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EVALUATION OF RADIOLOGICAL CONDITIONS IN THE VICINITY OF HANFORD FOR 1969

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EVALUATION OF RADIOLOGICAL CONDITIONS IN THE VICINITY OF HANFORD FOR 1969

By

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Edited by
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Radiation Protection Department
Operations and Services Division

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ABSTRACT

At the Hanford plant, 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 1969 continued to be reactor cooling water discharged to the Columbia River. The combined offsite effects of all radioactive wastes released from Hanford during 1969 were evaluated in terms of the radiation doses received by nearby population groups. Dose estimates for 1969 were generally lower than 1968 values. As in the annual report for 1968, the appropriate representatives of the population were considered to be the Maximum Individual and the Average Richland Resident. Doses were estimated for the skeletal bone, whole body, gastrointestinal tract, and thyroid. These estimated doses were less than one-tenth of the appropriate standards with the largest percentage of standard being that for the skeletal bone of the Maximum Individual (9% of the 1500 mrem/yr standard). A single radionuclide, ^{32}P, contributed 92% of this estimated skeletal bone dose with Columbia River fish the major source of intake.

Unusually high concentrations of radionuclides were observed in a duck collected from a reactor cooling water trench, but were not representative of concentrations in gamebirds available to the public, based on routine sampling near public hunting areas.

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EVALUATION OF RADIOLOGICAL CONDITIONS IN THE VICINITY OF HANFORD FOR 1969

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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 plant 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 1969, the plant facilities were operated for the Atomic Energy Commission by: Atlantic Richfield Hanford Company; Pacific Northwest Laboratories of Battelle Memorial Institute; Douglas United Nuclear, Incorporated; and ITT Federal Support Services, Incorporated.

The purpose of this annual report is to present an evaluation of the combined offsite effects of the radioactive effluents released to uncontrolled areas by all Hanford contractors during 1969. Analytical data on which this evaluation is based have been published as a separate report (BNWL-1505 APP).[2] The previous reports in this series were BNWL-1341 and BNWL-1341 APP.[3]

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

The term "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.

SUMMARY AND CONCLUSIONS

The Hanford environmental surveillance program for 1969 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 operations continued to be reactor cooling water discharged to the Columbia River.

Exceptionally high radionuclide concentrations were observed in one of two ducks collected at a trench receiving undiluted reactor cooling water within the Hanford boundaries. Immediate consumption of one-half pound of this duck would theoretically result in a radiation dose of 4.7 rem to the skeletal bone of a Standard Man (310% of the standard for individuals in the population). However, ducks found on swamps, trenches, and ponds within the boundaries are not considered to be representative of those available to members of the general population based on years of routine sampling nearer to public hunting areas.

As in the past, radiation doses were estimated for the bone, whole body, GI tract and thyroid of a hypothetical Maximum Individual and for the Average Richland Resident.[3,4,5,6] During 1969, radiation doses of Hanford origin were less than one-tenth of the appropriate dose standards and reflected a general decrease from comparable 1968 values for most organs. The gradual shutdown of Hanford facilities has contributed to the decrease in environmental doses over the past few years.

An individual with the unlikely but plausible combination of living and dietary habits postulated for the Maximum Individual probably would receive the largest radiation dose from radionuclides of Hanford origin. Such habits include:

- 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 municipal system.

During 1969, the Maximum Individual's bone dose from ingested radionuclides (mostly ^{32}P) and from shoreline exposure was estimated to be 9% of the standard (1500 mrem/yr) for individual members of the population. Doses to the whole body and GI tract from such sources were estimated to be 4% and 3%, respectively, of the appropriate standards.

For purposes of estimating thyroid dose, it is appropriate to consider an infant (2 gram thyroid). Dietary habits postulated for the Maximum Individual infant could have resulted in a thyroid dose of 4% of the standard (1500 mrem/yr) during 1969.

The Average Richland Resident(3,4) is defined as an adult for purposes of estimating bone, whole body, and GI tract doses and as an infant for estimating thyroid dose. The adult dietary habits of the Average Richland Resident have been determined from local dietary surveys.

Radiation doses received by this population group from Hanford sources originate, for the most part, from drinking water derived from the Columbia River. Radionuclide concentrations measured in the Richland municipal water supply were adjusted for radioactive decay and dilution in the water distribution system. For the adult, the GI tract dose is normally the largest percentage of appropriate dose standards for the mixture of radionuclides present in drinking water. During 1969, this dose was 4% of the standard (500 mrem/yr) for the general population. The thyroid dose to the Average Richland infant (2 gram thyroid) for 1969 was 5% of the appropriate standard (500 mrem/yr), including a contribution from short-lived radioiodines.

Estimated radiation doses to the above-defined residents resulting from the combined effects of Hanford contractor operations are summarized in Table 1 with the appropriate standards[7] listed for comparison.

TABLE 1. Summary of Radiation Doses[a] in the Hanford Environs - 1969

Organ	Annual Dose, mrem	Standard, mrem	% of Standard
Maximum Individual			
Bone	140	1500	9
Whole Body	18	500	4
GI Tract	40	1500	3
Thyroid (infant)	60	1500	4
Average Richland Resident			
Bone	15	500	3
Whole Body	4	170	2
GI Tract	19	500	4
Thyroid (infant)	23	500	5

a. *Doses from fallout and natural background not included.*

DOSE STANDARDS FOR EVALUATION

Radiation protection practices at Hanford, including radioactive waste disposal, are governed by the AEC Manual.[1] Chapters 0524 and RL-0524 provide the following standards for permissible radiation exposures in uncontrolled areas. The section of the Chapter 0524 Appendix to which this evaluation is addressed is as follows.

"TABLE 2. Radiation Protection Standards for External and Internal Exposure[7]

Type of Exposure	Annual Dose or Dose Commitment, rem: Based on Dose to Critical Individuals at Points of Maximum Probable Exposure	Based on an Average Dose to a Suitable Sample of the Exposed Population[a]
Whole body, gonads, or bone marrow	0.5	0.17
Other organs[b]	1.5	0.5

a. *See Par. 5.4, FRC Report No. 1, for discussion on concept of suitable sample of exposed population.*

b. *An acceptable alternate standard for bone for individuals is the ICRP standard of 0.003 μg of radium-226 or its biological equivalent. The alternate standard for populations would be one-third this ICRP standard.*"

As has been pointed out by the International Commission on Radiological Protection (ICRP),[8] it is not possible to determine precisely the radiation dose received by every individual because of variations in the kinds, quantities and sources of food and water consumed, variations in physiological characteristics with age and body size, 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 standards. The Federal Radiation Council (FRC) and the AEC have provided two sets of standards by which doses from environmental sources may be judged. One is for the greatest dose received by critical individuals and the other for the average dose received by the general population. (See Table 2.)

For the Hanford environs, doses from the various exposure pathways described in the following sections have been combined for comparisons with standards for both the individual and the general population. As in previous years, a hypothetical Maximum Individual has been assigned pessimistic dietary and other habits in order to estimate doses comparable to the standards for critical individuals in the preceding table. For thyroid dose considerations, the Maximum Individual has been assumed to be an infant.

For the general population, a dose has been estimated in recent years[3,4] for what is called the Average Richland Resident, using the best available information on dietary patterns. As in 1968, contributions from sources external to the body are included in the estimated doses for the GI tract, whole body, and bone. The thyroid dose estimate is for an infant who is assumed to have no exposure to external radiation of Hanford origin.

It is noted that the total dose received by a critical organ may result from three sources of exposure: (a) radionuclides deposited within that organ, (b) radionuclides elsewhere in the body, and (c) sources external to the body. However, for purposes of this analysis, the estimated dose to a critical organ from internal emitters does not include contributions from radionuclides deposited elsewhere in the body.

For thyroid dose calculations, the Federal Radiation Council has given specific guidance[9] for permissible daily ^{131}I 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, GI tract, and bone dose calculations, we have used ICRP values[10,11] for the several physiological parameters involved in translating intake to dose. Therefore, in 1969 all estimated organ doses were calculated in dose-equivalents and compared against the appropriate standards as defined in the AEC Manual.[7]

SITE DESCRIPTION

The Hanford site is in a semiarid region of southeastern Washington State (Figure 1) where the annual average rainfall is about 16 cm. This section of the state has a sparse covering of natural vegetation primarily suited for grazing, although large areas near the site 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 Hanford site 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 but 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 include Benton City, West Richland, Mesa, and Othello. The population of the communities near the plant, together with the surrounding agricultural area, is about 100,000.

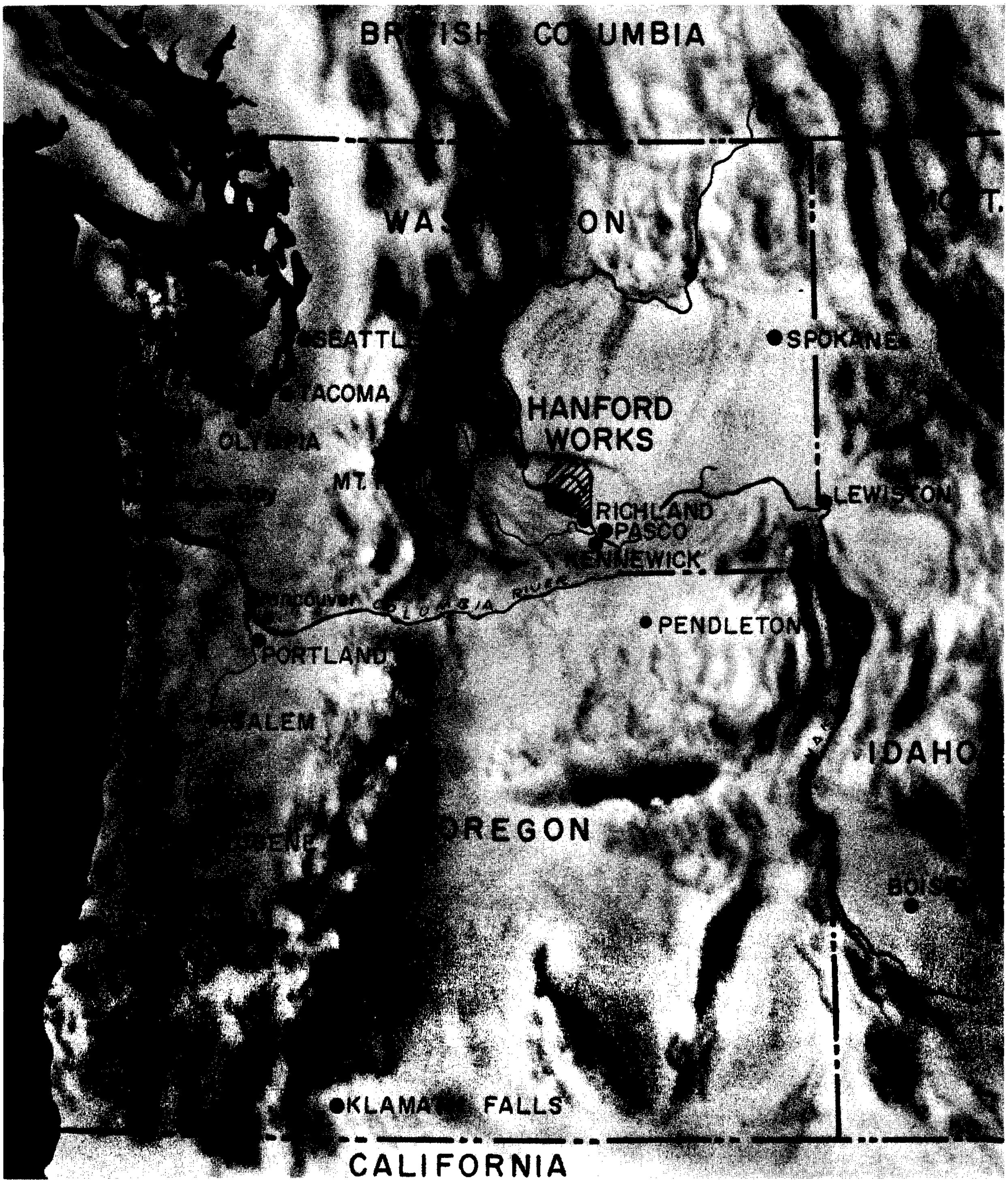

FIGURE 1. Geographical Relationship of Hanford to the Pacific Northwest

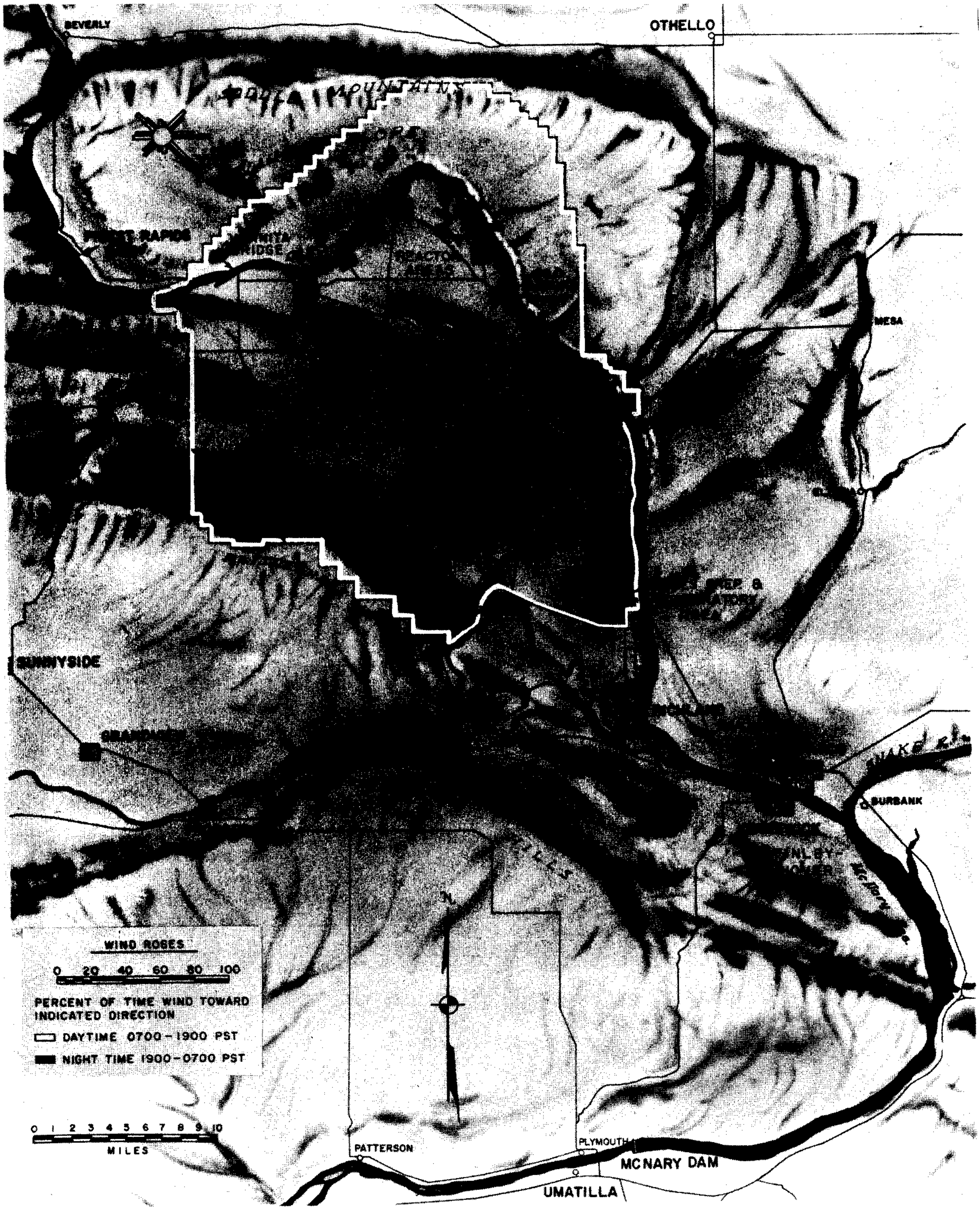

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FIGURE 2. Features of Hanford Project and Vicinity

SOURCES AND LEVELS OF ENVIRONMENTAL RADIOACTIVITY

Low-level wastes from Hanford 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: (1) the disposal of reactor cooling water to the Columbia River, (2) stack releases at the chemical separations areas and laboratory areas, and (3) 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 have contributed in past years to the thyroid doses of the local population, the major portion of the thyroid doses received in recent years has resulted from radioiodines in drinking water.

Noteworthy events during 1969 included the retirement in April of C Reactor, the sixth Hanford production reactor to be retired since 1964. Three plutonium production reactors (including the dual-purpose N reactor) remained in operation. Increased atmospheric total beta concentrations observed during June-August were attributed to an announced[12] foreign weapons test in December 1968.

In late December 1969, two ducks collected from a trench within the Hanford boundaries during routine surveillance were found to contain greater amounts of radioactivity than birds taken on the river. Exceptionally high concentrations of radioactivity (primarily ^{32}P) were noted in one of these two ducks. The trench receives reactor-associated liquid waste and the duck had probably frequented this site consuming algae.

The significance of this event is discussed on page 39. Action taken by the reactor-operating contractor to prevent recurrence was completed in the spring of 1970.

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. Waste water containing significant amounts of radioactive material is discharged to ground. 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 single pass reactors (C, KE, and KW).

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 3 shows the relative abundance of the radionuclides found in the cooling water of the older production reactors, adjusted to 4 hours after leaving the reactor.

Many of the radionuclides formed in reactor cooling water are shortlived 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 (during passage through the reactors) of natural uranium present in the river water, because of occasional fuel element cladding failures, and because of fallout from nuclear weapons testing.

TABLE 3. 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 made in 1964 and 1968*

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

Some radionuclides probably also enter the river from wastes disposed to ground, but their contribution to the total radioactivity in the river is not detectable. (See Radioactivity in Groundwater, page 26.)

