A.E.C. RESEARCH AND DEVELOPMENT REPORT

HW-63654 REV

OFF-PROJECT EXPOSURE FROM HANFORD REACTOR EFFLUENT

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HANFORD LABORATORIES

HANFORD ATOMIC PRODUCTS OPERATION
RICHLAND, WASHINGTON

GENERAL ELECTRIC

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ABSTRACT

This report is a review of the discharge of reactor effluent water to the Columbia River, including calculated and measured radioactivity downstream in relation to limits. It contains 1) a description of the quantities of radionuclides in the river, 2) calculated exposures from drinking Columbia River water, 3) measured exposures directly from the river, 4) estimated exposure from the consumption of foods, 5) a description of the distribution of Columbia River water in the ocean, 6) observations on the radionuclide content of marine organisms, and 7) recommendations for additional studies.

OFF-PROJECT EXPOSURE FROM HANFORD REACTOR EFFLUENT

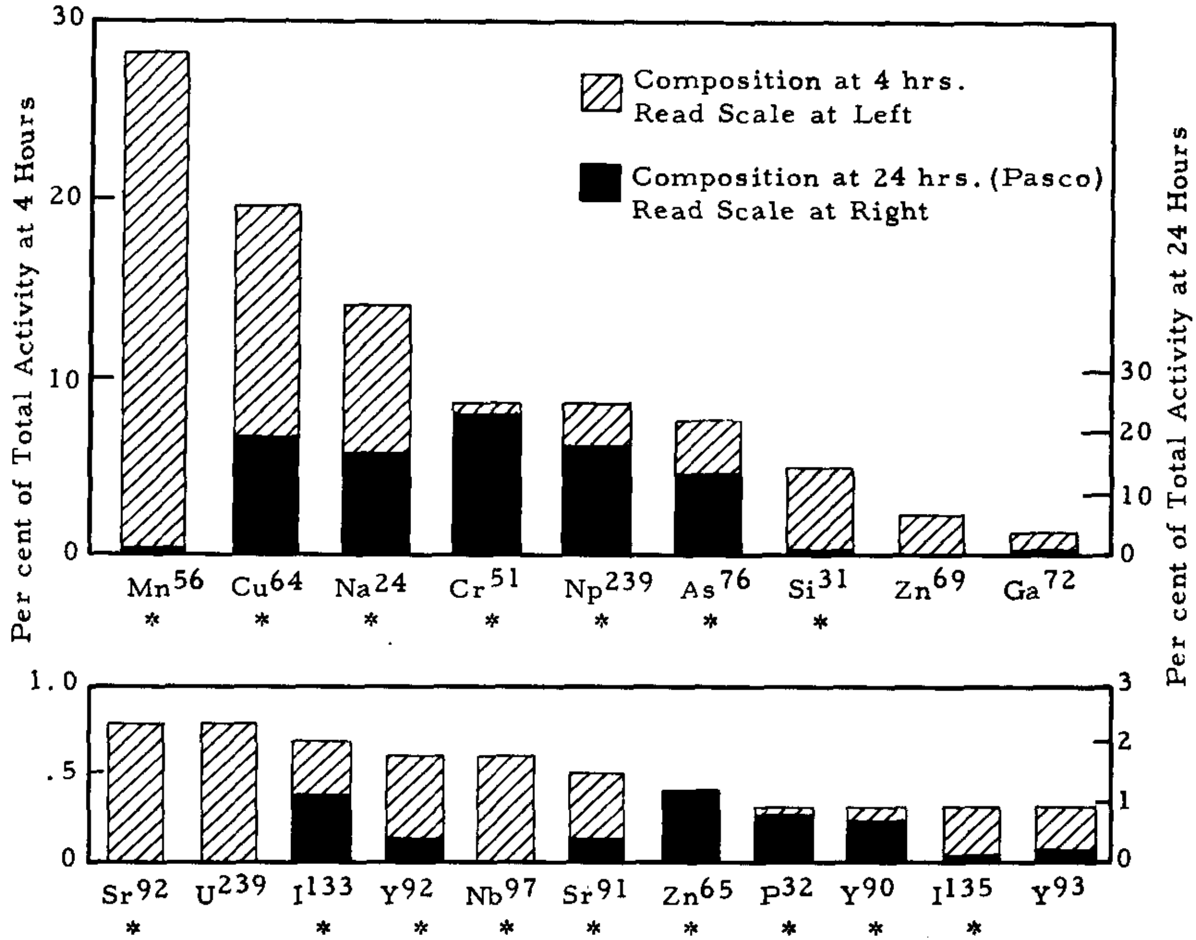
INTRODUCTION

The total quantity of radionuclides which enter the Columbia River from the eight production reactors is on the order of a few thousands of curies per day*. While this is a substantial quantity of radionuclides, the gross number has little meaning in terms of potential exposure to persons downriver. To evaluate the significance of the reactor effluent to exposure it is necessary to consider the great dilution afforded by the river, the decline in concentration of radioisotopes with distance which results both from radioactive decay and removal to the river bed and organisms, and the individual radionuclides present with respect to their biological importance, radiological characteristics, and the manner in which they may contribute to human exposure. Several of the radionuclides which are most abundant in the effluent at the time of release are of minor importance in downriver exposures while, on the other hand, a few isotopes (notably P^{32} and Zn^{65}) which are of comparatively low abundance in the effluent initially contribute most of the exposure which may be received from food products.

THE QUANTITIES OF RADIONUCLIDES IN THE COLUMBIA RIVER

