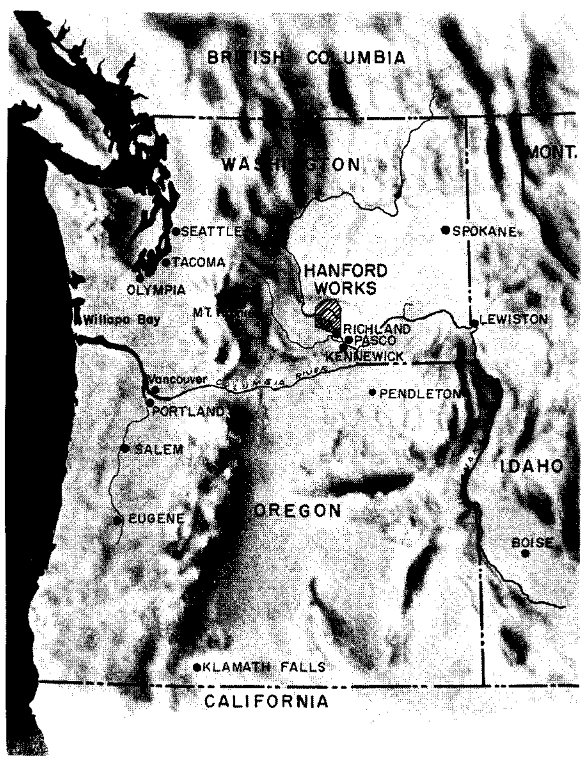

FIGURE 1. Geographical Relationship of Hanford to Pacific Northwest

* *Operated during 1966 for the Atomic Energy Commission by the Battelle-Memorial Institute; Douglas-United Nuclear, Incorporated; the General Electric Company; Isochem, Incorporated; and ITT/Federal Support Services, Incorporated.*

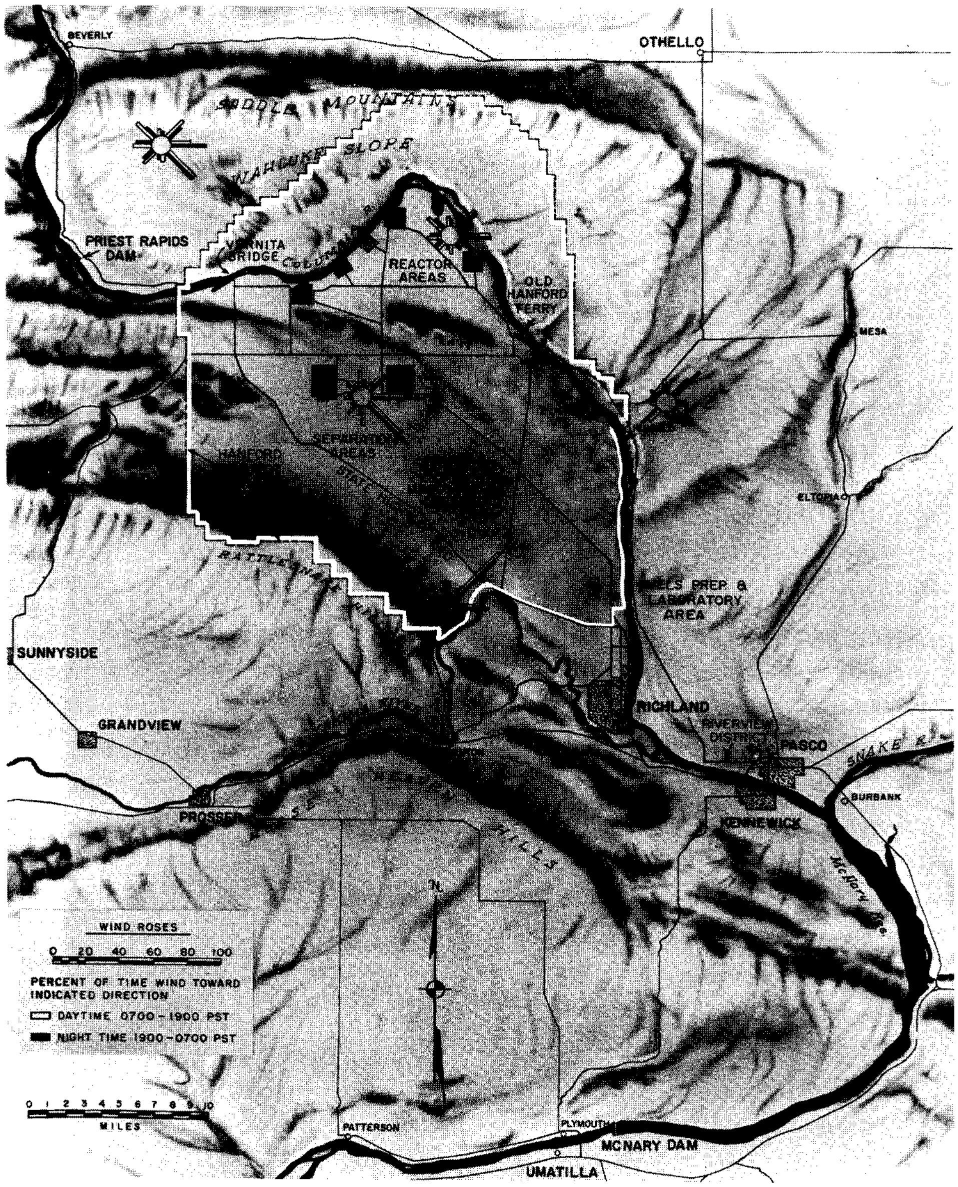

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FIGURE 2. Features of Hanford Project and Vicinity

It is the purpose of this report to present an evaluation of the combined off-project effects of the radioactive waste disposal practices of all Hanford contractors. Radiation protection practices, including radioactive waste disposal, are governed by AEC Manual Chapters 0524 and RL 0524.[2] The section to which this evaluation is addressed stipulates that radioactivity in effluents released to uncontrolled areas shall not result in a radiation dose to individuals exceeding 0.5 rem/yr to the whole body or gonads or 1.5 rem/yr to the thyroid or GI tract.

The significance of bone seekers, such as ^{32}P and ^{90}Sr, requires special consideration and treatment because the rate of intake of ^{32}P has not been specifically studied by the FRC[3,4,5] in relation to a dose-equivalent for the bone or bone marrow. We note that the FRC, in developing intake guides for ^{90}Sr and ^{89}Sr, apparently did not believe that a relative damage factor (n) should be used to change absorbed dose (rads) to a dose-equivalent (rem). Use of a computational scheme for ^{32}P that is like that used by the FRC for ^{90}Sr leads to a maximum permissible rate of intake that is substantially greater than that recommended by the ICRP (International Commission of Radiological Protection).[6] In the absence of definitive guidance, it is our judgment that the dose equivalent for ^{32}P in bone derived by the ICRP (with the use of an n factor of 5) is not directly comparable with the dose specified in the FRC guide (1.5 rem/yr). In view of the AEC instruction that ICRP-NCRP (National Committee on Radiation Protection and Measurement) dosimetry methods[6,7] be used where the FRC does not provide direct guidance, and in view of the more conservative rate of intake for ^{32}P implied by the ICRP-NCRP recommendations, we have continued to use the ICRP values as a reference base. Further, rather than introduce additional confusion associated with dose-equivalents for bone derived by different techniques, we have expressed the data for bone seekers in terms of a maximum permissible rate of intake (MPRI).

The MPRI is taken as the maximum permissible concentration (MPC) in water for a given radionuclide, as recommended by the ICRP for persons in the neighborhood of controlled areas, multiplied by the rate of water intake as defined for the standard man. This amounts to one-tenth of the MPC for continuous occupational exposure multiplied by intake rates of 2.2 liters/day or 800 liters/yr (for annual estimates). In the case of ^{32}P the MPRI is 16 μCi/yr.

It is noted that the ^{32}P MPC_w listed in the AEC Manual, Chaper 0524, (Annex I, Table II)[2] for the Maximum Individual is one-tenth of the ICRP[6] MPC_w for continuous occupational exposure (2×10^{-5} μCi/ml). Thus, an MPRI derived from either AEC Manual, Chapter 0524, or ICRP Publication 2 would be the same.

The radiological units used throughout most of this report are mrems (dose-equivalent). For the nuclides of interest at Hanford, the organs for which radiation doses (in mrads) and dose-equivalents (in mrems) are calculated, the units rad and rem are numerically equal.

This report presents estimates of the annual dose received by a hypothetical individual judged to have received the greatest amount of radiation dose from Hanford environmental sources. In addition, estimates of the dose received by people who are typical* of the population adjacent to the Hanford project are presented.

Included in this report are two types of measurements which are not directly relevant to dose evaluations. The concentrations of radionuclides in the Columbia River and concentration of ^{131}I in cattle thyroids serve as trend indicators and as support for data used in dose calculations.

The radiochemical data presented in Environmental Conditions section and in the appendices[8]** were supplied by the U. S. Testing Co., Inc., who performed all routine radioassays of environmental samples.

The term "analytical limit" is used in this report to provide an indication of the reliability of the data. The "analytical limit" is defined as the concentration at which the laboratory can measure a radionuclide with an accuracy (bias-precision composite) of ±100% at the 90% confidence level. The detection limit for a specific radionuclide varies with sample type, sample size, counting time, and the amounts of interfering radionuclides present. The "analytical limits" were chosen to represent upper bounds to these fluctuating detection limits.

* *The infeasibility of obtaining completely realistic dietary data for the typical resident leads to the assumptions which tend to slightly overestimate his dose. For example, it is assumed that no radioactive decay takes place during the transport of drinking water to the user, and that no radioactivity is lost from food during preparation.*

** *The Appendices mentioned above are a compilation of results from radiochemical analyses of samples collected in the Hanford environs during 1966. They are published as a supplemental report (BNWL-439 APP) which is available upon request.*

ENVIRONMENTAL CONDITIONS

An event which influenced almost all environmental conditions took place during July and August of 1966. A strike was called against Hanford contractors on July 8, 1966. Shortly afterward, all Hanford reactors were shut down until the end of the strike in late August. After the reactor shutdown, significant reductions in radionuclide concentrations were found in Columbia River water, drinking water derived from the Columbia River, and Columbia River fish. Slight reductions in radionuclide concentrations or radiation levels were found in several environmental media, while other media showed no discernible change. Within a short time following reactor startup in late August, concentrations of most radionuclides in the Hanford environs had returned to normally expected levels.

A discussion and interpretation of the results of the several Hanford environmental sampling programs are presented in the following text and figures. The raw data obtained from these programs are presented in the Appendices.[8]

RADIONUCLIDES IN THE COLUMBIA RIVER

All of Hanford's production reactors use Columbia River water for cooling. The N-Reactor uses recirculating demineralized water as a primary coolant. All waste water containing significant amounts of radioactive materials is filtered through the ground before it reaches the river. The amount of radioactive material reaching the river from N-Reactor is a negligibly small fraction of that released from the older reactors.

At the older reactors, some elements present in the cooling water are transformed into radionuclides during the single pass through the reactors. In addition, radioactive materials formed on the surfaces of fuel elements and process tubes are eventually carried away by the cooling water to the river. The relative abundance of the radionuclides found in the cooling water of the older production reactors, adjusted to 4 hr after leaving the reactor, is shown in Table I.

TABLE I. Relative Abundance of Reactor Effluent Radionuclides(a)

Major, 90%	Minor, 9%	Trace, 1%		
^{24}Na	^{32}P	^{3}H	^{91}Y(b)	^{143}Ce(b)
^{31}Si	^{69m}Zn	^{14}C	^{93}Y(b)	^{144}Ce(b)
^{51}Cr	^{72}Ga	^{35}S	^{95}Nb	^{142}Pr(b)
^{56}Mn	^{76}As	^{45}Ca	^{99}Mo	^{143}Pr(b)
^{64}Cu	^{92}Sr	^{46}Sc	^{103}Ru	^{147}Nd(b)
	^{132}I	^{54}Mn	^{106}Ru	^{147}Pm(b)
	^{140}La(b)	^{59}Fe	^{122}Sb	^{149}Pm(b)
	^{152m}Eu(b)	^{60}Co	^{124}Sb	^{151}Pm(b)
	^{153}Sm(b)	^{65}Ni	^{131}I	^{152}Eu(b)
	^{165}Dy(b)	^{65}Zn	^{133}I	^{156}Eu(b)
	^{239}Np	^{87m}Sr	^{135}I	^{153}Gd(b)
		^{89}Sr	^{136}Cs	^{159}Gd(b)
		^{90}Sr	^{137}Cs	^{160}Tb(b)
		^{91}Sr	^{140}Ba	^{161}Tb(b)
		^{90}Y(b)	^{141}Ce(b)	^{166}Ho(b)
				^{169}Er(b)
				^{171}Er(b)

(a) *Trace nuclide composition based on analyses by the Radiological Analysis Operation made in 1964.*

(b) *These radionuclides as a group are denoted hereafter as RE + Y (Rare Earth + Yttrium).*

Many of the radionuclides formed in reactor cooling water are short-lived. In addition to radioactive decay, some fraction of most radionuclides is removed from the river water by sedimentation and by uptake by aquatic organisms. Radionuclides contributed by fallout from nuclear weapons testing are also present in the river.

Samples of river water were collected above the production areas at Priest Rapids Dam and below the areas at the Richland water plant intake, NcNary Dam, and Bonneville Dam. Where possible, cumulative sampling equipment was used to provide a more representative sample than periodic "grab" samples. This cumulative sampling technique, however, makes it impractical to calculate the concentrations of very short-lived nuclides; these must still be measured from "grab" samples.

As shown in Figure 4, within a few days after the July-August reactor shutdown began, concentrations of reactor-effluent radionuclides in the Columbia River dropped to very low levels (in most cases, below the analytical limit). However, concentrations of ^{65}Zn did not drop as much as would be expected from known releases of this radionuclide to the river. It was evident that a significant amount of ^{65}Zn was retained in the river bed and was recycled to the water through continued scouring and leaching of the sediments.