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 associated with the sediments. This is notably true for ^{46}Sc and ^{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.

Figure 3 shows the weekly average flow rates of the Columbia River at Priest Rapids and Bonneville Dams determined from daily average flow rates published by the U.S. Geological Survey.(13) For 1969, the average river flow rate at Priest Rapids was 3830 m^3/sec (135,000 ft^3/sec) which was slightly above the 1948-1962 annual average of 3770 m^3/sec (133,000 ft^3/sec).

River Concentrations

During 1969, samples of river water were collected at Priest Rapids Dam upstream from the production reactors and below the reactors 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, prevents evaluation of the concentrations of

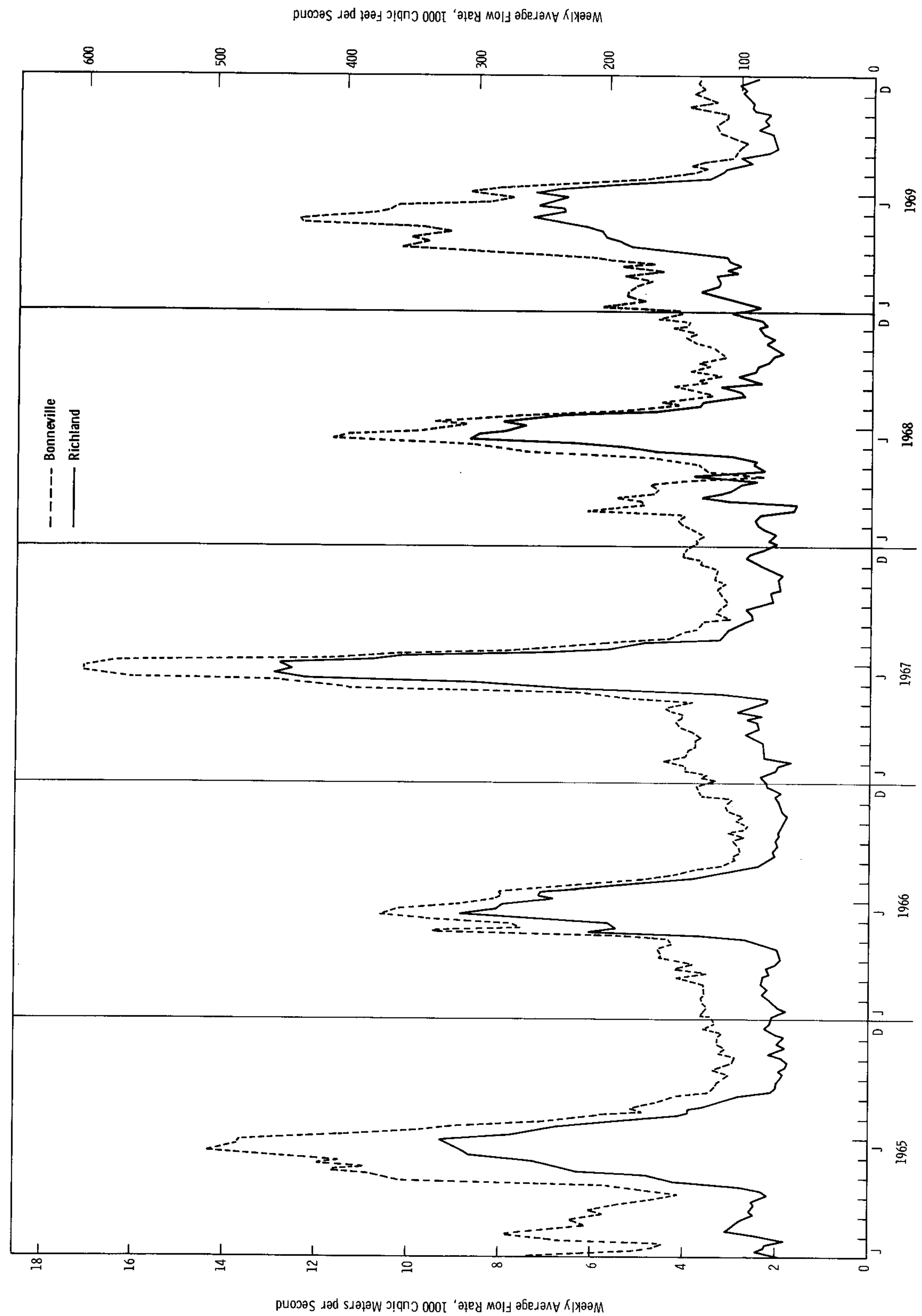

FIGURE 3. Weekly Average Flow Rate of the Columbia River at Richland and Bonneville Dams, 1965-1969

radionuclides with very short half-lives; the more prevalent of these radionuclides (RE + Y, ^{24}Na, ^{56}Mn, ^{64}Cu, ^{76}As, ^{122}Sb, and ^{239}Np) were measured in monthly "grab" samples. Detailed measurements are reported in the Appendices.(2)

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 just below Richland and of the Snake River just below Pasco 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.

Table 4 shows the annual average radionuclide concentrations in river water at Richland and at Bonneville Dam for 1966-1969. The data for 1966 reflect the effects of reactor outages during the July-August strike. Comparison of 1969 with 1968 concentrations indicates a general reduction for most radionuclides. The concentrations of several radionuclides, however, increased during 1969: ^{64}Cu concentrations increased slightly, while the RE + Y group (defined in Table 3) and ^{56}Mn showed significant increases. As in past years, total alpha concentrations measured in river water at Richland were near the analytical limit of 1 pCi/liter and were not significantly different from those measured in samples collected upstream from the Hanford plant.

Bonneville Dam, approximately 490 km (240 miles) below the Hanford reactors, is the farthest downstream location where river water is routinely sampled as part of the Hanford environmental surveillance program. Measurements at this location provide an upper limit to the annual transport of specific nuclides into the Pacific Ocean (Table 5).

TABLE 4. Annual Average Concentrations of Several Radionuclides in Columbia River Water, 1966-1969 (pCi/liter)

	1966		1967		1968		1969	
Radionuclide	Richland	Bonneville Dam	Richland	Bonneville Dam	Richland	Bonneville Dam	Richland	Bonneville Dam
RE + Y[a]	270	- [b]	390	-	290	-	750	-
^{3}H	-	-	1500	-	1700	-	1900	-
^{24}Na	2600	-	2600	-	2200	-	1600	-
^{32}P	140	23	190	25	92	15	73	14
^{46}Sc	30	-	60	18	100	20	72	-
^{51}Cr	3600	1300	3200	1400	1500	530	720	240
^{56}Mn	290	-	520	-	250	-	1000	-
^{64}Cu	1400	-	2000	-	1200	-	1700	-
^{65}Zn	200	43	220	62	86	<30	72	25
^{76}As	420	-	400	-	320	-	310	-
^{90}Sr	1	-	1	-	<0.6	-	<0.5	-
^{95}Zr-Nb	-	-	-	<5.0	<6.3	-	<3.8	-
^{99}Tc	-	-	<5.0	-	<11.	-	<4.3	-
^{106}Ru	-	-	-	<5.0	<5.0	-	<4.3	-
^{122}Sb	-	-	150	-	150	-	90	-
^{131}I	18	3	8	3	7.4	<3.2	4.0	-
^{239}Np	770	-	1100	-	1000	-	1100	-
Total Alpha	<1.3	-	<1.2	-	<1.3	-	<1.0	-

a. *See Table 2 for definition.*

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

Transport Rates

Figure 4 shows the river transport rates of several radionuclides past Richland. The transport rates at Richland in 1969 for the five radionuclides shown were, for the most part, lower than the 1968 values, except for ^{32}P and ^{65}Zn which were comparable with the 1968 values. Table 5 shows the annual average transport rates of selected radionuclides past Bonneville Dam. More detailed measurements are presented in the Appendices.(2)

TABLE 5. Annual Average Transport Rate of Selected Radionuclides Past Bonneville Dam, 1965-1969 (Ci/day)

Radionuclide	1965	1966	1967	1968	1969
^{32}P	11	9	12	6.2	7.1
^{46}Sc	-	-	10	7.5	-
^{51}Cr	800	430	610	200	100
^{65}Zn	49	21	40	<13	<15

Note: The (-) indicates no routine analysis was made.

Trend Indicator - Whitefish

The Columbia River is popular for sports fishing both above and below the Hanford reservation. Fish feeding downstream from the reactors acquire, for the most part through food chains, some radionuclides originating with reactor effluent. ^{32}P is the most significant nuclide with regard to population doses. Changes in river concentrations and temperatures may induce changes in concentrations in biological media. However, the ultimate uptake of radionuclides depends on complex environmental interrelationships. Whitefish are the sports fish that usually contain the greatest concentrations of radioactive materials. Furthermore, they can be caught during winter

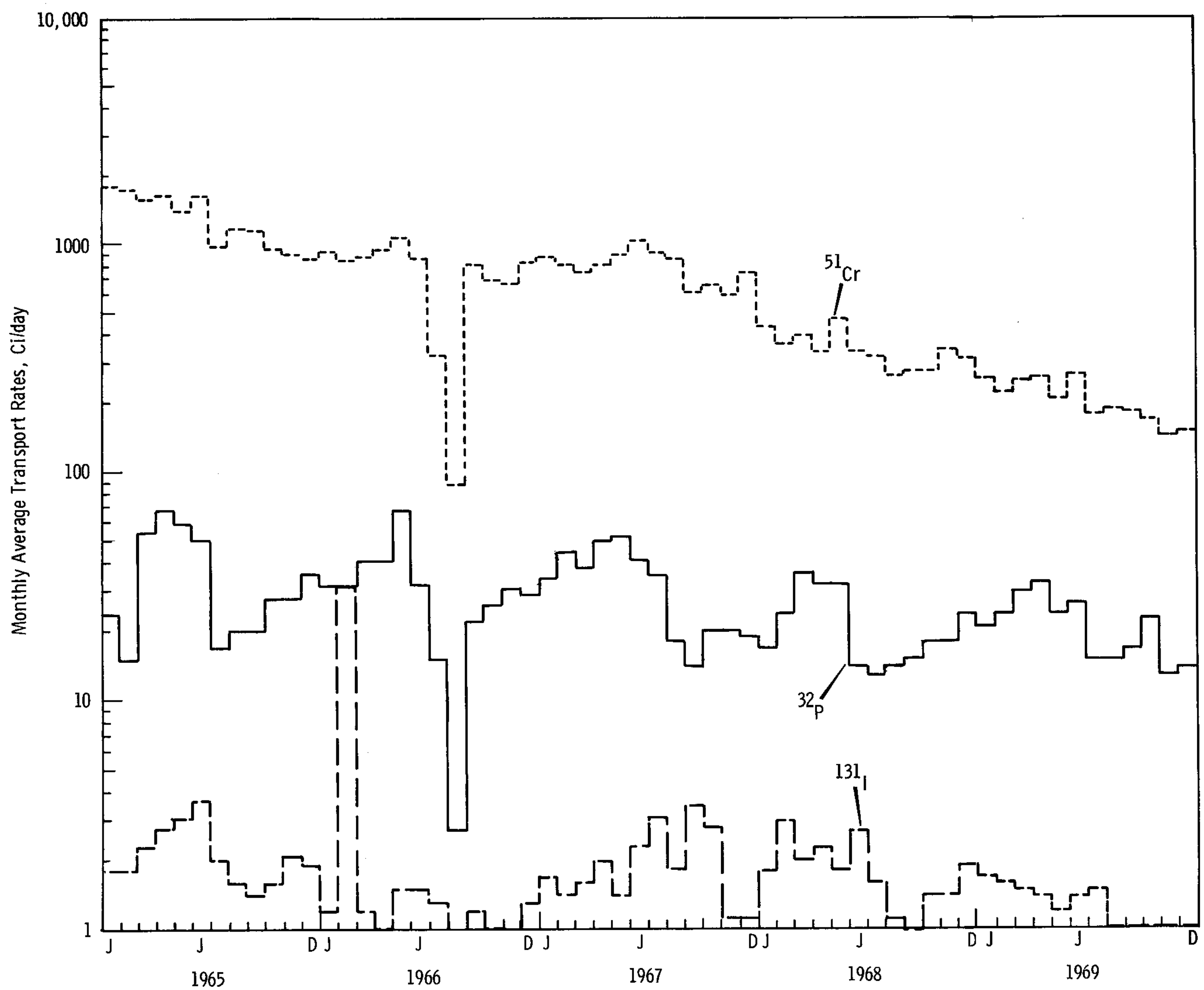

FIGURE 4a. ^{32}P, ^{51}Cr, and ^{131}I Transport Rates in the Columbia River at Richland, 1965-1969 (Ci/day)

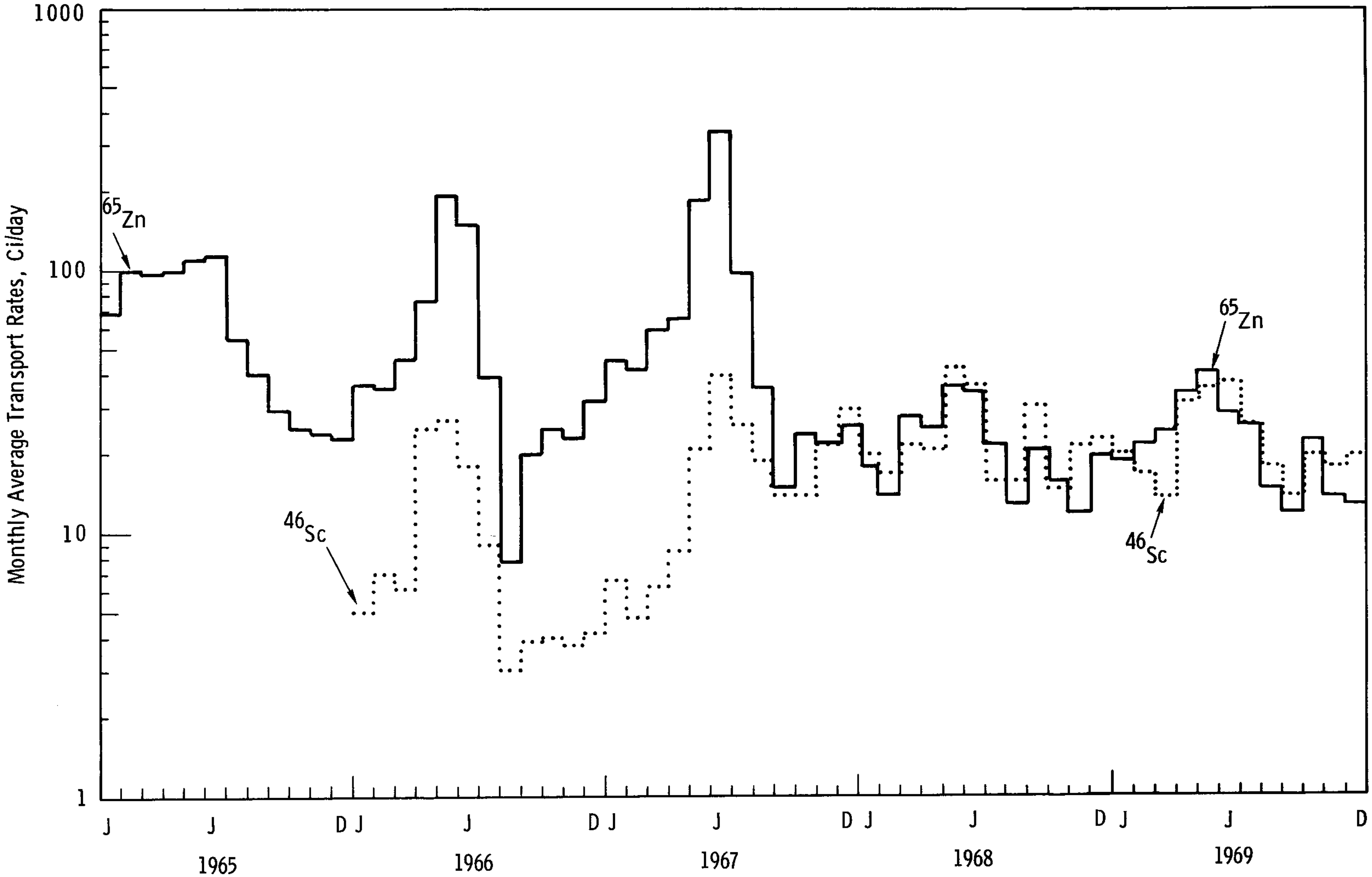

FIGURE 4b. ^{46}Sc and ^{65}Zn Transport Rates in the Columbia River at Richland, 1965-1969 (Ci/day)

months when other sports fish are difficult to sample. Therefore, ^{32}P data accumulated from whitefish sampling near the plant boundary (Figure 5) are useful as a long-term trend indicator of concentrations in biological media, even though whitefish are not the most significant source of radionuclides for the local population.

Concentrations of ^{32}P in whitefish during 1969 tended to follow the same seasonal trends observed in past years. But the average ^{32}P concentration in 1969 was much lower than expected based upon ^{32}P concentrations and river temperatures. The average concentration of ^{32}P in whitefish sampled downstream from the reactors during 1969 was 34 pCi/g as compared with 140 pCi ^{32}P/g during 1968.(3)

RADIOACTIVITY IN THE ATMOSPHERE

At Hanford, gaseous wastes from the chemical separations facilities are released to the atmosphere through tall stacks after most of the radioactive materials have been removed. Laboratory stacks, reactor-building stacks, and stacks from waste storage facilities release relatively minor amounts of radioactive materials under normal operating conditions. Figure 6 shows the locations of offsite air sampling stations.

