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EVALUATION OF RADIOLOGICAL CONDITIONS IN THE VICINITY OF HANFORD FOR 1967

MARCH 1969

AEC RESEARCH & DEVELOPMENT REPORT

BNWL-983

BATTELLE NORTHWEST
BATTELLE MEMORIAL INSTITUTE — PACIFIC NORTHWEST LABORATORY
BATTELLE BOULEVARD, P. O. BOX 999, RICHLAND, WASHINGTON 99352

PACIFIC NORTHWEST LABORATORY

RICHLAND, WASHINGTON

operated by

BATTELLE MEMORIAL INSTITUTE

for the

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

BNWL-983

UC-41, Health
and Safety

EVALUATION OF RADIOLOGICAL CONDITIONS IN THE VICINITY OF HANFORD FOR 1967

By

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Edited by

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Radiation Protection Department

Technical Services Division

March 1969

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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

ABSTRACT

At Hanford, controlled releases of a variety of low-level radioactive wastes are made to the Columbia River, to the ground, and to the atmosphere. The major source of low-level wastes released to the environment in 1967 continued to be reactor cooling water discharged to the Columbia River. Evaluation of the combined offsite effects of all radioactive waste releases during 1967 showed that concentrations of radionuclides in the environs and radiation doses received by nearby population groups were well within accepted limits. As in previous years, estimates were made of the whole body, gastrointestinal tract, and thyroid doses and the annual intake of bone-seeking nuclides. Population groups considered included Maximum Individuals and typical Richland residents as in previous years, and for the first time average Richland residents. Diet information accumulated from plant employees permitted calculation of both average dose values and dose distribution for Richland residents. The only population dose estimate exceeding one-tenth of the appropriate limit was 12% of the Maximum Permissible Rate of Intake to the bone of a hypothetical Maximum Individual, with ^{32}P contributing 99% of the estimated dose and Columbia River fish the major source of intake. Primarily because of the 1966 reactor outage, some 1967 dose estimates exceeded 1966 estimates, but not 1965 values.

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INTRODUCTION

A variety of radioactive wastes are generated by the Hanford production reactors, chemical separations plants, and laboratories. High level wastes are concentrated and retained in storage within the project boundaries. Controlled releases of low-level wastes, for which concentration and storage are not feasible, are made to the ground, to the atmosphere, and to the Columbia River. The Atomic Energy Commission regulations governing radioactive waste disposal at Hanford are described in the AEC Manual Chapter RL 0510.(1) During 1967, the plant facilities were operated for the Atomic Energy Commission by: Atlantic Richfield Hanford Company; Pacific Northwest Laboratory of Battelle Memorial Institute; Douglas United Nuclear, Incorporated; Isochem, Incorporated; and ITT Federal Support Services, Incorporated.

It is the purpose of this report to present an evaluation of the combined offsite effects of the radioactive waste management practices of all Hanford contractors during 1967. The analytical data on which this evaluation is based have been published as a separate report (BNWL-983 APP). The previous reports in this series were BNWL-439 and BNWL-439 APP.(2)

SUMMARY

Surveillance of the Hanford environs during 1967 showed that both the concentrations of radioactive materials and the environmental radiation doses of Hanford origin received by local residents were well within appropriate limits. The environmental surveillance program for 1967 also indicated that most of the environmental radiation dose for the majority of persons living in the Hanford environs was due to natural sources and worldwide fallout rather than to Hanford operations. The major source of low-level wastes released to the environment from Hanford plants continued to be reactor cooling water discharged to the Columbia River.

An announced foreign weapons test caused ^{131}I concentrations in the environment to increase abruptly in January 1967. Concentrations soon returned to the normally low values.

A hypothetical but plausible combination of living and dietary habits that would probably result in an individual's receiving the largest radiation dose from Hanford-effluent radionuclides has been postulated as:

- Consumption of 200 meals per year of fish caught down river from the reactors
- Spending 500 hr/yr 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 1967, the Maximum Individual could have conceivably ingested enough radioactive materials of Hanford origin (mostly ^{32}P) to provide an intake of 12% of the Maximum Permissible Rate of Intake (MPRI), with bone as the critical

organ, appropriate for individuals in the general population. This same intake would have resulted in annual doses for 1967 that were 5% and 6% of the appropriate limits for the GI tract and whole body, respectively.

A Typical Richland Resident has been defined in previous years as an adult consuming typical quantities (as given in the literature) of Richland drinking water derived from the Columbia River, and of milk, meat, and other foodstuffs from commercial sources. The radiation doses of Hanford origin received by such an individual come, for the most part, from the Richland drinking water, with the GI tract normally receiving the largest percentage of permissible dose to any organ. During 1967, the GI tract dose to a Typical Richland Resident was 24 mrem or 5% of the maximum permissible dose. The thyroid dose to a Typical Richland Infant for 1967 was 50 mrem or 10% of the appropriate limit. This estimate includes a dose contribution from short-lived radioiodine not included in previous years, and thus is not strictly comparable with dose estimates for previous years.

The dietary habits of an Average Richland Adult have been determined from local dietary surveys. The radiation dose from Hanford sources received by this population group also 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 1967, this dose was 6% of the limit for the general population. The thyroid dose to an average Richland infant (2 g thyroid) for 1967 was 8% of the appropriate limit, including a contribution from short-lived radioiodines but corrected for dilution and decay in the Richland water system.

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

Summary of Radiation Doses[a] in the Hanford Environs, 1967

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

(a) *Doses from fallout and natural background not included.*
(b) *Not calculated - see Standards for Evaluation, page 7.*
(c) *AEC-ICRP (International Commission on Radiological Protection) derived MPRI: for Maximum Individual - 16 μCi ^{32}P/yr and 800 μCi ^{65}Zn/yr; for Typical and Average Richland Resident - 5.3 μCi ^{32}P/yr and 270 μCi ^{65}Zn/yr.*

STANDARDS FOR EVALUATION

Radiation protection practices at Hanford, including radioactive waste disposal, are governed by the AEC Manual. More specifically, Chapters 0524 and RL 0524[3] provide standards for permissible radiation exposures. The section of RL 0524 (Appendix) to which this evaluation is addressed is as follows:

"II. RADIATION PROTECTION STANDARDS FOR INDIVIDUALS AND POPULATION GROUPS IN UNCONTROLLED AREAS

A. Radiation dose standards for external and internal exposure

Type of Exposure	Dose (rem/year): Based on exposure of individuals	Dose (rem/year): Based on the average exposure of a suitable sample of the exposed population
Whole body or gonads	0.5	0.17
Thyroid, bone or G.I. tract	1.5	0.5

"

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 (Federal Radiation Council)[4,5,6] 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 like that used by the FRC for ^{90}Sr leads to a maximum permissible rate of intake

* *Used for evaluation of fallout dose in this report.*

that is substantially greater than that recommended by the ICRP (International Commission on Radiological Protection).[7] 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 Measurements*) dosimetry methods[7,8] 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 <u>AEC Manual</u> Chapter 0524 (Annex I, Table II)[3] for the Maximum Individual in uncontrolled areas is one-tenth of the ICRP[7] MPC_w for continuous occupational exposure (2×10^{-5} μCi/ml). Thus an MPRI derived from either <u>AEC Manual</u> Chapter 0524 or <u>ICRP Publication 2</u> would be the same.

For thyroid dose calculations, the Federal Radiation Council has given specific guidance for permissible daily ^{131}I

* *Formerly the National Council on Radiation Protection.*

intake for infants, assuming a thyroid size of 2 grams. We have used this guidance, both for the translation of radioiodine intake to dose and for the selection of appropriate groups for dose evaluation.

For whole body and GI tract dose calculations, we have used ICRP values for the several physiological factors involved in translating intake to dose.

The radiological units used throughout most of this report are rems (dose-equivalent). When the nuclides of interest at Hanford are considered with the organs for which radiation doses (in rads) are calculated, the units rad and rem are numerically equal.

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 probable radiation doses in relation to various established limits. The FRC and AEC have 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 exposure pathways described in the following sections have been combined for comparisons with guides for both the individual and the general population. As for previous years, a hypothetical Maximum Individual has been assigned dietary and other habits that could result in what would seem to be the greatest probable dose. For the general population, a dose has for previous years been estimated for what was called the Typical Richland Resident. In each case, the best available information on dietary patterns was used.

The possibility exists that additional information on different age groups or persons with unique diet habits or physiological behavior will reveal individuals with a somewhat larger dose to specific organs than has been estimated for the Maximum Individual. The likelihood that any such person could have received a dose approaching the Standards is considered quite remote.

For 1967, sufficient diet information is available for the first time to make a reasonable estimate of average doses to Richland adults. In our judgment, this provides a more suitable comparison against dose standards applicable to the general population as given in AEC Manual Chapter 0524 than the assumptions previously used for a Typical Richland Resident. For continuity, we have included both types of estimates in this report.

SITE DESCRIPTION

The Hanford site is 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. As indicated by the wind roses shown in Figure 2, prevailing winds near the plant production sites 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 area (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 the communities near the plant, together with the surrounding agricultural area, is about 90,000.

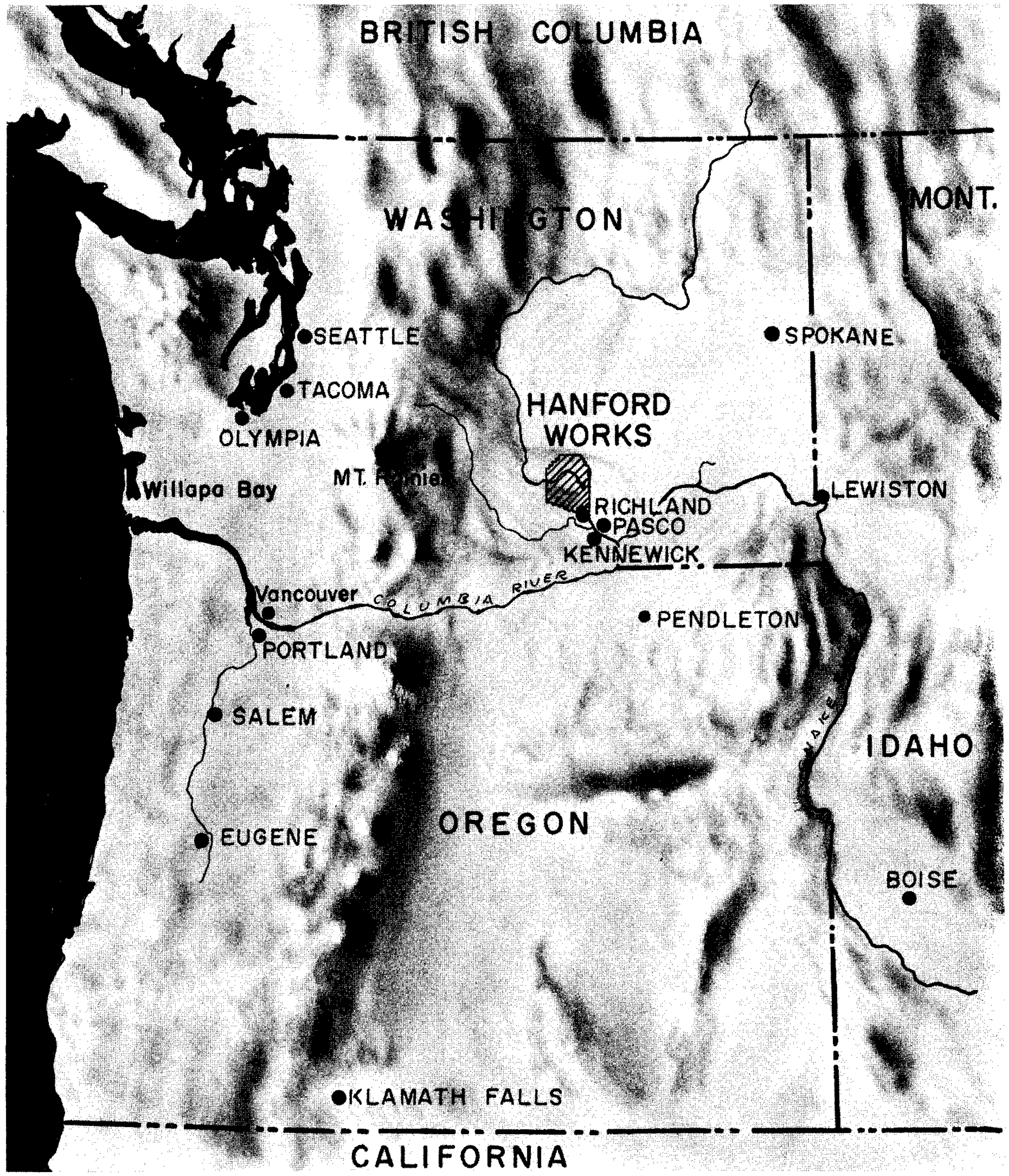

FIGURE 1. Geographical Relationship of Hanford to Pacific Northwest

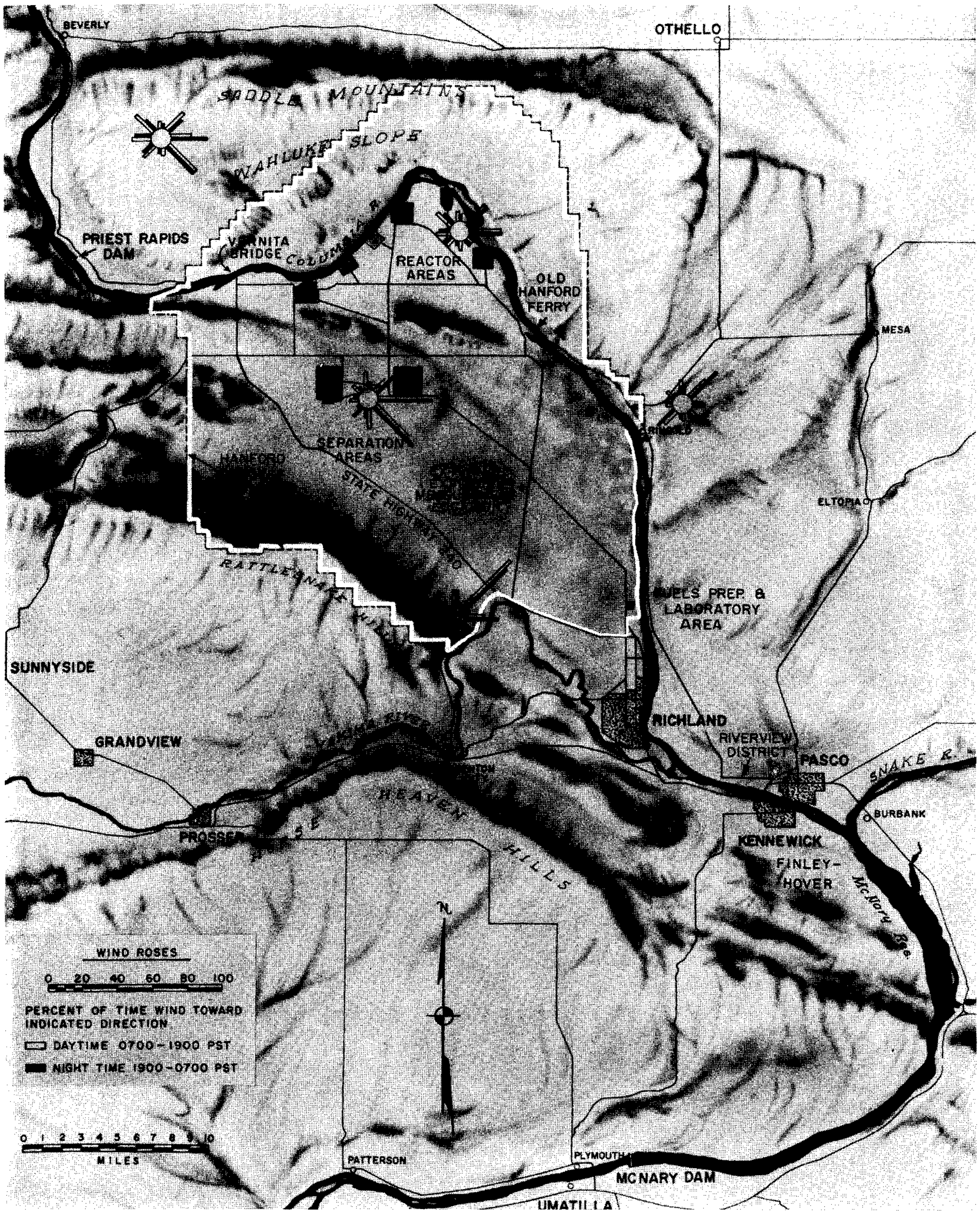

FIGURE 2. Features of Hanford Project and Vicinity

SOURCES AND LEVELS OF ENVIRONMENTAL RADIOACTIVITY

Low-level wastes from plant operations, fallout from nuclear weapons testing, naturally-occurring radioelements, and cosmic rays contribute to radioactivity in the Hanford environs. Hanford operations that could contribute to radioactivity outside the plant boundary are the disposal of reactor cooling water to the Columbia River, stack releases at the chemical separations areas and laboratory areas, and disposal of radioactive wastes to ground.

The most significant Hanford contributions to off-plant radioactivity and population doses usually originate with reactor cooling water released to the Columbia River. Although airborne releases of ^{131}I contributed to the thyroid doses of the local population, the major portion of the thyroid doses in 1967 resulted from radioiodines in drinking water.

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

RADIOACTIVITY IN THE COLUMBIA RIVER

Nuclides Present in Reactor Effluent

Cooling of the Hanford production reactors (with the exception of N Reactor) is accomplished by a single pass of treated Columbia River water. The N Reactor uses recirculating demineralized water as a primary coolant, and all waste water containing significant amounts of radioactive materials is discharged to a ground disposal site near the river. Although some of these radionuclides eventually enter the river, the total quantity of radioactivity entering the Columbia 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 activated 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. Table 1 shows the relative abundance of the radionuclides found in the cooling water of the older production reactors, adjusted to 4 hr after leaving the reactor.

Many of the radionuclides formed in reactor cooling water are short-lived and disappear quickly due to radioactive decay. In addition, sedimentation and uptake by aquatic organisms remove some fraction of most radionuclides from the river water. Relatively small amounts of fission products are present in the river because of the fissioning of natural uranium present in the river water, because of occasional ruptures of the fuel element jackets, and because of fallout from nuclear weapons testing.

River Flow Rates

The seasonal fluctuations in flow rate of the Columbia River affect radionuclide concentrations by varying the quantity of water available for dilution of reactor effluent released to the river. In addition, the seasonal scouring of sediments deposited in reservoirs behind each dam causes seasonal fluctuations in transport rates of those longer-lived nuclides adsorbed on the sediments. This is notably true for ^{65}Zn. Also affected by the flow rate is the time required for a specific volume of water to move from one location to another which in turn affects the amount of decay of the shorter lived nuclides.

TABLE 1. 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	^{46}Sc	^{14}C	^{93}Y(b)	^{144}Ce(b)
^{51}Cr	^{69m}Zn	^{35}S	^{95}Nb	^{142}Pr(b)
^{56}Mn	^{72}Ga	^{45}Ca	^{99}Mo	^{143}Pr(b)
^{64}Cu	^{76}As	^{54}Mn	^{103}Ru	^{147}Nd(b)
	^{92}Sr	^{59}Fe	^{106}Ru	^{147}Pm(b)
	^{122}Sb	^{60}Co	^{124}Sb	^{149}Pm(b)
	^{132}I	^{65}Ni	^{131}I	^{151}Pm(b)
	^{140}La(b)	^{65}Zn	^{133}I	^{152}Eu(b)
	^{152m}Eu(b)	^{87m}Sr	^{135}I	^{156}Eu(b)
	^{153}Sm(b)	^{89}Sr	^{136}Cs	^{153}Gd(b)
	^{165}Dy(b)	^{90}Sr	^{137}Cs	^{159}Gd(b)
	^{239}Np	^{91}Sr	^{140}Ba	^{160}Tb(b)
		^{90}Y(b)	^{141}Ce(b)	^{161}Tb(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 and 1968.*

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

Figure 3 shows the flow rates (data supplied by the USGS) of the Columbia River at Priest Rapids and Bonneville Dams. For 1967, the average river flow rate at Priest Rapids was 3790 m^3/sec (134,000 ft^3/sec) which only slightly exceeds the 1948-1962 annual average of 3770 m^3/sec (133,000 ft^3/sec).

River Concentrations

During 1967, samples of river water were collected above the production areas at Priest Rapids Dam and below the areas at the Richland water plant intake, McNary 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 in "grab" samples.