The annual average concentrations of radionuclides measured routinely at Richland and Bonneville Dam are shown in Table II. Results of analyses for several radionuclides in river water samples are available in Appendix A, Tables 1-6.[8]

Measurements on traverses across the river at Richland indicate a slightly nonuniform distribution of the longer-lived radioisotopes at this cross-section. Entries of the Yakima River some 16 km (10 mi) above Pasco and of the Snake River some 48 km (30 mi) above McNary Dam influence the distribution of radionuclides below these two points. The magnitude of the influence varies with seasonal changes in the flow rate of the tributaries. Bonneville Dam is approximately 490 km (240 mi) below the Hanford reactors and represents the farthest downstream location where river water is routinely sampled for Hanford's environmental surveillance program.

TABLE II. Annual Average Concentrations of Several Radionuclides in Columbia River Water-1966

Radionuclides	Richland (pCi/liter)	Bonneville Dam (pCi/liter)
RE + Y[a]	270	--[b]
^{24}Na	2600	--
^{32}P	140	23
^{51}Cr	3600	1300
^{64}Cu	1400	--
^{65}Zn	200	43
^{76}As	420	--
^{90}Sr	1	--
^{131}I	18	3
^{239}Np	770	--

(a) *See Table I for definition.*

(b) *The (-) indicates insufficient data to provide a meaningful annual average.*

The seasonal variation in flow rate of the Columbia River markedly affects the quantity of water available for dilution of reactor effluent released to the river. Also affected by the flow rate is the time required for a specific volume of water to move from one location to another. The flow rates (data supplied by the USGS) of the Columbia River at Priest Rapids and Bonneville Dams are shown in Figure 3; and the variation in concentrations of several radionuclides in river water at Richland are shown in Figure 4. The transport rate of these same radionuclides past Richland is shown in Figure 5 and Appendix A, Tables 8 and 9.[8] The transport rate of radionuclides at Bonneville Dam provides an estimate of the quantities entering the Pacific Ocean from the Columbia River. The annual average transport rate of selected radionuclides past this dam is given in Table III. Detailed measurements are available in Appendix A, Table 11.[8]

An estimate of the inventory of these radionuclides which exist in

TABLE III. Annual Average Transport Rate of Selected Radionuclides Past Bonneville Dam

Radionuclides	1966 (Ci/day)	1965 (Ci/day)	1964 (Ci/day)	1963[a] (Ci/day)
^{32}P	9	11	12	12
^{51}Cr	430	800	860	860
^{65}Zn	21	49	44	28

(a) *Rate of transport at Vancouver, Washington*

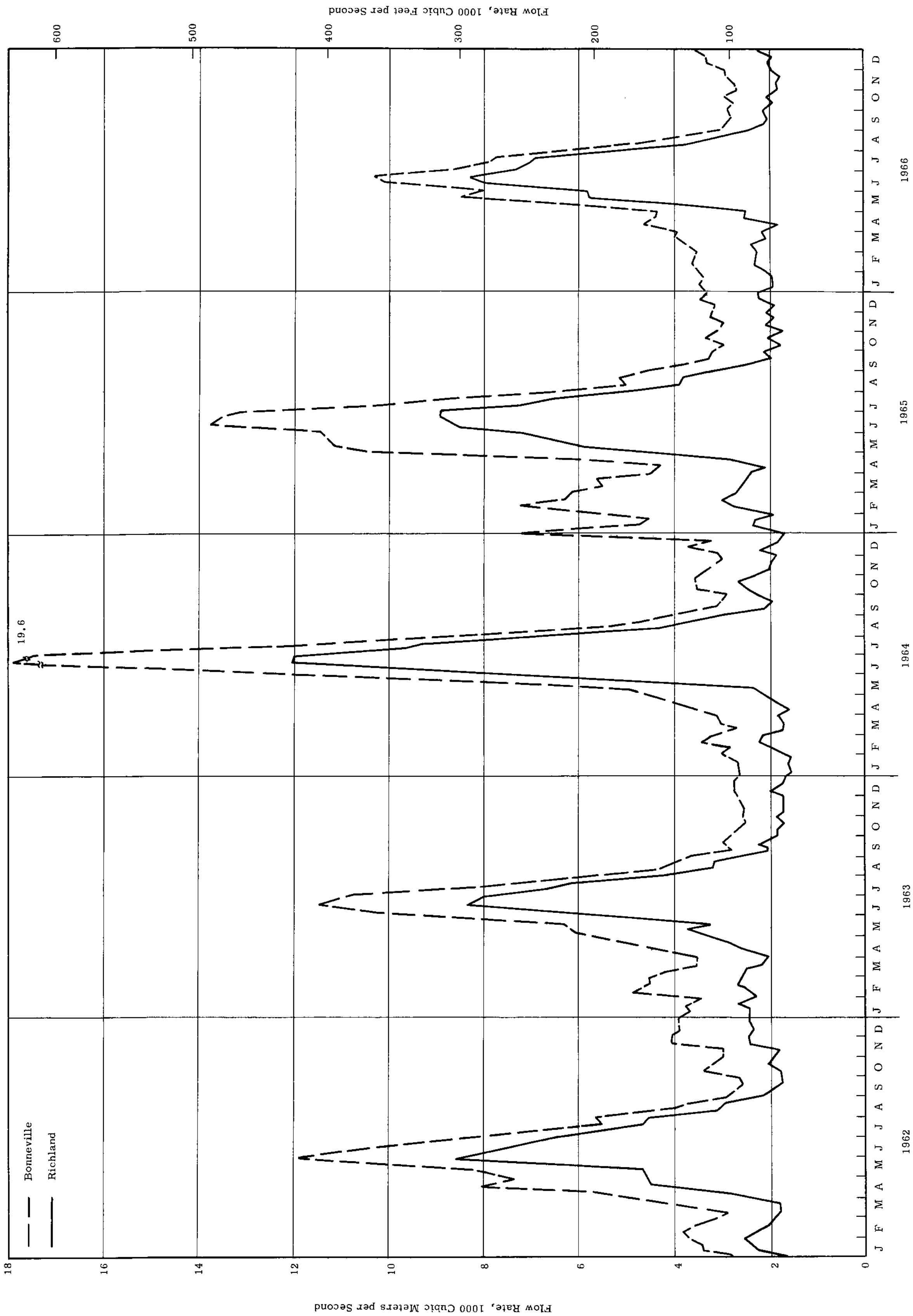

FIGURE 3. Flow Rate of Columbia River at Priest Rapids and Bonneville Dams

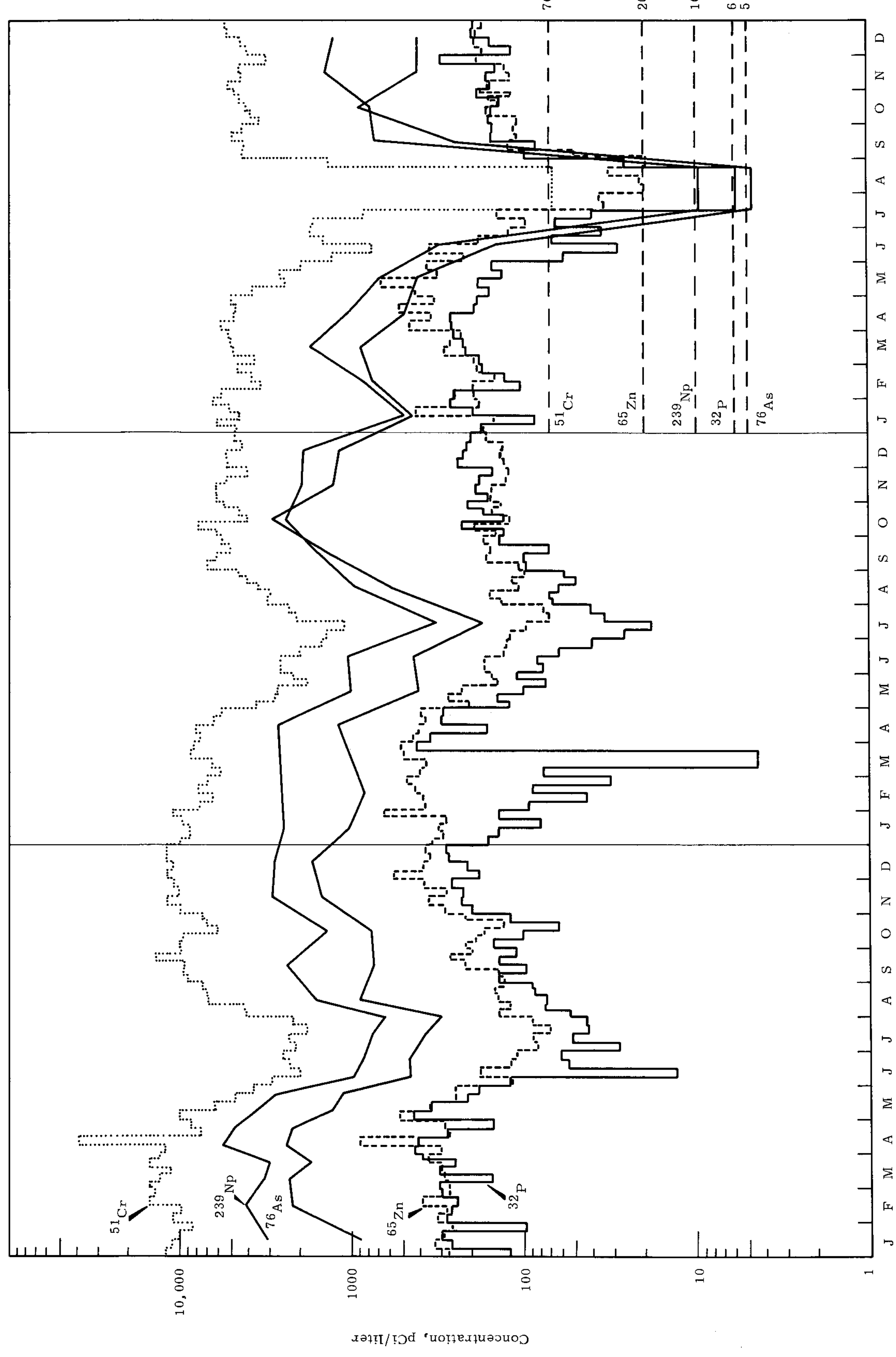

FIGURE 4. Radionuclides in Columbia River Water at Richland

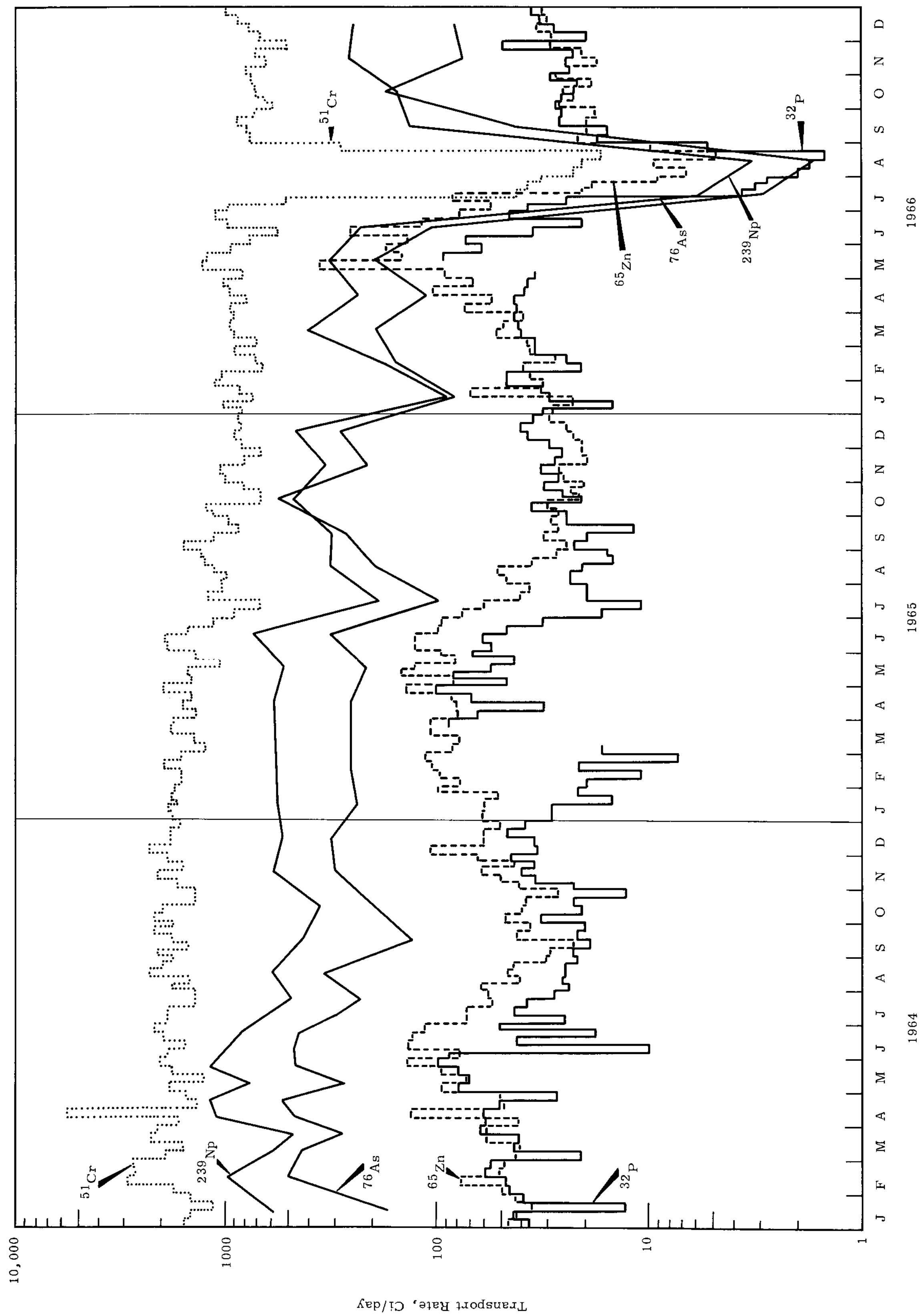

FIGURE 5. Transport Rate of Radionuclides at Richland

the ocean may be calculated by assuming an equilibrium between the rate of addition through the river and the rate of decay in the ocean. A constant rate of entry into the ocean equivalent to that indicated by the 1966 Bonneville Dam measurements would imply an inventory of about 190 Ci of ^{32}P, 17,000 Ci of ^{51}Cr, and 7400 Ci of ^{65}Zn.