Measurements of airborne ^{131}I, the radionuclide of primary interest, were made (as of the end of 1969) at 25 locations within and near the Hanford reservation. The sampling equipment draws air at a flow rate of 2.5 m^3/hr (1.5 ft^3/min) through HV-70 filter paper and then through a solution of NaOH for radioiodine collection. Figure 7 shows the data from offsite air samples from nearby locations in the direction of the prevailing wind (Southeast Quadrant). The results of ^{131}I measurements for four selected locations for the past few years, which include contributions from offsite weapons tests, are summarized in Table 6, with a more detailed tabulation in the

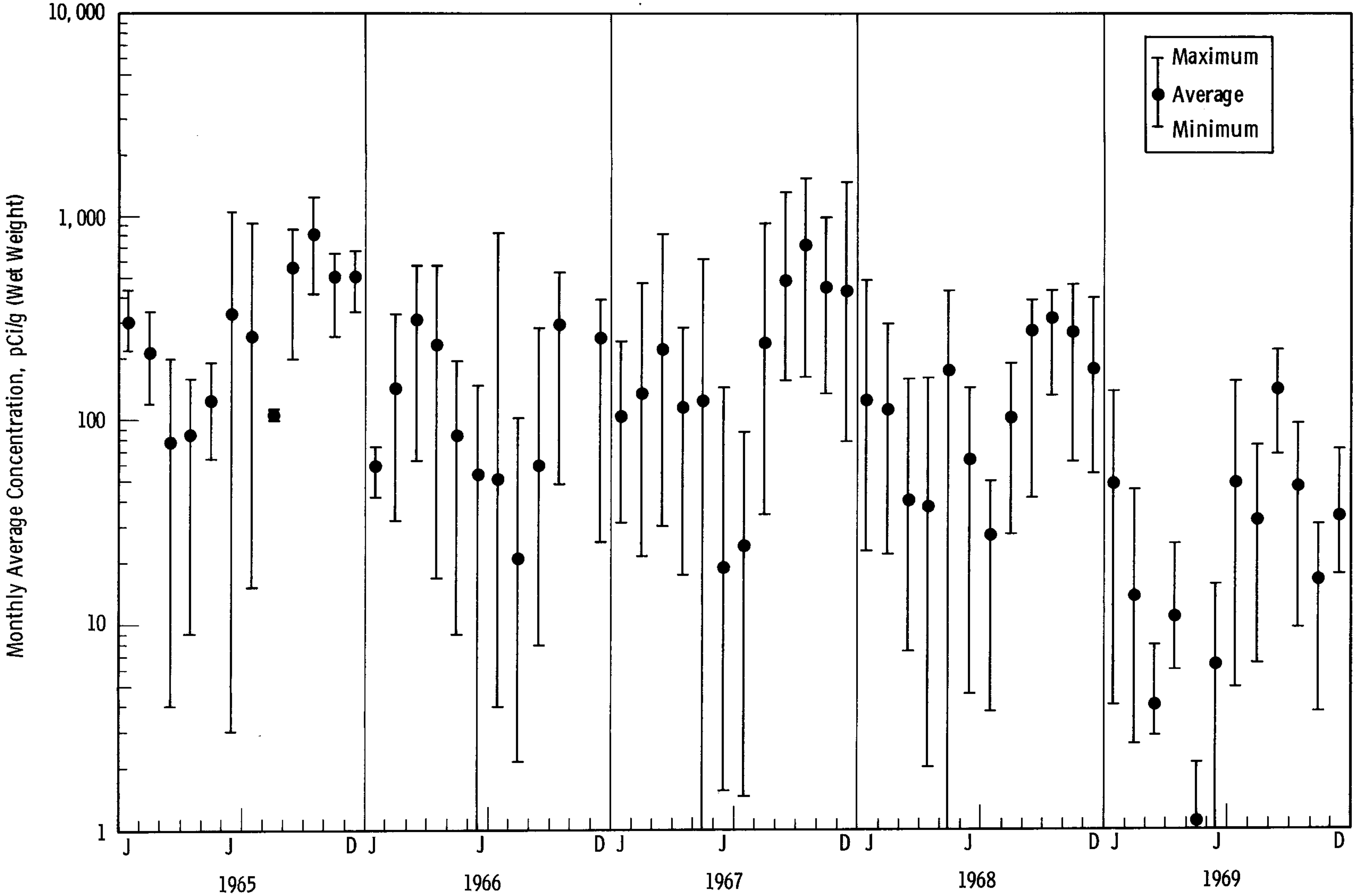

FIGURE 5. Monthly Average ^{32}P Concentrations in Flesh of Whitefish Caught in the Columbia River Between Ringold and Richland, 1965-1969 (pCi/g, wet weight)

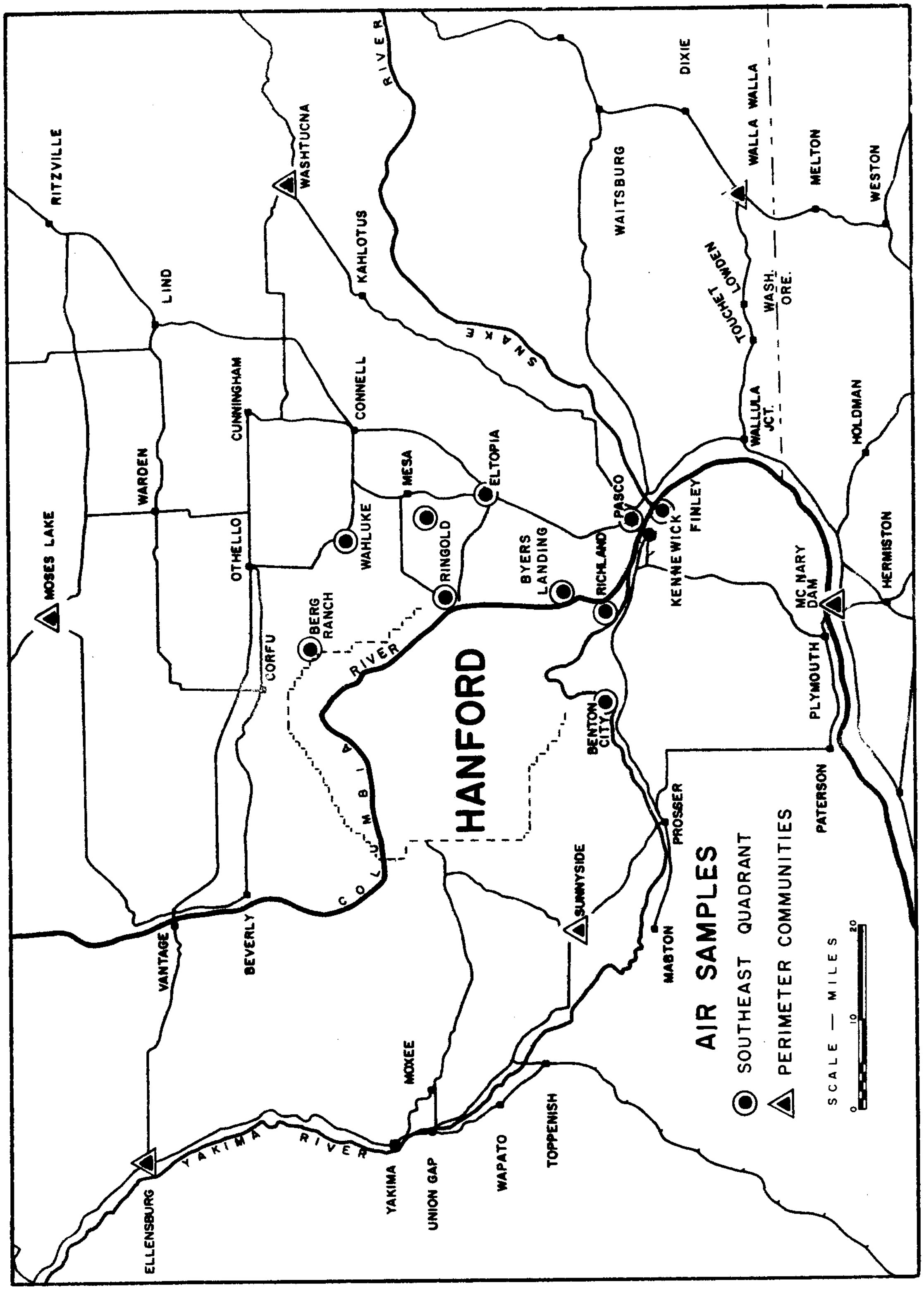

FIGURE 6. Offsite Air Sampling Locations

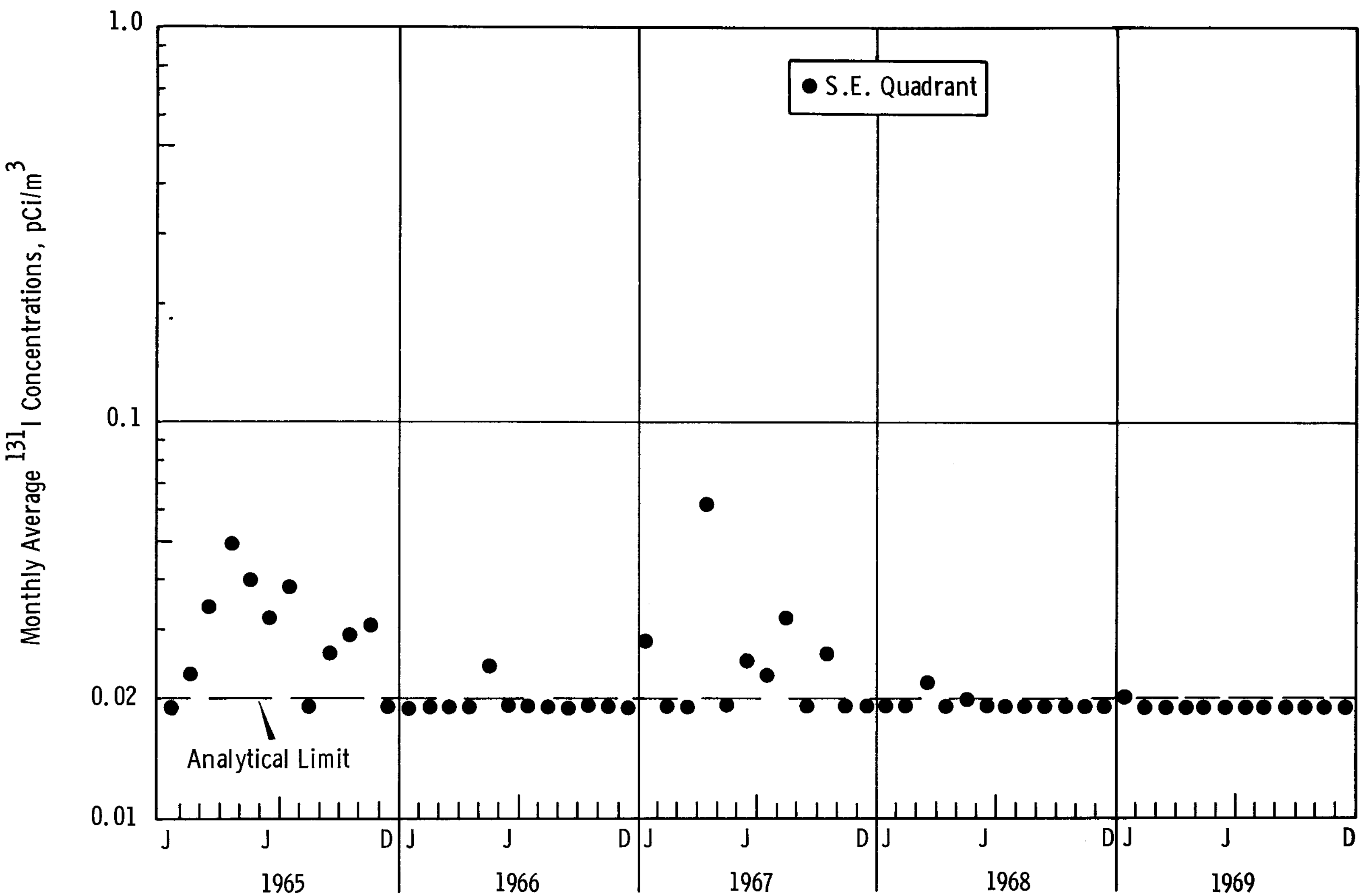

FIGURE 7. Monthly Average ^{131}I Concentrations in the Air of Hanford Environs, 1965-1969 (pCi/m^3)

Appendices.[2] The locations listed in Table 6 lie within a 90° sector southeast of the separations areas, and were selected according to prevailing wind directions and population center. The annual average ^{131}I concentrations for 1969 averaged 0.01 pCi/m^3 at Richland and Pasco. The annual thyroid dose from inhalation of ^{131}I at 0.01 pCi/m^3 for the 2 gram thyroid would be less than 1 mrem* based on appropriate metabolic parameters,[14] and assuming that the fractional uptake from inhalation is invariant with age.

TABLE 6. Annual Average ^{131}I Concentrations[a] in the Atmosphere, 1965-1969 (pCi/m^3)

Location	Distance from Separation Stacks, km	1965	1966	1967	1968	1969
Ringold	21	-	-	0.02[b]	0.02	0.02
Benton City	32	0.03	0.01	0.02	0.01	0.01
Richland	32	0.02	0.01	0.02	0.02	0.01
Pasco	51	0.03	0.01	0.02	0.02	0.01

a. *Concentration Guide (AEC Manual Chapter 0524,[7] Annex A, Table II, Column 1) - 100 pCi/m^3, for an individual infant in an uncontrolled area, assuming a 2 gram thyroid and a daily intake of 3×10^6 ml of air.*

b. *Air sampling at Ringold began in January 1967.*

Continuous sampling for radioactivity associated with airborne particulates was maintained as of the end of 1969 at 34 locations, including those within the Hanford reservation and around the plant perimeter at distances up to 120 kilometers (75 miles). The gross beta activity of each sample filter after

* *A sustained concentration of ^{131}I at this level in breathing air would imply an annual radiation dose to the thyroid of the Standard Man[9] that would also be less than 1 mrem.*

exposure was routinely measured (based on ^{90}Sr-Y calibration), with detailed radioanalyses performed on filters showing unusual beta activity.

Figure 8 shows average total beta concentrations for the group of samples collected from the Southeast Quadrant and from other more distant locations (Perimeter Communities), with a complete tabulation in the Appendices.(2) The higher atmospheric concentrations of radioactive particulate material during June-August of 1969 compared to the early part of the year were attributed primarily to fallout following a foreign nuclear weapons test in late December 1968. The principal gamma emitters found on filters during June-August were ^{95}Zr-Nb, ^{144}Ce-Pr, and ^{106}Ru-Rh. The concentrations were comparable to those observed during similar events of recent years.

RADIOACTIVITY IN GROUNDWATER

Radioactivity in the groundwater beneath the Hanford project results primarily from ground disposal of wastes in 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 meters. 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.

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* *High-level:* >100 μCi/ml

** *Intermediate-level:* 50 pCi/ml to 100 μCi/ml

† *Low-level:* <50 pCi/ml

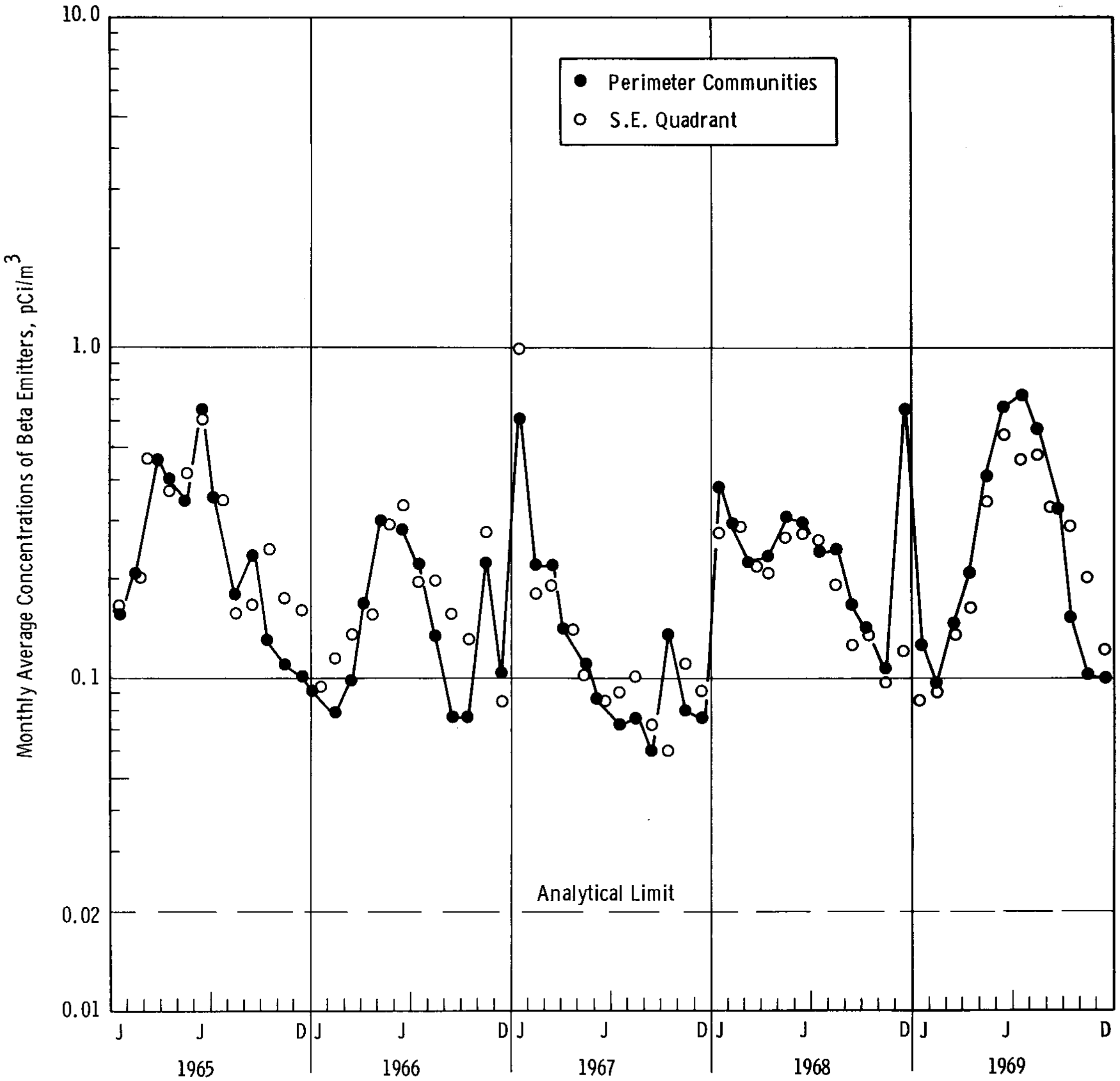

FIGURE 8. Monthly Average Particulate Total Beta Concentrations in the Air of Hanford Environs, 1965-1969 (pCi/m^3)

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. An extensive groundwater surveillance program is maintained at Hanford to aid in achieving this objective. 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.