Figure 4 shows seasonal variations due to flow rate and long-term trends in concentrations of several radionuclides in river water at Richland. Table 2 shows the annual average concentrations at Richland and Bonneville Dam for 1965-1967. The data for 1966 include the effects of reactor outages during the July-August strike. Comparison of 1967 with 1965 concentrations indicates a general reduction for most radionuclides, with the exception of ^{32}P. Lower concentrations of the short-lived radionuclides were expected in 1967 because production reactors remaining in operation are farther upstream than the retired reactors.

Sampling traverses across the Columbia River at Richland have indicated a slightly nonuniform distribution of the longer-lived radionuclides at this cross section. Entries of the Yakima River some 16 km (10 miles) above Pasco and of the Snake River some 48 km (30 miles) above McNary Dam influence the distribution of radionuclides in the Columbia below these two points. The magnitude of the influence varies with seasonal changes in the flow rate of the tributaries.

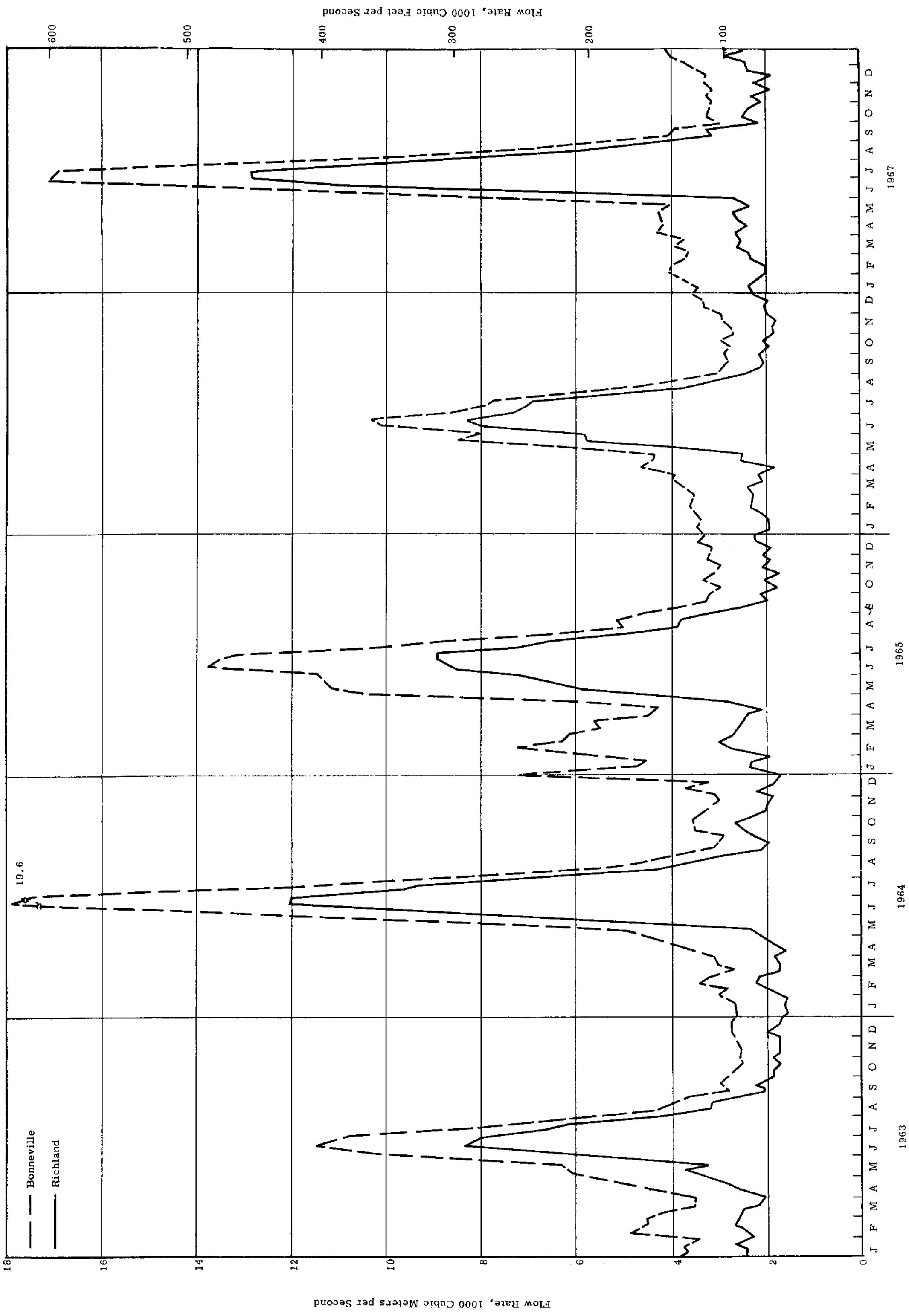

FIGURE 3. Flow Rate of Columbia River at Priest Rapids and Bonneville

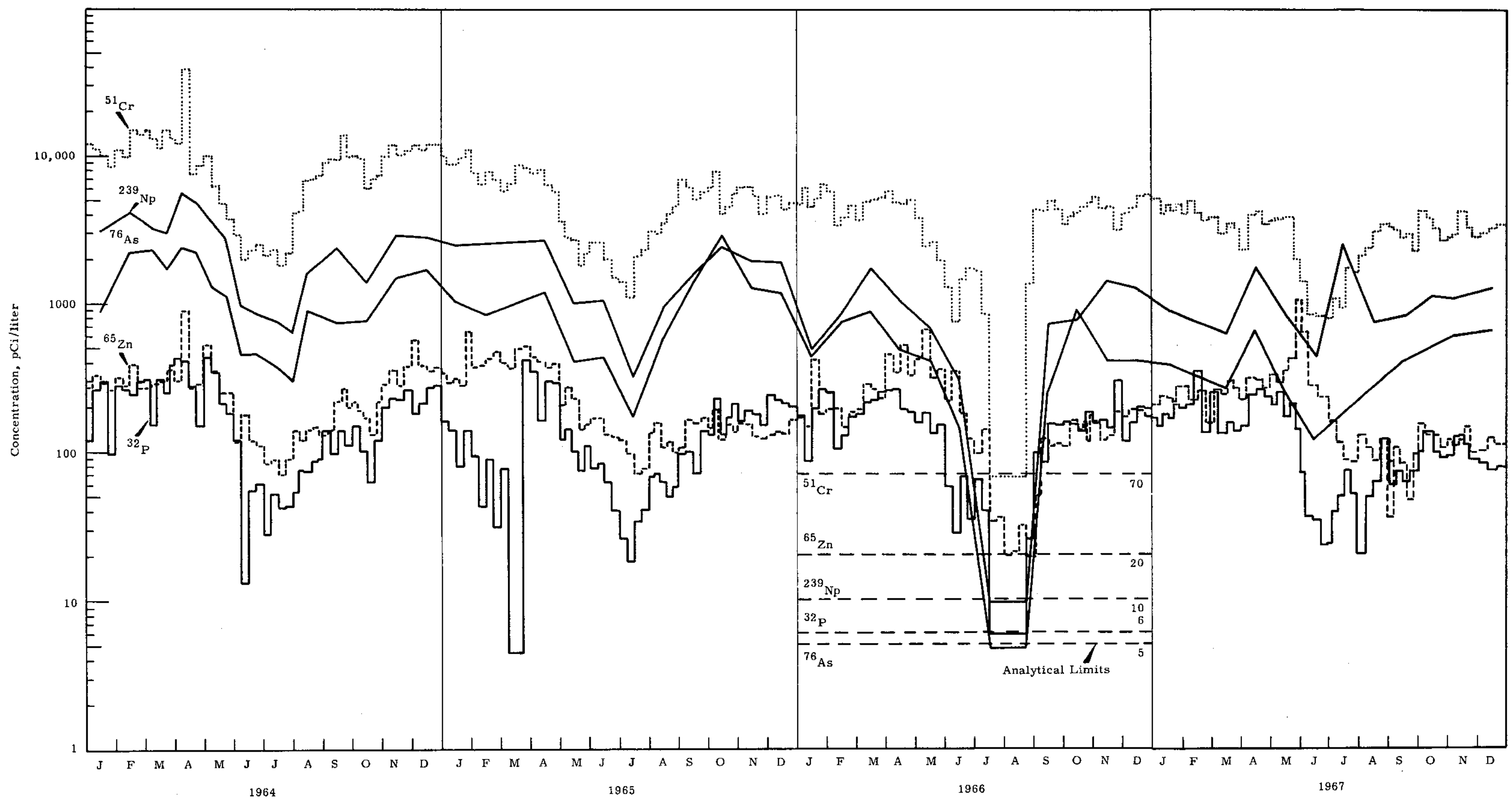

FIGURE 4. Radionuclides in Columbia River Water at Richland

TABLE 2. Annual Average Concentrations of Several Radionuclides in Columbia River Water (pCi/ℓ)

	1967		1966		1965	
Radionuclide	Richland	Bonneville Dam	Richland	Bonneville Dam	Richland	Bonneville Dam
RE+Y[a]	390	--	270	--	730	--
^{24}Na	2600	--	2600	--	3100	--
^{32}P	190	25	140	23	140	23
^{46}Sc	60	--	30	--	--	--
^{51}Cr	3200	1400	3600	1300	7000	1700
^{64}Cu	2000	--	1400	--	2500	--
^{65}Zn	220	62	200	43	180	70
^{76}As	400	--	420	--	1000	--
^{90}Sr	1	--	1	--	1	--
^{122}Sb	150	--	--	--	--	--
^{131}I	8	3	18	3	10	3
^{239}Np	1100	--	770	--	1600	--

(a) *See Table 1 for definition.*

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

Bonneville Dam, approximately 490 km (240 miles) below the Hanford reactors, is the farthest downstream location where river water is routinely sampled for Hanford's environmental surveillance program. Measurements at this location provide an upper limit to the annual transport of specific nuclides into the Pacific Ocean.

The term "analytical limit" (in Figure 4) 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 amounts of interfering radionuclides present. The "analytical limits" given represent upper bounds to these fluctuating detection limits.

Transport Rates

Figure 5 shows the river transport rates of several radionuclides past Richland. Table 3 shows the annual average transport rates of selected radionuclides past Bonneville Dam. More detailed measurements are presented in the Appendices.[9] Although transport rates at Richland in 1967 for ^{32}P, ^{51}Cr, and ^{65}Zn exceeded 1966 values, ^{51}Cr and ^{65}Zn transport rates were lower than in 1965 or 1964; ^{32}P transport rates were similar to those of past years. The reduced annual transport for 1966 was due to the extended reactor shutdown during July and August.

TABLE 3. Annual Average Transport Rate of Selected Radionuclides Past Bonneville Dam (Ci/day)

Radionuclide	1967	1966	1965	1964
^{32}P	12	9	11	12
^{51}Cr	610	430	800	860
^{65}Zn	40	21	49	44

An estimate of the inventory of these radionuclides which exists in 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 1967 Bonneville Dam measurements would imply an average inventory of about 250 Ci of ^{32}P, 24,000 Ci of ^{51}Cr, and 14,000 Ci of ^{65}Zn.

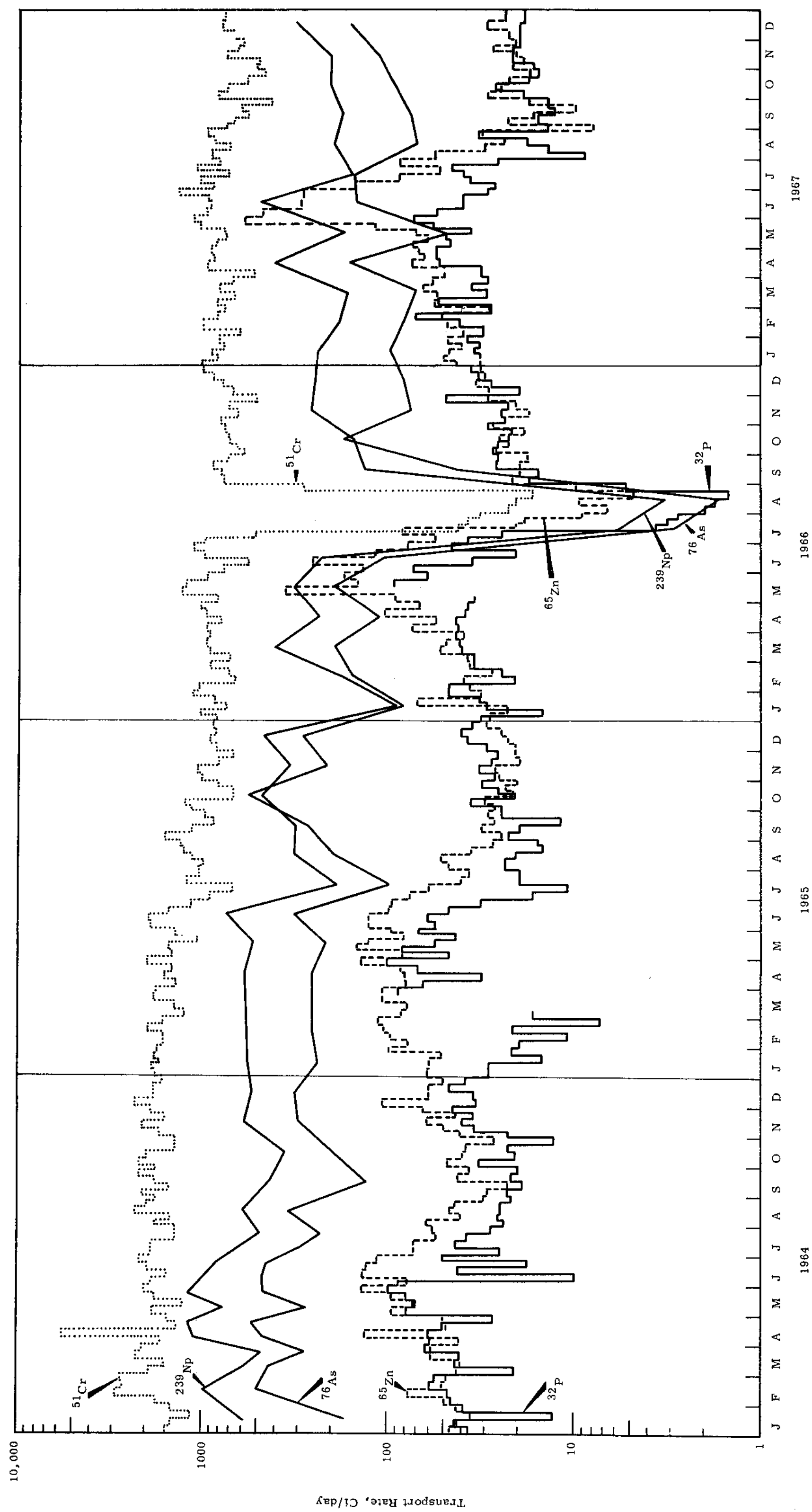

FIGURE 5. Transport Rates of Radionuclides at Richland

Trend Indicator - Whitefish

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. Changes in river concentrations and transport rates may induce changes in concentrations in biological media. However, the ultimate uptake of radionuclides depends on complex environmental interrelationships. To follow trends in biological concentrations, ^{32}P concentrations in whitefish taken from the Columbia River near the plant boundary are routinely measured. Whitefish are the sports fish that usually contain the greatest concentration of radioactive materials. Furthermore, they can be caught during winter months when other sports fish are difficult to sample. Therefore, data accumulated from whitefish sampling are useful as a trend indicator, even though whitefish are not the most significant source of radionuclides for the local population. ^{32}P is the radionuclide in fish of greatest significance with respect to population doses. Figure 6 illustrates the results.

Concentrations of ^{32}P in whitefish during 1967 tended to follow the same seasonal trends observed in past years. The average concentrations of ^{32}P in whitefish sampled downstream from the reactors during 1967 was 260 pCi/g, as compared with 110 pCi ^{32}P/g during 1966.[2] The lower average ^{32}P concentration in 1966 was attributed to the extended reactor shutdown during July and August.

RADIOACTIVITY IN THE ATMOSPHERE

At Hanford, gaseous waste from the chemical separations facilities is released to the atmosphere through elevated stacks after most of the radioactive materials have been removed.

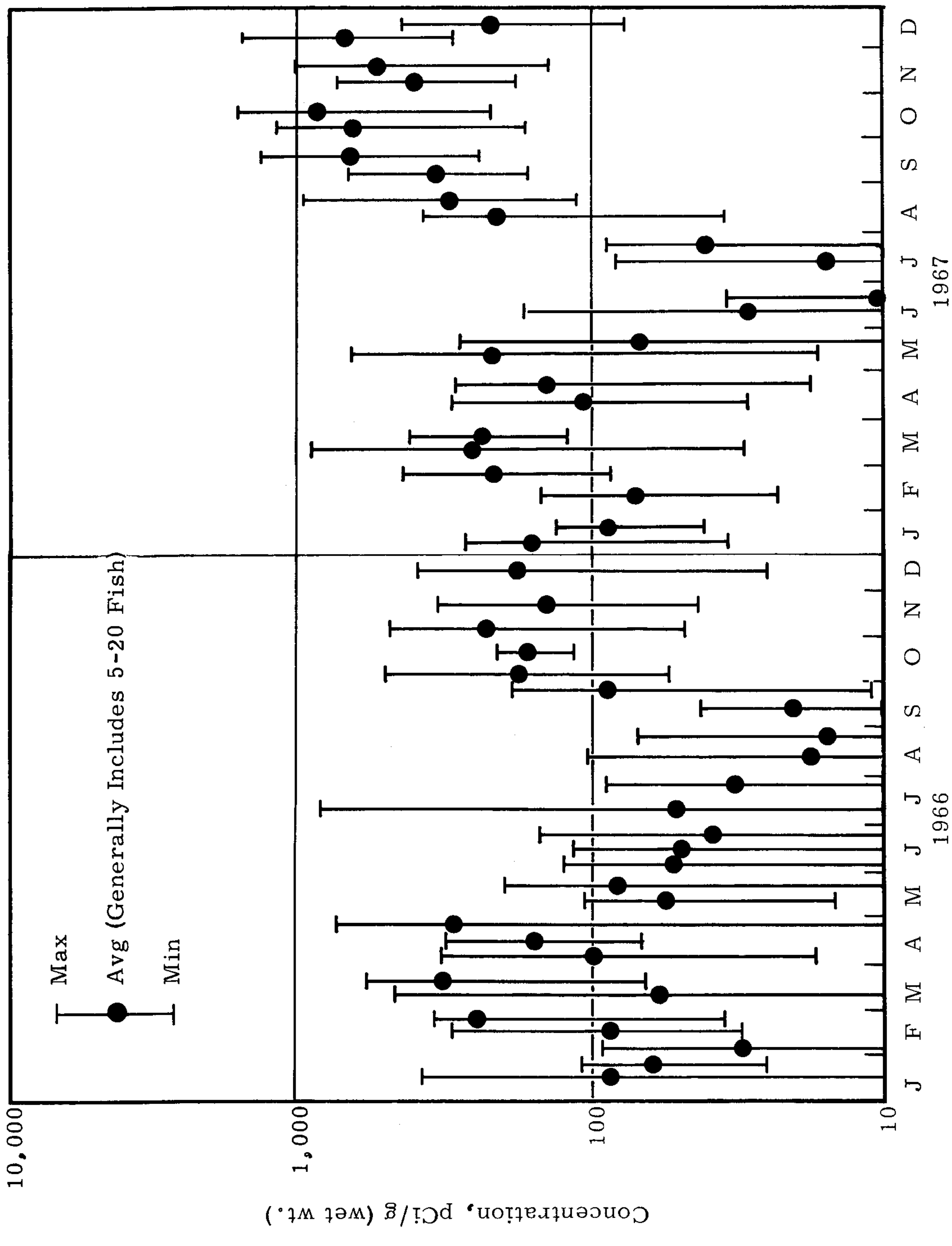

FIGURE 6. ^{32}P in Whitefish Caught in Columbia River Between Ringold and Richland

These radioactive materials are primarily associated with process vessel off-gases. Laboratory and reactor building stacks release relatively minor amounts of radioactive materials under normal operating conditions.

Beta Activity of Airborne Particulates

Continuous sampling for radioactivity associated with airborne particles was maintained during 1967 at 44 locations, including those within the Hanford reservation and around the plant perimeter at distances up to 90 miles. The gross beta activity of each sample filter was routinely measured, with specific radioanalysis on most filters showing unusual beta activity. Sudden increases in the gross beta activity on occasion also signaled the need for additional emphasis in other portions of the environmental monitoring program.