RADIONUCLIDES IN DRINKING WATER

The city of Richland is the first community downstream from the Hanford reactors that uses the Columbia River as a source of drinking water. Pasco and Kennewick, a few kilometers further downstream, also use the Columbia River as a source of drinking water. Continuous drinking water samples were collected at the Richland water plant, and periodic samples were collected at Pasco and Kennewick. All of these samples were analyzed for the important individual radionuclides. The detailed results of analyses of drinking water from these three cities are available in Appendix B, Tables 1-5,[8] and are summarized in Table IV.

The concentrations of short-lived radionuclides in the water at the time it is consumed are less than shown in Table IV because there is a significant transport time between the water plant and most consumers. The transport time may vary from hours to days depending upon the location of the customers on the distribution system and the water demand.

The calculated annual average dose to the whole body, GI tract, and thyroid and the percent MPRI for bone from sustained consumption of drinking water throughout the year at the three cities is presented in Table V.

The relative contribution of several radionuclides in the Richland drinking water to the calculated annual dose to the GI tract is shown in Figure 6, and long-term trends in the GI tract dose for Pasco and Richland drinking water are/shown in Figure 7.

The GI tract dose to Richland and Pasco residents from drinking water was somewhat lower in 1966 (about 10% and 30%, respectively) than in 1965[11] This is primarily attributed to the retirement of the three Hanford reactors and the extended shutdown of all reactors during the summer of 1966.

The thyroid dose, however, was somewhat higher during 1966 than during 1965,[11] because of the

TABLE IV. Annual Average Concentration of Several Radionuclides Measured in Drinking Water-1966

Radionuclide	Richland	Pasco	Kennewick
		pCi/liter	
RE + Y[(a)]	77	28	--[(b)]
^{24}Na	1700	540	64
^{32}P	92	36	11
^{51}Cr	4200	3100	1300
^{64}Cu	430	68	39
^{65}Zn	68	70	<20
^{76}As	200	46	12
^{90}Sr	<1	<1	--
^{131}I	14	9	12
^{239}Np	560	370	57
Total Beta (counts/min/ml)	5.6	1.7	0.32

(a) *See Table I for definition.*

(b) *The (--) indicates insufficient data to provide a meaningful annual average.*

TABLE V. Calculated Annual Dose for Selected Organs from Routine Ingestion of Drinking Water[(a)]-1966

	Whole Body, mrem	GI Tract, mrem	Bone, % MPRI	Thyroid (Small Child) (0.4 liter/day), mrem
Richland	1.9	31	0.8	35
Pasco	<1	9	0.1	22
Kennewick	<1	1	<0.1	30

(a) *Here and elsewhere in this report where a dose (mrem) from an ingested nuclide is expressed, the determination is made from parameters used by the ICRP to translate dose rates into Maximum Permissible Concentrations for drinking water. In most cases, the estimated annual intakes of individual radionuclides were multiplied by conversion factors derived from the ICRP parameters and published by Vennart and Minski.*[(12)]

The "standard man"[(6)] *average intake rate of 1.2 liter/day was used in this calculation.*

unusual release of radioiodines to the river on February 11, 1966. The estimated thyroid dose (as a direct result of the release) received by a Typical Richland Child (2 g thyroid) drinking 0.4 liter of water per day was 20 mrem. The annual thyroid dose (including the above) to the same child from drinking water for 1966 was estimated to be 35 mrem. The maximum dose to a 2 g thyroid was estimated from a water intake rate of 0.8 liter per day. Such an intake rate would have resulted in thyroid doses from drinking water of 40 mrem during February, 1966, and 70 mrem for the entire year. Corresponding thyroid doses for 1965 were 20 mrem for the Typical Richland Child and 40 mrem for the Maximum Child.

RADIONUCLIDES IN FISH AND WATERFOWL

The Columbia River is popular for sports fishing both above and below the Hanford reservation. Those fish that feed downstream from the reactors acquire some reactor-effluent radionuclides through food chains. The concentration of several radionuclides in different kinds of fish from several locations on the river are available

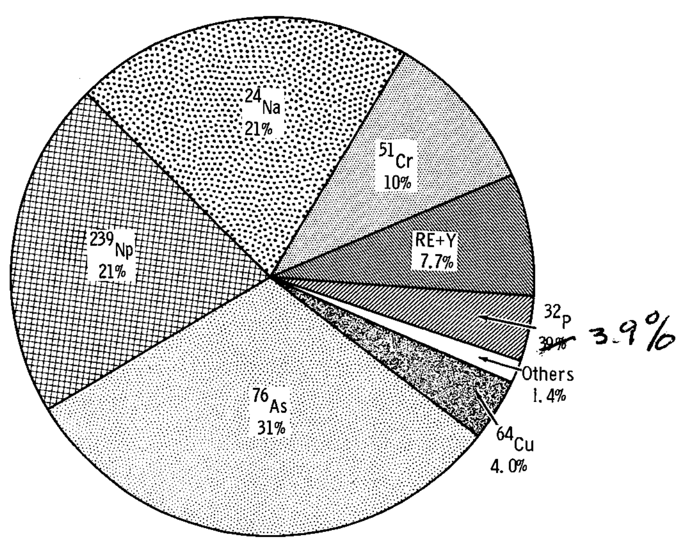

FIGURE 6. Relative Contributions of Radionuclides to GI Tract Dose Richland Drinking Water, 1966

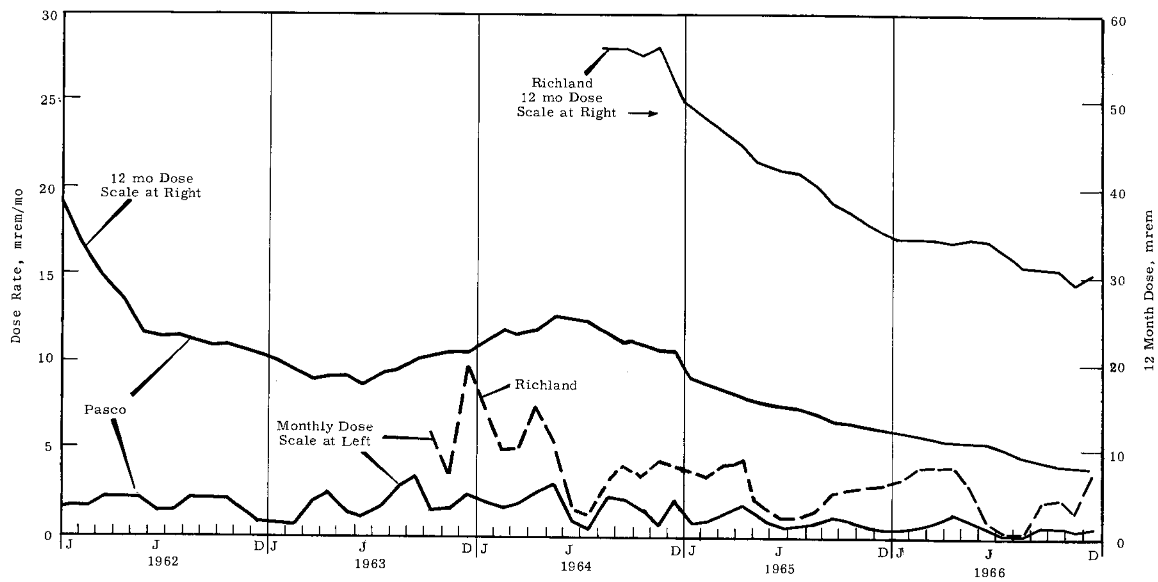

FIGURE 7. Calculated Dose to GI Tract from Pasco and Richland Drinking Water

in Appendix C, Tables 1-6.(8) ^{32}P is the radionuclide of greatest significance. Whitefish are the sports fish that usually contain the greatest concentration of radioactive materials. Further, they can be caught during winter months when other sports fish are difficult to sample. Therefore, data accumulated from whitefish sampling are used as trend indicators, even though whitefish are not the most significant source of radionuclides for the local population. The results of the measurements are illustrated in Figure 8. Concentrations of ^{32}P in whitefish during 1966 tended to follow seasonal trends observed in past years; however, ^{32}P concentrations in the fall months were at much lower levels than in previous years, primarily as a result of the extended reactor shutdown during the summer. Concentrations of ^{65}Zn in whitefish were affected little by the extended reactor shutdown, probably owing to recycling of this radionuclide from the river bottom during the shutdown period. The average concentrations of ^{32}P and ^{65}Zn in whitefish sampled downstream from the reactors during 1966 were 110 pCi/g and 23 pCi/g, as compared with 200 pCi ^{32}P/g and 27 pCi ^{65}Zn/g during 1965.(11)

The quantities and kinds of fish caught by local fishermen have been estimated previously from surveys carried out by personnel of the State of Washington, Department of Game; and additional dietary data collected during 1966 did not change these estimates. Those individuals who probably ingest the largest amounts of ^{32}P are fishermen who claim to eat bass, crappie, and perch as often as three to five times a week. This large number of fish meals indicates an

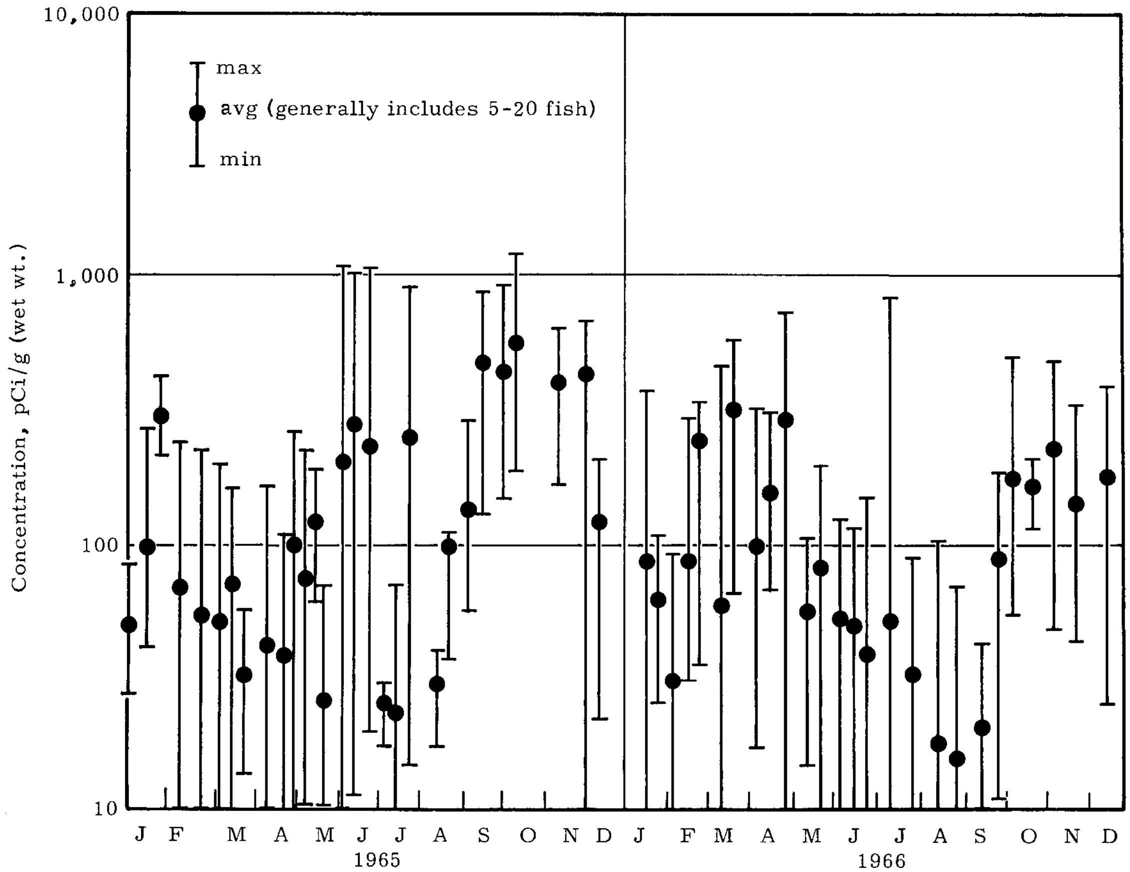

FIGURE 8. ^{32}P in Whitefish Caught in Columbia River Between Ringold and Richland

annual intake of about 40 kg of fish. On the basis of the 40 kg of fish consumption postulated for the Maximum Individual (200 fish meals/year), the intake of ^{32}P during 1966 could have been 1.0 μCi, or 6.2% of the MPRI (with bone as the critical organ).

Many persons have been counted in the Hanford Whole Body Counter, including some avid fishermen. Amounts of ^{65}Zn detected in these people were much less than expected on the basis of their stated consumption of fish. These results supported the findings of past years which suggested that fishermen tend to overestimate their fish consumption. Therefore, the actual ingestion rates of both ^{32}P and ^{65}Zn are undoubtedly substantially lower than we currently postulate from the fishermen's estimates.

Migratory waterfowl, such as ducks and geese, that have utilized the Hanford section of the Columbia River and the swamps and ponds within the project boundaries may contain ^{32}P, ^{65}Zn, and small amounts of other radionuclides. Some of these waterfowl remain in this general area throughout the year. Results of the radioassay of waterfowl samples collected within the Hanford project and in the environs are available in Appendix C, Table 7.[8] One hundred twenty-four of the water fowl samples collected in the Hanford environs during 1966 had concentrations of ^{32}P less than 50 pCi/g of flesh (wet weight), 51 samples were above 50 pCi/g but less than 500 pCi/g, and the remaining 10 samples were greater than 500 pCi/g. The maximum concentration was 2900 pCi ^{32}P/g. However, as a potential source of this radionuclide to people, the waterfowl are of much less significance than the fish because they cannot be harvested in such large numbers by individuals and because of "dilution" by large flights of migrating birds that move through the region at the time of the year when hunting is allowed.