The radioactivity in groundwater from the chemical separations areas outside the immediate vicinity of the 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, such as ^{90}Sr, have not been detected in groundwater except in the immediate vicinity of a few specific disposal sites.

Figures 9 and 10* show the probable extent of detectable ^{3}H and ^{106}Ru-Rh in groundwater beneath the Hanford project as of December 31, 1969.[15] The outer boundary of the contamination contours, i.e., 0.03% CG** for ^{3}H and 2% CG for ^{106}Ru-Rh, represent the detection levels routinely achievable for those radionuclides.

It is possible that 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 to people from them is negligible.

* *The legend on Figure 10 should have appeared on Figure 10 in the 1968 annual report.*[3]

** *The Concentration Guide (CG) used herein applies to critical individuals in uncontrolled areas as defined in AEC Manual Chapter 0524.*[7]

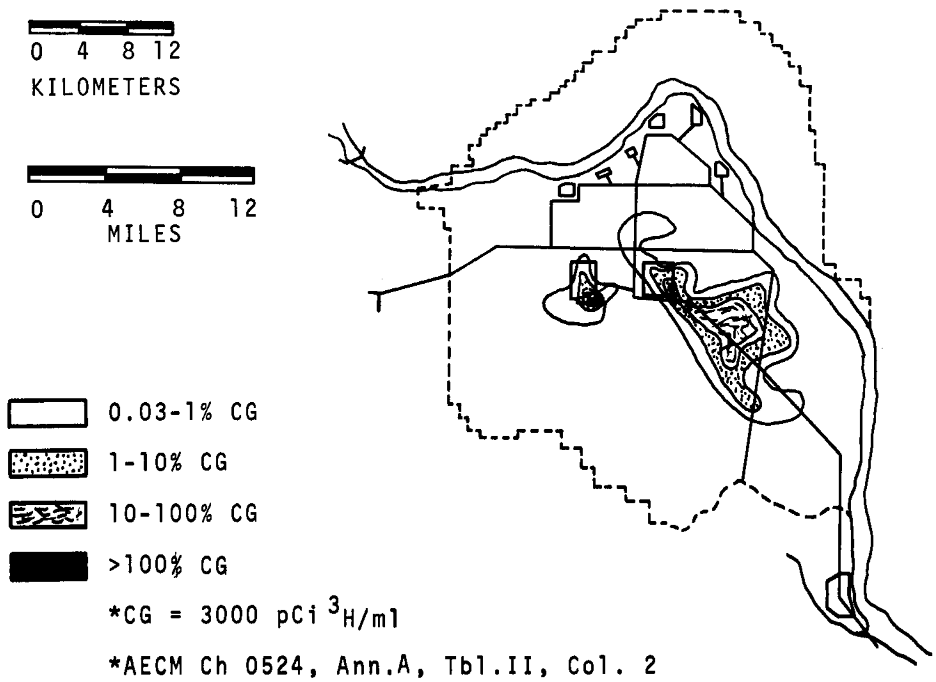

FIGURE 9. ^{3}H Concentrations in Groundwater - July-December, 1969

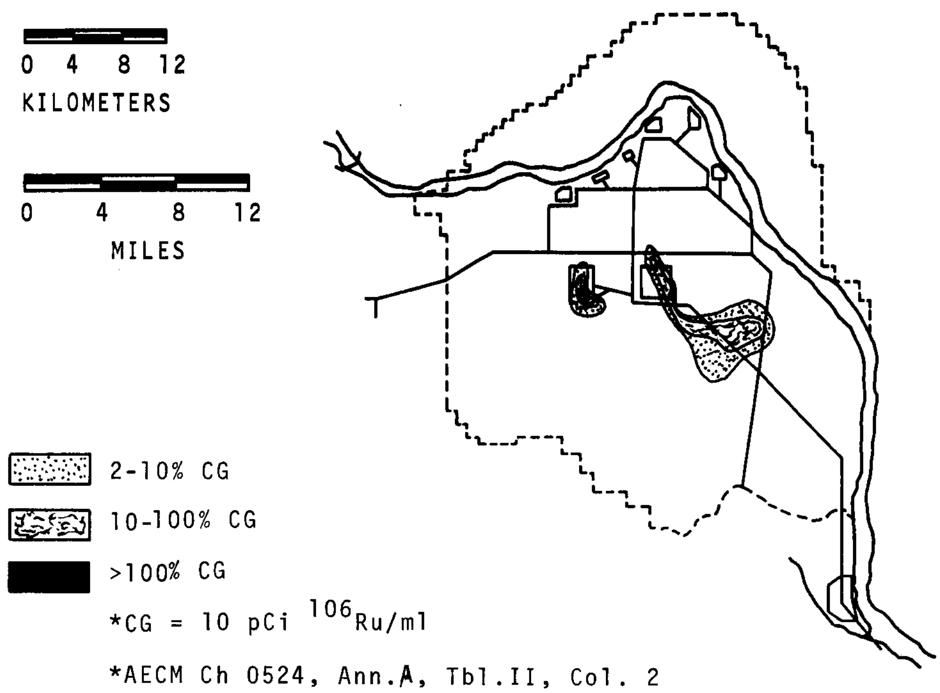

FIGURE 10. ^{106}Ru Concentrations in Groundwater - July-December, 1969

FALLOUT FROM NUCLEAR WEAPONS TESTS

Airborne fallout was detected during most of the spring and summer of 1969. Increases were attributed to the announced foreign nuclear weapons test on December 27, 1968.[12] Total beta concentrations in the atmosphere (Figure 8) began increasing in March and reached a peak of about 1 pCi/m^3 in June and again in late July-early August. ^{131}I concentrations in the atmosphere (Figure 7) remained at or below the analytical limit (0.02 pCi/m^3). Slightly increased concentrations of ^{131}I in milk during March (maximum 8 pCi/liter) were not attributed to this test because of the long time lag.

No significant contribution to atmospheric radiation levels was detected following the announced[16] foreign nuclear weapons tests of September 22 and 29, 1969.

Routine measurements in foods of the fallout nuclides ^{131}I, ^{90}Sr, and ^{137}Cs are discussed in the section on Exposure Pathways, page 31.

Concentrations of ^{3}H in river water are measured upstream from Hanford at Priest Rapids Dam (where fallout would be the only source of ^{3}H) and downstream from Hanford at Richland. The average concentration of ^{3}H at both Priest Rapids Dam and Richland in 1969 was 1.9 nCi/liter, which was slightly higher than the concentrations measured at these locations during 1968 (1.6 and 1.7 nCi/liter, respectively).

EXPOSURE PATHWAYS

RADIONUCLIDES IN DRINKING WATER

The city of Richland, about 75 km (47 miles) downstream from the Hanford reactors, is the first community below the project 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 method; water for Kennewick is pumped from Ranney well collectors (infiltration pipes) laid in the riverbank. During 1969, cumulative drinking water samples were collected at the Richland and Pasco water plants, and periodic grab samples were collected at all three communities. The Richland and Pasco samples were analyzed for selected individual radionuclides and gross beta activity (Table 7). Routine sampling at Kennewick was discontinued in June because of the low gross beta radioactivity (average 0.5 counts/min/ml). Previous experience has shown that concentrations of radionuclides in Kennewick drinking water are significantly lower than at Pasco or Richland. Analyses of drinking water from these three cities are given in the Appendices.[2]

The concentrations of short-lived radionuclides in the water at the time it is consumed are less than shown in Table 7 because there can be 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 times of the year when well water is used to supplement the system supply.

TABLE 7. Average Concentrations[a] of Several Radionuclides in Drinking Water - 1969 (pCi/liter)

Radionuclide	Richland	Pasco
RE + Y[b]	50	24
^{24}Na	1200	350
^{32}P	35	23
^{46}Sc[c]	24	37
^{51}Cr	660	600
^{64}Cu[c]	350	69
^{65}Zn[d]	34	30
^{76}As	99	38
^{122}Sb	56	43
^{131}I[d]	3.4	3.3
^{133}I	20[e]	13[f]
^{239}Np	450	250
Total Beta (counts/min/ml)	2.0	1.2

a. *Measured at the water plants*

b. *See Table 3 for definition.*

c. *January-June average*

d. *Results based on cumulative samples*

e. *Estimate based on an average ratio of* $^{133}I/^{131}I$ *of 6:1 measured in grab samples in 1969*

f. *Estimate based on an average ratio of* $^{133}I/^{131}I$ *of 4:1 measured in grab samples in 1968*

Table 8 presents calculated doses to the adult bone, whole body, and GI tract from consumption at an intake rate of 1.86 liters/day,* and to the infant 2 gram thyroid from consumption of 0.4 liters/day of drinking water in Richland and Pasco. Annual average concentrations of radionuclides measured at the water plants were used to calculate the doses to bone, whole body, and thyroid. The correlation between the GI tract dose rate at the water plant (established by direct measurement of individual radionuclide concentrations) and the gross beta activity was determined monthly. The correlation used in conjunction with thrice-weekly measurements of gross beta activity at the water plant provided the basis for estimation of the GI tract dose.

TABLE 8. Calculated Annual Doses to Selected Organs from Routine Ingestion of Drinking Water - 1969 (mrem)

	Adult (1.86 liters/day)			Infant (0.4 liters/day)
	Bone	Whole Body	GI Tract	Thyroid
Richland	5	1.8	17	24
Pasco	3	0.7	14	18

The dose estimates for Pasco residents reflect a continued downward trend from previous years. The thyroid dose for 1969 from Pasco drinking water (18 mrem) was significantly less than that for 1968 (32 mrem) because of decreased radioiodine concentrations. The average ratio for $^{133}I/^{131}I$ of 4:1 for Pasco was based on 1968 measurements on grab samples because the extremely low concentrations of both radionuclides observed in grab samples during 1969 prevented direct measurement of the ratio.

* *In previous years, an intake rate of 1.2 liters/day based on Standard Man was assumed. The revised intake rate (1.86 liters/day) is used for estimating doses received by the Average Richland (adult) Resident, based on local dietary surveys.*

The estimated GI-tract dose to Richland residents from the measured radionuclides in drinking water was somewhat lower in 1969 (11 mrem) than in 1968 (28 mrem). This resulted from the generally decreased concentrations of most measured radionuclides, as well as from the use of well water for over 99% of the city water supply in January when the water filter plant was temporarily shut down. Well water contributed between 4% and 61% of the total supply in other months. However, radionuclide concentrations measured at the water plant (not adjusted for radioactive decay or dilution in the water distribution system) were used for the dose estimates shown in Table 8 and Figure 12 to facilitate comparison with Pasco estimates and data. The infant thyroid dose during 1969 was about one-half that during 1968[3] because of the decreased concentrations of radioiodines.

Figure 11 shows the relative contribution of several radionuclides in the Richland drinking water to the calculated annual dose to the GI tract, and Figure 12 shows long-term trends in the GI tract dose from Pasco and Richland drinking water.

RADIONUCLIDES IN COLUMBIA RIVER FISH

The quantities and kinds of fish caught by local fishermen have been estimated previously from surveys carried out from 1961 to 1965 in cooperation with the Washington State Game Department. The maximum estimate of consumption by the fishermen interviewed was 200 meals per year of panfish species (crappie, bass, and perch) taken from the Columbia River. Additional dietary data[17] collected during 1966 and 1967 from household questionnaires and interviews also showed individual consumption estimates as high as 200 meals of fish per year. 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 annual consumption by species was 73% crappie, 16% bass, and 11% perch. Based on

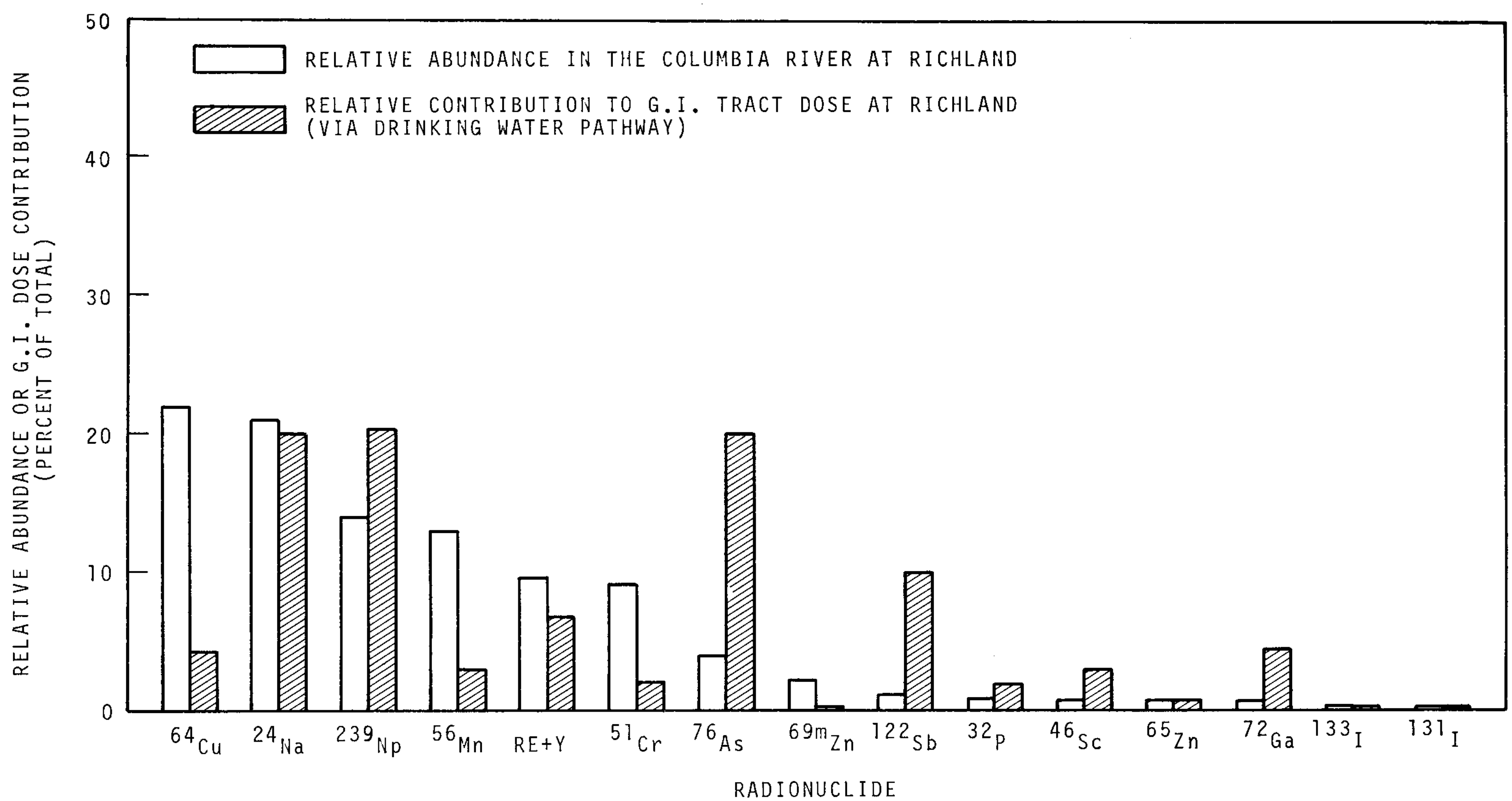

FIGURE 11. Relative Contribution of Various Radionuclides in Richland Drinking Water to the GI Tract Dose for 1969

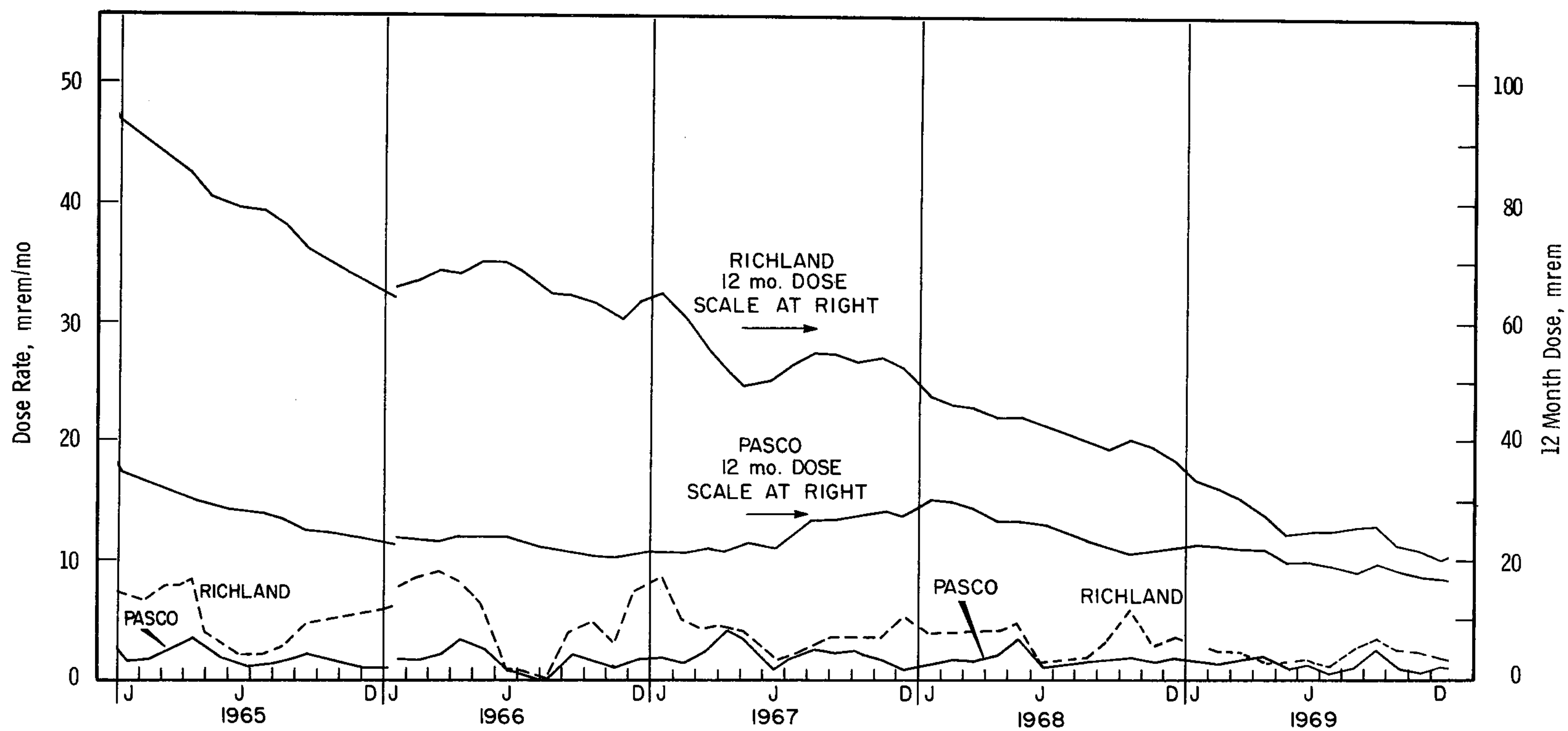

FIGURE 12. Doses to the GI Tract from Richland and Pasco Drinking Water, 1965-1969 (1.86 liter/day intake rate)

data collected during 1969, the average concentration of ^{32}P in such a mixture of panfish was about 12 pCi/g, and that of ^{65}Zn was 5.5 pCi/g.