Gross beta activities at most locations during 1967 are shown in Figure 7, with a complete tabulation in the Appendices.[9] Although the measurements indicated that the ambient air was not a significant source of radiation dose in the environs, radionuclides attributable to plant sources were occasionally detected following increased stack releases. Weapons testing also caused higher than usual beta activity on air filters in January and August, as indicated by the general presence of typical fallout nuclides. The sudden increase in October 1967, was uniform geographically and probably also represented a fall influx of fallout nuclides.

^{131}I Concentrations

Measurements 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, which include contributions from off-site weapons tests, are summarized in Table 4, with a more detailed

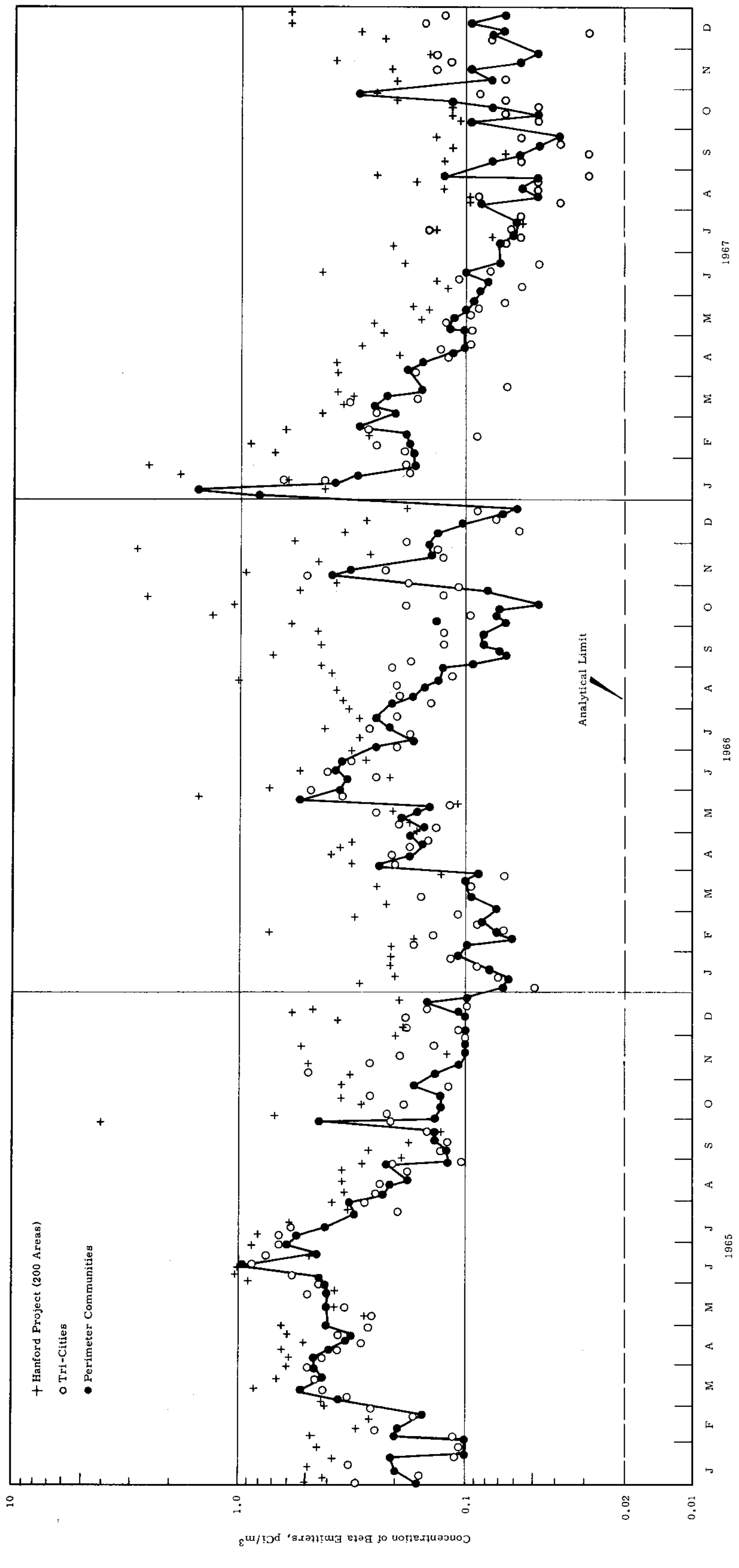

FIGURE 7. Radioactive Particulate Material in the Air of Hanford Environs

tabulation in the Appendices.[9] The four locations listed in Table 4 lie within a 45° sector southeast to south of the separations areas. During 1967, the measured ^{131}I concentrations, shown in Figure 8, indicated thyroid doses of less than 1 mrem from inspired air.

TABLE 4. Annual Average ^{131}I Concentrations in the Atmosphere (pCi/m^3)

Location*	Distance from Separation Stacks, km	1967	1966	1965	1964
Prosser Barricade	23	0.02	0.02	0.03	0.02
Benton City	32	0.02	0.01	0.03	0.06
Richland	37	0.02	0.01	0.02	0.02
Pasco	51	0.02	0.01	0.03	0.01

* *Maximum Permissible Concentration (AEC Manual Chapter 0524, Annex I, Table II, Column 1) - 100 pCi/m^3.*

Trend Indicator - Beef Thyroids

Since the concentration of ^{131}I in the thyroids of cattle is about three orders of magnitude higher than in associated pasture grass or milk, it is advantageous to use thyroid measurements to follow probable low-level trends in concentrations of ^{131}I in milk and farm produce.

Thyroids of cattle were collected periodically for radioanalysis from slaughter houses in Moses Lake, Yakima, Walla Walla, Wenatchee, and Pasco during 1967. Figure 9 shows the average concentrations of ^{131}I measured in these thyroids. The maximum concentration in a single thyroid of 160 pCi $^{131}I/g$ was collected in January at Walla Walla following an announced weapons test. Data obtained from the thyroid program for 1967 are tabulated in the Appendices.[9]

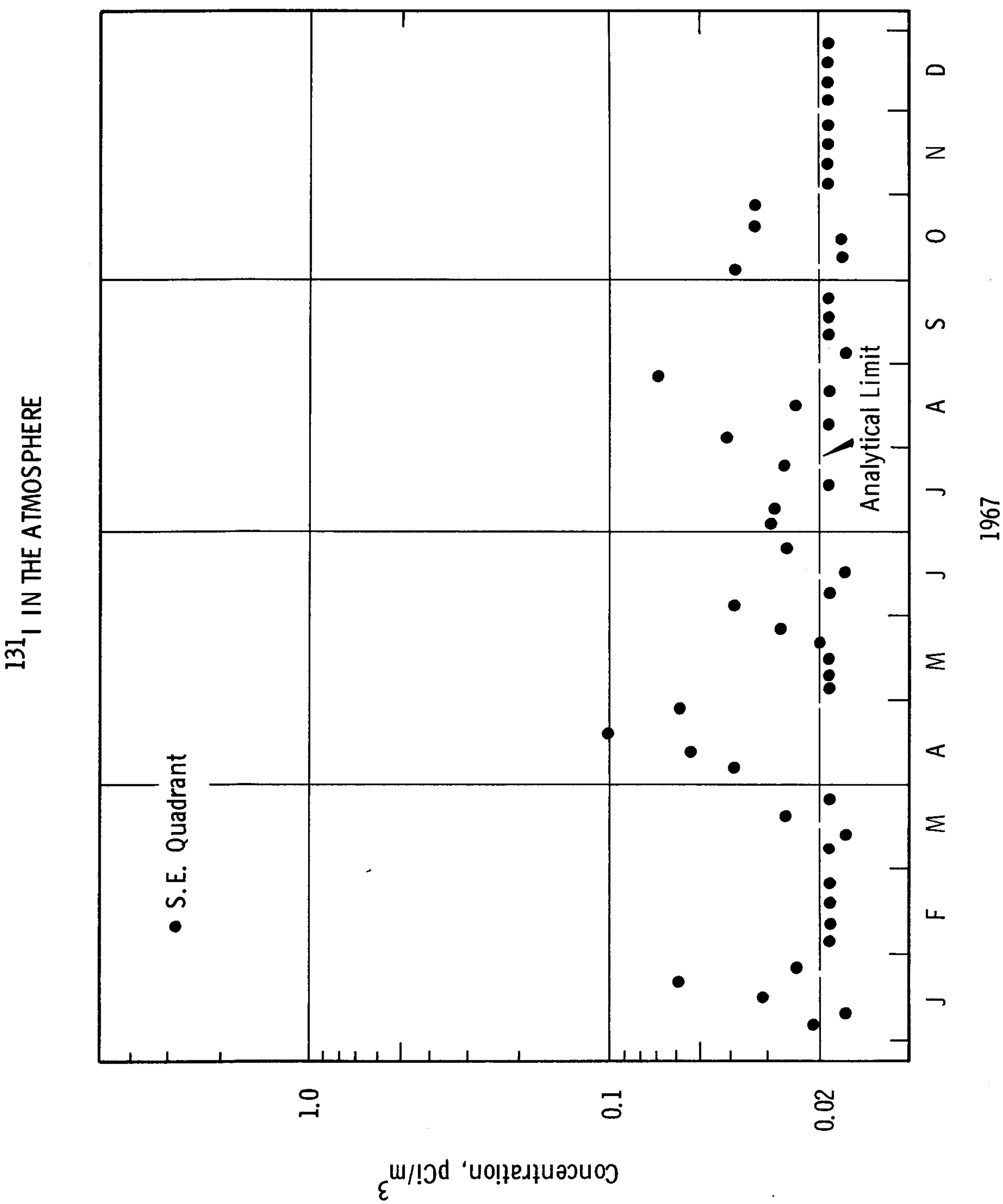

FIGURE 8. ^{131}I in the Air of Hanford Environs

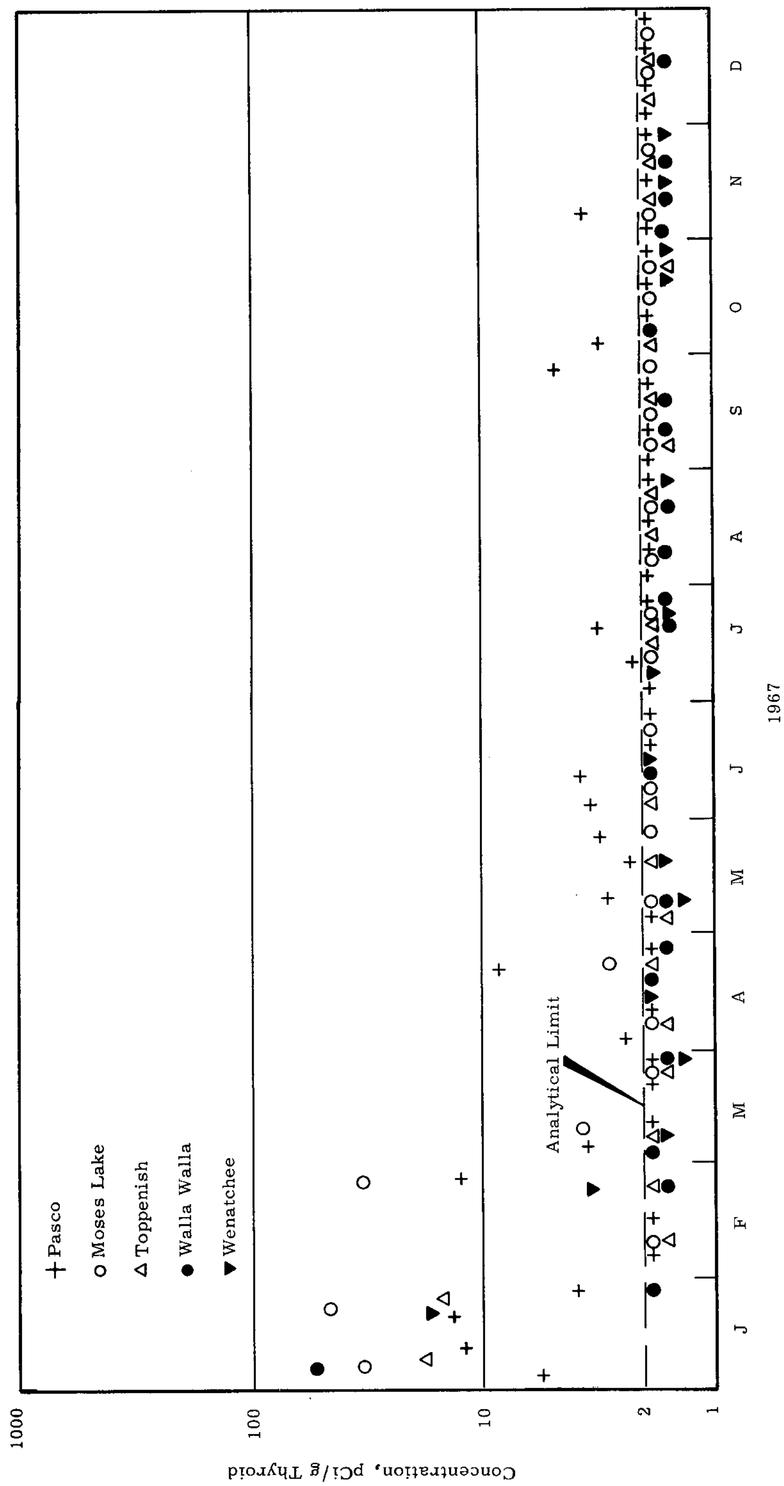

FIGURE 9. Average ^{131}I Concentrations in Thyroids of Beef

RADIOACTIVITY IN GROUNDWATER

The presence of radioactivity in the groundwater beneath the Hanford project arises primarily from ground disposal of wastes from the chemical separations areas. These wastes are routed to various facilities, dependent upon their radionuclide burden and chemical content. High-level wastes* are stored in underground concrete tanks lined with steel. Intermediate-level wastes* are sent to underground "cribs" (covered liquid waste disposal sites) from which they percolate into the soil. The areas selected for intermediate-level waste disposal and high-level waste storage have soil with good ion exchange capacity and groundwater depths of 50 to 100 m. Low-level wastes* are usually sent to depressions in the ground where surface ponds or "swamps" have been formed as the result of the continuous addition of relatively large volumes of water.

One important objective in the management of wastes placed in the ground is the prevention of radiologically important radionuclides from reaching the groundwater in quantities that could ultimately cause significant human radiation exposure should they migrate to the Columbia River. For this reason, an extensive groundwater surveillance program is maintained at Hanford. Hundreds of wells have been drilled at various locations around the Hanford project, including sites within and near crib and tank storage areas, to monitor the movement of radionuclides in the groundwater.

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* *Locally, these wastes are normally classified for convenience of reference by activity level as follows:*

High-level	*>100 μCi/ml*
Intermediate-level	*50 pCi/ml - 100 μCi/ml*
Low-level	*<50 pCi/ml*

Outside the exclusion areas, the radioactivity in groundwater from the chemical separations areas disposal sites is primarily ^{3}H and ^{106}Ru-Rh. ^{60}Co and ^{99}Tc have also been found, but at much lower concentrations. The more radiotoxic nuclides (e.g., ^{90}Sr) have been detected in groundwater only near certain disposal sites.

Figures 10 and 11 show the probable extent of detectable ^{3}H and ^{106}Ru-Rh in groundwater beneath the Hanford project as of December 1967.[10] The outer boundary of the contamination contours, i.e., 0.1% MPC* for ^{3}H and 2% MPC* for ^{106}Ru-Rh, represent the detection levels routinely achievable for these radionuclides.

In all probability, some radionuclides from the chemical processing areas are presently entering the Columbia River. However, the concentrations of these nuclides are too small to be routinely measurable in the groundwater near the river or in the river itself, and any radiation dose from them is negligible.

* *The MPC referred to is that for continuous exposure to individual members of the public, which is about three times the permissible concentration for a suitable sample of the exposed population.*

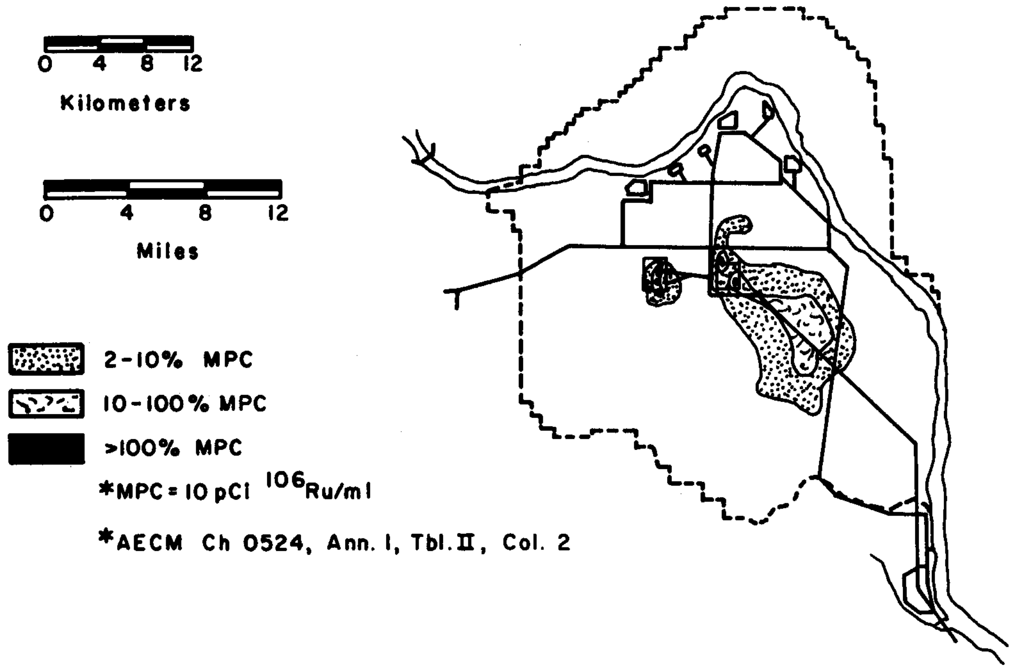

FIGURE 10. ^{106}Ru Concentrations in Groundwater, July-December 1967

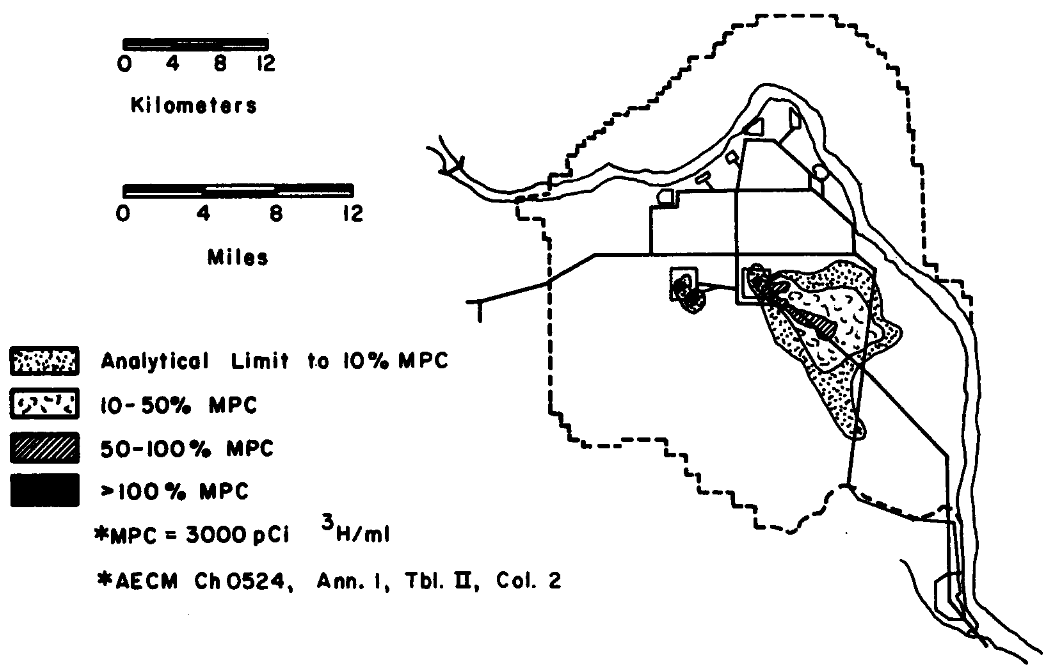

FIGURE 11. ^{3}H Concentrations in Groundwater, July-December 1967

FALLOUT FROM NUCLEAR WEAPONS TESTS

Fresh fallout in 1967 resulted from announced nuclear weapons tests in December 1966 and June 1967. Airborne particulate radioactivity (Figure 7) showed a definite but temporary increase associated with the December 1966 event. ^{131}I concentrations measured in the atmosphere (Figure 8) were within the normal range of fluctuation from plant sources, but ^{131}I concentrations in milk samples reached a peak of 83 pCi/liter on January 3, the highest milk concentration from fallout observed since October 1962.