RADIONUCLIDES IN MARINE ORGANISMS

^{65}Zn and ^{32}P are the only radionuclides in the reactor effluent that are found in sufficient abundance beyond the mouth of the Columbia River to be of radiological interest. Oysters have been found to contain higher concentrations of ^{65}Zn than other common sea food organisms. Concentrations of ^{65}Zn and ^{32}P periodically measured in oysters grown in the Willapa Bay area are shown in Figure 9, and the analytical results are available in Appendix D, Table 1.[8] The extended reactor shutdown during the summer of 1966 had very little effect on concentrations of ^{32}P and ^{65}Zn in oysters. In the case of ^{32}P, a normal seasonal minimum occurs in the late summer; and in the case of ^{65}Zn, recycling from the river bottom held ^{65}Zn concentrations near their normally expected levels. Annual average concentrations of ^{65}Zn have decreased over the past three years while ^{32}P concentrations have remained at about the same level during that time.[9,10,11] The average concentrations in samples taken throughout 1966 were 28 pCi ^{65}Zn/g and 2.9 pCi ^{32}P/g.

Consumption of oysters containing these concentrations at the rate of 50 g/day* would result in an annual dose of about 6 mrem to the GI tract and 4 mrem to the whole body. These intakes represent 0.4% of the MPRI for bone as the critical organ.

RADIONUCLIDES IN THE ATMOSPHERE

At Hanford, gaseous waste from the chemical separations facilities is released to the atmosphere through 70-meter stacks after most of the radioactive materials have been removed. These radioactive materials are primarily associated with process vessel off-gases. Ventilation air from laboratory and reactor buildings contains comparatively minor amounts of radioactive materials under normal operating conditions.

Measurement of airborne ^{131}I were made routinely at numerous locations within the Hanford reservation and around the plant perimeter. The results of ^{131}I measurements for the past few years are summarized in Table VI with a more detailed tabulation in Appendix E, Table 1.[8] The four locations listed in Table VI lie within a 45° sector southeast to south of the separations areas. ^{131}I concentrations sustained in inspired air

* *Expected to be used as a reference consumption rate in future national shellfish quality standards.*

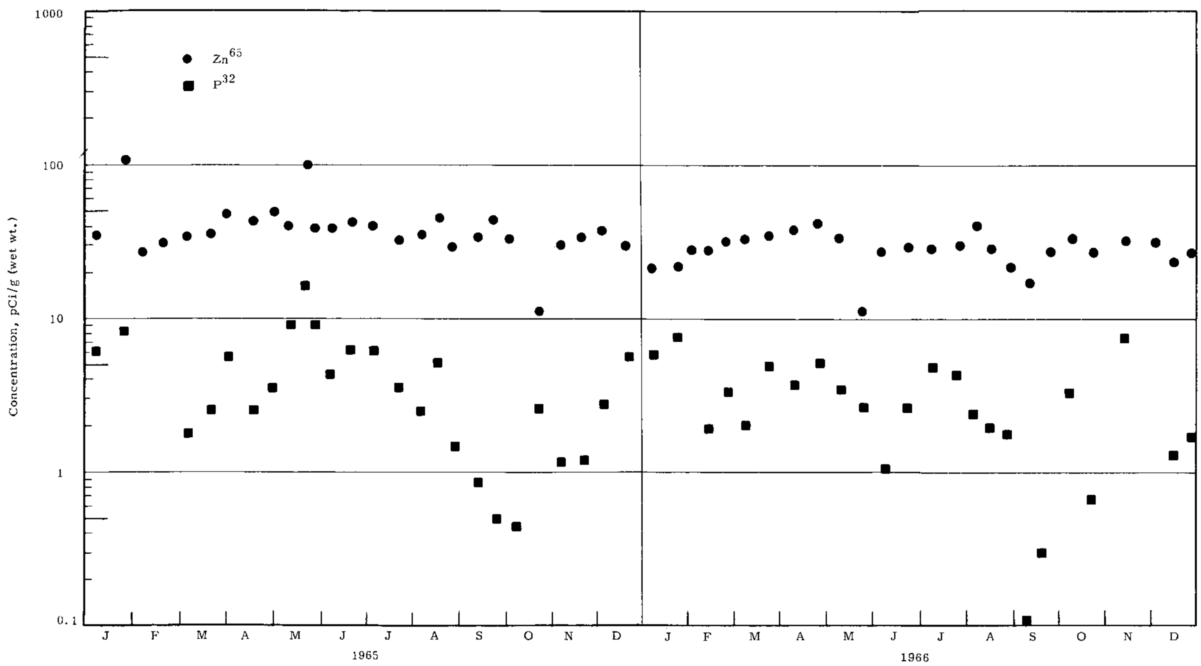

FIGURE 9. ^{32}P *and* ^{65}Zn *in Willapa Bay Oysters*

TABLE VI. Annual Average ^{131}I *Concentrations in the Atmosphere*

Location	Distance from Separation Stacks, km	1966	1965	1964	1963
		pCi/m^3			
Prosser Barricade[a]	23	0.02	0.03	0.02	--
Benton City	32	0.01	0.03	0.06	0.03
Richland	37	0.01	0.02	0.02	0.02
Pasco	51	0.01	0.03	0.01	0.02

(a) *Installed during October 1963.*

imply a dose to the thyroid of the "standard man" of less than 1 mrem during 1966.

Air filter sampling is maintained at several locations within the Hanford reservation and around the plant perimeter. The results of air sampling at these locations are shown in Figure 10 and are tabulated in detail in Appendix E, Table 2.[8] Air filter results are not used in radiation dose estimates but serve to illustrate the

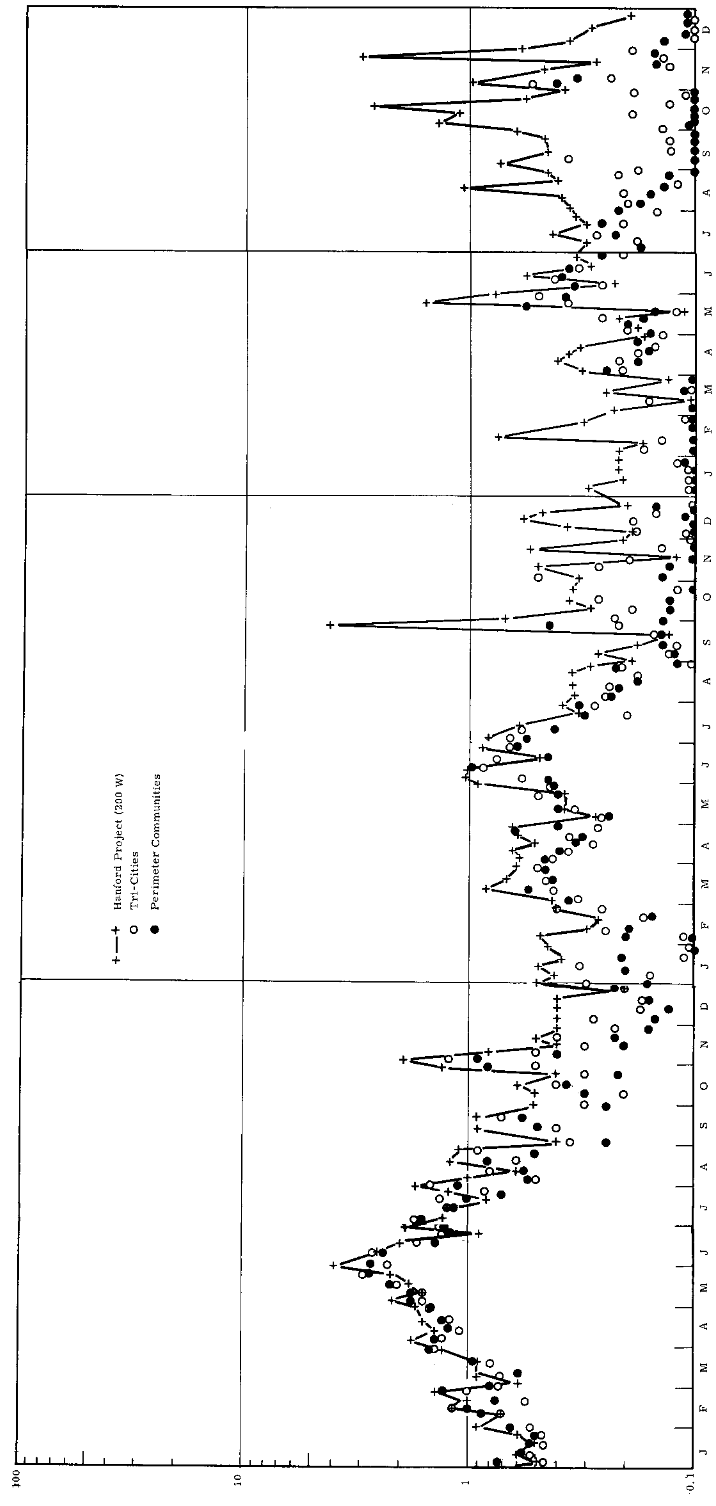

FIGURE 10. Radioactive Particulates in the Air of Hanford Environs

trends in atmospheric contamination. Sudden changes in concentration (such as those caused by fallout from nuclear weapons tests) are used to signal the need for shifted emphasis in other portions of the environmental monitoring program related to atmospheric contamination.

RADIONUCLIDES IN MILK AND PRODUCE

The radioactivity found in locally grown agricultural produce can be influenced by deposition of airborne radionuclides or by irrigation with river water containing reactor effluent radionuclides. The chemical separations facilities are generally the principal local source of airborne radionuclides. The closest farming area to the separations facilities is about 21 km (13 mi) away. Radioactive materials released from ventilation stacks of the reactors or laboratory facilities could, under certain conditions, become of some small interest.

Most irrigated farms near the Hanford plant obtain water from the Yakima River, or from the Columbia River above the project. There are, however, two small areas which regularly take water from the Columbia River downstream from the reactors for irrigation. They are the Ringold farms and the Riverview district west of Pasco, located respectively 24 and 48 km (15 and 30 mi) downstream from the reactors. The Ringold farms, approximately 21 km east of the production areas, involve about 20 people working some 2 km^2 (500 acres) of land with fruit as the principal product. The Riverview farm areas consists of about 21 km^2 (5300 acres) supporting about 1000 families, the majority of which live on plots of 4000 m^2 (1 acre) or less and raise family gardens. The principal products from the larger farm plots are hay, fruit, beef, and dairy products. This area is centered 48 km southeast of the chemical separations plants. Another agricultural area near the project is Benton City, located on the Yakima River about 32 km (20 mi) directly south of the separations facilities.

A comprehensive milk surveillance program maintained during 1966 included samples from local farms and dairies and from commercial supplies available to people in the Tri-Cities. The concentrations of radionuclides found in milk sold by commercial outlets were similar to that reported by the U. S. Public Health Service[13] and the Wahsington State Department of Health.[14] Milk from local farms irrigated with water drawn from the river downstream from the reactors contained ^{32}P and ^{65}Zn as well as fission products of fallout origin.

The concentrations of ^{131}I measured in milk samples collected during 1966 are shown in Figures 11 and 12. Generally, the average concentration of ^{131}I in both local and commercial milk was at or below the analytical limit of 3 pCi/liter. Brief increases in ^{131}I concentrations were noted in June, following the Chinese nuclear weapons test on May 9; in July and October, following small, transient increases in the release rate of ^{131}I from a chemical separations facility; and in November, following the Chinese and Russian nuclear tests on October 27. The maximum concentration of ^{131}I