From this species distribution and radiochemical analyses of the specimens collected,(2) the Maximum Individual's estimated intakes during 1969 were 0.47 μCi ^{32}P and 0.22 μCi ^{65}Zn which are about one-half the corresponding intakes during 1968.

The average consumption of Columbia River fish by Richland residents was estimated from diet questionnaires(4) completed by Hanford plant employees. With the use of the mixture of species as for the Maximum Individual, the Average Richland Resident's intake during 1968 was 0.006 μCi ^{32}P and 0.003 μCi ^{65}Zn. These intakes correspond to a bone dose of about 1 mrem or about 0.2% of the standard of 500 mrem per year for the population average. For comparison, intakes during 1968 were 0.012 μCi ^{32}P and 0.004 μCi ^{65}Zn.

RADIONUCLIDES IN GAMEBIRDS

Waterfowl and other gamebirds utilizing the river downstream from the reactors or open low-level waste disposal sites within the plant boundaries may contain ^{32}P, ^{65}Zn, and other radionuclides as a result of ingestion of insects, algae, vegetation, and water containing these radionuclides, and could be a significant exposure pathway for persons who consume such birds. Some waterfowl remain in this general area throughout the year. The concentrations of radionuclides in game birds at the time of consumption are dependent upon the bird species, the geographical locations of the birds, their current feeding habits, and the elapsed time between killing and consumption of the birds.

For the past three years, about 16 km^2 (4000 acres) of the Hanford reservation north of Ringold on the eastern side of the Columbia River have been opened to hunters during the hunting season. This area, which is adjacent to the river, was visited in 1969 by an estimated 3,050 hunters for an average of about 63 hunters on each of the 48 open days. The U.S. Fish and Wildlife Service has estimated that 3,400 waterfowl, 50 pheasants, 45 quail, and 20 chukar were harvested.(18) For comparison, the average number of hunters for 1968 was about 33 on each of the 46 open days with a harvest of 1,037 waterfowl, 16 pheasant, 75 quail, and 3 chukar.(19)

The average of the monthly average concentrations of ^{32}P in the muscle (the edible portion) of waterfowl collected on the river within the Hanford project for the environmental monitoring program during hunting seasons in 1969 was 72 pCi/g for 46 ducks and 3.6 pCi/g for 12 geese. The maximum concentration in such waterfowl during 1969 was 510 pCi ^{32}P/g, which is not significantly different from the maximum observed in 1968 for birds collected in the same area.

In addition to the birds collected on the river, nine waterfowl were sampled from swamps and a trench within the plant boundaries. Seven of the samples were collected from swamps receiving low-level liquid wastes near the chemical separations areas. The muscle of these birds contained on the average 34 pCi ^{32}P/g and <1 pCi ^{65}Zn/g. The predominant radionuclide in birds utilizing these swamps, ^{137}Cs, was detected in concentrations ranging from 70 to 420 pCi/g and averaging 300 pCi/g. For comparison, ^{137}Cs was detected in the muscle of only one waterfowl collected on the river, with a concentration of 1.4 pCi/g which was considerably below the typical range of concentrations observed in muscle of waterfowl collected from swamps near the chemical separations areas. If an adult had consumed one-half pound of the bird containing the maximum ^{137}Cs concentration found in muscle from birds collected on the Hanford swamps during 1969, the resulting estimated radiation doses would be 8 mrem for the skeletal bone and 6 mrem for the whole body, about 1% of the appropriate standards for individual members of the public.

Near the 100-K reactor area, two waterfowl were collected in late December on a trench utilized for the temporary retention of reactor cooling water. As expected, the same radionuclides were found in these ducks as were normally found in birds collected on the river. However, because the sources of radioactivity for birds collected from the trench were derived from undiluted reactor cooling water rather than water diluted by the Columbia River, concentrations significantly higher than in river birds were possible. The predominant radionuclide in the muscle of these two birds, ^{32}P, was found at 0.003 and 0.110 μCi/g. Immediate consumption of one-half pound of the latter duck (ingestion of a little less than 25 μCi of ^{32}P) would result in a radiation dose of 4.7 rem to the skeletal bone of a Standard Man.[10] However, the consumption of such a bird by any member of the public is considered to be unlikely in view of the fact that very few birds (out of over 200,000 in the area) would be likely to spend sufficient time on the trenches near the reactor areas to accumulate such large amounts of radioactive materials. Any delays between the time a bird left a trench to the time of shooting or resulting from the frequent practice of freezing gamebirds for later consumption would permit radioactive decay and would further reduce the probability of consuming flesh containing the high concentrations of ^{32}P. For example, in the case we have considered here, a delay of 4 weeks would have reduced the skeletal bone dose to less than 1500 mrem (the annual standard). As in past years, it is our judgment that ducks collected on swamps, trenches, or ponds are not representative of those available to the general population and that dose estimates derived therefrom are not pertinent for comparison with the established dose standards. Action taken by the reactor-operating contractor to prevent recurrence consisted of screening and partially filling the trenches in the two operating reactor areas. This work to prevent access to the water surfaces was completed in the spring of 1970.

Average concentrations in muscle for upland game birds collected at the Hanford site appear in Table 9. The maximum ^{32}P concentration in upland game bird muscle was 340 pCi/g in a pheasant sample. For comparison, the maximum ^{32}P concentration in similar samples in 1968 was 490 pCi/g in a quail sample.

Data from a dietary survey of Hanford employees(4) and from a special survey of local hunters,(20) and concentration data for the various species(2) have been combined in Tables 10 and 11. 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. Past analyses have shown that pheasants collected beyond this distance contain little, if any, radioactivity of Hanford origin. About 44% of all birds eaten were reported to have been placed in frozen storage, which would permit appreciable decay of any ^{32}P before consumption.

TABLE 9. Average ^{32}P and ^{65}Zn Concentrations in Muscle of River Birds,[a] 1969 (pCi/g)

Species	^{32}P	^{65}Zn
Duck	72	5.1
Goose	3.6	8.3
Quail	19	2.0
Pheasant	18	2.7
Chukar[b]	5	3.1

a. Waterfowl collected on the Columbia River and other birds collected within 5 km (3 miles) of the river within the Hanford boundary.

b. Estimate based on past data and comparison with quail.

TABLE 10. Species Distribution of Local Game Birds

	Duck, %	Goose, %	Quail, %	Pheasant, %	Grouse, %	Dove, %
River Birds[a] 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[a] Meals of Each Species of All Bird Meals	8.5	1.8	2.3	16	<1	No data

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

TABLE 11. Contribution[a] of Each Species to 100 Grams of an Average Game Bird Meal, 1969

Species	Weight, g	Radionuclide Content, pCi ^{32}P	^{65}Zn
Duck	23	344	43
Goose	6	4	16
Quail	12	25	5
Pheasant	47	156	42
Grouse	13	3	3
TOTAL	100	503	110

a. *Weighted for location of kill by using measured concentrations for river birds and assuming no ^{32}P or ^{65}Zn in other birds. Also weighted for frozen storage by assuming complete decay of ^{32}P, but no significant decay of ^{65}Zn during frozen storage of 44% of the birds.*

The maximum total game bird consumption by adults reported to date is 100 meals per year, which we assume to be about 23 kg/yr. Consumption of this weight of the average game bird meal (Table 11) would result in intakes of 0.12 μCi ^{32}P and 0.03 μCi ^{65}Zn, implying 23 mrem to the skeleton of a Standard Man or less than 2% of the standard for individual members of the population with bone as the critical organ. Consumption of 1.24 kg/yr--the estimated annual intake for the Average Richland Resident (adult)--would result in intakes of 0.006 μCi ^{32}P and 0.001 μCi ^{65}Zn, implying a total dose of about 1 mrem to the skeleton, less than 1% of the appropriate standard (500 mrem/yr).

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.[21] Monthly average concentrations of ^{65}Zn and ^{32}P, periodically measured in oysters grown commercially in the Willapa Bay area, are shown in Figure 13; the analytical results for 1969 are tabulated in the Appendices.[2] A normal seasonal minimum for ^{32}P occurs in the late summer. In 1969, ^{32}P average concentrations remained at or below 1 pCi/g from August through December as in 1968. The annual average concentrations for 1969 were 19 pCi $^{65}Zn/g$ and 2.8 pCi $^{32}P/g$.

Consumption of oysters containing the 1969 average concentrations at the rate of 50 g/day[22] would result in annual doses of about 4 mrem to the GI tract, 3 mrem to the whole body, and 11 mrem to the bone of a Standard Man.[10] Fresh shellfish are not an important item in the average Tri-Cities diet, but residents of some 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.

RADIONUCLIDES IN MILK AND PRODUCE

Irrigation with river water containing reactor effluent radionuclides can influence the radioactivity found in locally grown farm produce. Deposition of airborne materials from Hanford sources and from fallout can be an additional source of radionuclides in these products. Chemical separations facilities are generally the principal local source of airborne radionuclides, although radioactive materials released from ventilation stacks of reactor 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 in the path of airborne releases.

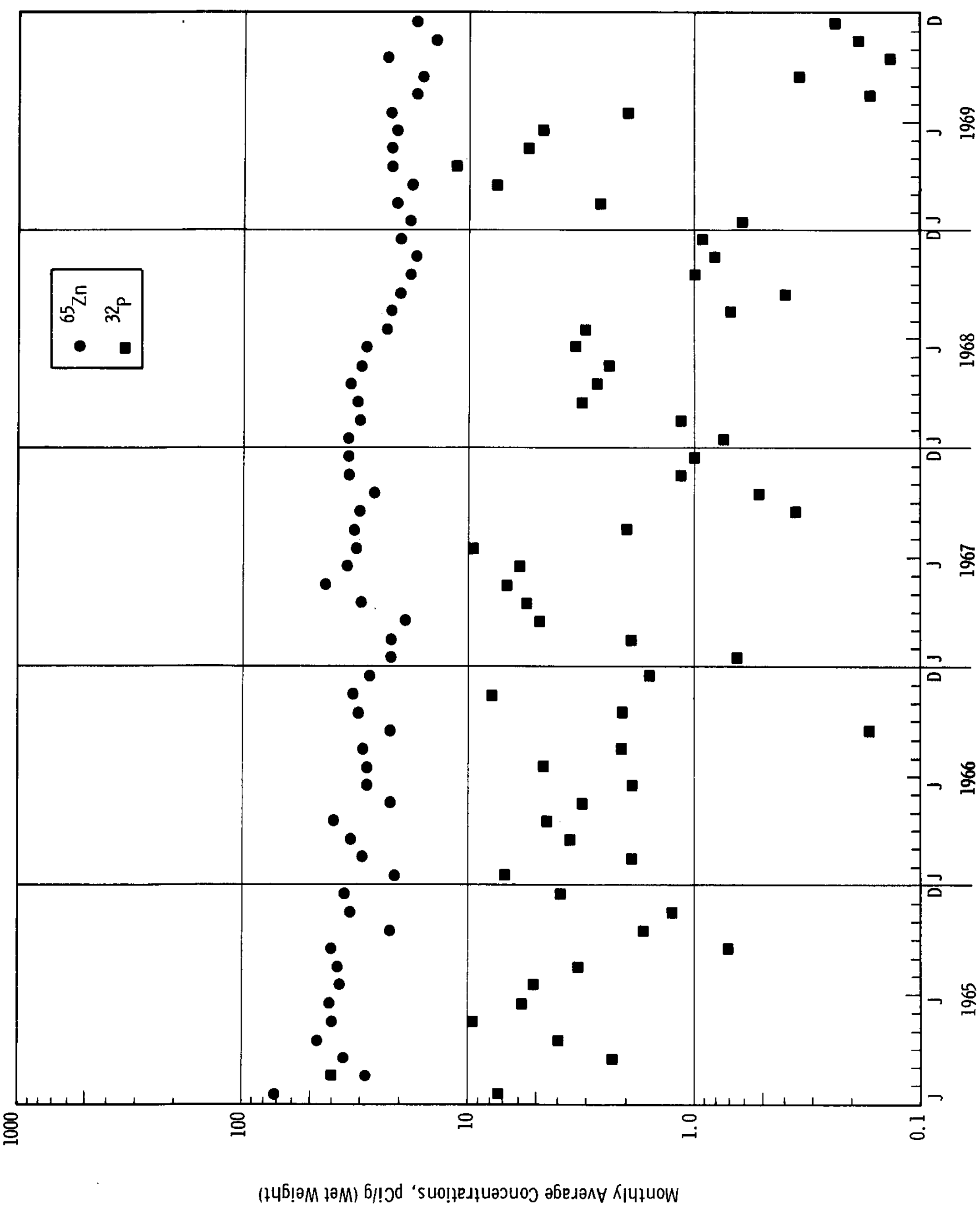

FIGURE 13. ^{32}P and ^{65}Zn Concentrations in Willapa Bay Oysters 1965-1969 (pCi/g, wet weight)

Most irrigated farms near the Hanford plant obtain water from the Yakima River or from the Columbia River above the plant. 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. These 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 1969 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[23] and the Washington State Department of Health.[24] 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 only a small fraction of the milk is produced on farms irrigated with water drawn from the Columbia River below the Hanford reactors.

Figure 14 shows the monthly average concentrations of ^{32}P and ^{65}Zn in milk from river-irrigated farms in the Ringold and Riverview areas for 1965-1969. In 1968 and 1969 river-irrigated farms were sampled only in Riverview. Although two farms were sampled during a few months of 1969, the majority of the data

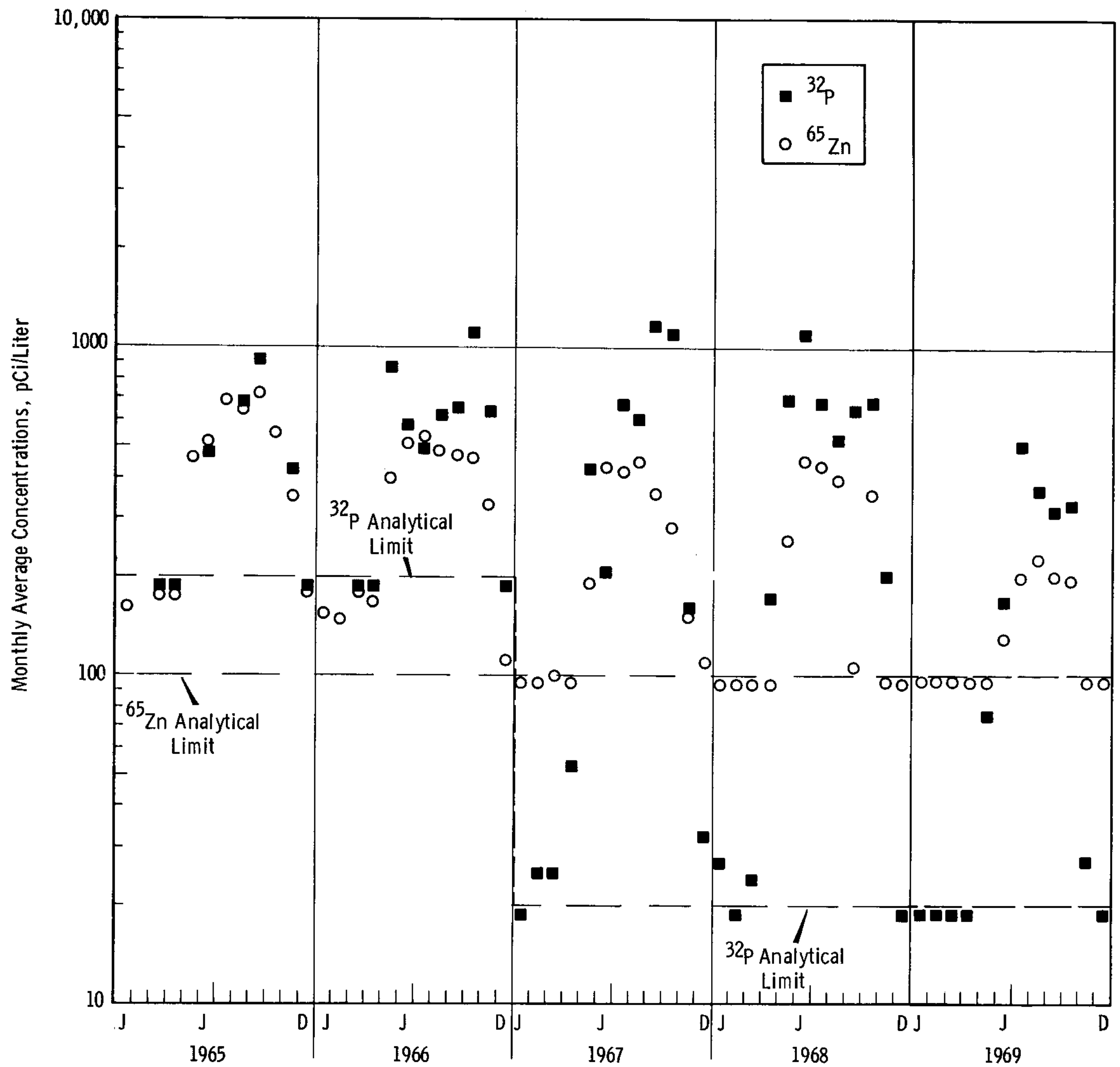

FIGURE 14. Monthly Average ^{32}P and ^{65}Zn Concentrations in Milk from River-Irrigated Farms, 1965-1969 (pCi/liter)

for this year represents a single location. During 1969, the annual average concentrations of ^{32}P and ^{65}Zn for this Riverview farm were 160 and 110 pCi/liter compared to 1968 averages of 310 and 130 pCi/liter, respectively, for the same farm. Seasonal fluctuations in concentrations of both ^{32}P and ^{65}Zn, caused primarily by irrigation and feeding practices, followed expected trends.