Routine measurements in foods of the fallout nuclides ^{131}I, ^{90}Sr, and ^{137}Cs are discussed in Exposure Pathways, page 35.

Concentrations of ^{3}H in river water are measured upstream from Hanford at Priest Rapids Dam and downstream from Hanford at Richland. The average concentrations of ^{3}H at Priest Rapids Dam and Richland were not significantly different at 1.4 nCi/liter and 1.5 nCi/liter, respectively, compared to 2.0 nCi/liter at both locations during 1966.[2]

EXPOSURE PATHWAYS

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 farther downstream, also use the Columbia River as a source of drinking water. The Richland and Pasco water plants use a modern flocculation-filtration treatment of the water; Kennewick water is pumped from Rainey well collectors (infiltration pipes) laid in the riverbank. During 1967, cumulative drinking water samples were collected at the Richland and Pasco water plants, and periodic samples at all three communities. All of these samples were analyzed for important individual radionuclides. Detailed analyses of drinking water from these three cities are available in the Appendices,(9) and are summarized in Table 5.

The concentrations of short-lived radionuclides in the water at the time it is consumed are less than shown in Table 5 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. In Richland, many residents receive no radioactivity of Hanford origin in drinking water during the part of the year when well water is used to bolster the system supply.

Table 6 shows calculated annual average doses to the whole body, GI tract, and thyroid and the percent MPRI for bone from sustained consumption (at a standard intake of 1.2 liters/day) of drinking water throughout 1967 at the three cities.

The estimated GI tract dose to Pasco residents from the measured radionuclides in drinking water was somewhat higher in 1967 (15 mrem) than in 1966 (11 mrem) as a result of the

TABLE 5. Annual Average Concentrations[a] of Several Radionuclides in Drinking Water, 1967 (pCi/ℓ)

Radionuclide	Richland	Pasco	Kennewick
RE+Y[b]	87	46	--[c]
^{24}Na	1700	790	94
^{32}P	58	52	15
^{51}Cr	3100	2700	1200
^{64}Cu	570	160	44
^{65}Zn	86	65	<20
^{76}As	160	56	16
^{90}Sr	1	1	--
^{133}I[d]	30	25	<9.2
^{131}I	7.5	6.3	<2.3
^{122}Sb	140	120	18
^{239}Np	600	420	55

(a) *Measured at the water plants.*
(b) *See Table 1 for definition.*
(c) *The (--) indicates insufficient data to provide a meaningful average.*
(d) *Because no ^{133}I data were obtained in 1967, a ratio of ^{133}I to ^{131}I of 4 to 1 was estimated from 1968 data.*

TABLE 6. Calculated Annual Doses to Selected Organs from Routine Ingestion of Drinking Water,* 1967

	Whole Body, mrem	GI Tract, mrem	Bone, % MPRI	Thyroid (Infant) (0.4 liters/day), mrem
Richland	1.7	28	0.5	41
Pasco	1.1	15	0.1	35
Kennewick	<1	2.8	<0.1	13

* *The "standard man"[7] average intake rate of 1.2 liters/day was used in this calculation.*

extended shutdown of all reactors during the summer of 1966. However, the calculated GI tract dose for Richland residents was lower in 1967 (28 mrem) than was reported for 1966 (34 mrem). Although the shutdown of an additional reactor in 1967 played a part in the apparently reduced dose at Richland, the major difference was due to a change in the basis for the calculation. Measurements from a continuous monitor of gross activity in the Richland drinking water were substituted during part of the year for complete reliance on periodic "grab" sampling. The infant thyroid dose appears somewhat higher during 1967 than during 1966[2] because a contribution from ^{133}I was included in the 1967 estimate. Without the increment from ^{133}I, the estimated thyroid dose for 1967 would have been lower than for 1966.

Figure 12 shows the relative contribution of several radionuclides in the Richland drinking water to the calculated annual dose to the GI tract, and Figure 13 shows long-term trends in the GI tract dose from Pasco and Richland drinking water.

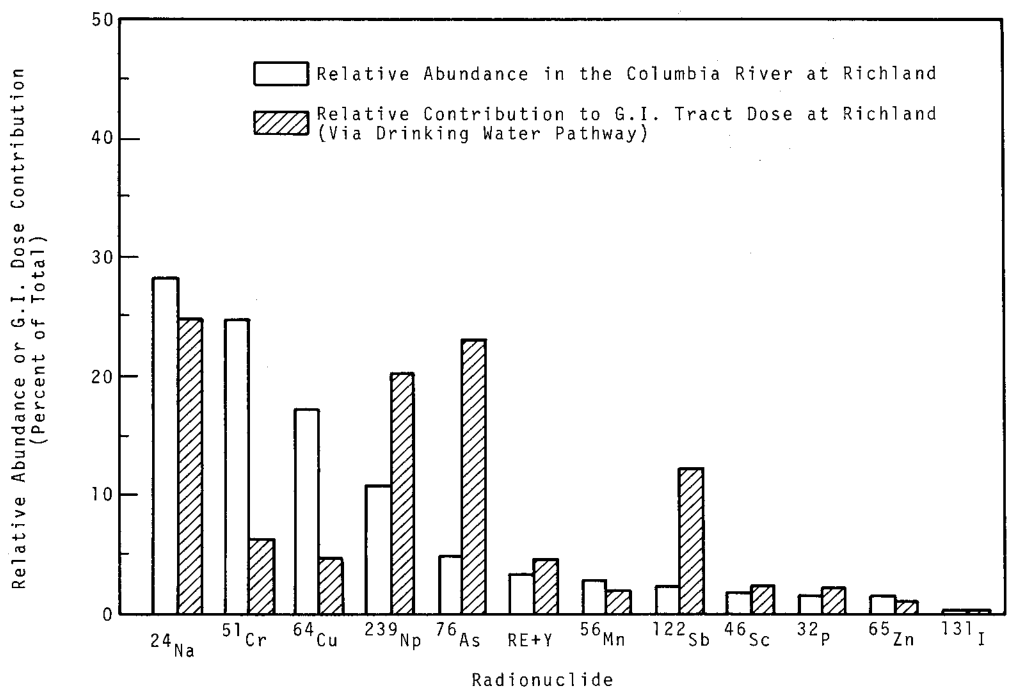

FIGURE 12. Relative Contributions of Radionuclides to GI Tract Dose from Richland Drinking Water, 1967

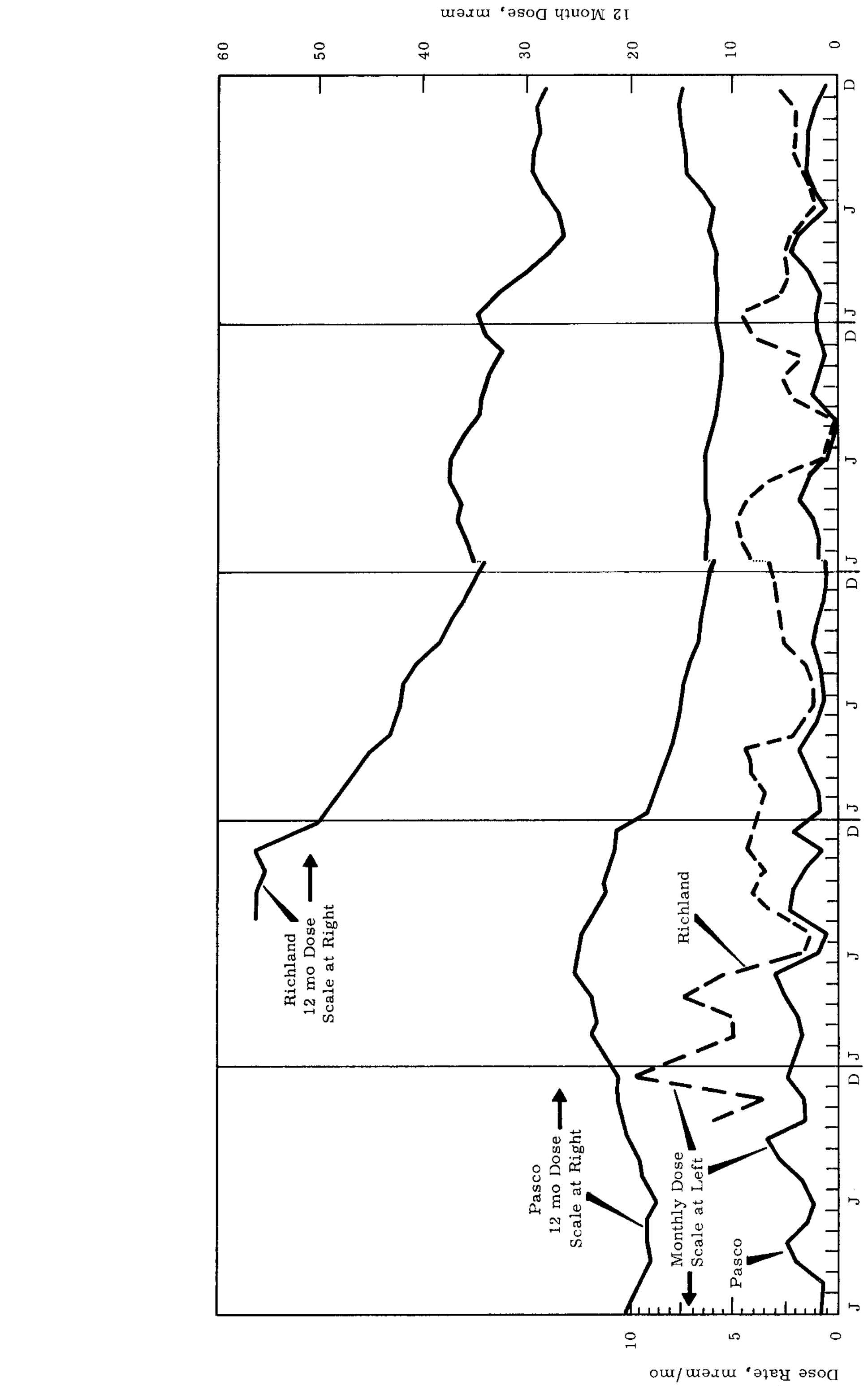

FIGURE 13. Calculated Dose to GI Tract from Pasco and Richland Drinking Water

RADIONUCLIDES IN COLUMBIA RIVER FISH

The quantities and kinds of fish caught by local fishermen have been previously estimated from surveys carried out from 1963 to 1965 in cooperation with the Washington State Game Department. The maximum estimate of consumption by the fishermen interviewed was 200 meals/yr of panfish species (crappie, perch, and bass) taken from the Columbia River. Additional dietary data collected during 1966-1967 from household questionnaires and interview surveys(12) also showed individual consumption estimates as high as 200 meals/yr of fish. The primary fishing locations for the catch of these fish were Burbank, Hover-Finley, and Island View (see Figure 2). The average percentage of the maximum catch by species was 73% crappie, 16% bass, and 11% perch.

From this species distribution and radiochemical analyses of the specimens collected(9) the maximum fish consumer would have received intakes during 1967 of 1.6 μCi ^{32}P and 0.4 μCi ^{65}Zn. Such an intake would have amounted to 10% of the maximum permissible intake with bone as the critical organ. Comparable values for 1966 were 1.0 μCi ^{32}P and 0.5 μCi ^{65}Zn.

The average consumption of Columbia River fish by Richland residents was estimated from plant employee diet questionnaires. With the use of the same mixture of species as for the maximum fish consumer, the average intake during 1967 was 0.019 μCi ^{32}P and 0.004 μCi ^{65}Zn, or about 0.1% of the MPRI with bone as the critical organ.

RADIONUCLIDES IN GAME BIRDS

Migratory waterfowl utilizing the river downstream from the reactors and upland game birds living near the river may be a significant source of the bone-seeking radionuclides ^{32}P and ^{65}Zn for persons who consume such birds. The concentrations of radionuclides in game birds at the time of consumption is dependent upon the bird species, the geographical locations of the birds, and the elapsed time between killing and consumption of the birds.

The average concentration of ^{32}P in the muscle (the edible portion) of waterfowl collected at the Hanford site during 1967 was about 160 pCi/g. The maximum concentration was 2800 pCi $^{32}P/g$, the highest concentration found in local ducks since 1963. Upland game birds collected at the Hanford site had the following average concentrations in muscle: Chukar - 330 pCi $^{32}P/g$, 11 pCi $^{65}Zn/g$; Pheasant - 84 pCi $^{32}P/g$, 12 pCi $^{65}Zn/g$; Quail - 12 pCi $^{32}P/g$, 3.9 pCi $^{65}Zn/g$. The maximum upland game bird concentration in muscle was 2000 pCi $^{32}P/g$ in a pheasant sample.

Data from a dietary survey (see Distribution of Dose Estimates from Individual Diets, page 67), a special survey of local hunters,[13] and concentration data for the various species[9] have been combined in Tables 7 and 8. About 30% of the game bird meals consumed by local hunters were reported to be birds shot within about 5 km (3 miles) of the Columbia River between Ringold and McNary Dam. Analyses showed that birds collected beyond this distance contained little if any radioactivity of Hanford origin. About 43% of all birds eaten were placed in frozen storage which would permit appreciable decay of ^{32}P before consumption.

TABLE 7. Species Distribution of Local Game Birds

	Duck, %	Goose, %	Quail, %	Pheasant, %	Grouse, %	Dove, %
River Birds* of Each Species	37	32	19	33	8	20
Meals of Each Species of All Bird Meals	23	6	12	47	13	No data
River Bird* Meals of Each Species of All Bird Meals	8.5	1.8	2.3	16	<1	No data

* *River birds are defined to be birds shot within 5 km (3 miles) of the Columbia River between Ringold and McNary Dam.*

TABLE 8. Contribution* of Each Species to 1 g of an Average Game Bird Meal

Species	Weight, g	Radionuclide Content, pCi ^{32}P	^{65}Zn
Duck	0.23	7.5	0.85
Goose	0.06	1.6	0.19
Quail	0.12	0.2	0.09
Pheasant	0.47	7.3	1.9
Grouse	0.13	1.8	0.11
Total	1.0 g	18.4 pCi	3.14 pCi

* *Weighted for location of kill and for frozen storage.*

The maximum total game bird consumption reported to date is 23 kg/yr. Consumption of this weight of the average game bird meal tabulated in Table 8 would result in an intake of 0.4 μCi ^{32}P/yr and 0.07 μCi ^{65}Zn/yr, or about 3% of the MPRI with bone as the critical organ. Consumption of the 1.24 kg/yr estimated for an average Richland adult of such an average game bird meal would result in a total intake of 0.4% of the MPRI with bone as the critical organ.

RADIONUCLIDES IN SHELLFISH

^{65}Zn and ^{32}P are the only radionuclides in the reactor effluent that are found in sufficient abundance in food organisms 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 seafoods. Concentrations of ^{65}Zn and ^{32}P periodically measured in oysters grown commercially in the Willapa Bay area are shown in Figure 14; the analytical results are tabulated in the Appendices.(9) A normal seasonal minimum for ^{32}P occurs in the late summer. In August 1967, ^{32}P concentrations were below 1 pCi/g and remained at this low level through December. The annual average concentrations of 30 pCi of ^{65}Zn/g and 3.3 pCi ^{32}P/g for 1967 were similar to those of 1966.

Consumption of oysters containing these average concentrations at the rate of 50 g/day(14) would result in an annual dose of about 6 mrem to the GI tract and 4 mrem to the whole body. The intakes represent 0.4% of the MPRI for individuals with bone as the critical organ. Fresh shellfish are not an important item in the average Tri-Cities diet, although some residents of coastal areas may consume more than the reference value of 50 g/day. For such individuals, shellfish are assumed to be their only source of radionuclides of Hanford origin.

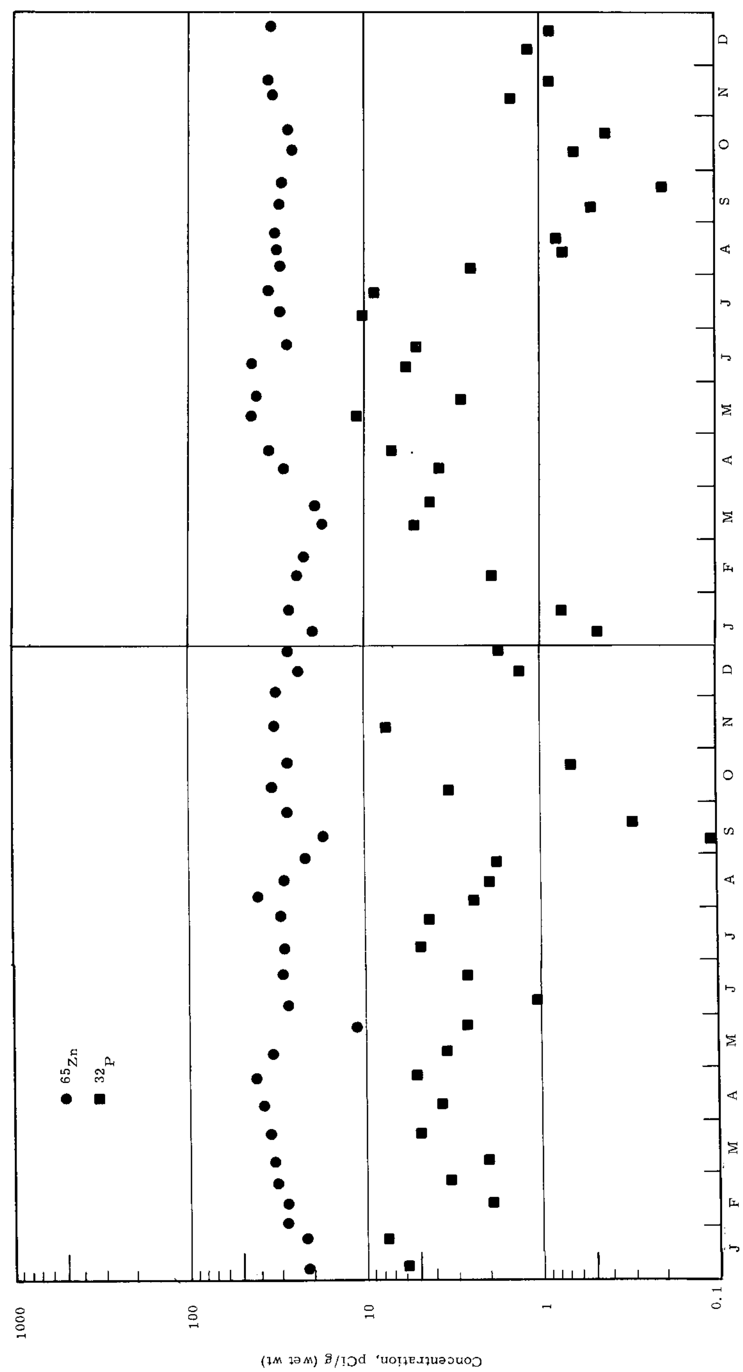

FIGURE 14. ^{32}P and ^{65}Zn in Willapa Bay Oysters

RADIONUCLIDES IN MILK AND PRODUCE

Irrigation with river water containing reactor effluent radionuclides can influence the radioactivity found in locally grown products. Deposition of airborne materials from Hanford sources and from fallout can be an additional source of radionuclides in these products. The chemical separations facilities are generally the principal local source of airborne radionuclides, although radioactive materials released from ventilation stacks of the reactors or laboratory facilities could, under certain conditions, be of interest.

The farming area closest to the separations facilities is at Ringold about 21 km (13 miles) away. However, much of the land east and south of the project boundary (see Figure 2) is under cultivation and may be subjected to airborne releases.

Most irrigated farms near the Hanford plant obtain water from the Yakima River, or from the Columbia River above the project. However, two small irrigated areas using Columbia River water taken downstream from the reactors are the Ringold farms and the Riverview district west of Pasco. They are 40 and 65 km (25 and 40 miles) respectively downstream from the operating reactors. The Ringold farms, about 21 km east of the separations areas, involve some 20 people working 2 km^2 (500 acres) of land with fruit as the principal product. The Riverview district comprises 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 40 km (25 miles) southeast of the chemical separations plants.