The relative abundance of the more than 60 different radionuclides which have been measured in reactor effluent water is illustrated in Figure 1. The values are given at four hours after leaving the reactor for practical reasons. The four-hour base-line represents a reasonable time to which analytical results may be corrected in order to approximate conditions in the river near the reactor outfalls. It must be pointed out, however, that retention time before release of the effluent to the river varies from about one-half to three hours for the different reactors and thus there is no single value

* Current amounts from each reactor are recorded in HW-63653.



In addition to the isotopes shown above, which contribute about 98 per cent of the activity 4 hours after irradiation, trace amounts of the following have also been found.

Eu-152	Eu-157	I-131*	Y-91	Pr-145	Cs-137
Sm-153	Ba-140*	Ce-141	Fe-59*	Pm-151	Sr-85
W-187	Mo-99	Pr-142	Sr-89*	Co-60	U-238*
La-141	Sm-156	C-14	Mn-54	Pr-143	Pu-239*
Nd-149	Sc-46*	Nd-147	Zr-95	Ru-103	Ac-227
La-140	Cd-115	Ca-45*	Pm-149	Sc-47	Po-210*
I-132*	Ce-143	Ag-111	Eu-156	Sr-90*	

* Routine measurements are made on these isotopes.

FIGURE 1

Isotopic Composition of Reactor Effluent
4 Hours and 24 Hours after Irradiation

which is characteristic of the age of the effluent at the time of release. Further, the reactor sites are distributed along the river over a distance of about 15 miles as indicated in Figure 2 and the effluent from the upriver reactors may have aged as much as four hours in transit with the Columbia River water by the time fresh effluent is added by the most downriver reactor[(1)]. Other factors which discourage the adoption of any single set of isotope concentrations as truly representative of effluent contamination in the river in the immediate vicinity of the reactor outfalls is the variability in effluent composition between the several reactors[(2)] and the strong tendency for the effluent to remain in channels rather than disperse rapidly across the river[(3)]. The relative amounts of isotopes shown in Figure 1 should, therefore, be considered in light of these complexities and not viewed as a precise representation of the mixture of isotopes at any particular site along the river.