Figure 15 shows the monthly average concentrations of ^{131}I in locally available milk. During 1969, ^{131}I concentrations in both farm milk and commercial milk were generally near or below the analytical limit (3 pCi/liter). The maximum ^{131}I concentration for the period (8 pCi/liter) was measured in a single sample of farm milk collected on March 11. The average concentration for the year in farm milk was <1.3 pCi ^{131}I/liter.

Adult residents consuming milk (1 liter/day) obtained from the Riverview area could have received an annual dose from ^{32}P and ^{65}Zn amounting to about 2 mrem to the GI tract, 1 mrem to the whole body, and 11 mrem to the bone. The same intake of milk by a child with a 2 kg skeleton would result in an estimated bone dose of 39 mrem.* The intake of ^{131}I would have resulted in a dose of about 8 mrem to the 2 gram thyroid of an infant. Concentrations of radionuclides measured in milk are tabulated in the Appendices.(2)

Miscellaneous fresh produce from local farms was sampled periodically for radioanalysis during the 1969 growing season. Results of these measurements, tabulated in the Appendices,(2) were similar to those of previous years 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

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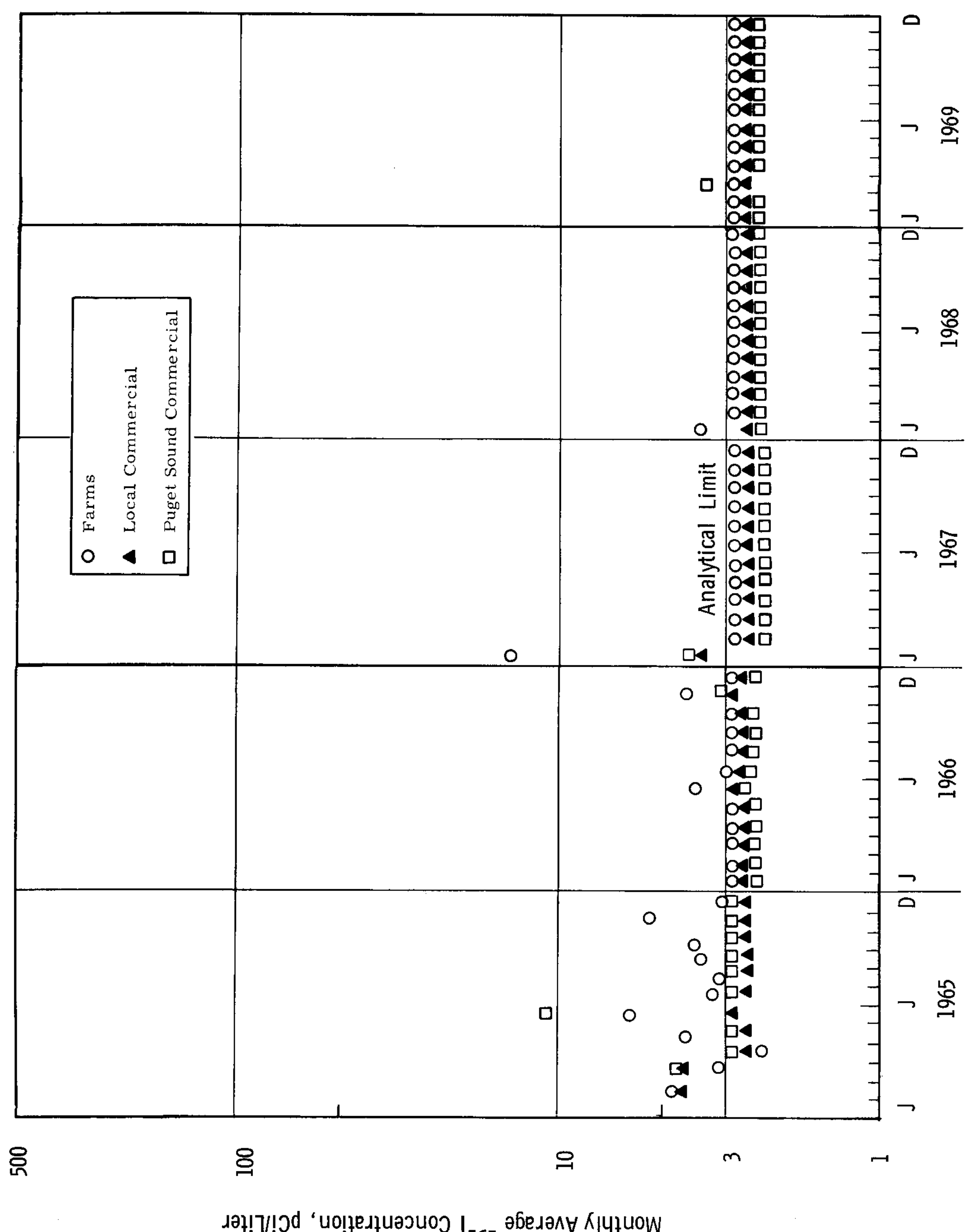
* *Based on dose factors of 660 mrem/μCi for ^{32}P and and 11 mrem/μCi for ^{65}Zn for the 2 kg skeletal weight.*(25)



<u>FIGURE 15.</u> Monthly Average ^{131}I Concentrations in Locally Available Milk, 1965-1969 (pCi/liter)

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.

EXTERNAL RADIATION

Clusters of three ionization chambers* at the Hanford Test Location within the reservation (Figure 2) and at Richland measure the gamma radiation exposure at 1 meter above ground level (Figure 16 and Table 12). Data for January 1969 were lost. Data collected during the remainder of the year indicated slightly higher average exposures at both locations as compared to 1968 values. For 1969, the measured exposure was 110 mR at Richland and about 140 mR at the Hanford Test Location. Essentially all of the exposure at Richland is from natural background and worldwide fallout from nuclear testing.

TABLE 12. Radiation Exposure Rates, 1965-1969 (mR/day)

Location	1965	1966	1967	1968	1969
Hanford Test Location	0.33	0.35	0.35	0.36	0.37
Richland	0.30	0.28	0.26	0.28	0.30

Estimates of the external radiation dose received from recreational use of the Columbia River in the vicinity of the Hanford project are based on routine measurements at the shoreline at Richland and Sacajawea Park (where the Snake River enters the Columbia) and below the surface of the river at Richland.

The monthly average exposure rates at the two shoreline locations (Figure 17) are taken from measurements with a large (40-liter) ionization chamber at 1 meter back from the water's edge and centered 1 meter above the ground and approximate the

* *Victoreen stray radiation chambers.*

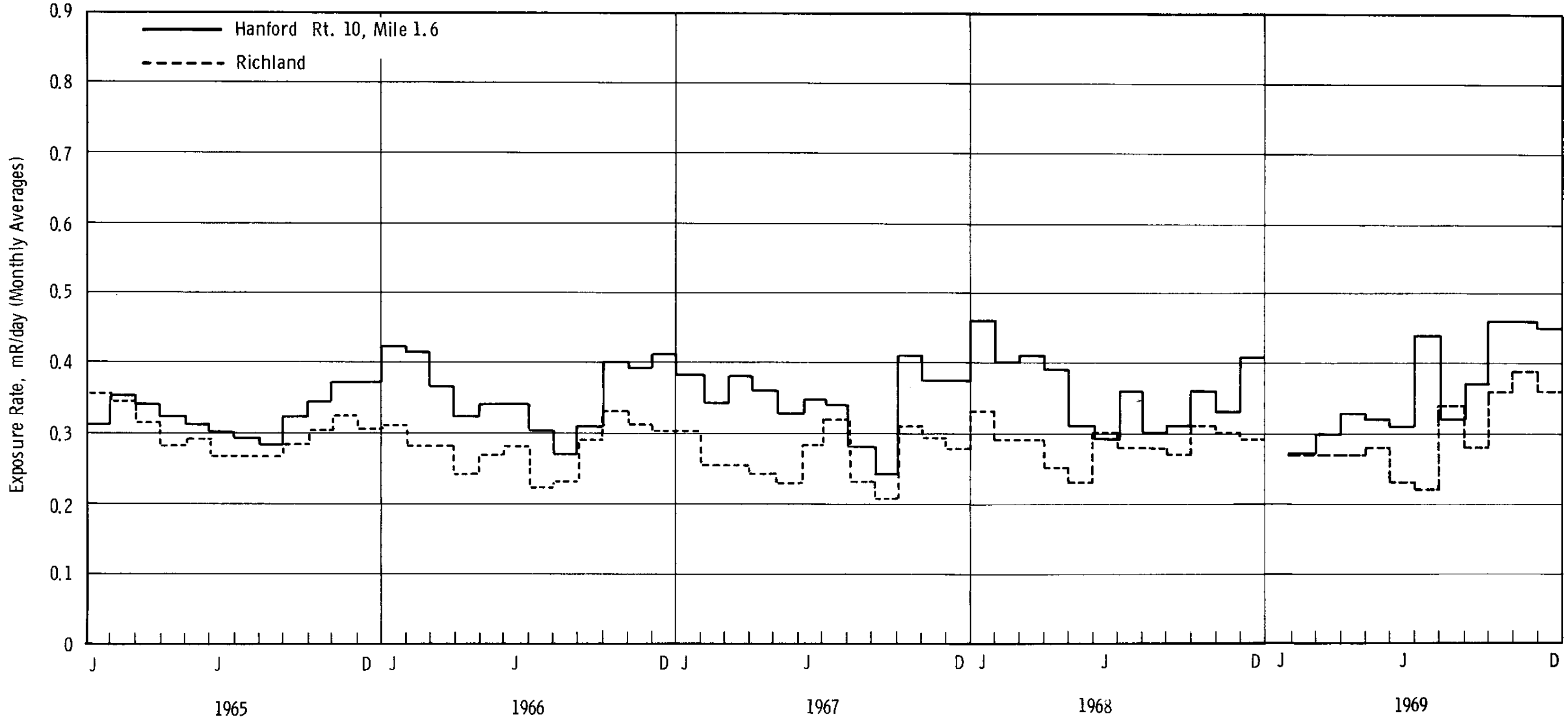


FIGURE 16. Monthly Average Gamma Exposure Rates at Hanford Test Location and at Richland, 1965-1969

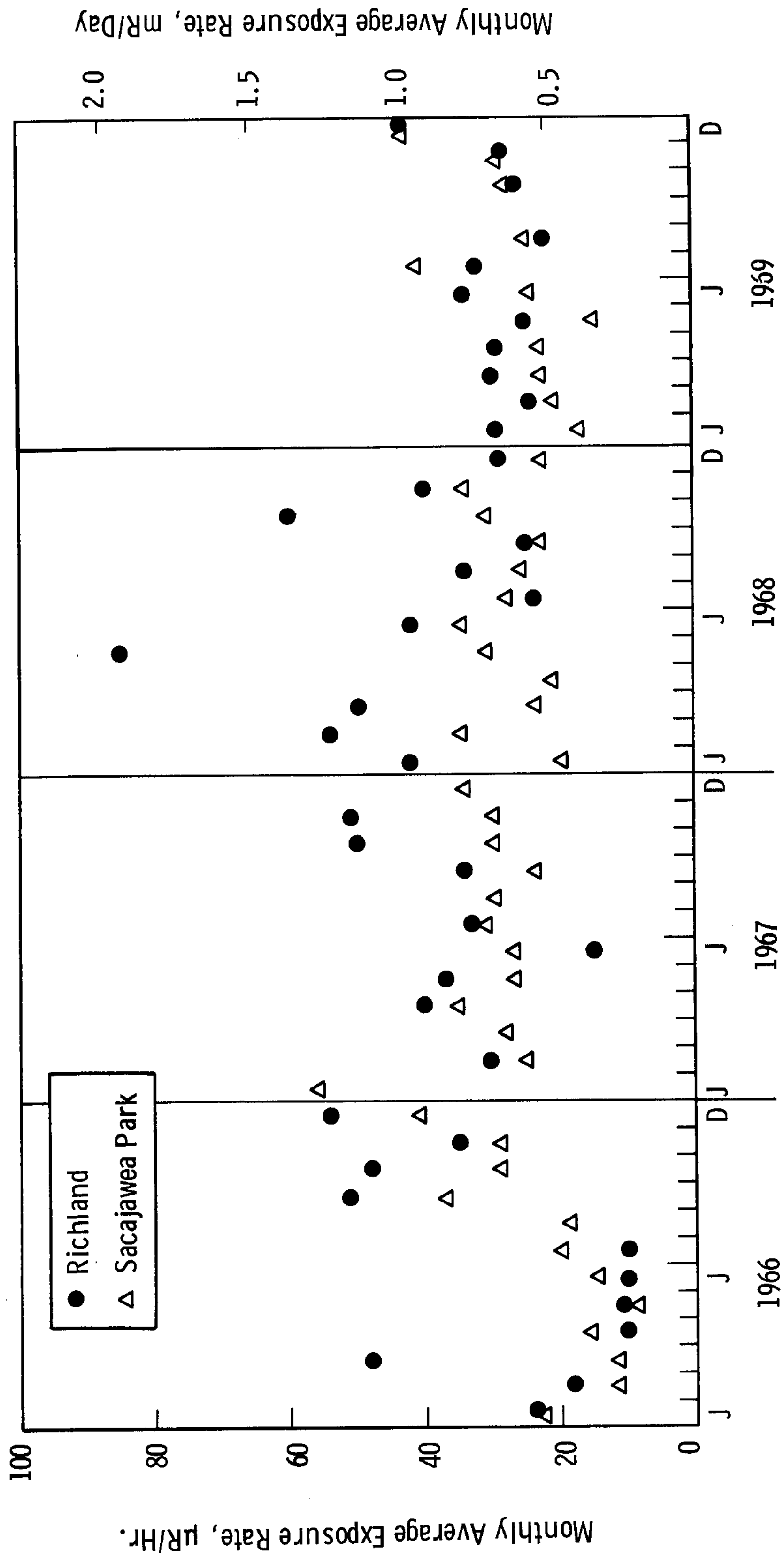


FIGURE 17. Monthly Average External Gamma Exposure Rates at the Columbia River Shoreline at Richland and Sacajawea Park, 1966-1969

dose rates to the gonads of a person on the riverbank. The exposure rates measured at the shoreline include components from radioactivity accumulated in sediment deposits and algal growths at the river's edge as well as from radioactive material in the water. Gamma spectra have shown that ^{46}Sc and ^{65}Zn were the major contributors to the shoreline component, and ^{24}Na to the water component.[26] Daily and seasonal fluctuations in the river flow rate affect the shoreline radiation levels in several ways including changes in the volume of water diluting the reactor effluent, in the time required for short-lived radionuclides to reach downstream locations, and in the amount of sediment exposed. Other seasonal variations may reflect such things as changes in parent nuclides (such as the spring increase in ^{56}Mn) or in biological cycles (shoreline insect deposits of debris). In addition to seasonal variations, the effect of the extended reactor outages in 1966 is apparent in Figure 17. For the panfish species consumed in the largest quantities the primary fishing locations are downstream from Richland. The radiation dose received by fishermen while fishing these locations is estimated from measurements at Sacajawea Park, where the Snake River enters the Columbia (Table 13).

TABLE 13. Radiation Exposure Rates at the Columbia River Shoreline,[a] 1966-1969 (mR/day)

Location	1966	1967	1968	1969
Richland	0.70	0.89	0.91	0.70
Sacajawea Park	0.51	0.72	0.65	0.60

a. Includes natural background radiation estimated to be 0.19 mR/day

An avid fisherman (such as the Maximum Individual), standing on the shoreline at Sacajawea Park for as much as 500 hours during 1969, could have had a gonad exposure to external gamma radiation of Hanford origin of 8.5 mR (about 2% of standard for whole body).