The milk surveillance program maintained during 1967 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 those reported by the U. S. Public Health Service[15] and the Washington State Department of Health.[16] Milk from local farms irrigated with water drawn from the river downstream from the reactors contained ^{32}P, ^{65}Zn, and ^{131}I as well as fission products of fallout origin. Commercial milk distributed in the Tri-Cities usually does not contain detectable ^{32}P and ^{65}Zn because the vast majority of the milk is produced on farms not irrigated with Columbia River water.

Figure 15 shows the concentrations of ^{32}P in milk from farms in the Ringold and Riverview areas. During 1967, the average concentration was 320 pCi/liter. In 1967, the analytical limit for ^{32}P analyses in milk was reduced from 200 to 20 pCi/liter, to better interpret trends during the winter and spring of the year. The monthly average concentration of ^{65}Zn in local farm milk shown in Figure 16 was 200 pCi/liter. Seasonal fluctuations, in concentrations of both ^{32}P and ^{65}Zn, caused primarily by irrigation and feeding practices, followed expected trends.

Figure 17 shows the concentrations of ^{131}I measured in milk samples collected during 1967. During 1967, ^{131}I concentrations in both local and commercial milk were generally near or below the analytical limit (3 pCi/liter), except for a sharp increase during an influx of fresh fallout in January. Brief increases in ^{131}I concentrations were noted in May, following small transient increases in the release rates of ^{131}I from a chemical separations facility. The average concentration for the year in farm milk was 4 pCi ^{131}I/liter.

Adult residents consuming milk (1 liter/day) obtained from the Ringold-Riverview areas could have received an annual dose

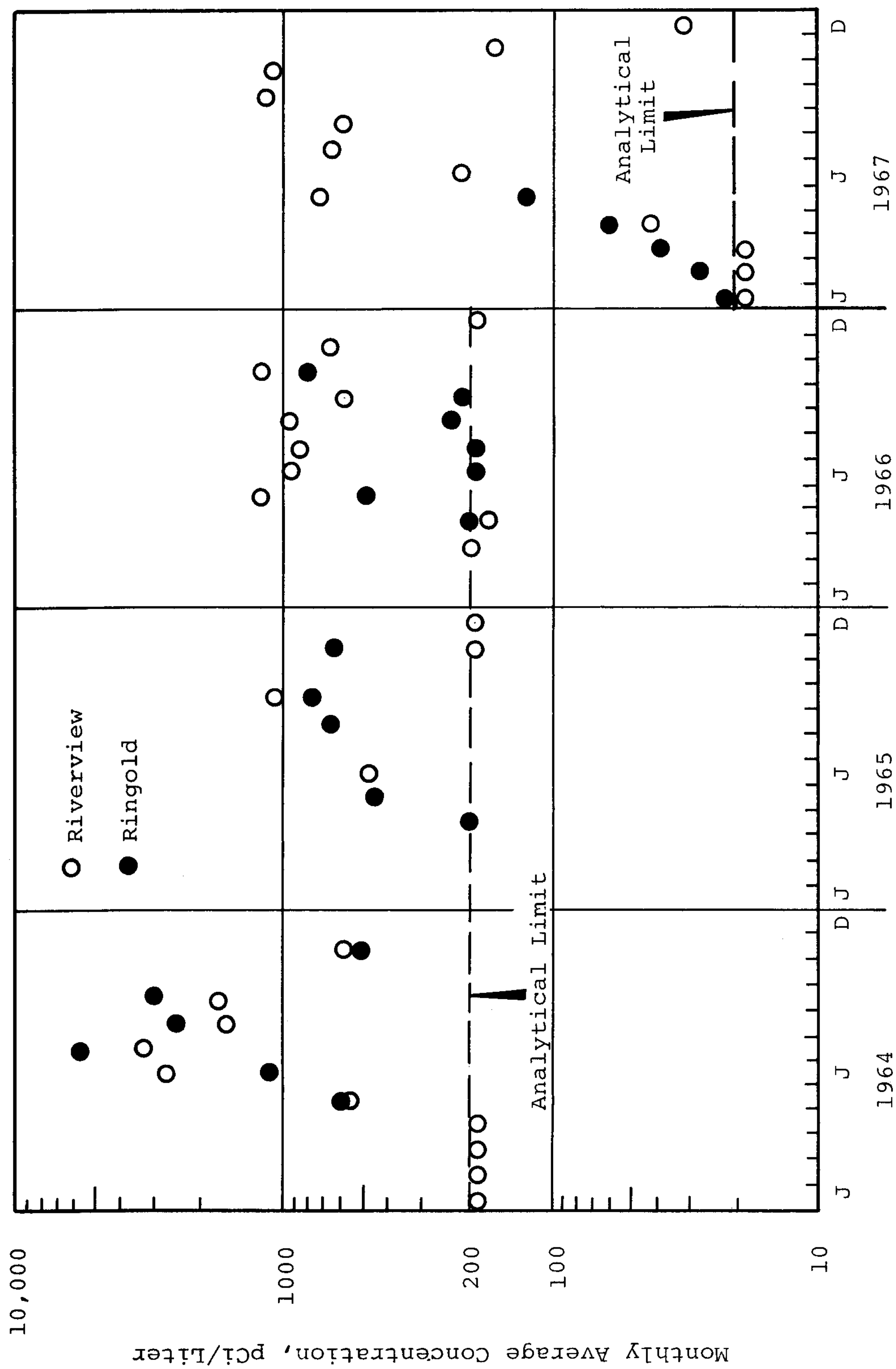

FIGURE 15. ^{32}P in Locally Produced Milk

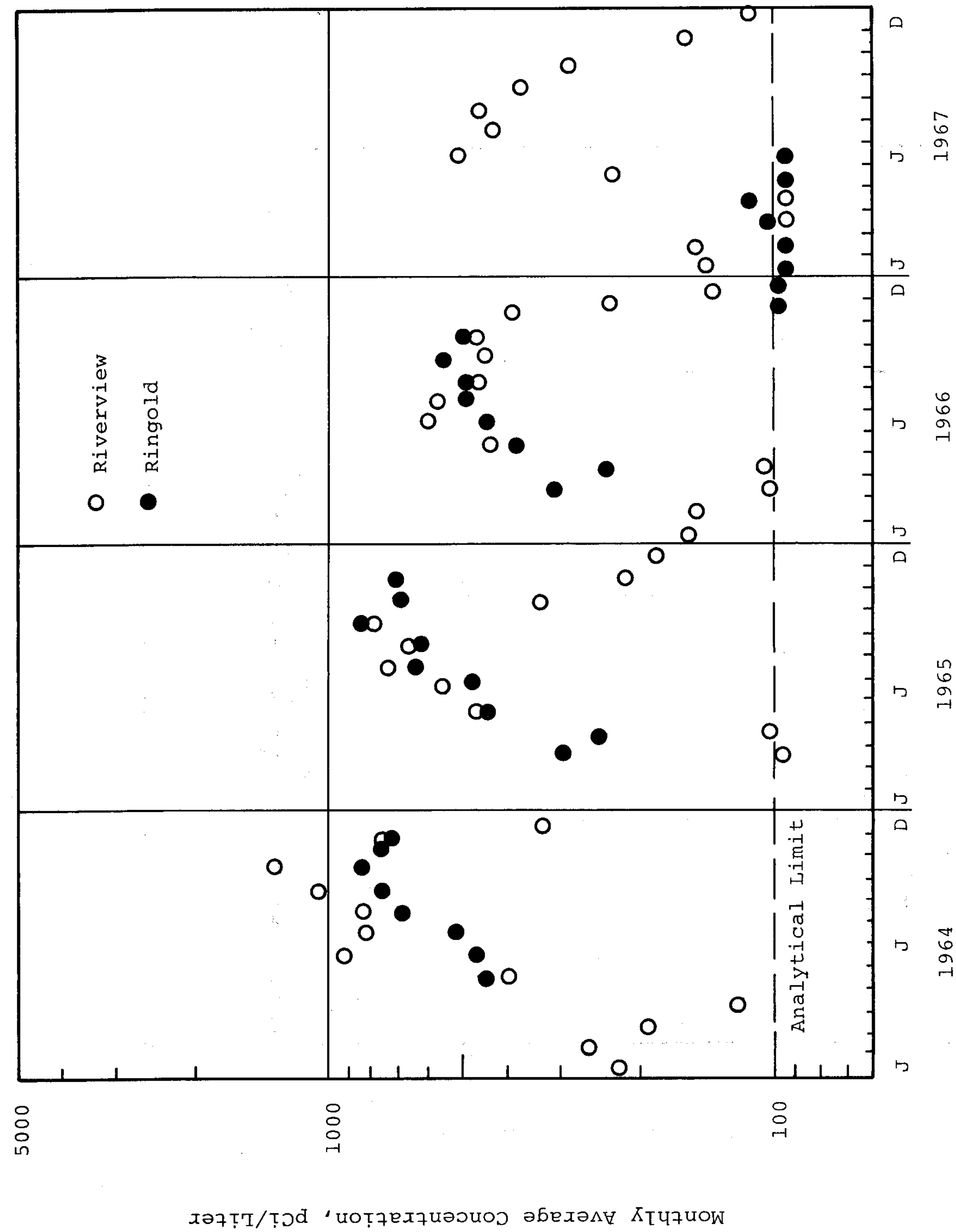

FIGURE 16. ^{65}Zn in Locally Produced Milk

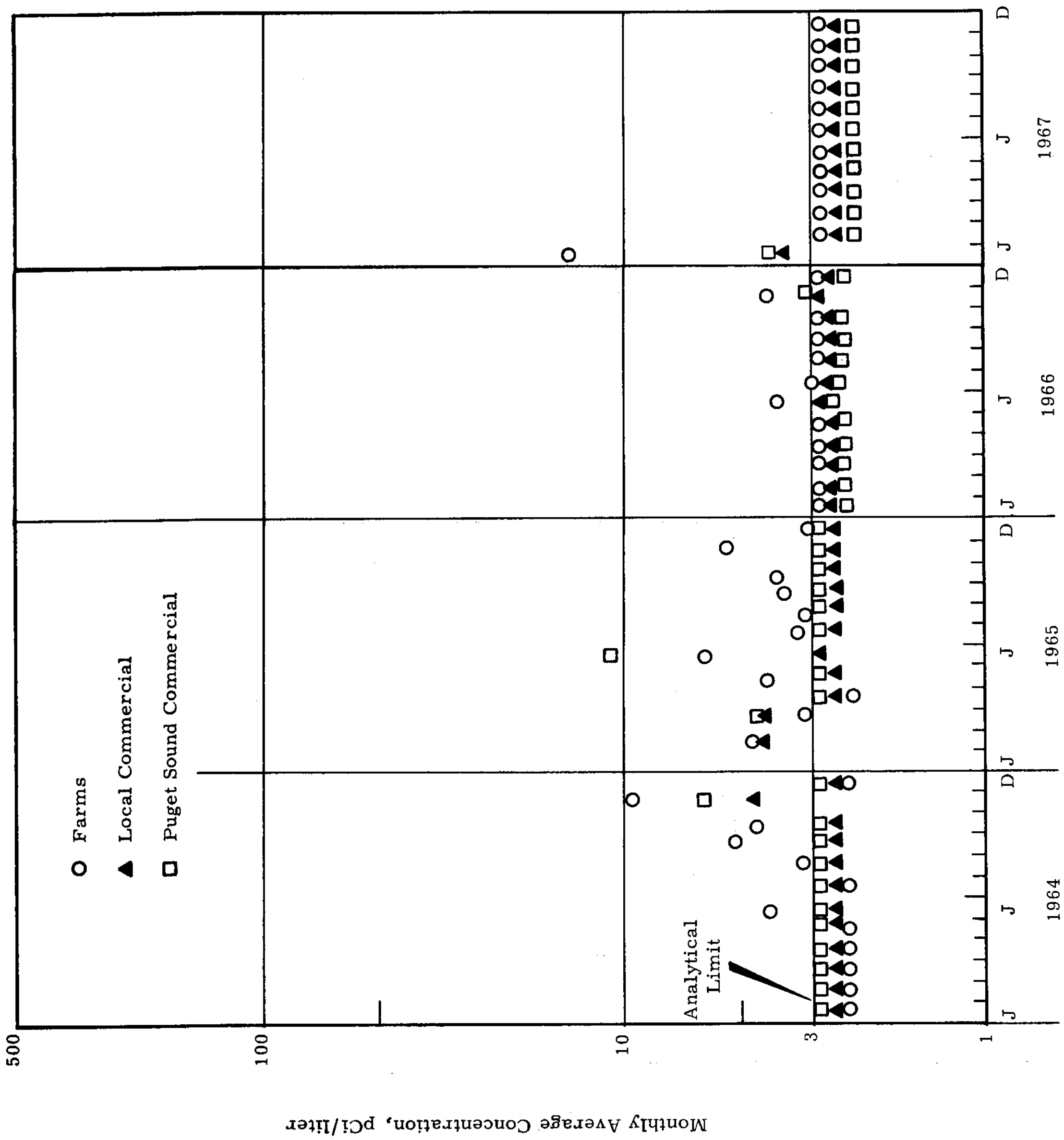

FIGURE 17. ^{131}I in Locally Available Milk

from ^{32}P and ^{65}Zn amounting to about 3 mrem to the GI tract and 1.3 mrem to the whole body. The intake of ^{32}P and ^{65}Zn would be equal to about 0.7% of the MPRI for individuals with bone as the critical organ. The intake of ^{131}I would have resulted in a dose of about 25 mrem to the 2 g thyroid of an infant. Concentrations of radionuclides measured in milk are tabulated in the Appendices.[9]

Miscellaneous fresh produce from local farms was sampled periodically for radioanalysis during the 1967 growing season. Results of these measurements, tabulated in the Appendices, were similar to those of previous years[2,17,18] and indicated that only small quantities of radionuclides are present in locally grown produce.

Specifically, the concentrations of ^{131}I found in samples of fresh leafy 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. If such fresh leafy vegetables had been consumed at the rate of 100 g/day throughout the year, the annual intake from this source would have been about 380 pCi ^{131}I, based on an assumed average concentration of 0.025 pCi/g. Such an intake would imply an annual dose of about 0.6 mrem to the thyroid of an adult. An intake of 50 g/day of the same vegetables by a small child would imply an annual dose of about 4 mrem to a 2 g thyroid.

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 m above ground level during 1967 averaged about 0.35 mR/day or 130 mR/yr at

Hanford (Figure 18) and 0.26 mR/day or 100 mR/yr at Richland (Figure 18). These were not significantly different from 1966 values. Essentially all of the exposure at Richland is from natural background and worldwide fallout from nuclear testing. Measurements of external radiation are tabulated in the Appendices.[9]

An estimate of the external radiation dose received by shoreline fishermen in the vicinity of the Hanford project is made from routine measurements at the river shoreline. These measurements are made with a large (40 liter) ionization chamber centered at 3 ft above the ground to approximate the dose to the gonads. Figure 19 shows monthly averages of the data for 1966 and 1967 for two locations, at Richland and Sacajawea Park where the Snake River enters the Columbia. The measured radiation includes components from radioactivity in the river water as well as from radioactivity accumulated in sediment deposits and algal growths on the substrate at the river's edge. Gamma spectra show that ^{46}Sc and ^{65}Zn were the major contributors to the shoreline component during 1967, ^{24}Na to the water component. The shoreline radiation levels are affected by both the daily and seasonal fluctuations in the flow rate and river level. Also apparent in Figure 19 is the effect of the extended reactor outage of 1966. The primary fishing locations for the panfish species consumed in the largest quantities are downstream from Richland and the appropriate average dose rate for such fishermen is represented by measurements at Sacajawea Park. During 1967, the average exposure rate at Sacajawea Park was 30 μR/hr with an estimated 8 μR/hr due to natural background radiation. An avid fisherman standing on the river shoreline at Sacajawea Park for as much as 500 hr during the year would have had a gonad and torso exposure to gamma radiation of about 11 mR, not including natural background radiation.

Direct radiation measurements are also made in the Columbia River at several locations with pocket-type ionization

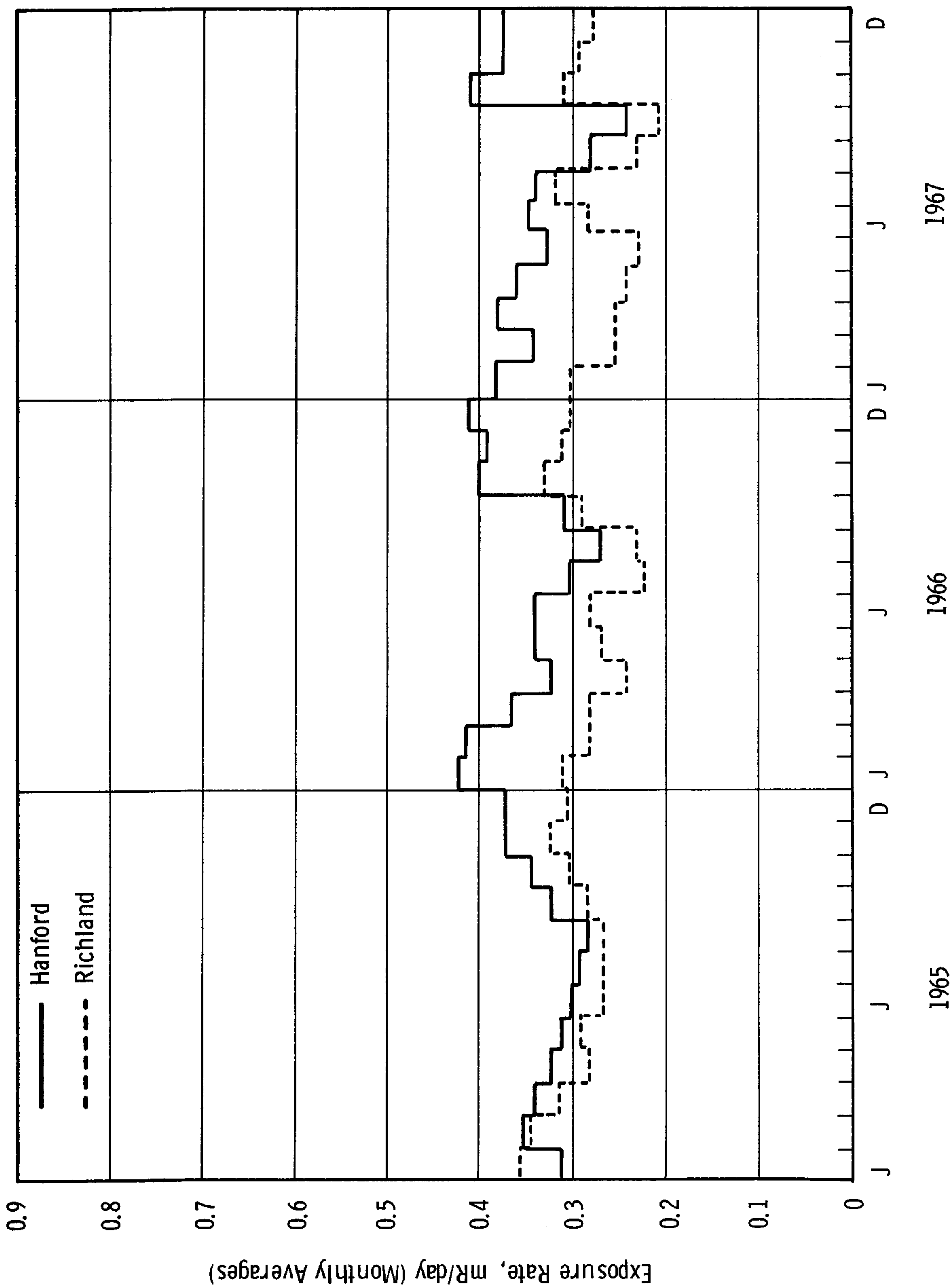

FIGURE 18. External Exposure Rates at Hanford Test Location and at Richland

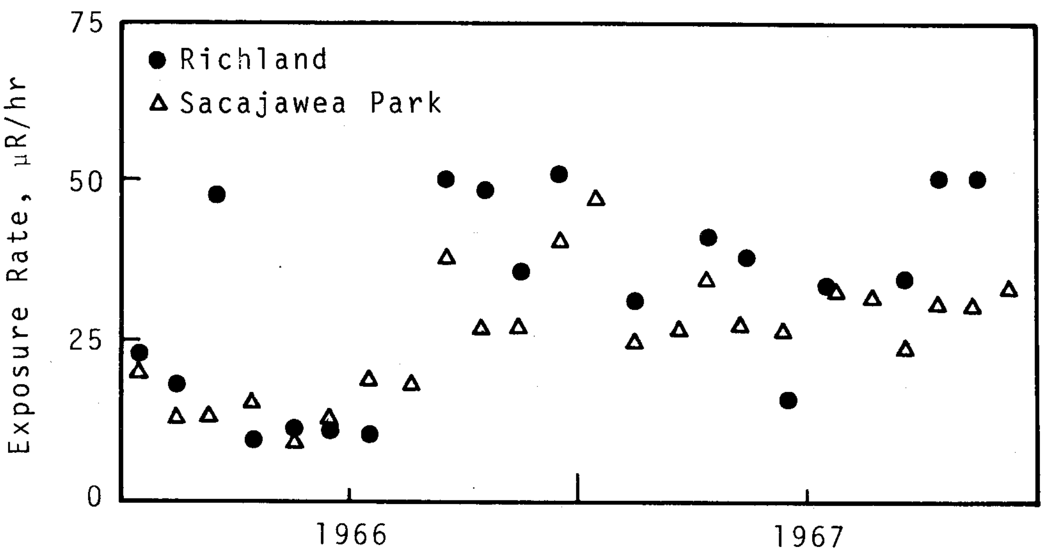

FIGURE 19. Shoreline Exposure Rates at Richland and Sacajawea Park

chambers submerged 0.6 to 1.5 m below the surface of the water. Exposure rates are primarily due to the presence of gamma emitters (especially ^{24}Na) in reactor effluent. In the vicinity of Richland, the average exposure rate in the water from April through October of 1967 was about 2.5 mR/day. An enthusiastic swimmer or water skier spending 240 hr in or on the water during the summer months would have had a whole body exposure of 25 mR. The average whole body exposure of Richland residents during recreational use of the river is estimated to have been about 2 mR from this source during 1967.