A typical decay curve of the gross beta emitters in reactor effluent is represented in Figure 3. For the same reasons given above, this curve is somewhat hypothetical and applies to the actual conditions in the river only in a very generalized way. It is not intended to describe the total depletion of radioactive material with distance since this is influenced by both radioactive decay and retention of the radionuclides in river sediments, bottom strata, and biological forms. The importance of "hold up" in the river as a mechanism for reducing downriver contamination of particular radionuclides has been described by Nielsen and Perkins[(4)] and is indicated in Figure 4. Radioactive decay is not included in the loss represented in Figure 4.

Although there are a few small farms in the vicinity of Ringold which pump water from the river for irrigation, the Tri-City area of Richland, Pasco, and Kennewick is the first point of extensive use of the Columbia River water downstream from the reactors. The river serves as the source of water for the municipal supplies of Pasco and Kennewick and water sports, including

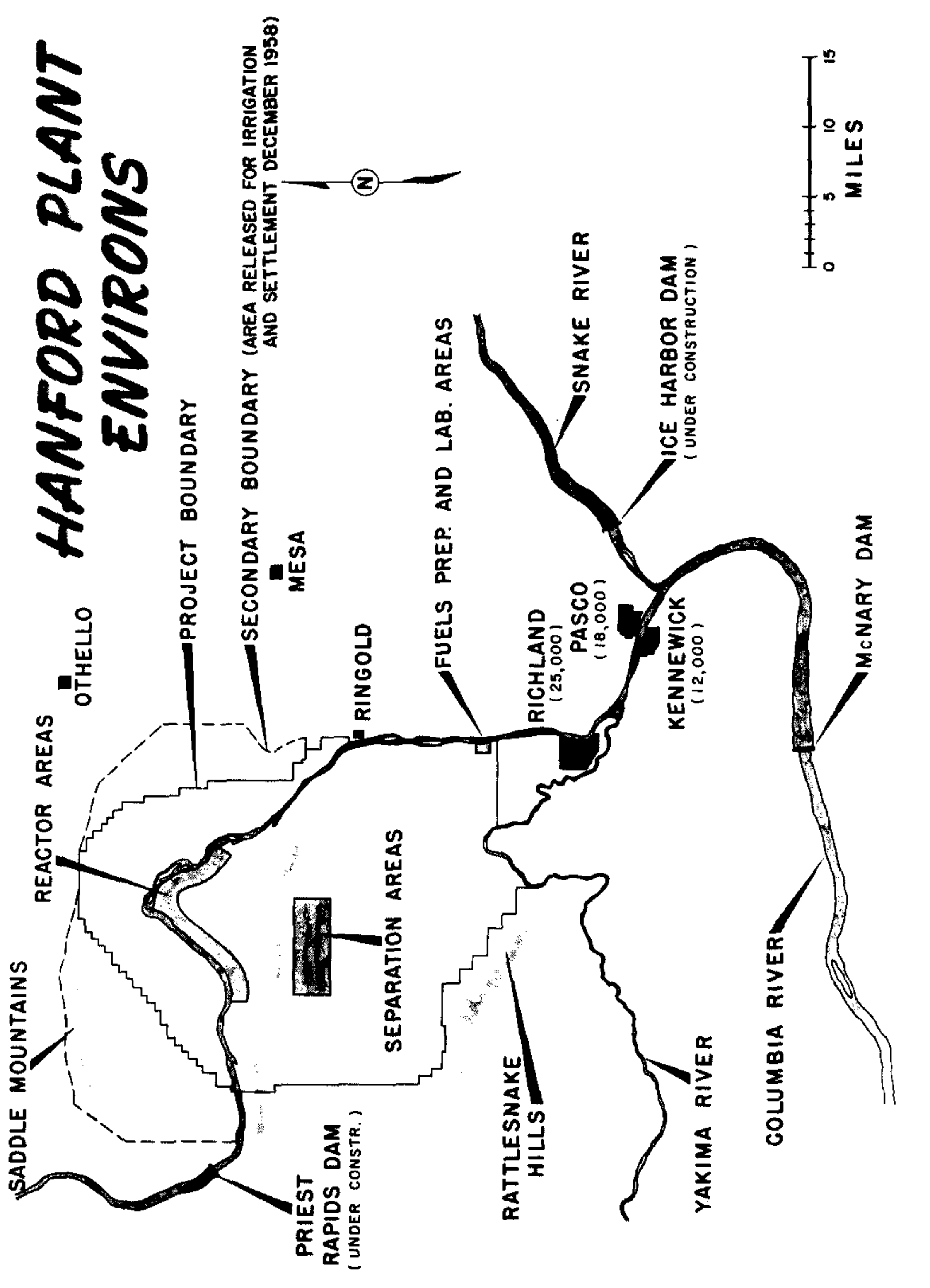

HANFORD PLANT ENVIRONS
SADDLE MOUNTAINS
REACTOR AREAS
OTHELLO
PROJECT BOUNDARY
SECONDARY BOUNDARY (AREA RELEASED FOR IRRIGATION AND SETTLEMENT DECEMBER 1958)
MESA
RINGOLD
FUELS PREP. AND LAB. AREAS
SEPARATION AREAS
RICHLAND (25,000)
PASCO (18,000)
KENNEWICK (12,000)
SNAKE RIVER
ICE HARBOR DAM (UNDER CONSTRUCTION)
N
0 5 10 15
MILES
McNARY DAM
COLUMBIA RIVER
YAKIMA RIVER
RATTLESNAKE HILLS
PRIEST RAPIDS DAM (UNDER CONSTR.)