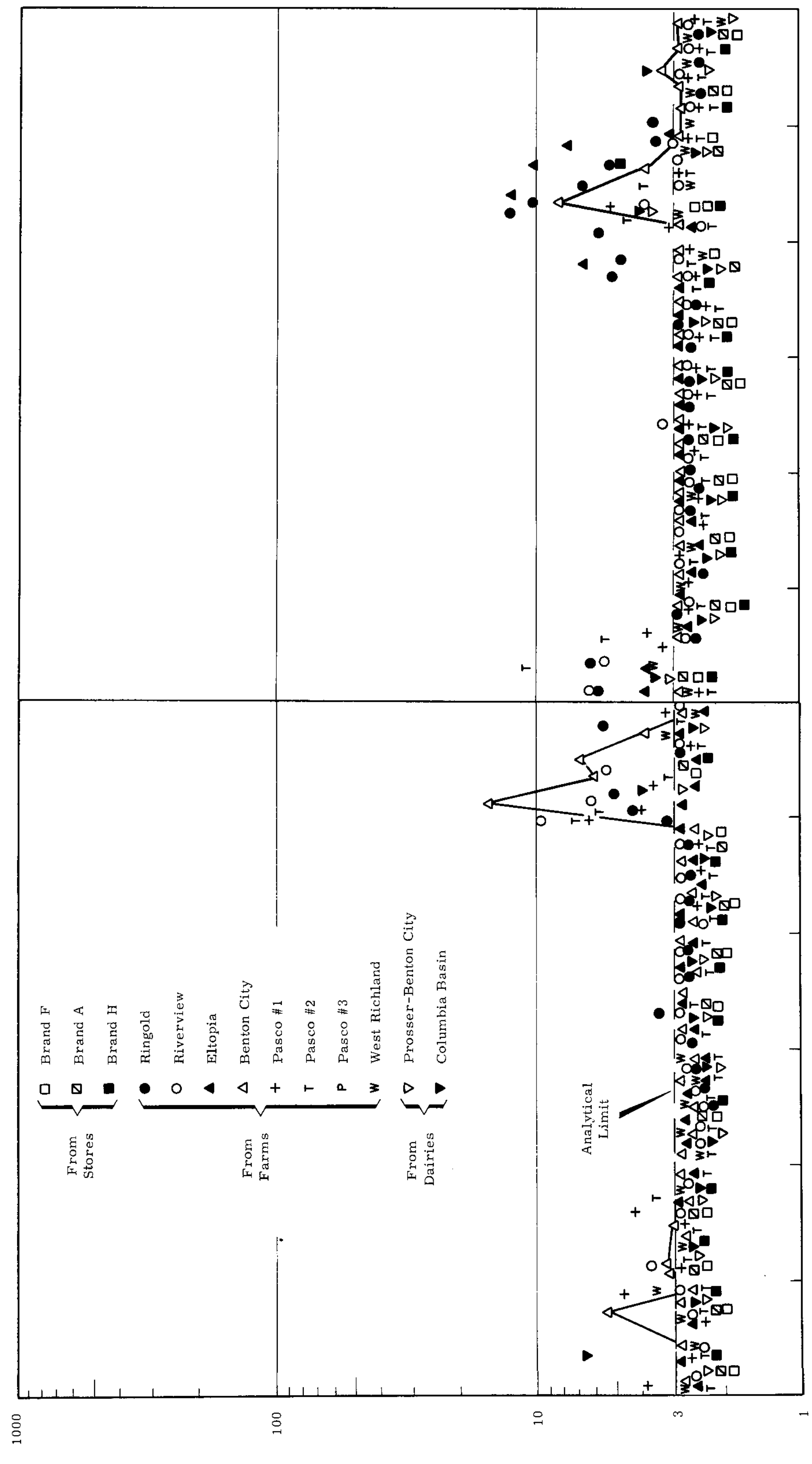

FIGURE 11. ^{131}I *in Local Milk*

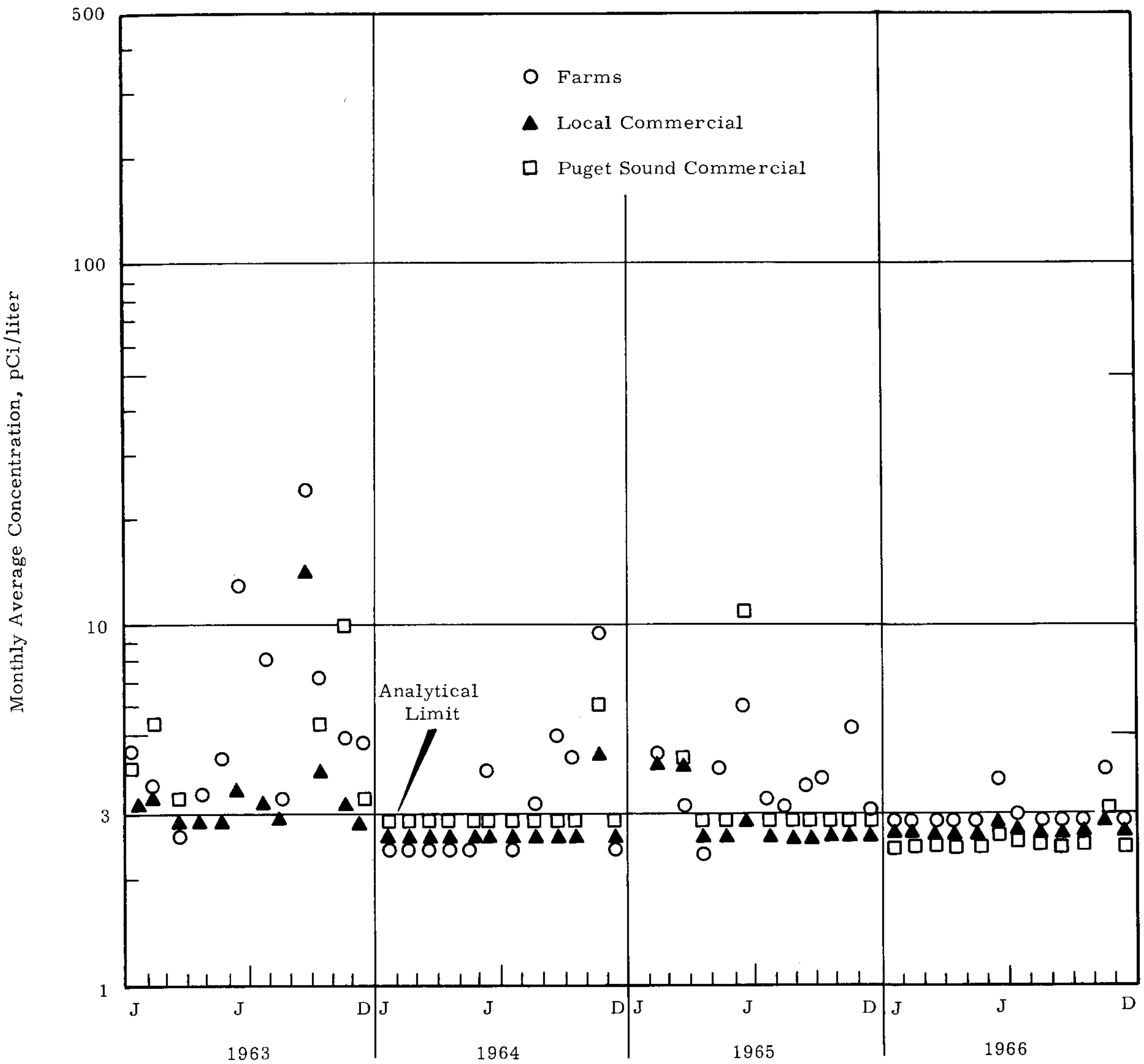

FIGURE 12. ^{131}I *in Locally Available Milk*

observed in milk was 15 pCi/liter on June 2, 1966.

Dairy farms in the Ringold and Riverview area that utilize the Columbia River for irrigation of pasture land and hay fields produce milk containing both ^{32}P and ^{65}Zn (Figures 13 and 14). The extended reactor shutdown during July and August had very little effect on the concentrations of these two nuclides in milk because of other variables, such as irrigation and feeding practices. During 1966, the average concentration of ^{32}P in milk from Ringold and Riverview farms was 480 pCi/liter and the average concentration of ^{65}Zn was 370 pCi/liter. Commercial milk distributed in the Tri-Cities usually does not contain ^{32}P and ^{65}Zn because it is obtained principally from areas not irrigated with Columbia River water.

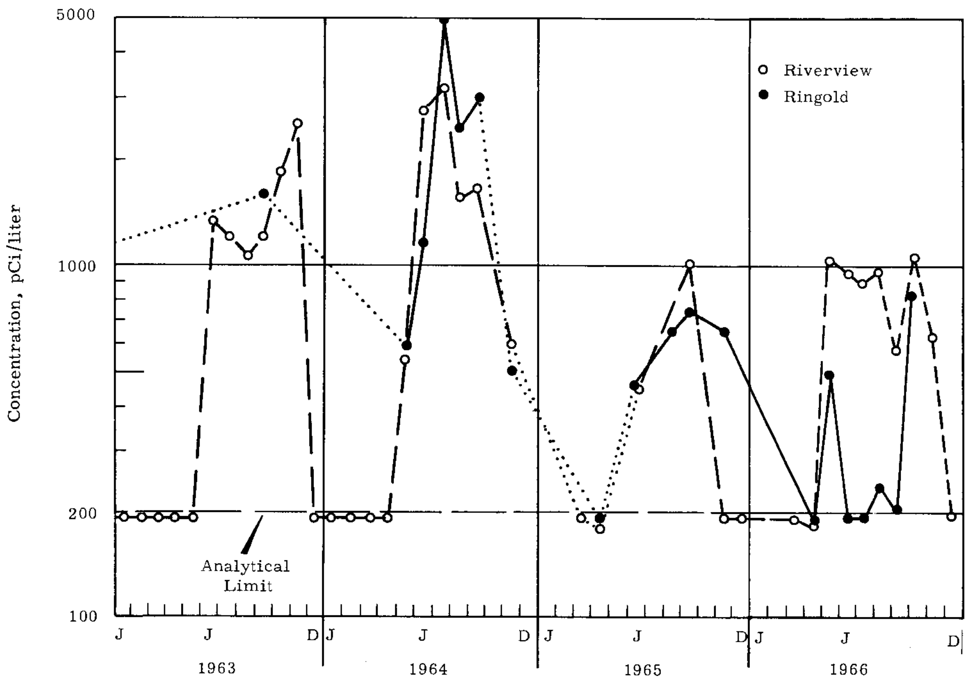

FIGURE 13. ^{32}P *in Locally Produced Milk*

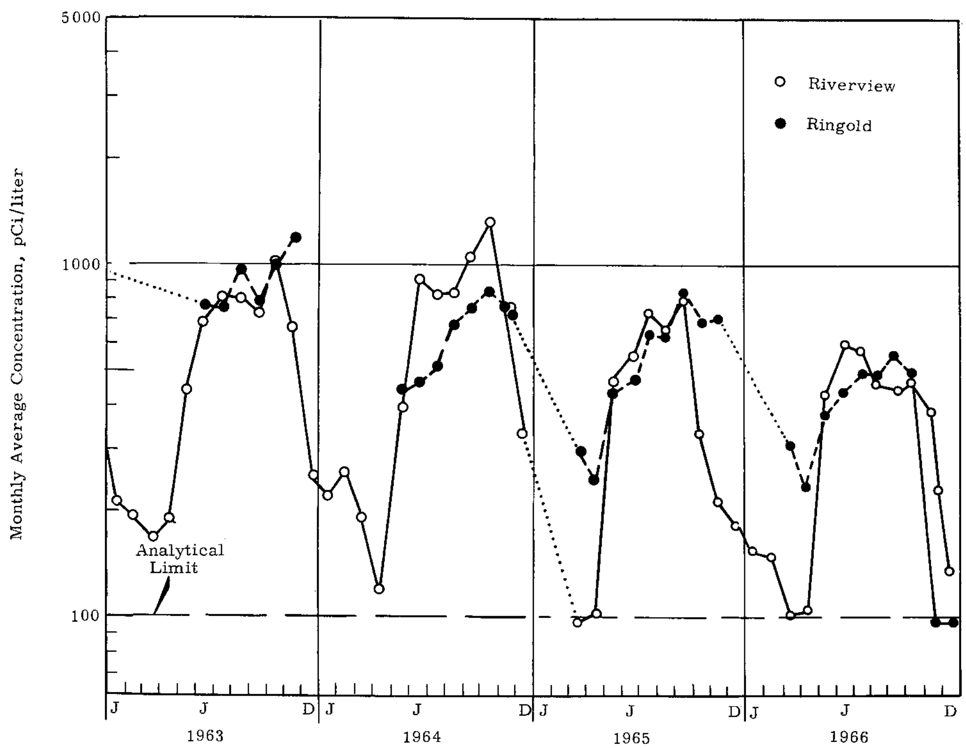

FIGURE 14. ^{65}Zn *in Locally Produced Milk*

Adult residents consuming milk (1 liter/day) obtained from the Ringold-Riverview area would receive an annual dose from ^{32}P and ^{65}Zn amounting to about 5 mrem to the GI tract and 2 mrem to the whole body. The intake of ^{32}P and ^{65}Zn would be equal to about 1.2% of the MPRI for bone. The intake of ^{131}I would have resulted in a dose of about 2 mrem to the thyroid. Concentrations of radionuclides measured in milk are tabulated in Appendix F, Table 1.[8]

Miscellaneous fresh farm produce was sampled periodically for radioanalysis during the 1966 growing season from local farms and commercial outlets. Results of these measurements, tabulated in Appendix F, Tables 3 through 5,[8] were similar to those of previous years[9,10,11] and indicated that only small quantities of radionuclides are present in locally grown produce.

The concentrations of ^{131}I found in samples of fresh vegetables collected from local farms and markets during the period of May through September were less than or approximately equal to the analytical limit of 0.05 pCi/g. There was no significant difference noted in concentrations found in local farm produce and in produce purchased from commercial outlets. If these fresh vegetables had been consumed at the rate of 100 g/day throughout the year, the annual intake from this source would have been about 730 pCi ^{131}I. Such an intake would imply an annual dose of about 1 mrem to the thyroid of a typical adult Richland resident.

CONCENTRATIONS OF ^{131}I IN CATTLE THYROIDS

Thyroids of cattle are collected periodically from slaughter houses in Moses Lake, Yakima, Walla Walla, Wenatchee, and Pasco, and are sent to Hanford for radioanalysis. Since the concentration of ^{131}I in bovine thyroids is about three orders of magnitude higher than that in the pasture grass or in milk, it is advantageous to use thyroid measurements to follow probable trends in concentrations of ^{131}I in milk and farm produce, especially when the levels in milk and vegetables are below the analytical limit. The average concentrations measured in beef thyroids during 1966 are shown in Figure 15. The maximum concentration was 150 pCi ^{131}I/g from samples collected in November at Pasco and Walla Walla.