FALLOUT FROM NUCLEAR WEAPONS TESTS

Dose increments received by residents of the Hanford environs from fallout nuclides have routinely been estimated, although they are not included in the assessment of dose due to Hanford operations. Locally, this increment is below the national average because of the low rainfall. Measurements of fallout, as do measurements of natural background radiation, help to put the radiation doses resulting from Hanford operations in proper perspective.

During a large influx of fresh fallout early in 1967, the ^{131}I concentration in milk increased to a peak value of 83 pCi/liter in a single sample collected on January 3, which is the highest concentration from fallout measured locally since October 1962 (Figure 17).

Figure 20 shows concentrations of ^{90}Sr in locally available milk. These values are similar to concentrations found in commercial milk produced in other areas of low rainfall remote from the Hanford plant. ^{90}Sr in locally available milk averaged about 4 pCi/liter during 1967, which is slightly lower than the average for 1966 of 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 source of ^{90}Sr and ^{137}Cs in milk.

With the use of the assumption(6) that 40% of the total ^{90}Sr intake from fallout is obtained from milk, the daily intake of ^{90}Sr during 1967 was about 8 pCi/day for the Maximum Individual, 9 pCi/day for the Typical Richland Resident, and 5 pCi/day for the Average Adult Richland resident. These values represent 25 to 40% reductions from the intakes estimated for 1966. The total intake of ^{137}Cs during 1967 was about 0.08 μCi for the Maximum Individual, 0.01 μCi for the Typical Richland Resident, and 0.01 μCi for the Average Adult Richland resident.

Table 9 shows a summary of the estimated annual doses from fallout nuclides present in the Hanford environs. The MPRI's for ^{90}Sr are derived from Federal Radiation Council guides.(5)

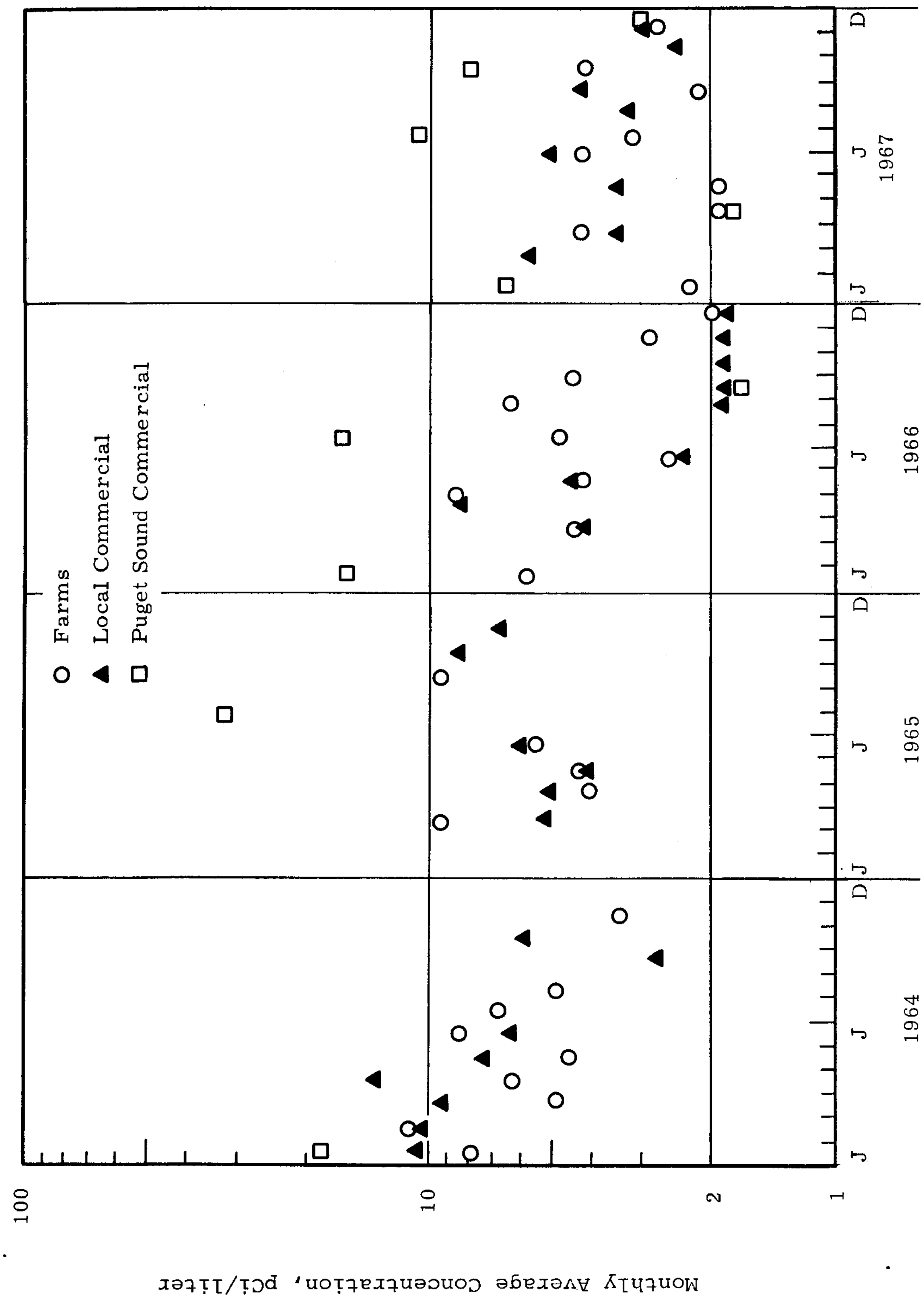

FIGURE 20. ^{90}Sr in Locally Available Milk

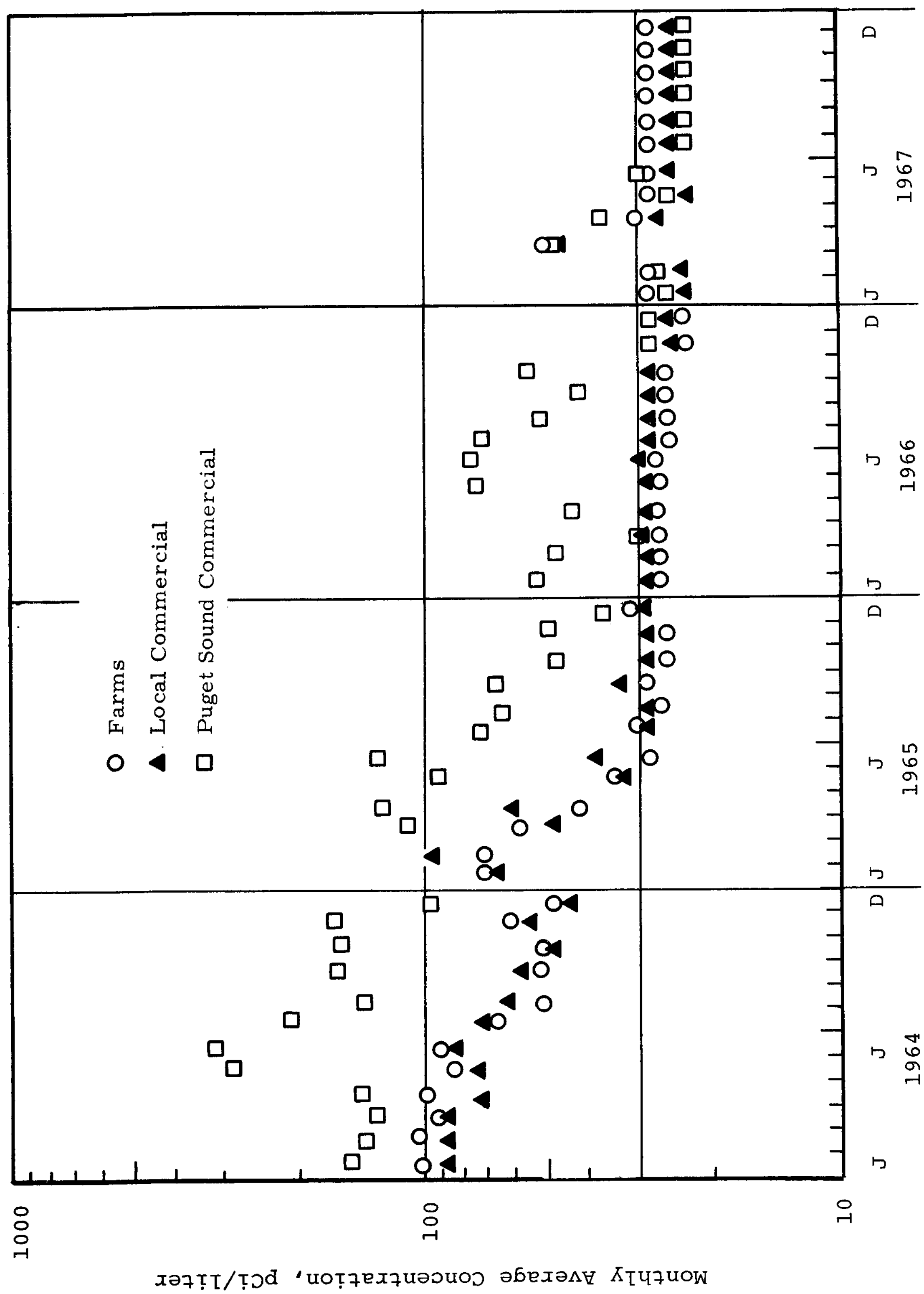

FIGURE 21. ^{137}Cs in Locally Available Milk

TABLE 9. 1967 Annual Radiation Dose from Fallout Nuclides[a] (mrem)

Nuclide	Organ	Maximum Individual	Typical Richland Resident	Average Richland Resident
^{3}H	Whole Body	<1	<1	<1
^{90}Sr	Whole Body	3	3	<2
	GI Tract	<1	<1	<1
	Bone[b]	(1% MPRI)	(4% MPRI)	(3% MPRI)
^{137}Cs	Whole Body	2	<1	<1
	GI Tract	<1	<1	<1
	Bone	(0.2% MPRI)	(0.1% MPRI)	(0.1% MPRI)

Organ	Maximum Individual 1967	Maximum Individual 1966	Typical Richland Resident 1967	Typical Richland Resident 1966	Average Richland Resident 1967	Average Richland Resident 1966
Whole Body	5	6	3	5	2	3
GI Tract	<1	<1	<1	<1	<1	<1
Bone	(2% MPRI)	(5% MPRI)	(5% MPRI)	(8% MPRI)	(3% MPRI)	(4% MPRI)

(a) *Not included in dose summaries presented elsewhere.*
(b) *MPRI based on the FRC guide[15] of 200 pCi/day for the average intake by a suitable sample of the exposed population or 600 pCi/day intake by an individual.*

COMPOSITE ESTIMATES OF RADIATION DOSE

THE MAXIMUM INDIVIDUAL

Experience accumulated from the environmental surveillance program and associated research studies indicates that those individuals receiving the greatest percentage of permissible radiation dose from Hanford sources consume some combination of the following: fish caught locally in the Columbia River; game birds shot near the river; foodstuffs produced on local farms irrigated with Columbia River water drawn from below the reactors; and municipal water with the Columbia River as the source. A hypothetical Maximum Individual has been assigned maximized but plausible dietary habits as shown in Table 10. These are identical to assumptions used in the 1966 Annual Report,[2] and have been documented separately in detail.[19]

The consumption rates of most foods for this hypothetical Maximum Individual were compiled from intake rates described in published dietary surveys. The postulated sources include water from the Pasco municipal system (Radionuclides in Drinking Water, page 35) and milk, meat, and produce from river-irrigated farms in the Riverview district (Radionuclides in Milk and Produce, page 44). The consumption of 200 meals/yr of panfish taken from the Columbia River (Radionuclides in Columbia River Fish, page 37) is based on the maximum reported in local surveys. A total of 500 hr/yr along the river bank (External Radiation, page 49) to catch these fish is also assumed. The composite dose for this Maximum Individual is summarized in Table 11 and illustrated in Figure 22. Estimated doses to the GI tract for the Maximum Individual during 1967 and 1966 were both about 5% of the appropriate limit, with ^{32}P contributing about 50% of the total dose in each case. The 1967 GI tract dose was 82 mrem. For the whole body dose,

TABLE 10. Dietary Assumptions

Foodstuffs	Maximum Individual	Typical Adult Richland Resident	Average Adult Richland Resident
Water	730 ℓ/yr	440 ℓ/yr	680 ℓ/yr[a]
Milk	380 ℓ/yr	310 ℓ/yr	130 ℓ/yr[a]
Meat	80 kg/yr	80 kg/yr	74 kg/yr[a]
Chicken	8 kg/yr	5.4 kg/yr	5.4 kg/yr
Eggs	30 kg/yr	15 kg/yr	15 kg/yr
Seafood	0	5.5 kg/yr[b]	1.4 kg/yr[a,b]
Col. Riv. Fish	40 kg/yr	0	0.48 kg/yr[a]
Game Birds	0	0	1.2 kg/yr[a]
Leafy Veg.	36.5 kg/yr	36.5 kg/yr	36.5 kg/yr
Other Veg. and Fruits	215 kg/yr	36.5 kg/yr	73 kg/yr

Foodstuffs	Maximum Infant	Typical Richland Infant	Average Richland Infant
Water	0.8 ℓ/day	0.4 ℓ/day	0.4 ℓ/day
Milk	1.0 ℓ/day	0.6 ℓ/day	0.6 ℓ/day
Leafy Veg.	50 g/day	25 g/day	25 g/day

(a) *Based on dietary questionnaires of Richland residents employed at Hanford reported in Distribution of Dose Estimates from Individual Diets, page 67.*
(b) *One-tenth of the total is assumed to be Willapa Bay Oysters, the remainder free of radionuclides of Hanford origin.*

TABLE 11. Summary of Radiation Doses[a] in the Hanford Environs, 1967

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

(a) *Doses from fallout and natural background not included.*
(b) *Not calculated - see Standards for Evaluation, page 7.*
(c) *AEC-ICRP derived MPRI: for Maximum Individual - 16 μCi ^{32}P/yr and 800 μCi ^{65}Zn/yr; for Typical and Average Richland Resident - 5.3 μCi ^{32}P/yr and 270 μCi ^{65}Zn/yr.*

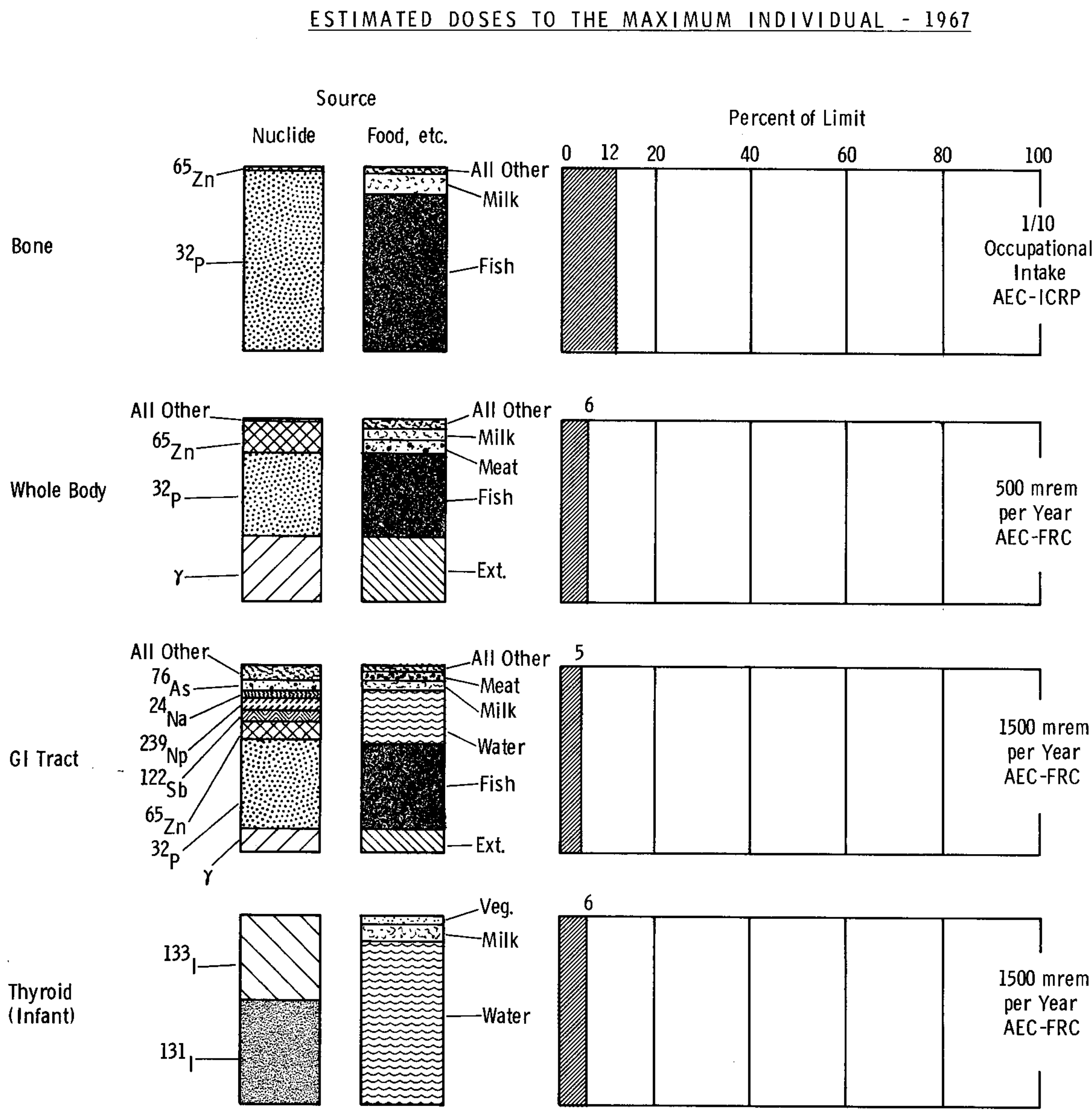

FIGURE 22. Estimated Doses to Maximum Individual, 1967

32 mrem or about 6% of the appropriate limit, the 1967 estimate was not significantly different from the 1966 estimate of 31 mrem. The estimated percent of the Maximum Permissible Rate of Intake for bone as the critical organ was 12% during 1967, compared to 10% for 1966.