The immersion dose received by Tri-City swimmers is based on April through October exposure rates at Richland measured with clusters of five pocket-type ionization chambers positioned about 1 meter below the surface of the Columbia River. Measured immersion exposure rates were primarily due to the gamma emitters (especially ^{24}Na) introduced into the river with reactor cooling water. In the vicinity of Richland, the average immersion exposure rate during April through October 1969 was 2.7 mR/day. Because the contribution of natural background external radiation during immersion would be quite small relative to the inaccuracies of the measurement, the measured immersion exposure rate is attributed entirely to radioactivity of Hanford origin.

In 1968, teenagers were recognized as the major recreational users of the river. A survey of 430 Richland teenagers indicated an average exposure time of about 115 hours in or along the river for members of this group. About one-third of the time was probably immersion and about two-thirds was shoreline exposure.(27) Using the annual average shoreline exposure rate and the April through October average immersion exposure rate at Richland, the average exposure to the teenage population was estimated to be about 6 mR during 1969. This was somewhat higher than in 1968 because of the slightly increased immersion exposure rate.

The exposures to teenagers who reported considerably greater river exposure time than the average were estimated. The 38 teenagers reporting 300 hours or more per year of Columbia River recreation time were taken to be representative of the critical population group for this exposure pathway. The estimated exposures to external radiation of Hanford origin for individual members of this group ranged from 8 to 53 mR with an average of about 23 mR. Expressed as whole body dose, this average (23 mrem) for the critical population group with respect to external exposure represents less than 5% of the appropriate standard (500 mrem/yr) for critical individuals.

The average whole body dose received by the Richland population from recreational use of the Columbia River can be estimated by assuming that other age groups use the river less than teenagers, but with the same proportion of immersion and shoreline exposure times. For the average exposure of the Richland population, an annual Columbia River (recreation) time of 32 hours was assumed. Based on 11 hours of immersion and 21 hours of shoreline exposure in the vicinity of Richland,[27] the whole body dose received by the Average Richland Resident during 1969 was estimated to be about 2 mrem, or about 1% of the appropriate standard of 170 mrem/yr.

FALLOUT FROM NUCLEAR WEAPONS TESTS

Dose increments received by residents of the Hanford environs from the fallout nuclides ^{3}H, ^{90}Sr, and ^{137}Cs have been estimated routinely, although they are not included in the assessment of dose attributable to Hanford operations. The concentrations of fallout nuclides in the local environs are below the national average because of the low rainfall. Measurements of fallout, like measurements of natural background radiation, help to put the radiation doses resulting from Hanford operations in proper perspective.

Unlike previous years, no increases of ^{131}I concentrations in milk attributable to fallout from weapons testing were observed during 1969, even though foreign weapons tests were conducted in late December 1968[12] and September 1969.[16]

Estimates of ^{3}H intakes from drinking water were based on concentrations measured in river water (see page 30). Concentrations of ^{90}Sr in locally produced farm and commercial milk

(Figure 18) are similar to those in commercial milk produced in other areas of low rainfall remote from the Hanford plant.[23] ^{90}Sr in locally produced commercial milk averaged 3.4 pCi/liter during 1969, slightly less than in 1968; ^{90}Sr in farm milk in 1969 averaged about 4.3 pCi/liter. Concentrations of ^{137}Cs (Figure 19) averaged below the analytical limit of 30 pCi/liter for both types of milk worldwide. Worldwide fallout is the source of ^{90}Sr and ^{137}Cs in milk.

Assuming that 40% of the total ^{90}Sr intake from fallout is obtained from milk,[28] the daily intake of ^{90}Sr during 1969 was estimated to be 12 pCi/day for the Maximum Individual and 4 pCi/day for the Average Adult Richland Resident, similar to the intakes estimated for 1968 (10 and 5 pCi/day, respectively. The total intake of ^{137}Cs during 1969 was about 0.03 μCi for the Maximum Individual and 0.009 μCi for the Average Adult Richland Resident, similar to those for 1968.

Table 14 shows a summary of the estimated annual dose commitments from fallout nuclide present in the Hanford environs. The ^{90}Sr annual intakes evaluated in terms of the Federal Radiation Council guides[9] for the Maximum Individual and the Average Richland Resident both correspond to 2% of the FRC intake guides[9] for the upper end of Range II (200 pCi/day for the average intake by a suitable sample of the exposed population, and 600 pCi/day for individuals).

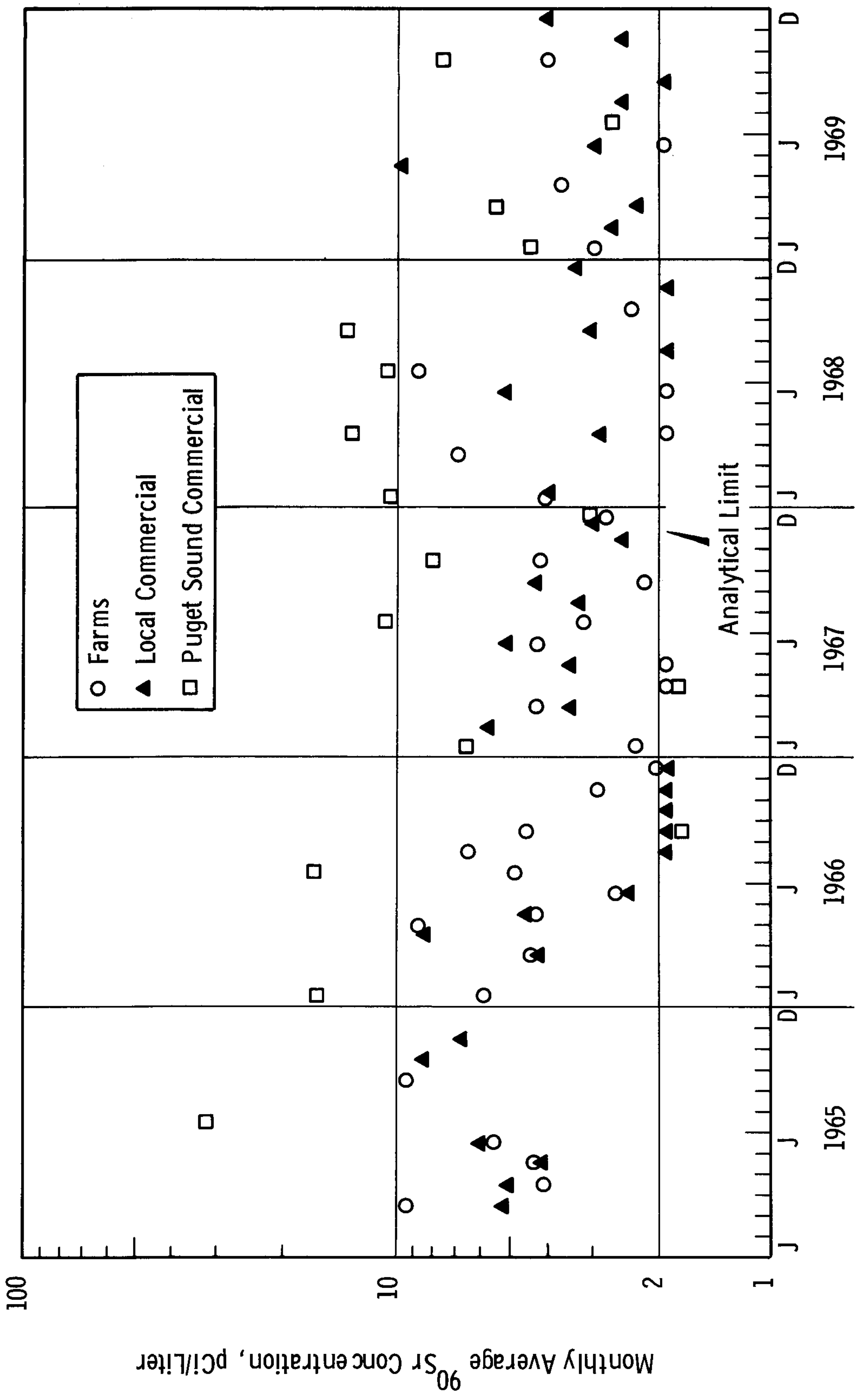


FIGURE 18. Monthly Average ^{90}Sr Concentrations in Locally Available Milk, 1965-1969 (pCi/liter)

TABLE 14. Radiation Dose Commitments from Ingestion of Individual Fallout Nuclides,[a] 1969 (mrem)

	^{3}H	^{90}Sr	^{137}Cs	Total
Maximum Individual				
Bone	- o	37[b]	2	39
Whole Body	<1	4[b]	2[c]	5
GI Tract	- <1	<1	<1	<1
Average Richland Resident				
Bone	-	12[b]	<1	13
Whole Body	<1	1[b]	<1[c]	2
GI Tract	-	<1	<1	<1

a. *Not included in dose summaries presented elsewhere.*

b. *The radiation dose commitments shown for bone and whole body represent the dose received over a period of 50 years based on ICRP methods.*[25,10,11] *Only a few percent of the total dose commitment from* ^{90}Sr *intake is received during the first year for each of these organs.*

c. *For the whole body dose commitment from ingestion of* ^{137}Cs *by an adult, the FRC dose conversion factor of 0.06 rem/µCi was used.*[29] *For previous reports in this series, the factor 0.031 rem/µCi based on ICRP values*[10] *was used. The principal reason for the difference in the two factors is a change in the value for biological half life of* ^{137}Cs *from 70 to 100 days in the adult.*

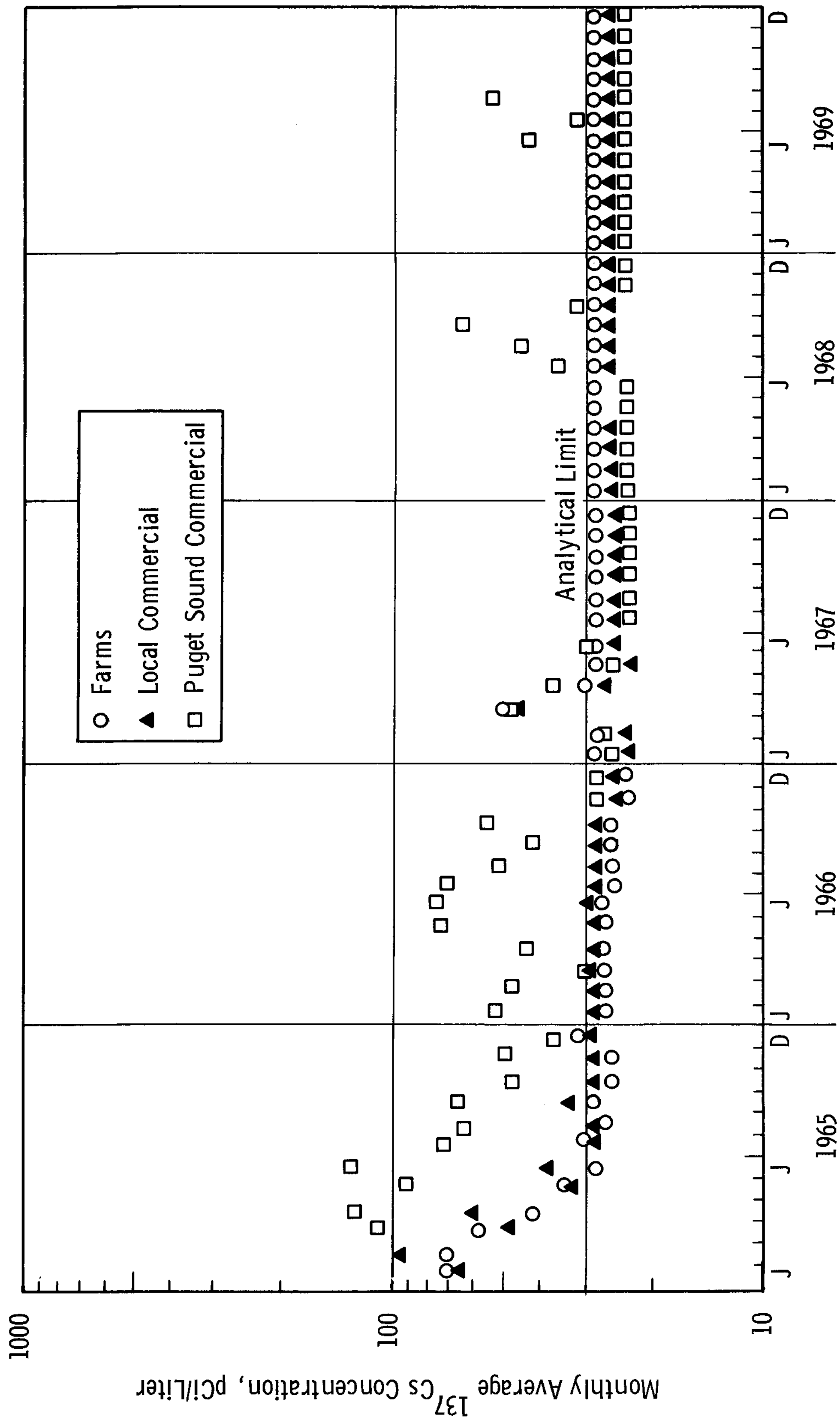


FIGURE 19. Monthly Average ^{137}Cs Concentrations in Locally Available Milk, 1965-1969 (pCi/liter)

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 standards 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 its source. A hypothetical Maximum Individual has been assigned assumed dietary habits (Table 15) which are identical to those used in the 1966, 1967, and 1968 Annual Reports.[30,4,3]

The consumption rates of most foods for this hypothetical Maximum Individual were compiled from intake rates described in published dietary surveys and have been documented separately in detail.[5,6] The postulated sources include water from the Pasco municipal system (Radionuclides in Drinking Water, page 31) and milk, meat, and produce from river-irrigated farms in the Riverview district (Radionuclides in Milk and Produce, page 43). The consumption of 200 meals per year of panfish taken from the Columbia River (Radionuclides in Columbia River Fish, page 34) and a total of 500 hours per year along the riverbank (External Radiation, page 49) to catch these fish are based on the values reported in local surveys.

The composite doses estimated for this Maximum Individual for 1969 (Figure 20) are summarized in Table 16 with 1968 estimates for comparison. Decreases were noted for all estimated organ doses with the largest decreases being for the infant thyroid and the adult bone doses.

TABLE 15. Dietary Assumptions

Foodstuffs	Maximum Individual	Average (Adult) Richland Resident
Water	730 ℓ/yr	680 ℓ/yr[a]
Milk	380 ℓ/yr	130 ℓ/yr[a]
Meat	80 kg/yr	74 kg/yr[a]
Chicken	8 kg/yr	5.4 kg/yr
Eggs	30 kg/yr	15 kg/yr
Seafood	0	1.4 kg/yr[a,b]
Col. Riv. Fish	40 kg/yr	0.48 kg/yr[a]
Game Birds	0	1.2 kg/yr[a]
Leafy Veg.	73 kg/yr[c]	36.5 kg/yr
Other Veg. and Fruits	530 kg/yr[c]	200 kg/yr

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

a. *Based on dietary questionnaires of Richland residents employed at Hanford.*[4]

b. *One-tenth of the total is assumed to be Willapa Bay oysters, the remainder free of radionuclides of Hanford origin.*

c. *Fresh produce from the Riverview area is assumed to be available only during five months of the year.*

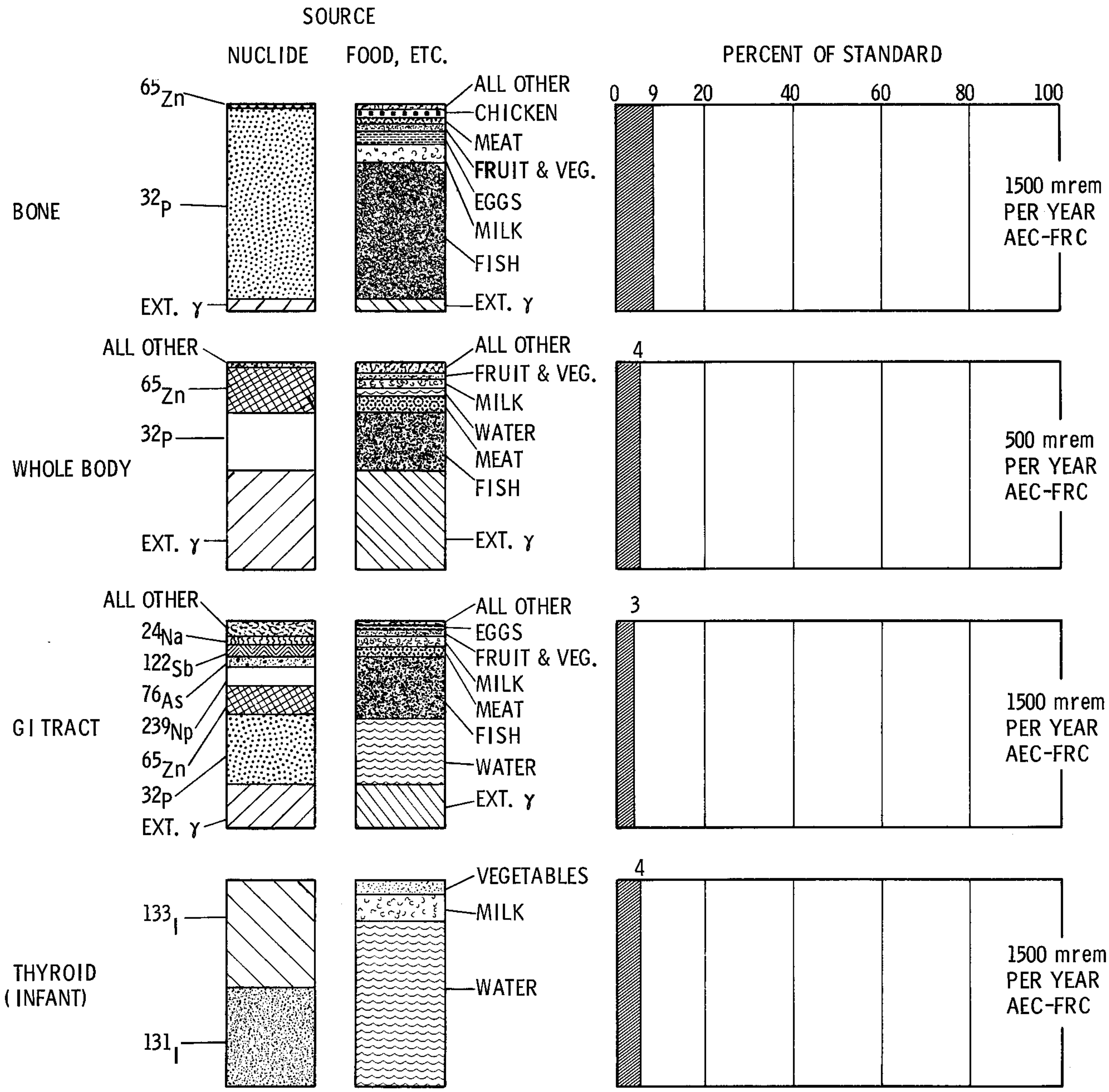


FIGURE 20. Estimated Doses to the Maximum Individual, 1969

TABLE 16. Summary of Radiation Doses[a] in the Hanford Environs, 1968-1969

Organ	1968 Annual Dose, mrem	1968 % of Standard	1969 Annual Dose, mrem	1969 % of Standard	Standard, mrem
Maximum Individual					
Bone	250	17	140	9	1500
Whole Body	24	5	18	4	500
GI Tract	62	4	40	3	1500
Thyroid (Infant)	110	7	60	4	1500
Average Richland Resident					
Bone	13	3	15	3	500
Whole Body	3	2	4	2	170
GI Tract	25	5	19	4	500
Thyroid (Infant)	39	8	23	5	500

a. Doses from fallout and natural background radiation are not included.