Data obtained from the cattle thyroids program for 1966 are tabulated in Appendix G, Table 1.[8]

EXTERNAL RADIATION

Ionization chambers are stationed on the Hanford reservation and in Richland to estimate the gamma radiation exposure from external sources. Measurements in air 1 meter above ground during 1966 averaged about 0.36 mR/day or 130 mR/yr at Hanford (Figure 16) and 0.28 mR/day or 100 mR/yr at Richland (Figure 17), somewhat lower than measured during the past three years.[9,10,11] Essentially, all of this exposure is from natural background and worldwide fallout from nuclear testing. Measurement of external radiation are tabulated in Appendix H, Table 1.[8]

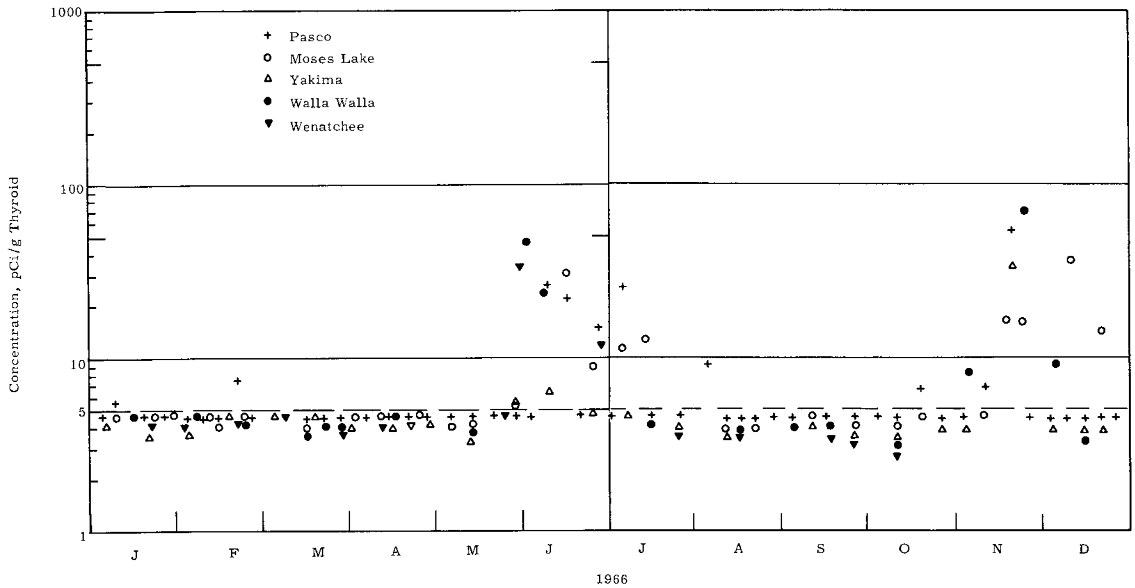

FIGURE 15. ^{131}I in Thyroids of Beef

Direct radiation measurements are also made in the Columbia River at several locations with pocket-type ionization chambers submerged 0.6 to 1.5 meters below the surface of the water. Exposure rates are higher in the river than over ground because of the presence of gamma emitters (especially ^{24}Na) in reactor effluent. In the vicinity of Richland, the average exposure rate in the water during the months of April through October of 1966 was about 2 mR/day, as in 1965.(11) A person swimming or boating in the river for a total of 240 hr during the year could have received a whole body exposure of about 20 mR. Measurements of immersion exposure rates in the river are tabulated in Appendix H, Table 2.(8)

An estimate of the external radiation exposure received by people that fish from the shore in the vicinity of the Hanford project is complicated by the daily fluctuation in the level of the river, but the exposure rate at the river's edge during 1966 was lowest during the period from late June (river freshet) through August (extended reactor shutdown), and was highest during low river flow rates in the fall months. Measurements of the gamma ray spectrum indicate that ^{65}Zn accumulated by algae growth on the substrate at the river's edge is responsible for a major portion of a fisherman's external radiation exposure. Assuming that an avid fisherman spent as many as 500 hr on the river bank in the vicinity of Richland during 1966, his external exposure could have been about 13 mR.

RADIOACTIVE WASTES RELEASED TO GROUND

Liquid wastes from the chemical separations areas are routed to various facilities dependent upon their burden of radionuclides. High level wastes (normally containing concentrations greater than 100 μCi/ml) are stored in underground concrete tanks lined with steel. Intermediate level wastes (ordinarily containing concentrations in the range of 5 x 10^{-5} μCi/ml to 100 μCi/ml) are sent to underground "cribs" (covered liquid waste disposal sites) from which they percolate into the soil. The areas selected for intermediate waste disposal and high level waste storage have soil with good ion exchange capacity and ground water depths of 50 to 100 meters. Low level wastes (usually containing less than 10^{-5} μCi/ml) are sent to depressions in the ground where surface ponds or "swamps" have been formed as a result of the continuous addition of the relatively large volumes of water.

One important objective in the management of wastes placed in the ground is the prevention or radiologically important radionuclides from reaching the ground water in quantities that could ultimately cause significant human radiation exposure should they migrate to the Columbia River. For this reason, wells have been drilled in and around crib and tank storage areas to detect any leaks in the tanks and to measure radionuclides that have reached the ground water. Virtually all of the radionuclides present in the ground water have been introduced with liquids sent to the cribs. Figure 18 shows the probable extent and concentration of

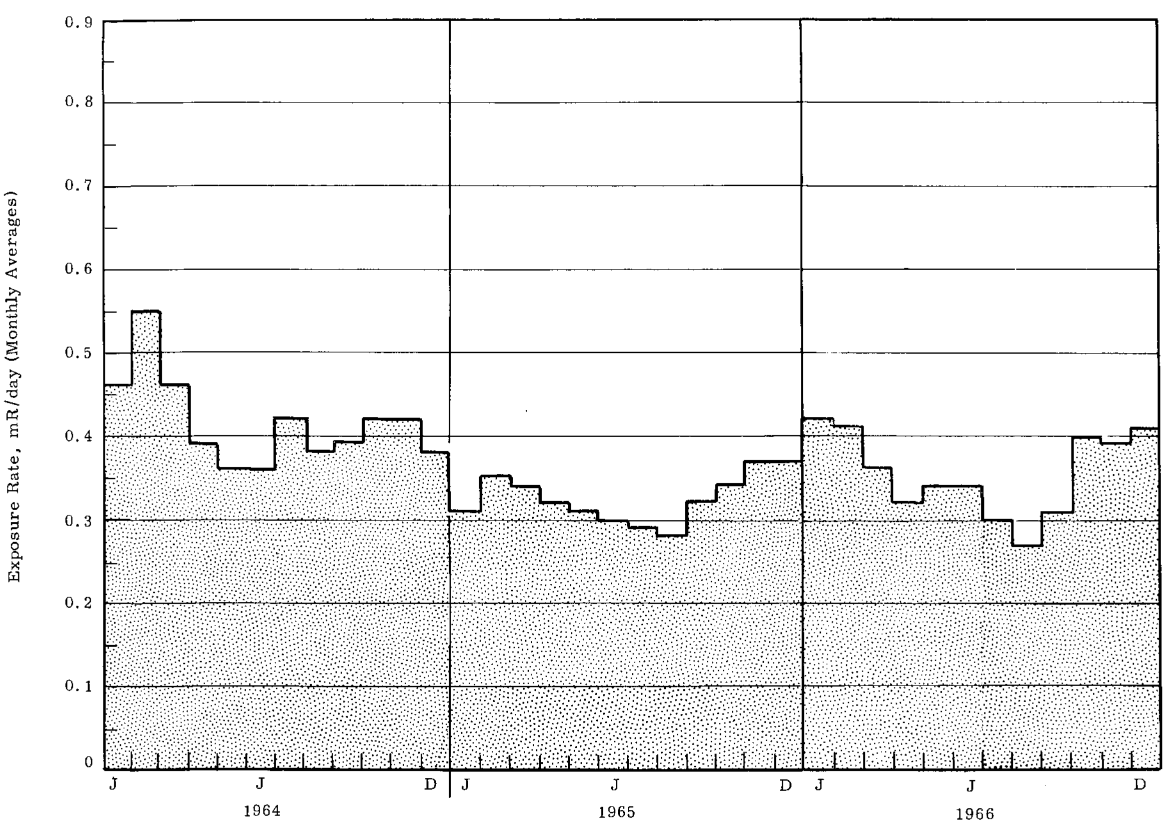

FIGURE 16. External Exposure Rate as Measured at Hanford Test Location

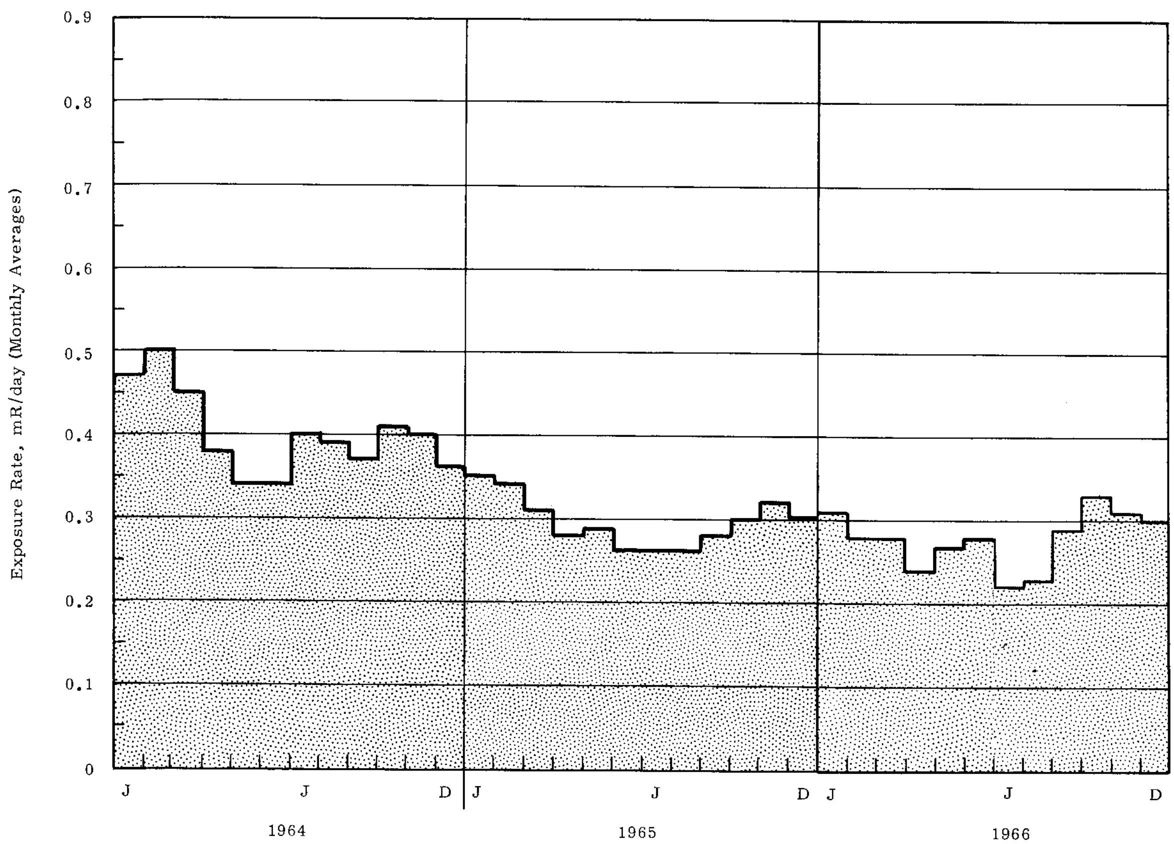

FIGURE 17. External Exposure Rate as Measured at Richland

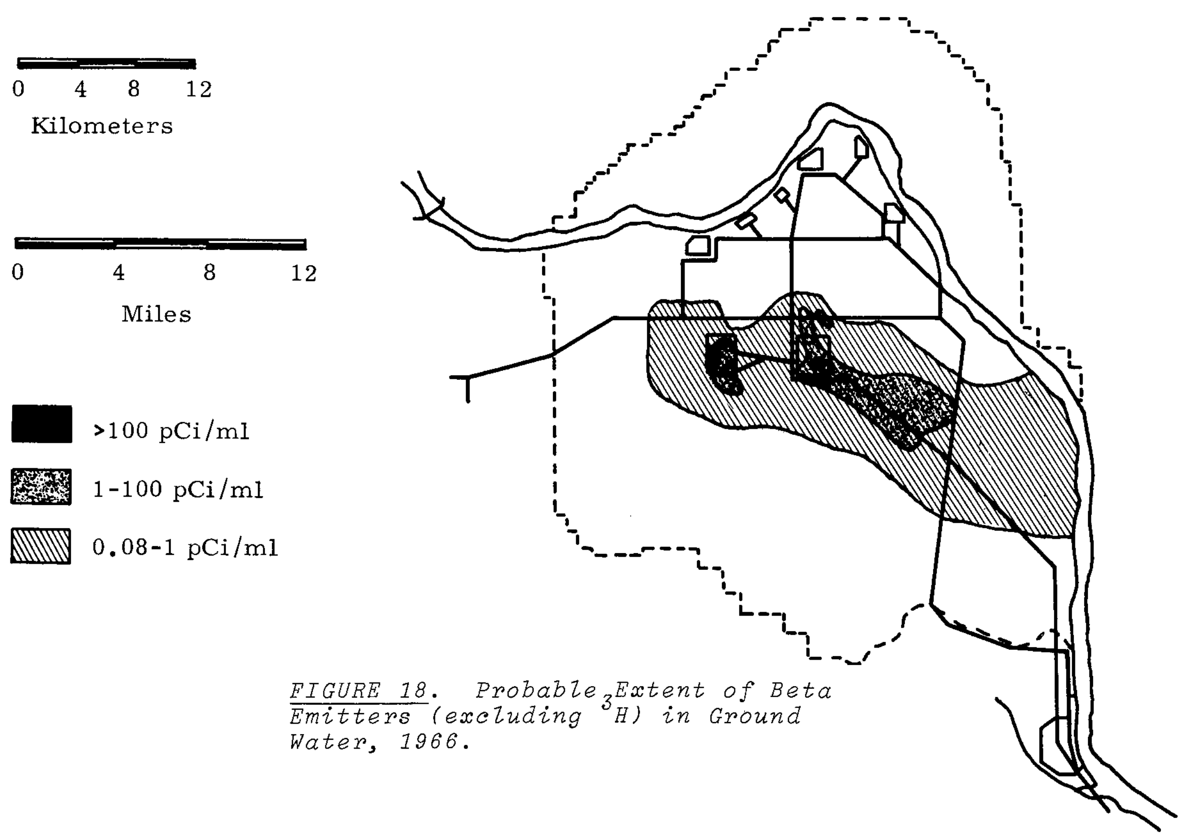

FIGURE 18. Probable Extent of Beta Emitters (excluding ^3H) in Ground Water, 1966.

radioactive materials (excluding ^{3}H) in the ground water as of December, 1966.(15) The major portion of this radioactivity is ^{106}Ru-Rh.

A substantial amount of ^{3}H has also been sent to the ground with the intermediate level liquid wastes from the separations plants. Figure 19 shows the probable extent and concentration of tritium in the ground water in December, 1966.(15) In all probability, some ^{3}H and ^{106}Ru-Rh originating at the chemical processing areas is now entering the Columbia River. However, the contribution of these nuclides is too small to be detectable in the river water and any radiation dose from them is therefore negligible.