In the case of the thyroid gland, the highest radiation doses are those received by infants because of the relatively small thyroid mass (assumed to be 2 g). For 1967, the estimated thyroid dose received by a Riverview infant with foods from the same sources as the Maximum Individual was 87 mrem. A Richland infant of similar dietary habits (Table 10) but different food and liquid sources received an estimated 97 mrem (6% of the appropriate limit). These values are similar to the maximum infant thyroid dose estimated for 1966. However, the estimates are not directly comparable, because the estimate of thyroid dose for 1967, unlike that for 1966, included contributions from both ^{131}I and ^{133}I in the drinking water. The estimate of ^{133}I intake by the maximum Richland infant gave a contribution to the thyroid dose for 1967 of 47 mrem, or about one-half of the total.

Table 12 shows the trend of Maximum Individual dose estimates for the period 1964-1967. The 1967 thyroid dose has been adjusted to a comparable basis (from ^{131}I only). The increase observed in the thyroid dose during 1966 reflects an unusual release of radioiodine to the Columbia River from a production reactor.[2] The long trend for Whole Body and GI tract doses is obviously downward. Bone doses for the Maximum Individual, which appear to have leveled off at $\sim$10 to 12% for the past 3 yr, are heavily dependent upon ^{32}P concentrations in Columbia River fish. The latter concentrations are, in turn, dependent on river conditions as well as radionuclide release rates. The 1966 estimate reflects to some extent the extended reactor outage of that year.[2]

TABLE 12. Dose Estimates[a] for Maximum Individual, 1964 to 1967 (% Limit)

	1964, %	1965, %	1966, %	1967, %	Limit, mrem
GI Tract	9	6	5	5	1500
Whole Body	18	8	7	6	500
Bone	23	12	10	12	--
Thyroid (infant)	5	4	6	3[b]	1500

(a) *Does not include fallout and natural background.*
(b) *For comparison, includes dose from ^{131}I only.*

THE TYPICAL RICHLAND RESIDENT

The majority of people who live in Richland obtain their food from local commercial stores (rather than from farms), and consume little or no Columbia River fish or local game birds. The principal source of radionuclides of Hanford origin ingested by such people is drinking water obtained from the Columbia River. For continuity with previous years, the doses for several organs of the body for the Typical Richland Resident have been calculated for 1967. Table 10 shows the dietary assumptions for this group.

The estimated dose to the GI tract of the Typical Richland Resident from nuclides of Hanford origin during 1967 was about 24 mrem or 5% of the maximum permissible dose, compared to 7% for 1966. Ninety percent of the GI tract dose was contributed by drinking water. The estimated rate of intake of bone-seeking nuclides was <1% of the MPRI for a suitable sample of the population for both 1966 and 1967. The estimated whole body dose of the Typical Richland Resident for 1967 was 4 mrem or 3% of the appropriate limits, the same as for 1966.

For comparison, whole body doses from natural background (excluded from the FRC guide) and from fallout in this region are estimated at about 100 mrem/yr and 3 mrem/yr, respectively.

For dose to the thyroid, the most appropriate sample of the exposed population would seem to be Richland infants, Table 10 lists the assigned consumption rates. The water is from the municipal system, the milk is from commercial sources, and a few leafy vegetables in season are obtained from local markets. From these sources, a thyroid dose for the typical Richland infant for 1967 was 50 mrem, or 10% of the appropriate limit, including an estimated contribution of 23 mrem from ^{133}I in the drinking water. For comparison, the calculated thyroid dose for 1966 from the same sources was 44 mrem for ^{131}I only.

Figure 23 shows the source and nuclide contribution to the doses to various organs for the Typical Richland Resident.

THE AVERAGE RICHLAND RESIDENT

Diet Estimates

Estimates of average consumption rates of several food items were obtained for Richland adults from analysis of dietary questionnaires completed by plant employees. The program and the data are further discussed on page 67, Distribution of Dose Estimates from Individual Diets. The principal changes from the consumption values assumed for the Typical Richland Resident were an increase of 55% for tap water (of which a substantial portion was consumed as coffee), a decrease of 58% for milk, a 75% decrease for seafood (one-tenth of which is still assumed to be Willapa Bay oysters), and the inclusion of 0.48 kg/yr of Columbia River fish and 1.24 kg/yr of game birds. Table 10 is a summary of this average Richland adult diet.

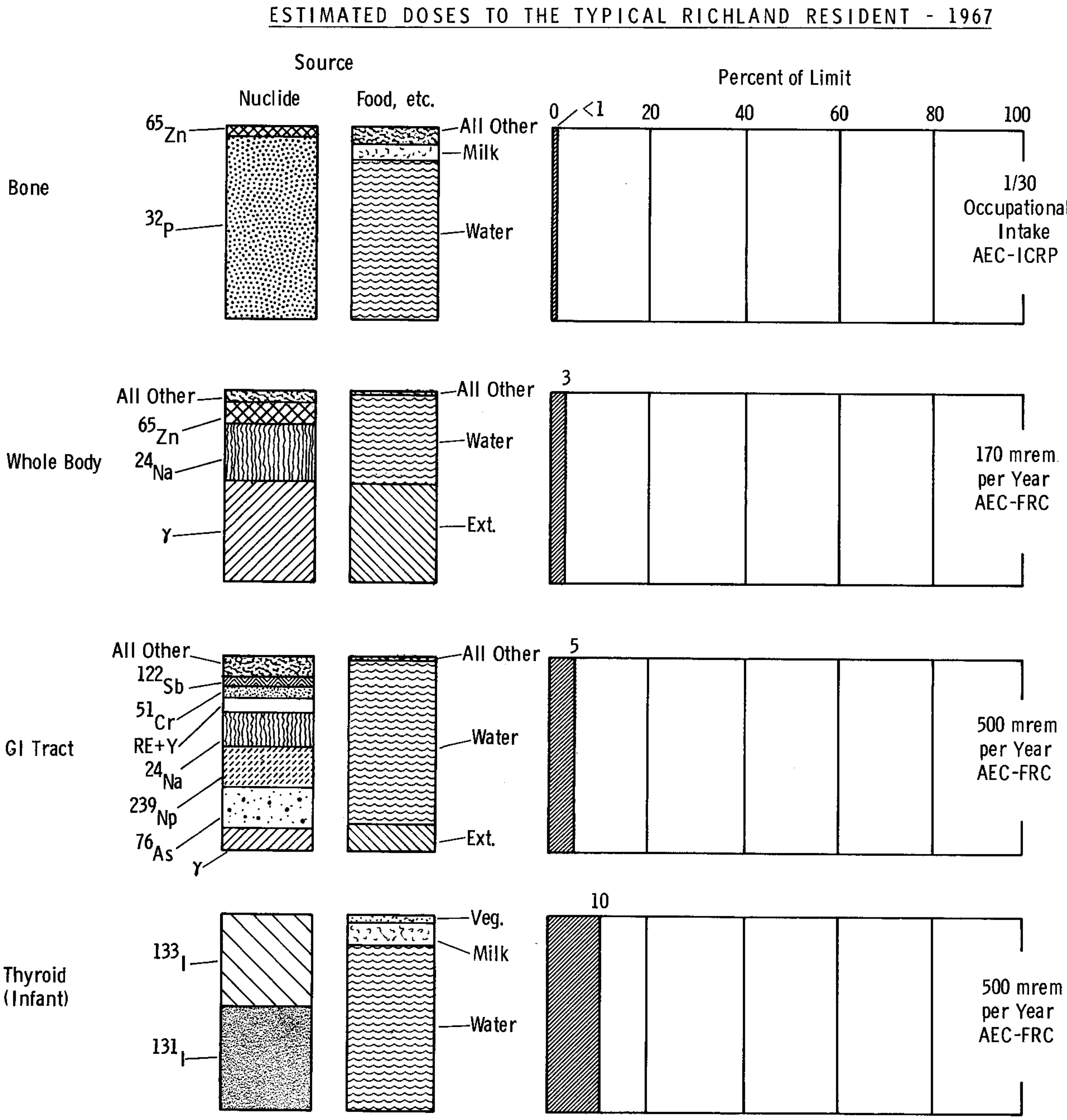

FIGURE 23. Estimated Doses to Typical Richland Resident, 1967

In computing doses for the Average Richland Resident, the assumed food sources were Richland drinking water with average concentrations adjusted for decay and dilution (Radionuclides in Drinking Water, page 35), Columbia River fish with the average species composition of fish ingested by the Maximum Individual (Radionuclides in Columbia River Fish, page 39), "average game birds" (Radionuclides in Game Birds, page 40), and milk, meat, and produce from local stores (Radionuclides in Milk and Produce, page 44).

Because no significant contribution from Hanford operations to the background radiation levels in Richland can be discerned, the entire Hanford contribution to external dose for the Average Adult Richland Resident is assumed to result from recreational use of the Columbia River. An estimated dose increment of 2 mR from the river while swimming or water skiing was included in the GI tract and whole body doses.

Dose Estimates from Average Consumption Rates

The organ of the Average Adult Richland Resident that received the highest percentage of the appropriate dose limit during 1967 was the GI tract, at 6% of the limit (30 mrem). The principal source (89% of the total dose) was drinking water. The whole body dose due to Hanford nuclides during 1967 was estimated to be 4.4 mrem (3% of the limit), one-half of which resulted from recreational use of the Columbia River. The percent MPRI with bone as the critical organ was 1.6% MPRI for the Average Adult Richland Resident. About 44% of this was derived from drinking water, 29% from game birds, 23% from fish, with 4% from remaining food items. The single radionuclide ^{32}P accounted for 98% of the total percent MPRI. Dose estimates for the Average Richland Resident are illustrated in Figure 24 and summarized in Table 10.

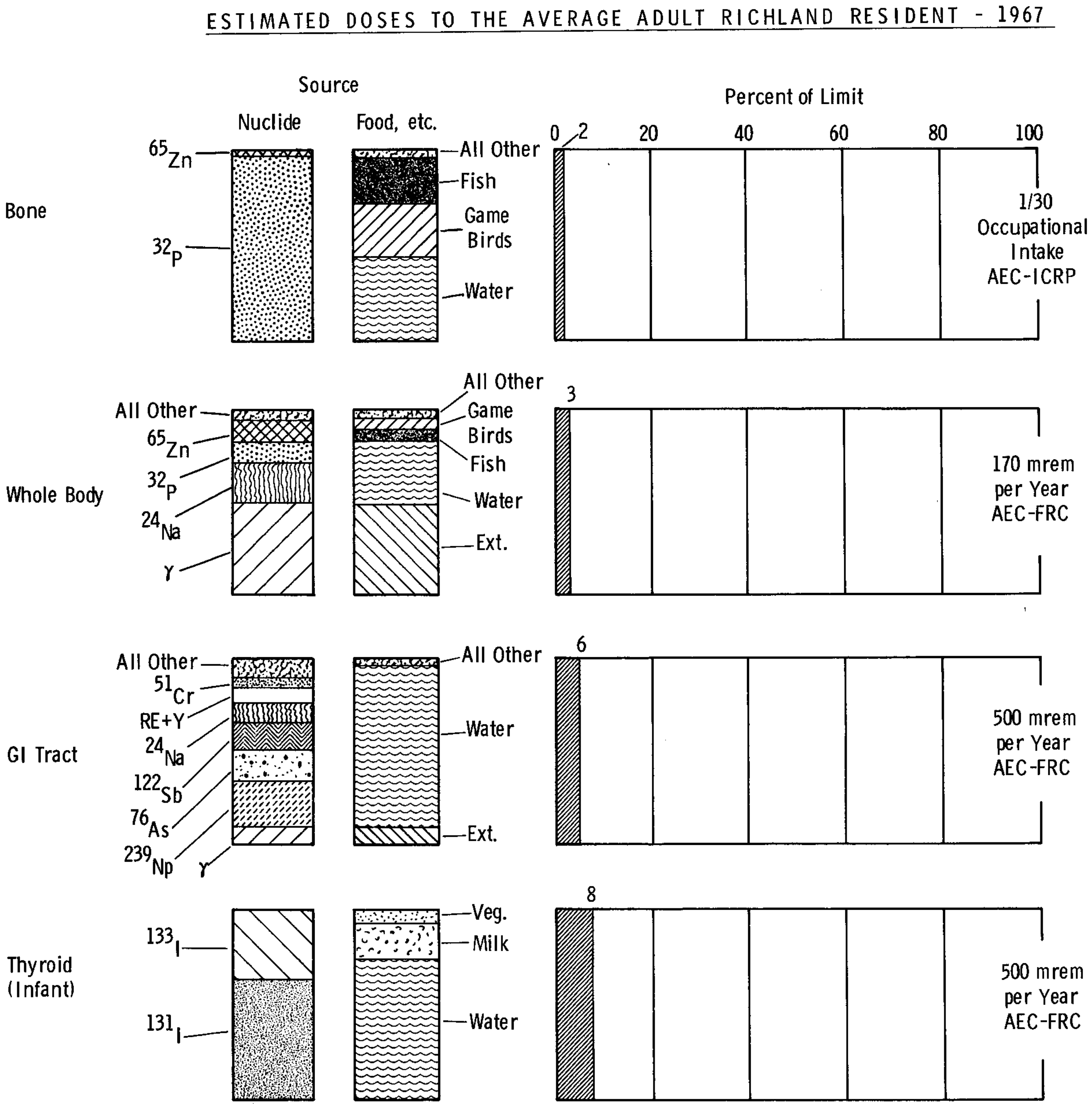

FIGURE 24. Estimated Doses to Average Richland Residents, 1967

Because no new dietary data were available for infants, the average Richland infant was assumed to have the same food intakes and sources as were used for the Typical Richland Infant. However, use of an average composition of drinking water (adjusted for decay and dilution) resulted in a lower thyroid dose of 38 mrem or about 8% of the limit.

DISTRIBUTION OF DOSE ESTIMATES FROM INDIVIDUAL DIETS

Of the several steps in the transfer of radionuclides through environmental pathways to people, the final one—in which material is incorporated into the human diet or becomes accessible to man as a result of his activities—is the most difficult to measure quantitatively. At Hanford, continuing studies have been aimed at the determination of the diets and activities of average residents as well as the identification of those individuals or groups with the greatest radiation exposure. Since 1962, plant employees and local residents have, as part of such studies, been asked to fill out a questionnaire that reveals pertinent dietary habits when a whole-body count is made. This file currently contains multiple diet records for some 4500 individuals, 3300 of which live in Richland. Since the diet questionnaires ask for only the number of servings, the serving sizes must be estimated.

The diet records can be used in two ways. An average diet can be calculated and appropriate radionuclide concentrations applied to compute an average dose. Alternatively, individual doses for each diet record can be calculated and averaged, using the same concentrations. With computer processing, both approaches have been used. The first approach was used to calculate the average Richland diet on page 63.

With the use of the alternative approach, 1967 doses for adult residents of Richland, Pasco, and Kennewick were calculated and are presented as dose-distribution curves in

Figures 25 through 27. The mean dose to each organ is obviously much lower than the maximum dose estimates resulting from the unusual habits of a very few individuals.

Table 13 shows a comparison of maximum and average doses for 1967 from the Individual Richland resident diet records with the doses calculated for the Maximum Individual and the Average Richland diet on pages 57 and 63, respectively. Average doses calculated by either method discussed in the preceeding paragraph are almost identical. The relative importance of drinking water as a source of GI tract exposure for Richland residents and Columbia River fish as a source of bone exposure is illustrated by the respective differences between estimates for the hypothetical Maximum Individual and for the maximum individual diet (a Richland resident).

TABLE 13. Comparison of Maximum and Average Dose Calculations, 1967 (% Limit)

	Standardized Diets		Individual Diets	
	Maximum Individual, %	Average Richland Resident, %	Maximum, %	Average, %
GI Tract	5	6	7	6
Whole Body	6	3	4	3
Bone	12	2	8	2

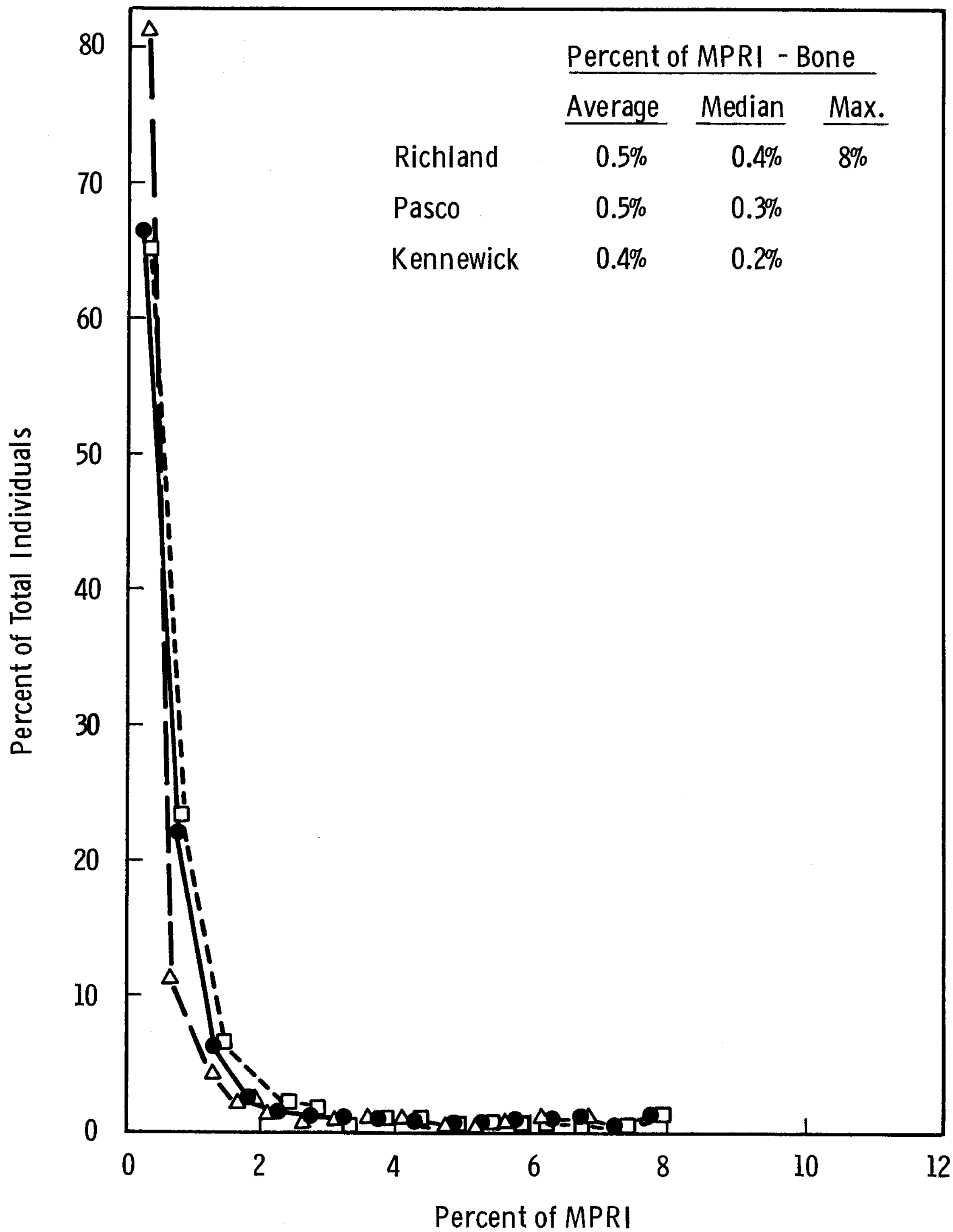

FIGURE 25. Distribution of Estimated Doses to Bone for Tri-Cities Residents, 1967