The estimated bone dose received by the Maximum Individual in 1969 was 140 mrem (9% of the appropriate standard) derived from both radionuclide intake and external radiation. About 66% of the bone dose resulted from ingestion of Columbia River fish and about 6% from exposure to shoreline radiation while fishing. About 9% of the total bone dose was derived from milk, 6% from eggs, 4% from fruit and vegetables, 3% from meat, 3% from chicken, and about 3% from drinking water. A single radionuclide, ^{32}P, accounted for 92% of the total bone dose. For comparison, the 1968 estimated bone dose was 250 mrem (17% of standard).

The whole body dose estimate for 1969 was 18 mrem (4% of standard), somewhat lower than the 1968 estimate of 24 mrem (5% of standard). For 1969, about 48% of the whole body dose resulted from exposure to shoreline radiation while fishing.

The estimated dose to the GI tract for the Maximum Individual during 1969 was 40 mrem (3% of standard), also lower than the 1968 estimate of 62 mrem (4% of standard). In 1969, the principal sources were drinking water, panfish, and external radiation contributing 32%, 30%, and 21% of the total dose, respectively.

The highest radiation doses to human thyroids are those received by infants because of the relatively small thyroid mass (assumed to be 2 grams). For the purpose of estimating thyroid dose for comparison with the standard, the Maximum Individual is defined as an infant drinking water with radionuclide concentrations equal to those at the Richland water plant and consuming food and milk obtained from commercial sources. Dietary assumptions for 1969 (Table 15) were identical to those used in 1968 and 1967.

The estimated thyroid dose for such an infant in 1969 was 60 mrem (4% of standard), which is significantly less than the 1968 estimate of 110 mrem (7% of standard). This decrease resulted from a decrease in the measured concentrations of ^{131}I in Richland drinking water in 1969. Measurements of monthly grab samples of drinking water during 1969 indicated the same ratio of concentrations of the short-lived ^{133}I to ^{131}I (6:1) that was observed in 1968. The annual average ^{133}I concentration was estimated by multiplying the annual average ^{131}I concentration in cumulative samples by the average measured ^{133}I to ^{131}I ratio. In 1969, ^{133}I and ^{131}I in drinking water contributed 52% and 28% of the Maximum Individual (infant) thyroid dose. ^{131}I in milk and in leafy vegetables accounted for the remainder.

Table 17 shows the significant decreases in estimated doses to the Maximum Individual over the years from 1965 to 1969, with organ doses adjusted to a comparable basis where

TABLE 17. Comparable Dose Estimates[a] for Maximum Individual, 1965-1969

	% of Standard					Standard,
	1965	1966	1967	1968	1969	mrem
Bone	24	22	24	16[b]	8[b]	1500
Whole Body	8	7	6	5	3	500
GI Tract	6	5	5	4	3	1500
Thyroid (infant)	4	6	3[d]	3[d]	2[d]	1500

a. *Not including contributions from fallout or natural background radiation.*

b. *For comparison, bone doses from ingested radionuclides only are shown for all years, although in 1968[3] and 1969 a contribution from external radiation was included in the total bone dose estimates.*

c. *The annual dose contributions to the whole body and GI tract from external radiation for the years 1965 through 1969 were estimated to be 15, 13, 11, 9.5, and 8.5 mrem and have been included in the doses listed for these organs.*

d. *For comparison, the thyroid doses listed are from ^{131}I only, although in 1967,[4] and 1968,[3] and 1969, a contribution from ^{133}I was included in the total thyroid dose estimate.*

necessary to clarify trends. The long-term trend for all organ doses is obviously downward. The bone doses from ingested radionuclides only are shown, because, although exposure to shoreline radiation had been assumed for previous years, no external radiation contribution to the bone dose was evaluated until 1968 when radionuclide intakes were evaluated in terms of mrem rather than expressed as a percentage of the maximum permissible rate of intake (MPRI). The thyroid doses shown are those from intake of ^{131}I only, because ^{133}I contributions were not routinely evaluated until 1967, although ^{133}I was undoubtedly present in drinking water to some extent in previous years.

THE AVERAGE RICHLAND RESIDENT

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 have been discussed in a previous report.[4] Table 15 includes a summary of the diet for the Average Richland Resident whose food is assumed to come from commercial sources.

In computing doses for the Average Richland Resident, these assumed sources were Richland drinking water with average concentrations adjusted for radioactive decay and dilution (Radionuclides in Drinking Water, page 31), Columbia River fish with the average species composition of fish ingested by the Maximum Individual (Radionuclides in Columbia River Fish, page 34), "average game birds" (Radionuclides in Game Birds, page 38), and milk, meat, and produce from local stores (Radionuclides in Milk and Produce, page 43).

Because no significant contribution from Hanford operations to the background radiation levels in Richland can be discerned, the external dose to the Average Richland Resident is assumed to result only from recreational use of the Columbia River. An estimated annual dose increment of 2 mrem (see pages 53 and 54) from immersion in the river and activities along the shoreline was included in the GI tract, whole body, and bone doses. No such increment was included in the thyroid dose which is calculated for the infant because of the limited use of the river by this age group.

The composite doses estimated for the Average Richland Resident for 1969 (Figure 21) are summarized in Table 16 with 1968 estimates for comparison. The 1969 doses estimated for the GI tract of the Average Richland Resident and for the

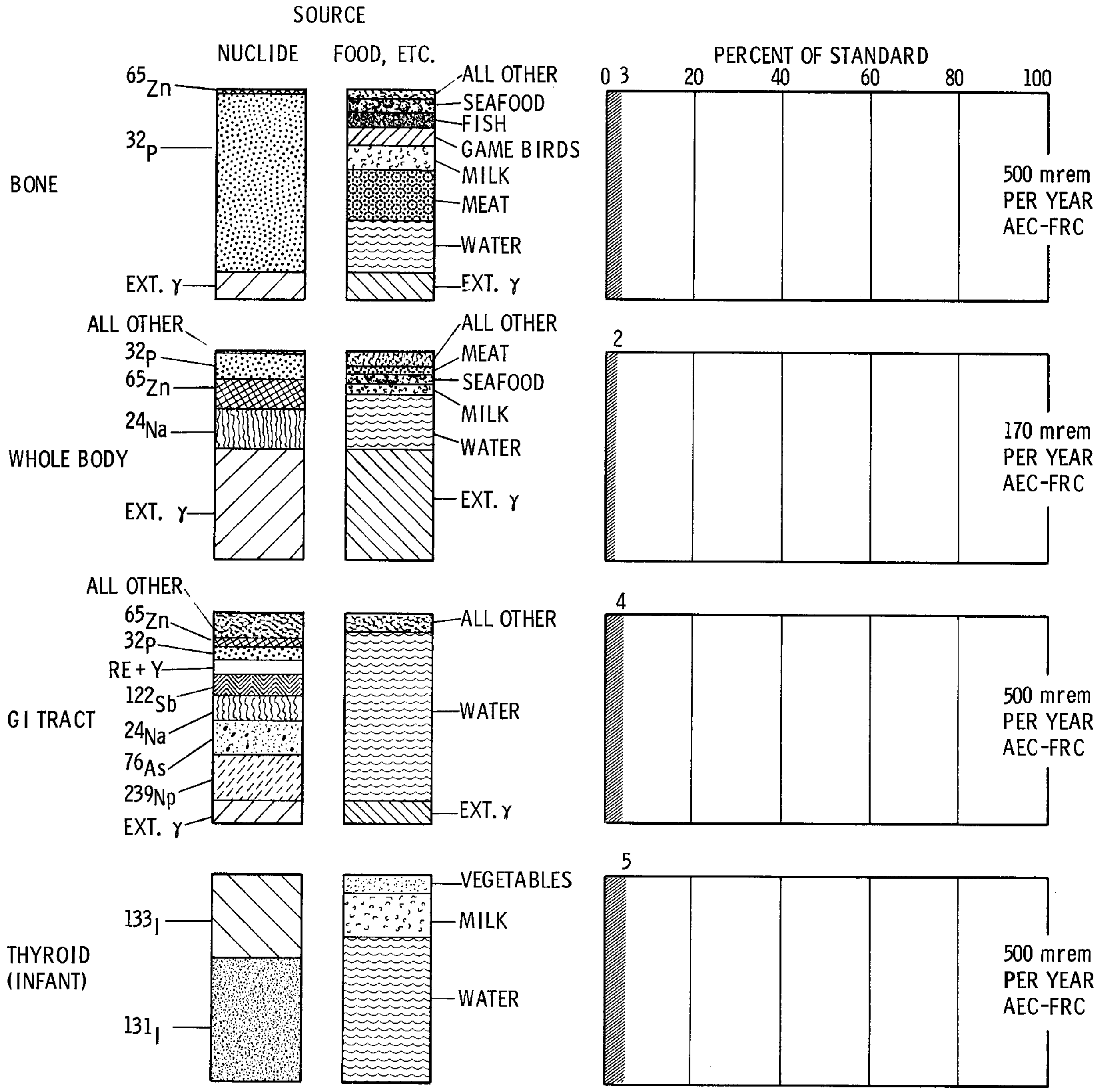


FIGURE 21. Estimated Doses to the Average Richland Resident, 1969

thyroid of the average Richland infant decreased significantly. No significant differences between 1968 and 1969 dose estimates were noted for the bone and whole body.

The estimated bone dose received by the Average Richland Resident in 1969 was 15 mrem (3% of standard) derived from both radionuclide intake and (as in 1968) external radiation. About 25% of the total bone dose was derived from drinking water, 24% from meat, 13% from external radiation, 13% from milk, 8% from game birds, 7% from panfish, 6% from seafood, with 4% from remaining food items. A single radionuclide, ^{32}P, accounted for 85% of the total bone dose. For comparison, the 1968 estimated bone dose was 13 mrem (3% of standard).

The whole-body dose estimate for 1969 was 4 mrem (2% of standard), not significantly different from the 1968 estimate of 3 mrem (2% of standard). For 1969, about 53% of the whole body dose resulted from recreational use of the Columbia River.

The estimated dose to the GI tract for the Average Richland Resident during 1969 was 19 mrem (4% of standard), somewhat lower than the 1968 estimate of 25 mrem (5% of standard). As in 1968, the principal source was drinking water (81% of the total 1969 dose).

The Average Richland infant is defined as an infant drinking Richland municipal water, with radionuclide concentrations adjusted for radioactive decay and dilution. Dietary assumptions for 1969 (Table 15) were identical to those used in 1968 and 1967.

The estimated thyroid dose for such an infant in 1969 was 23 mrem (5% of standard), significantly less than the 1968 estimate of 39 mrem (8% of standard). This decrease resulted from decreased concentrations of radioiodines in Richland drinking water which was, as in 1968, the principal source of radioiodines. In 1969, ^{133}I and ^{131}I in drinking water contributed 40% and 30% of the Average Richland infant's thyroid dose. ^{131}I in milk and in leafy vegetables accounted for the remainder.

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REFERENCES

1. "Waste Disposal," AEC Manual, Chapter RL-0510. U.S. Atomic Energy Commission, Richland Operations Office, Richland, Washington, July 1967.

2. Evaluation of Radiological Conditions in the Vicinity of Hanford for 1969 (Appendices), edited by C. B. Wilson, BNWL-1505 APP. Battelle-Northwest, Richland, Washington, November 1970.

3. Evaluation of Radiological Conditions in the Vicinity of Hanford for 1968, edited by C. B. Wilson, BNWL-1341 and BNWL-1341 APP (Appendices). Battelle-Northwest, Richland, Washington, May 1970.

4. Evaluation of Radiological Conditions in the Vicinity of Hanford for 1967, edited by C. B. Wooldridge, BNWL-983 and BNWL-983 APP (Appendices). Battelle-Northwest, Richland, Washington, March 1969.

5. R. H. Wilson and T. H. Essig. Criteria Used to Estimate Radiation Doses Received by Persons Living in the Vicinity of Hanford: Interim Report, BNWL-706. Battelle-Northwest, Richland, Washington, July 1968.

6. T. H. Essig and J. P. Corley. Criteria Used to Estimate Radiation Doses Received by Persons Living in the Vicinity of Hanford: Interim Report No. 2, BNWL-1019. Battelle-Northwest, Richland, Washington, April 1969.

7. "Standards for Radiation Protection," AEC Manual, Chapter 0524. U.S. Atomic Energy Commission, Washington, D.C., 1963. Revised November 1968 and February 1969.

8. International Commission on Radiological Protection. "Principles of Environmental Monitoring Related to the Handling of Radioactive Materials," ICRP Publication 7. Pergamon Press, New York, 1965.

9. "Background Materials for the Development of Radiation Protection Standards," Staff Report of the Federal Radiation Council. Report No. 2. September 1961.

10. International Commission on Radiological Protection. "Report of ICRP Committee II on Permissible Dose for Internal Radiation (1959), with Bibliography for Biological, Mathematical, and Physical Data," Health Physics, vol. 3, no. 1, 1960.

11. *International Commission on Radiological Protection. "Recommendations of the International Commission on Radiological Protection (As Amended 1959 and Adopted 1962)," ICRP Publication 6. Pergamon Press, New York, 1964.*

12. *"Reported Nuclear Detonations, December 1968," Radiological Health Data and Reports, vol. 10, no. 1, p. 45. January 1969.*

13. *Weekly Runoff Reports - Pacific Northwest Water Resources (1969), U.S. Department of the Interior, U.S.G.S., Northwest Water Resources Data Center, Portland, Oregon, 1969.*

14. *P. S. Rohwer and S. V. Kaye. Age-Dependent Models for Estimated Internal Dose in Feasibility Evaluations of Plowshare Events, Plowshare Research and Development Program Report for October 1, 1967 to April 1, 1968, ORNL-TM-2229. Oak Ridge National Laboratory, Oak Ridge, Tennessee.*

15. *D. H. Denham. Radiological Status of the Groundwater Beneath the Hanford Project - July-December, 1969, BNWL-1233. Battelle-Northwest, Richland, Washington.*

16. *"Reported Nuclear Detonations, September 1969," Radiological Health Data and Reports, vol. 10, no. 10, p.473 October, 1969.*

17. *J. K. Soldat. Unpublished Fisherman Survey Data. Battelle-Northwest, Richland, Washington. (Report in preparation.)*

18. *Annual Ringold Hunting Summary 1969-1970. U.S. Fish and Wildlife Service. McNary National Wildlife Refuge, Burbank, Washington.*

19. *Annual Ringold Hunting Summary 1968-1969. U.S. Fish and Wildlife Service. McNary National Wildlife Refuge, Burbank, Washington.*

20. *J. K. Soldat. Unpublished Game Bird Data. Battelle-Northwest, Richland, Washington. (Report in preparation.)*

21. *A. H. Seymour and G. B. Lewis. Radionuclides of Columbia River Origin in Marine Organisms, Sediments, and Water Collected from the Coastal and Off-Shore Waters of Washington and Oregon, 1961-1963, UWFL-86. University of Washington, Seattle, Washington, December 10, 1964.*

22. *National Shellfish Sanitation Program Manual of Operations, Publ. No. 33. Public Health Service, Washington, D.C., 1965.*

23. *Radiological Health Data and Reports*, vol. 11 no. 4. U.S. Department of Health, Education, and Welfare, Public Health Service, Washington, D.C. April 1970.

24. *Environmental Radiation Surveillance Quarterly Data Reports - 1969*. Washington State Department of Health, Office of Air Quality Control, Olympia, Washington.

25. J. K. Soldat. Unpublished Bone Dose-Estimation Data. Battelle-Northwest, Richland, Washington.

26. D. H. Denham. Unpublished Shoreline Data. Battelle-Northwest, Richland, Washington, 1969.

27. J. F. Honstead. Unpublished Recreational Use Data. Battelle-Northwest, Richland, Washington, 1969.

28. *Summary of Available Data on the Sr-90 Content of Foods and of Total Diets in the United States*, HASL-90. U. S. Atomic Energy Commission, Health and Safety Laboratory, August 1960.

29. "Background Materials for the Development of Radiation Protection Standards." *Staff Report of the Federal Radiation Council*. Report No. 7. May 1965.

30. *Evaluation of Radiological Conditions in the Vicinity of Hanford for 1966*, edited by T. H. Essig and J. K. Soldat, BNWL-439 and BNWL-439 APP (Appendices). Battelle-Northwest, Richland, Washington, June 1967.

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