FALLOUT FROM NUCLEAR WEAPONS TESTING

In addition to the radiation dose received by residents of the Hanford environs from Hanford originated radionuclides and from natural background radiation, a dose increment due to fallout nuclides is also received (not included in the assessment of dose due to Hanford operations). Locally, this increment is below the national average because of the low rainfall (16 cm/yr). Measurements of fallout, like measurements of natural background radiation, are necessary to place the radiation dose resulting from Hanford operations into proper perspective. The fallout nuclides of interest during 1966 were ^{3}H, ^{90}Sr, ^{131}I, and

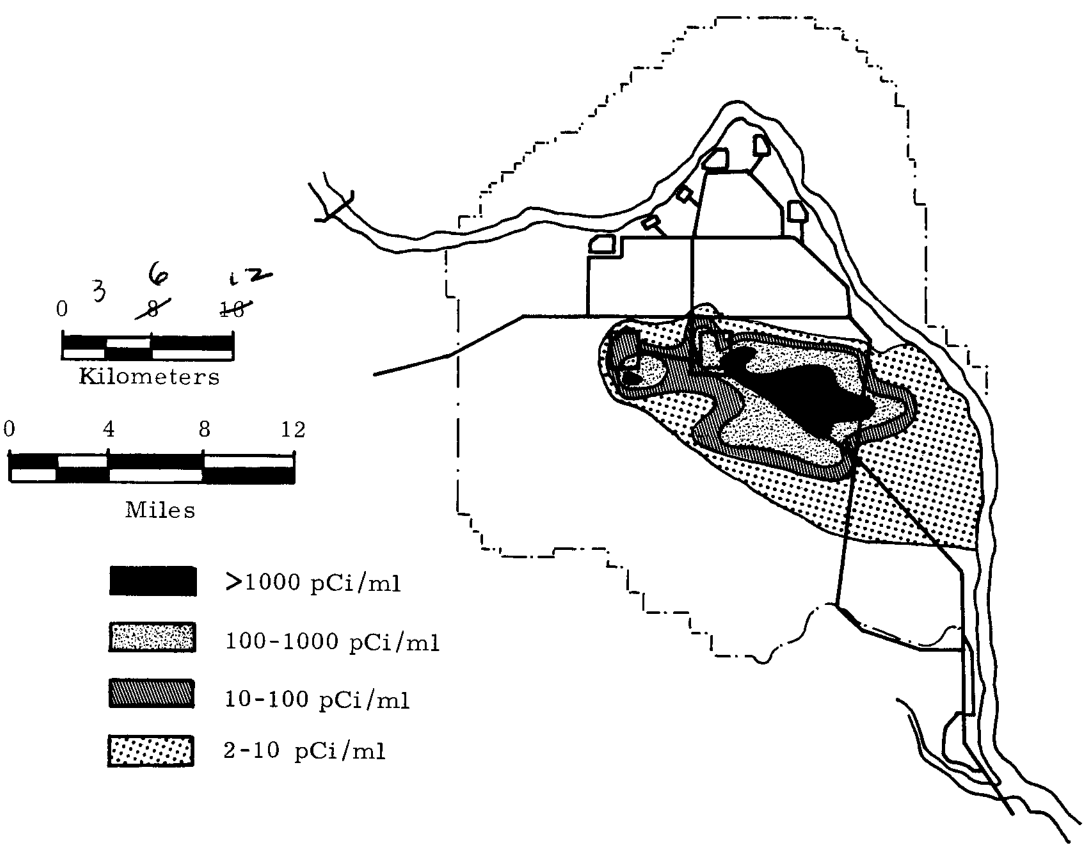

FIGURE 19. Probable Extent of Tritium in Ground Water, 1966

^{137}Cs. Although small, transient increases in ^{131}I concentrations were observed in June and November (following the Chinese and Russian nuclear weapons tests), the resulting thyroid doses were negligible.

Tritium (another fallout nuclide), although occasionally detectable in Columbia River water, was at such low levels (2 nCi/liter) that routine consumption of water obtained from the Columbia River implied an annual dose to the whole body of the Maximum Individual of less than 1 mrem.

Concentrations of ^{90}Sr measured in locally available milk are shown in Figure 20. These values are similar to concentrations found in commercial milk produced in areas that are remote from the Hanford plant. ^{90}Sr found in milk from local farms averaged about 5 pCi/liter. The concentration of ^{137}Cs in milk (Figure 21) analyzed at Hanford was generally near the analytical limit of 30 pCi ^{137}Cs/liter. Worldwide fallout is the principal source of ^{90}Sr and ^{137}Cs in milk.

About 10% of the total intake of ^{90}Sr by local residents during 1966 came from drinking water obtained from the Columbia River. As in the case of milk, this ^{90}Sr was of fallout origin.

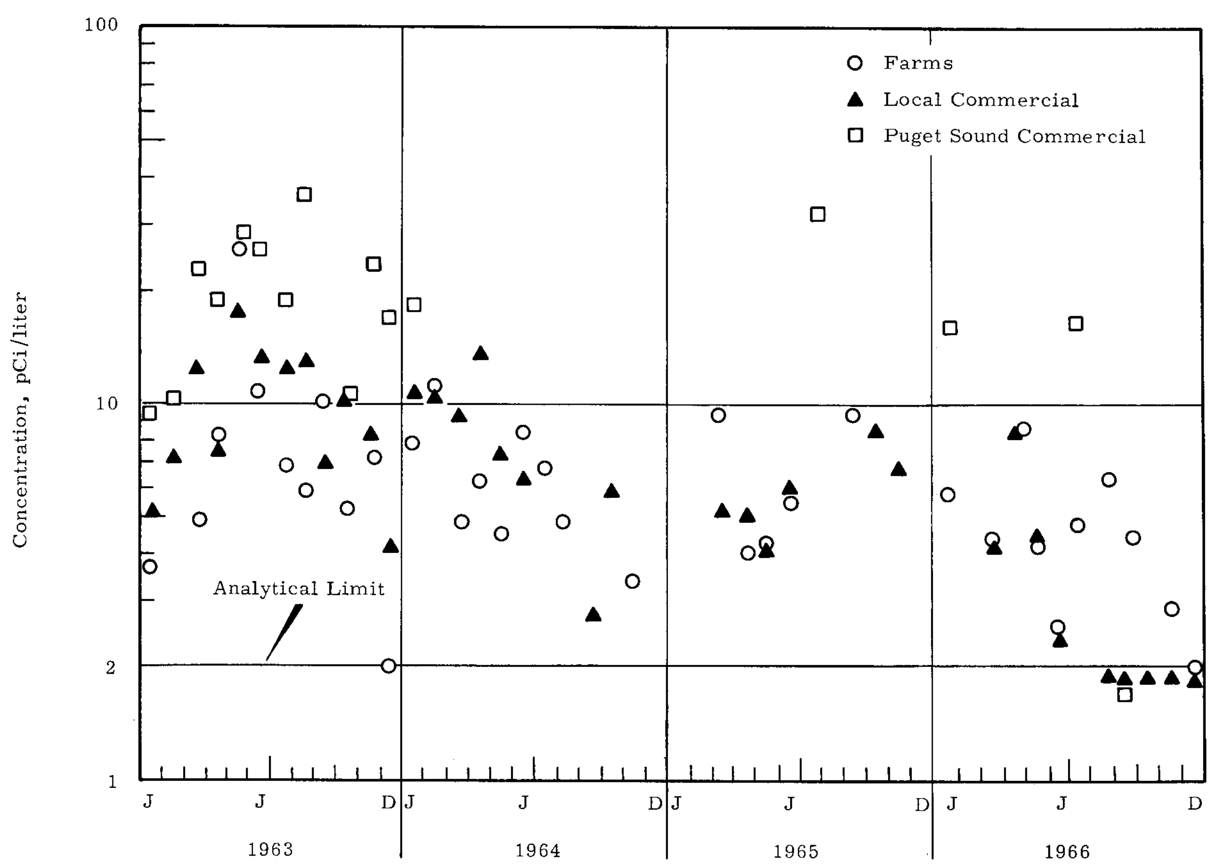

FIGURE 20. ^{90}Sr *in Locally Available Milk*

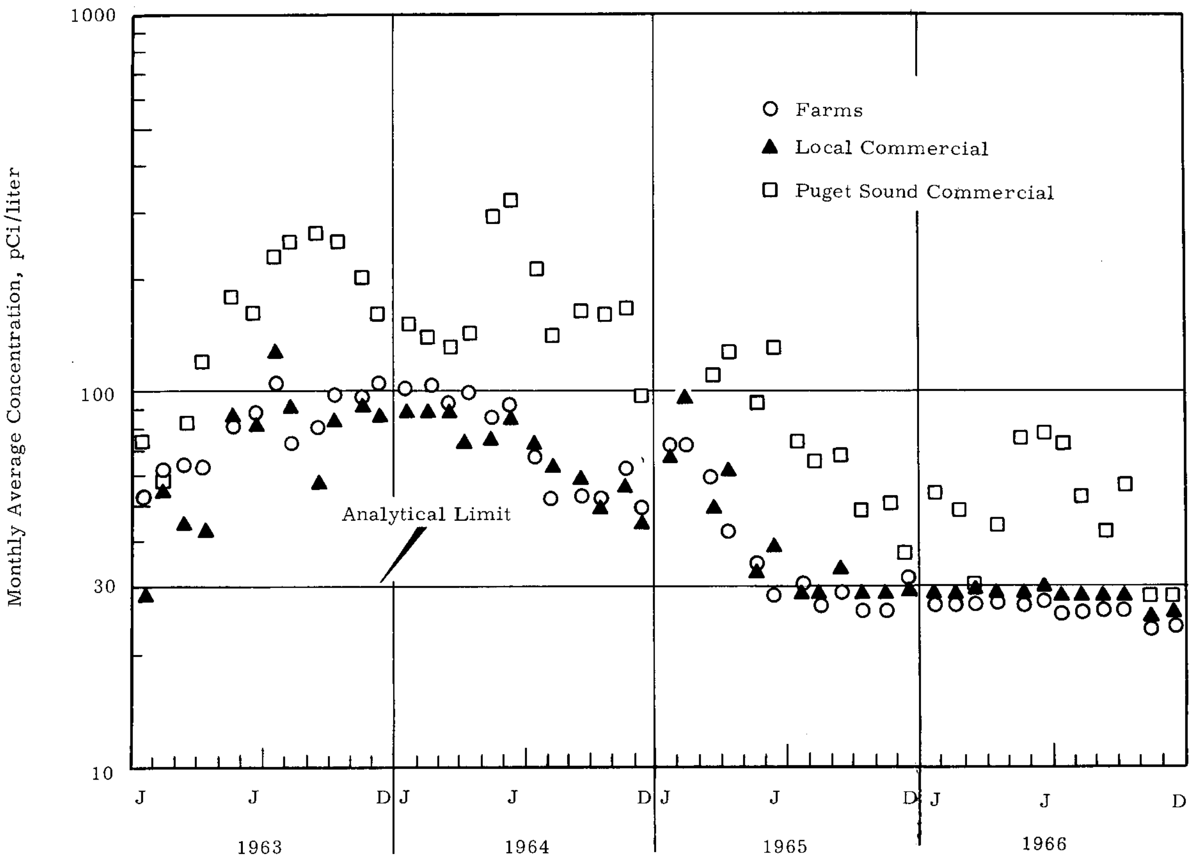

FIGURE 21. ^{137}Cs in Locally Available Milk

Based on the same dietary information used in other sections of this report, the total intake of ^{90}Sr during 1966 was about 0.006 μCi for the Maximum Individual and 0.005 μCi for the Typical Richland Resident. The total intake of ^{137}Cs during 1966 was about 0.02 μCi for both the Maximum Individual and the Typical Richland Resident. The estimated annual dose from fallout radionuclides present in the Hanford environs is given in Table VII. The dose calculations assume an equilibrium concentration in the organ of interest at the 1966 rate of intake and are based on ICRP parameters.

TABLE VII. Annual Radiation Dose from Fallout Nuclides-1966(a)

Nuclide	Organ	Maximum Individual (mrem)	Typical Richland Resident (mrem)
^{3}H	Whole Body	<1	<1
^{90}Sr	GI Tract	<1	<1
	Whole Body	5	5
	Bone	(2% MPRI)	(5% MPRI)
^{137}Cs	GI Tract	<1	<1
	Whole Body	<1	<1
	Bone	(0.1% MPRI)	(0.1% MPRI)

(a) *Not included in the dose summary table (p. iv) or in Figures 22 and 23.*

RADIATION EXPOSURE SUMMARY

It is not possible to determine the precise radiation dose received by every individual because of variations in the kinds and quantity of food consumed, variations in sources of food supply, and many variations in personal living habits. These inherent variations between individuals require a somewhat subjective approach when estimating the probable radiation dose in relation to various established limits. The FRC has provided two sets of guides against which doses from environmental sources may be judged; i.e., one for the individuals that receive the greatest dose, and the other for the average dose received by the general population (taken as one-third of that set for individuals). For the Hanford environs, doses from the various sources described in the preceding sections have been compiled in two ways to allow comparisons with guides for both the individual and the general population. In one case a hypothetical, but plausible, individual has been assigned dietary and other habits that would result in what would seem to be the greatest rational dose. For the general population, a dose has been estimated for what is called the Typical Richland Resident. Some residents may receive a larger dose than calculated for the Typical Richland Resident but it is improbable that any receive as much as that calculated for the Maximum Individual. Included in this intermediate group are families that subsist largely on foodstuffs produced on farms irrigated with water taken from the Columbia River downstream from the reactors.