FIGURE 2

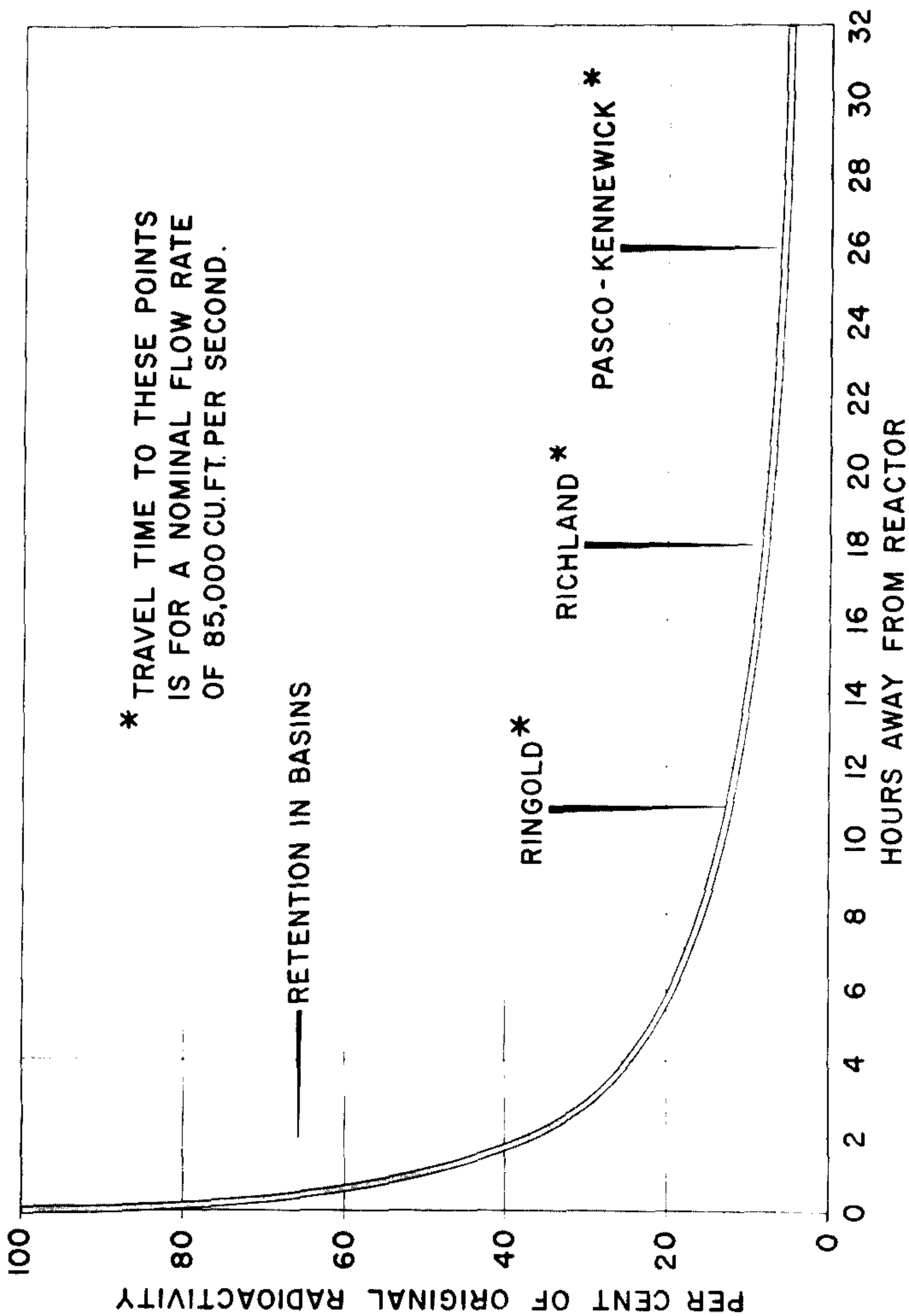


FIGURE 3

Reduction in Radioactivity of Reactor Effluent with Time

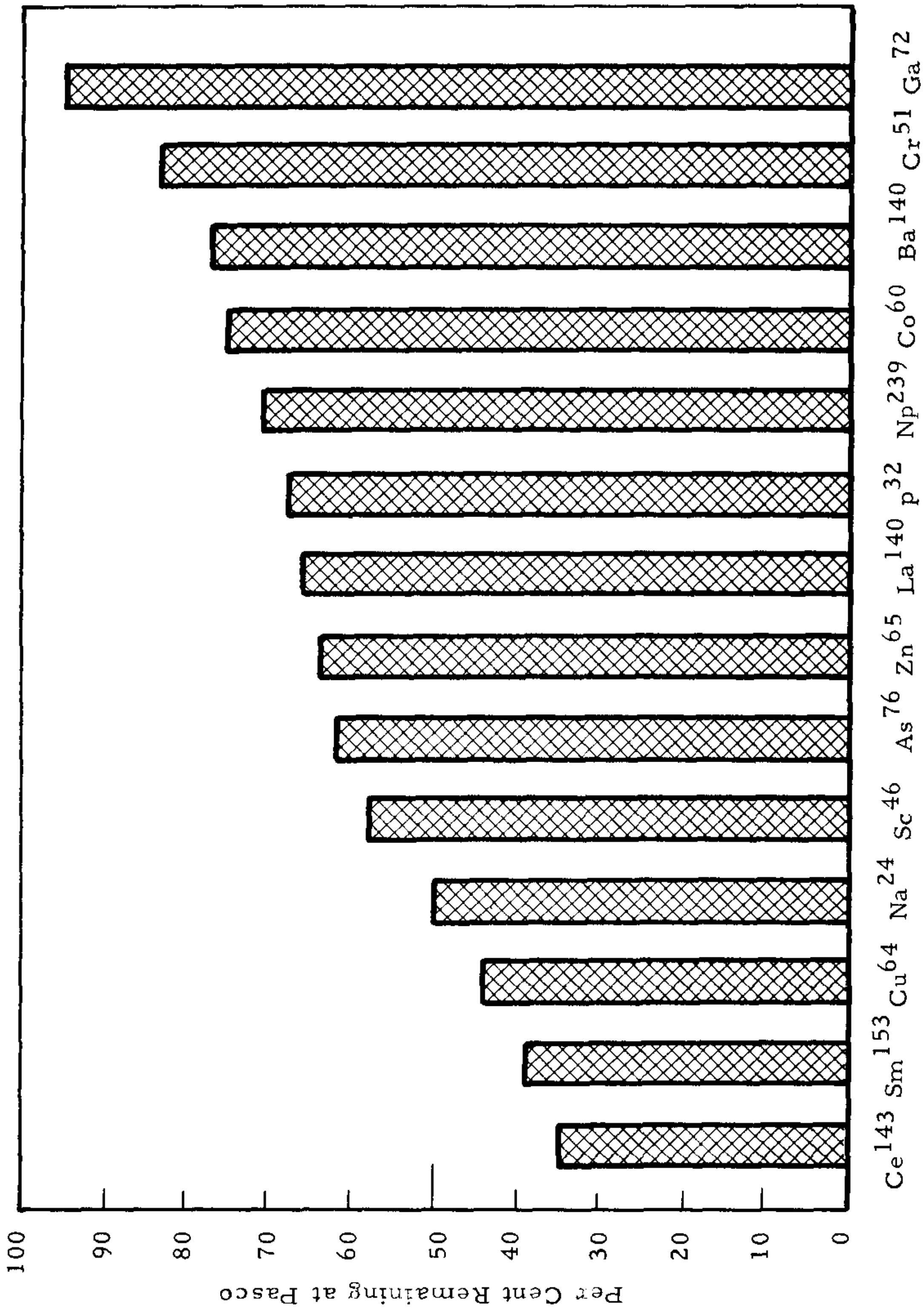


FIGURE 4

Portion of Nuclides not Retained in Columbia River Between Reactors and Pasco
(Data supplied by J.M. Nielsen of Radiological Chemistry Operation)

boating, water skiing, swimming, and fishing, attract several hundred people to the river in this area. Approximately 5,000 acres of farm land in this vicinity are irrigated with water pumped from the river. There is also some commercial transport and industry which makes use of the river in this area. Although measurements of the isotopic content of the effluent are made at the time of release, extrapolation from these measurements to the exposure which may be received by persons downriver who use the water cannot be made with the desired degree of accuracy in light of the several factors which may affect the true concentration of the individual radionuclides in the water and in foodstuffs. The most reliable estimates result from measurements made at the various points of use. Measurements made in the Tri-City area are generally considered to be maximum, with exposure diminishing with distance.

Samples of water collected from the river in the vicinity of Pasco are analyzed each week for those radionuclides, or groups of radionuclides, which make a measurable contribution to the radiation exposure which results from the use of the river for drinking purposes. Table I summarizes these measurements for 1959. Ten-gallon samples of water are collected from Vancouver, Washington, about 230 miles downstream from Pasco, on a less frequent basis and the measurements for radionuclides which predominate are shown in Table II. The concentrations are lowest during the spring and early summer when the volume of water flowing down the river is greatest. Figure 5 shows the flow rate of the river at Pasco during 1959; the flow near Vancouver is included for comparison.

Vancouver has been selected as the furthest downriver station for routine collection of samples for several reasons: the salt content of the water closer to the mouth complicates quantitative measurement of the very low concentrations of isotopes present, tidal movements near the mouth increase variability in results, and, since the very short-lived isotopes have been depleted, radioactive decay of the isotopes remaining in the lower