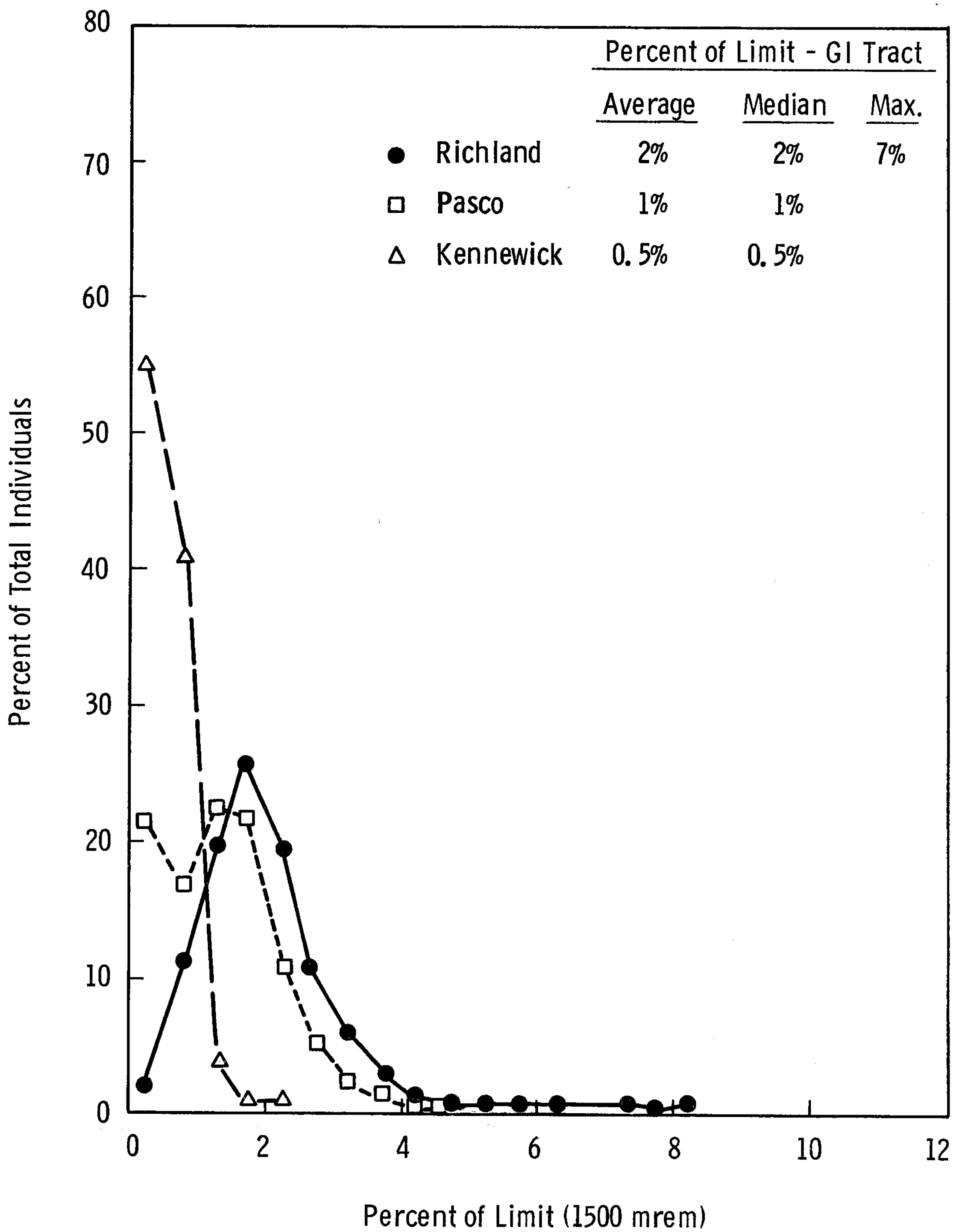

FIGURE 26. Distribution of Estimated Doses to the GI Tract for Tri-Cities Residents, 1967

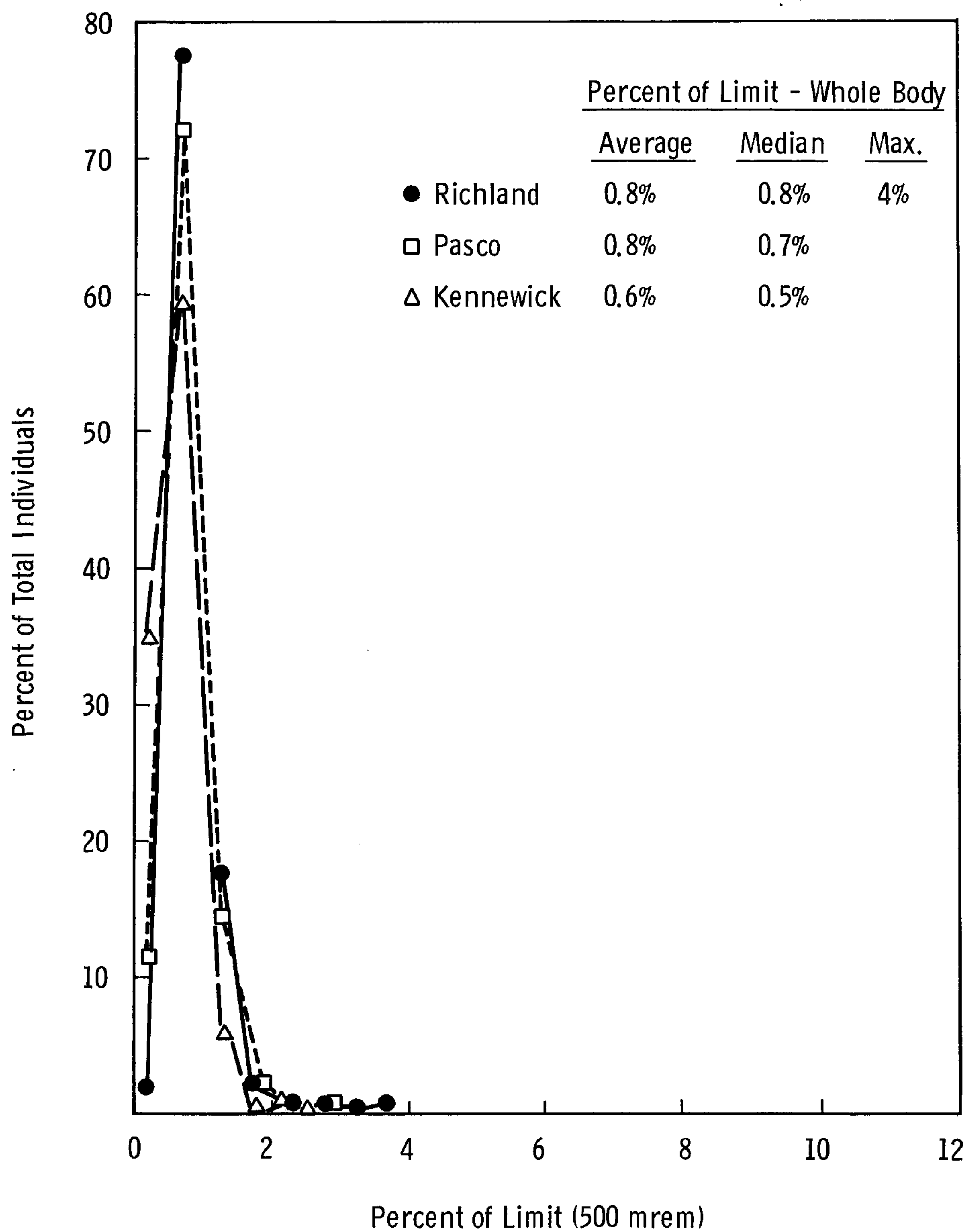

FIGURE 27. Distribution of Estimated Doses to the Whole Body for Tri-Cities Residents, 1967

Since statistical analyses have shown a close approximation to a log-normal distribution for the central mass of the data, the individual dose estimates for Richland residents have also been plotted on log-probability paper (Figures 28 through 30). The departure from a single log-normal distribution of the estimates for bone, Figure 28, is significant at the upper end of the distribution. Two separate population groupings are indicated, one consisting of Richland residents who hunt and fish locally, the other of residents who do neither. The low end of the distribution of GI tract dose estimates, Figure 29, is affected by the inclusion of a number of individuals who obtain their drinking water from wells containing no radionuclides of Hanford origin. The lower end of the whole body dose plot, Figure 30, is affected by the constant 2 mR added for recreational exposure from the river. Without this increment, the distribution would be almost log-normal.

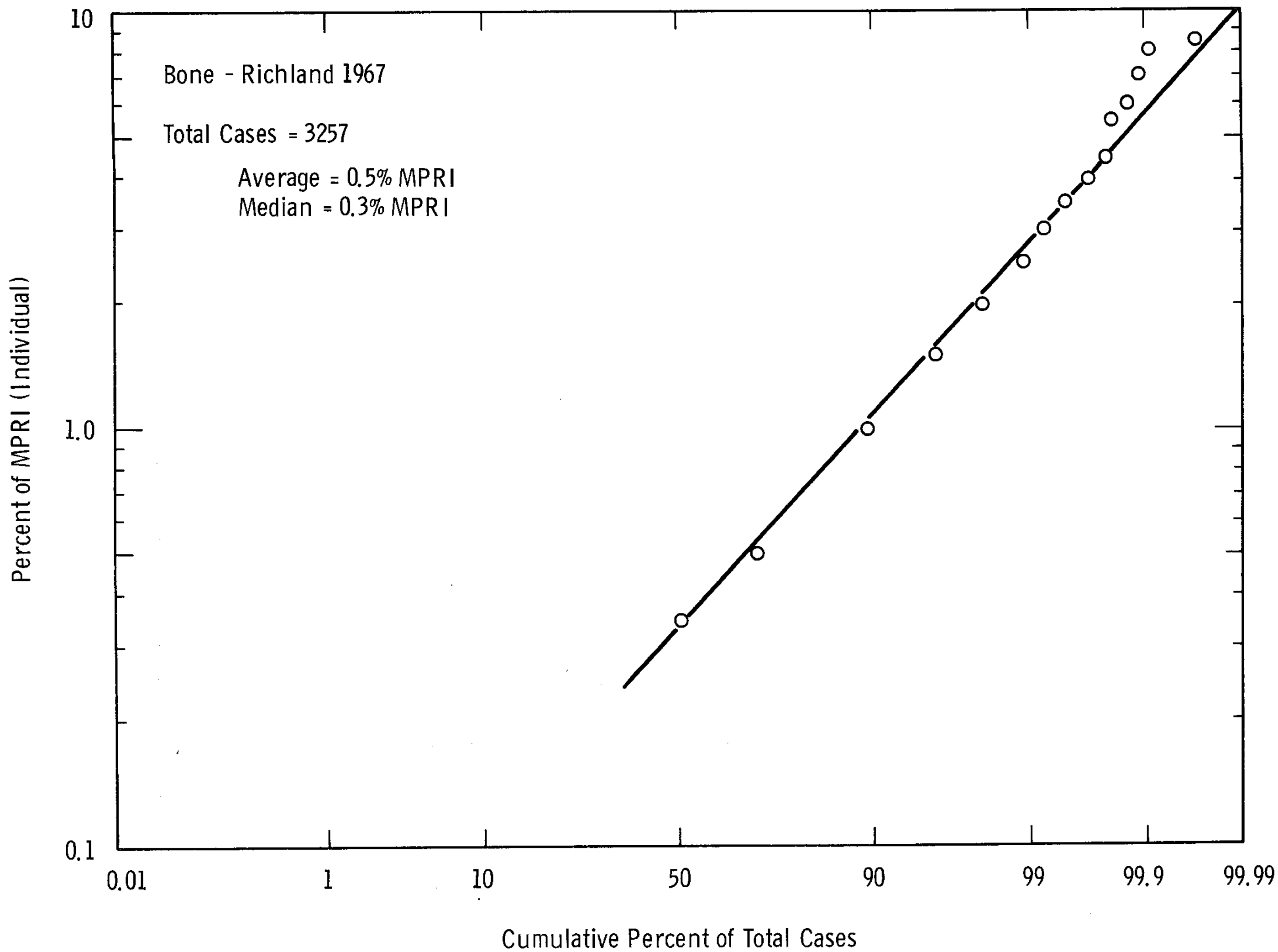

FIGURE 28. Probability Distribution of Percentage of Permissible Bone Intake Based on Individual Diets of Richland Residents, 1967

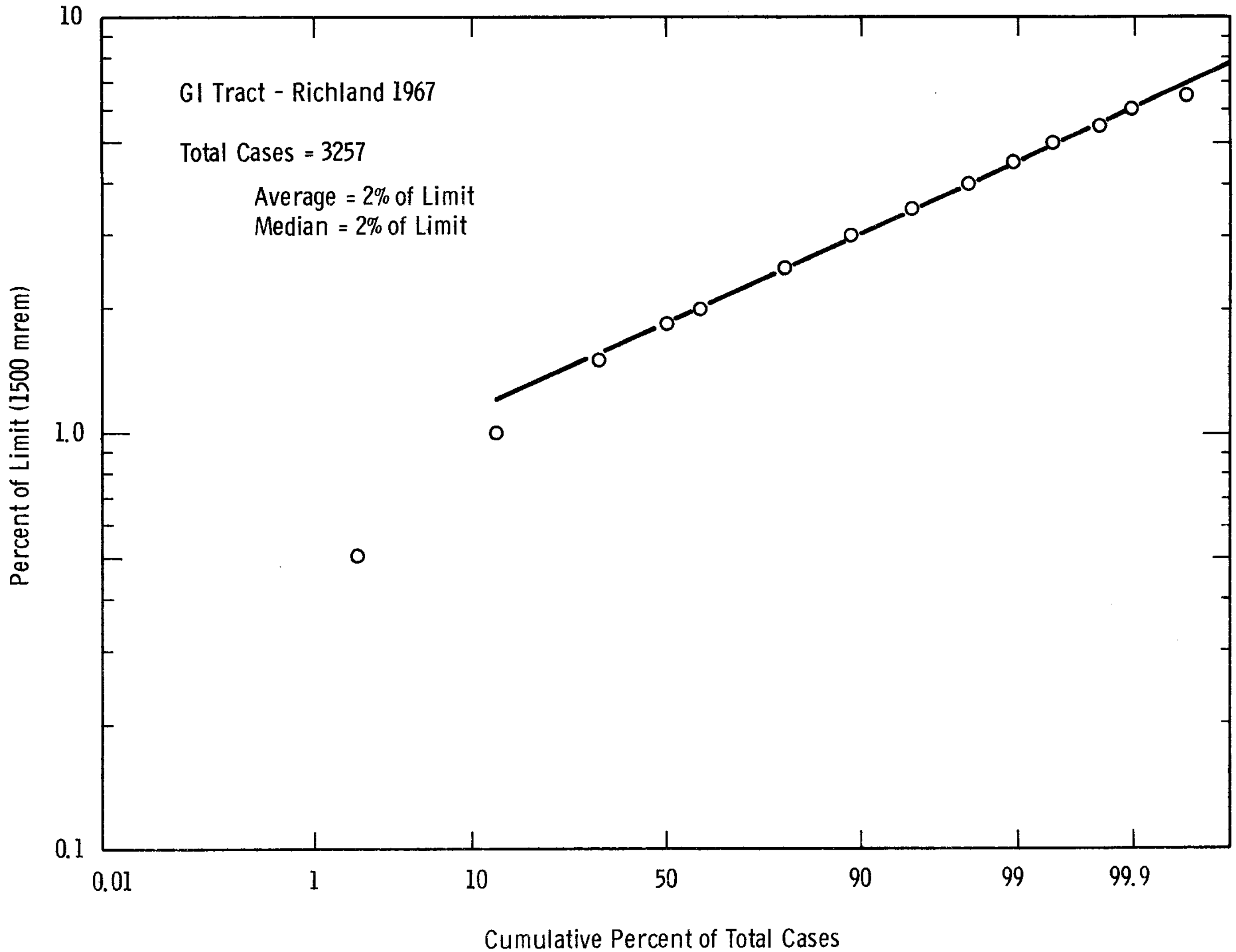

FIGURE 29. Probability Distribution of GI Tract Doses Based on Individual Diets of Richland Residents, 1967

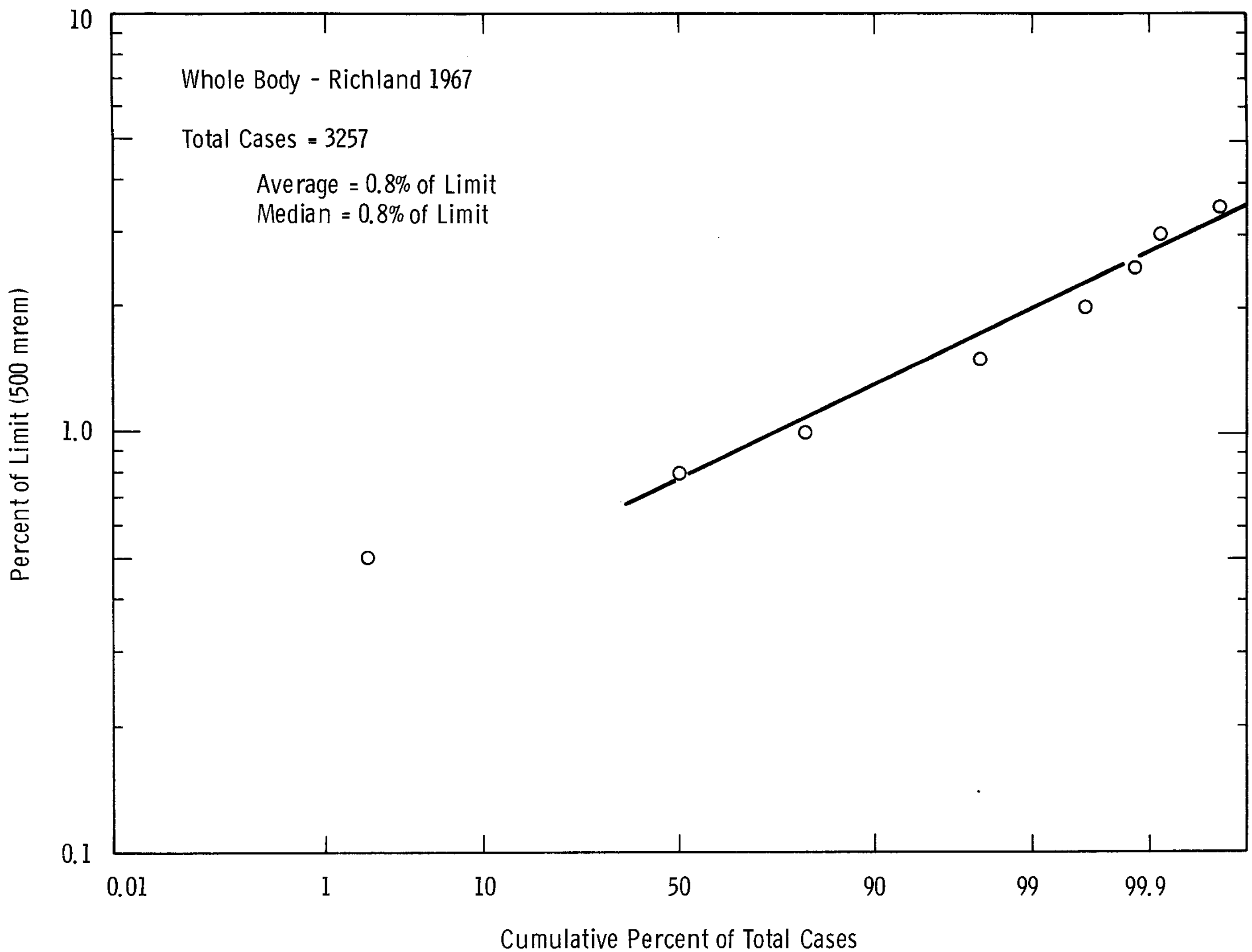

FIGURE 30. Probability Distribution of Whole Body Doses Based on Individual Diets of Richland Residents, 1967

CONCLUSIONS

The results of the 1967 environmental surveillance program at Hanford again showed that the amounts of radionuclides as measured in the environs were well within accepted limits. The only estimate exceeding one-tenth of the appropriate limit was 12% MPRI for the bone of the hypothetical Maximum Individual. Because of the 1966 reactor outage, some 1967 dose estimates for the environmental population exceeded 1966 levels, but not 1965 levels. The shutdown of plant facilities and process improvements have both contributed to a decrease in most dose estimates from 1965 to 1967.

ACKNOWLEDGMENTS

The radiochemical data presented here and in the Appendices were supplied by the U. S. Testing Co., Inc., which performed all routine radioassays of environmental samples.

The cooperation of many Battelle-Northwest staff members who collected samples, performed many tedious radioassays, prepared and provided data, and reviewed this document is gratefully acknowledged. Of special note were the efforts of W. C. Horton and his environmental Monitoring group, J. K. Soldat who provided technical support, and J. F. Honstead who was in charge of the overall environmental studies program during 1967.

The cooperation and contributions of the several city, state, and federal agencies listed below are 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

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: N. Atterberry, Benton City, Washington; H. G. Bleazard, Eltopia, Washington; D. N. Dinneen, West Richland, Washington; W. F. Harris, Pasco, Washington; D. G. Hodges, Pasco, Washington; M. C. Kinne, Mesa, Washington; L. M. Monson, Eltopia, Washington; W. M. Nichols, West Richland, Washington; H. H. Olson, Pasco, Washington; A. W. Taylor, Pasco, Washington; Twin City Creamery, Kennewick, Washington.

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