THE MAXIMUM INDIVIDUAL

Attempts have been continued to identify the individuals living in the Hanford environs that receive the greatest radiation dose. Experience accumulated from the environmental surveillance program indicates such individuals are undoubtedly persons that frequently eat fish caught locally in the Columbia River and foodstuffs grown on farms irrigated with Columbia River water. Additional data collected during 1966 continued to support the assumption that fish, consisting mainly of crappie, perch, and bass caught near Burbank (Figure 2), are the most important source of radionuclides for the Maximum Individual. On the basis of an assumed consumption of 200 meals/yr and radiochemical analyses of such fish, the intakes of ^{32}P and ^{65}Zn for the Maximum Individual during 1966 would have amounted to 1.0 and 0.5 μCi, respectively. Whether this amount of fish was actually eaten by the individual was not confirmed. However, other persons reporting an unusually high consumption of local fish were counted in the Whole Body Counter and were found to have far less ^{65}Zn deposited than predicted on the basis of their estimates of the quantities of fish eaten. As a basis for calculating the intake of radionuclides from fish, we have continued to use the maximum reported consumption of 200 fish meals per year, pending more comprehensive data.

The consumption rates of other foods for the hypothetical maximum individual are based on the maximum intakes described in various dietary surveys. It is assumed that this individual consumes each day 2 liters of water from the Pasco system, 1 liter of milk, 230 g of beef, 20 g of chicken, 80 g of eggs, 200 g of fresh leafy vegetables (in season), and 1400 g of all other vegetables and fruits, all produced on river irrigated farms in the Riverview District. The composite doses* from these sources are illustrated in Figure 22.

* *For both the Maximum Individual and the Typical Richland Resident, the same dose calculation methods have been used in 1966 that were used in 1965.*[11]

In the case of the thyroid gland, it is probable that the maximum radiation dose occurred in small children because of the relatively small thyroid mass in which the ^{131}I accumulates. The thyroid of a small child is assumed to weigh 2 g compared with 20 g for the adult. In past years[9,10,11] the maximum thyroid dose has been attributed to a child living in the Riverview farm district

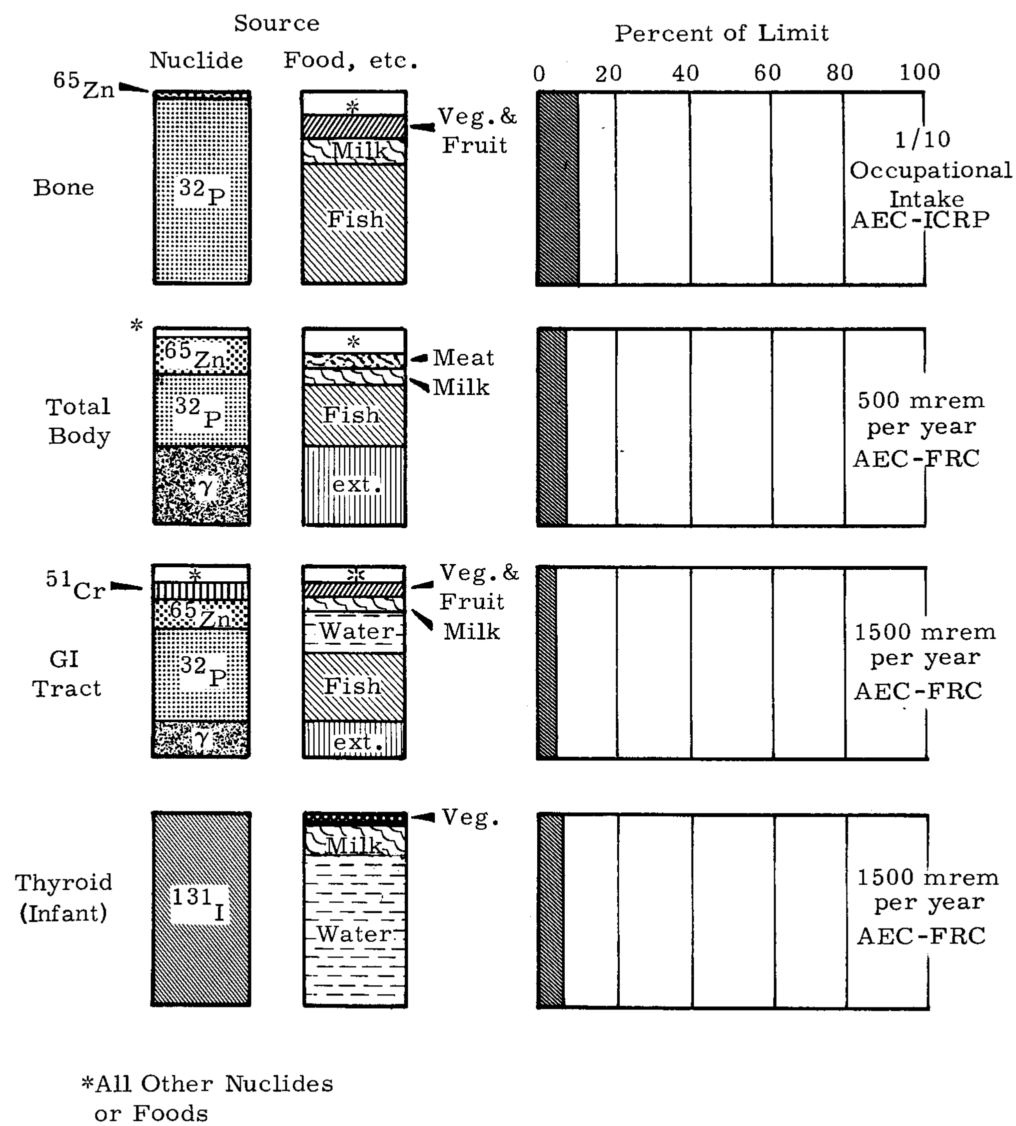

FIGURE 22. Estimated Dose to Maximum Individual, 1966

(Pasco). On the basis of a daily intake of 1 liter of farm milk, 50 g of fresh leafy farm vegetables, and 0.8 liter of water from the Pasco system, the thyroid dose received by a Riverview child during 1966 was 61 mrem (4% of the limit). However, a Richland child with similar dietary habits received a higher thyroid dose during 1966 than the Riverview child as a result of the radioiodine release during February. On the basis of a daily intake of 1 liter of commercial milk, 50 g of fresh leafy commercial vegetables, and 0.8 liter of water from the Richland system, the thyroid dose received by the Maximum Child during 1966 was 86 mrem, or 6% of the FRC Radiation Protection Guide for individuals.[4] (Figure 22).

THE TYPICAL RICHLAND RESIDENT

The vast majority of people who live in Richland obtain their food from local commercial stores (rather than directly from farms) and consume little or no fish caught from the Columbia River. The principal sources of radionuclides ingested by these people are worldwide fallout (see the section Fallout from Nuclear Weapons Testing) and drinking water obtained from the Columbia River.

The contribution from Hanford created radionuclides in drinking water is substantially different for Richland, Pasco, and Kennewick, as discussed previously in the section, Radionuclides in Drinking Water. The GI tract dose in Richland was greater than in the cities further downriver because the short-lived nuclides are in greater abundance. As shown in Figure 23, the estimated total dose to the GI tract of a Typical Richland Resident during 1966 was about 33 mrem or 7% of the maximum permissible dose. Ninety-three percent of the GI tract dose was contributed by drinking water.

For calculating a dose to the thyroid gland, the most appropriate sample of the exposed population would appear to be small children living in Richland who drank water from the municipal system (0.4 liter/day), milk (0.6 liter/day) obtained from the local stores, and fresh vegetables (25 g/day) obtained from local markets. The total intake of ^{131}I by the Typical Richland Child during the year from these sources would be about 2600 pCi or an average of about 7 pCi/day. This intake is within FRC Range I[4] (the most favorable range) and indicates a radiation dose of 44 mrem (9% of the limit) for 1966 (Figure 23).

The estimated whole body dose (Figure 23) of the Typical Richland Resident from nuclides of Hanford origin was 4 mrem. Whole body doses from natural background (excluded from the FRC Guide) and fallout sources in this region are estimated at about 100 mrem/yr and 5 mrem/yr, respectively.

CONCLUSIONS

During 1966, the environmental surveillance program of the Hanford environs again showed that the amounts of radioactive materials present were well within nationally accepted limits at all times.

A release of radioiodines to the river from a production reactor on February 11, 1966 warranted special assessment of the radiation dose to

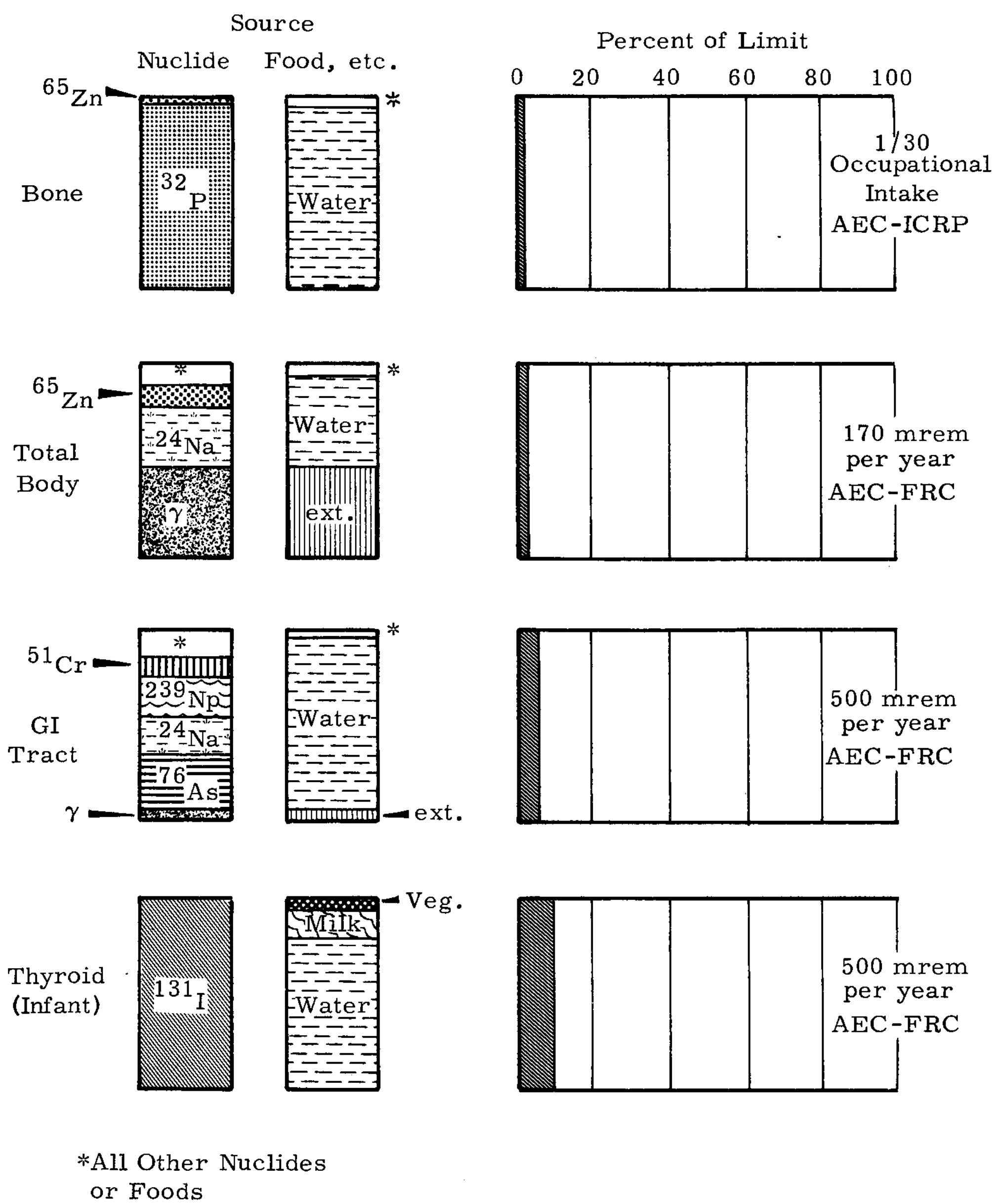

FIGURE 23. Estimated Dose to Typical Richland Resident, 1966

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

The effect of the two-month reactor shutdown period following the July 8 strike against Hanford contractors was to contribute to a reduction in the GI tract and whole body doses by about 1% of the applicable limits and then to help reduce the percent MPRI (bone) for the Maximum Individual from 12% (1965) to slightly less than 10% during 1966. The retirement of three Hanford reactors during 1964-1965 also contributed to the reduction in environmental radiation doses during 1966.

ACKNOWLEDGEMENTS

The cooperation of many individuals who collected samples, performed the many tedious radioassays, prepared and provided data and reviewed this document is gratefully acknowledged.

The cooperation and contributions of the several city, state, and federal agencies listed below is also gratefully acknowledged.

Federal Aviation Agency
Walla Walla, Washington
Pendleton, Oregon

Kennewick Water Department
Kennewick, Washington

Pasco Water Department
Pasco, Washington

Richland Water Department
Richland, Washington

U. S. Army Corps of Engineers
McNary, Oregon
Bonneville, Oregon

U. S. ESSA-Weather Bureau
Spokane, Washington
Yakima, Washington

U. S. Public Health Service
Portland, Oregon

Washington State Department of Game
Olympia, Washington

Washington State Department of Highways
Ellensburg, Washington
Wenatchee, Washington

Washington State Patrol
Yakima, Washington

Many samples supplied during the year by the following individuals provided valuable information about the radiological status of the environs.

Beef Thyroids: Dr. P. M. Aldrich, Walla Walla, Washington; Dr. L. M. Bodie, Moses Lake, Washington; Dr. J. Christopher, Pasco, Washington; Dr. R. J. Donahue, Toppenish, Washington; Dr. W. E. Welsh, Wenatchee, Washington.

Oysters: Coast Oyster Company, South Bend, Washington.

Milk and Pasture Grass: Mr. N. Atterberry, Benton City, Washington; Mr. J. B. Barker, Richland, Washington; Mr. H. G. Bleazard, Eltopia, Washington; Mr. W. F. Harris, Pasco, Washington; Mr. M. C. Kinne, Mesa, Washington; Mr. W. M. Nichols, West Richland, Washington; Mr. H. H. Olson, Pasco, Washington; Mr. J. K. Potter, Mesa, Washington; Mr. A. W. Taylor, Pasco, Washington; Twin City Creamery, Kennewick, Washington.

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