COLUMBIA RIVER FLOW AT PASCO AND VANCOUVER – 1959

FROM DATA PUBLISHED BY THE U.S. GEOLOGICAL SURVEY

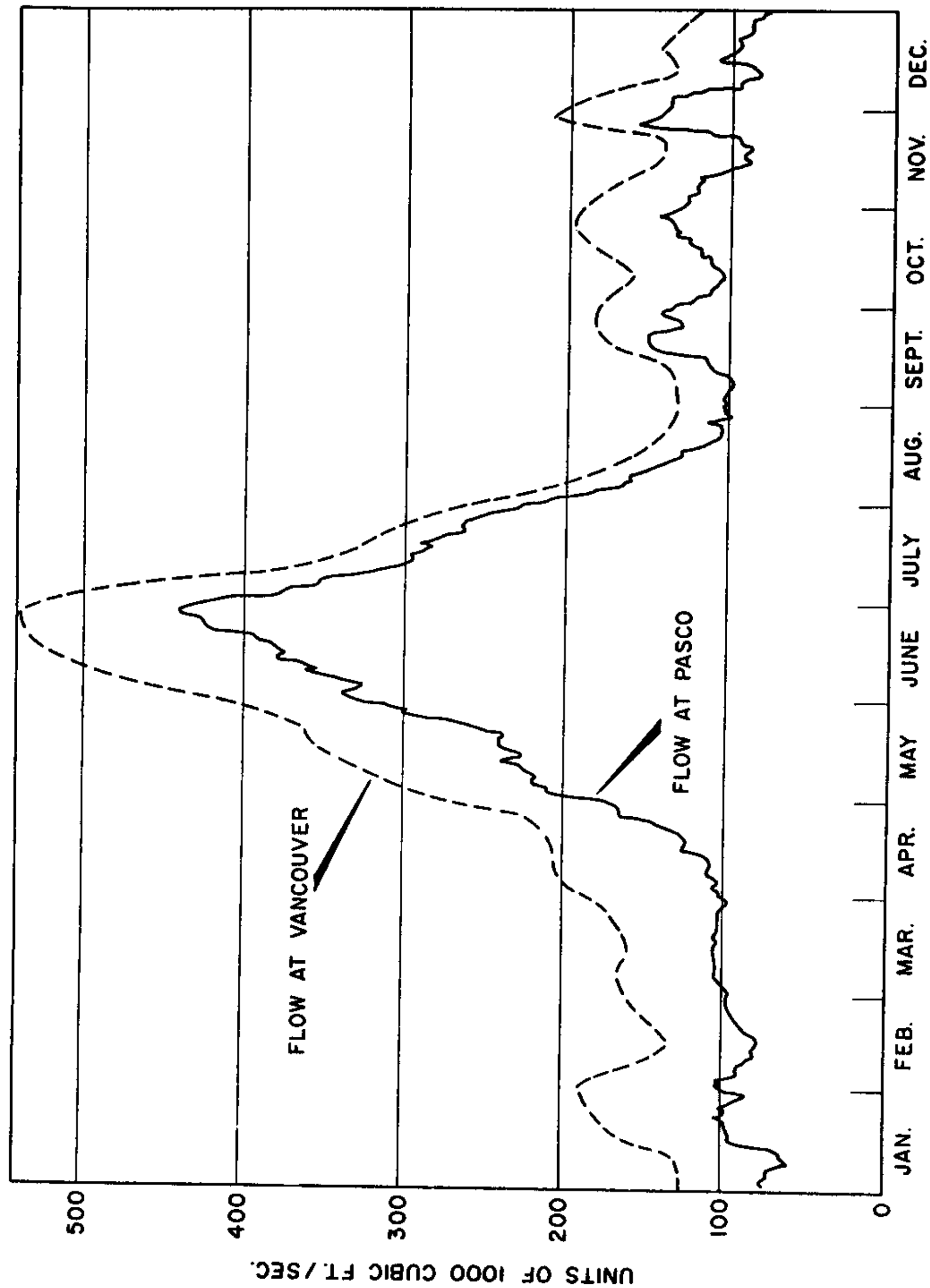


FIGURE 5

TABLE I

RADIONUCLIDE CONCENTRATIONS IN COLUMBIA RIVER WATER AT PASCO, WASHINGTON - 1959

10^{-9} μc/ml

Date	Total Beta	RE+Y	Na^{24}	P^{32}	Cr^{51}	Cu^{64}	Zn^{65}	As^{76}	Sr^{89}+ Sr^{90}	Sr^{90}	Np^{239}	Zn^{69m}
1-6-59	15,000	120	1,000	430	7,800	1,400	410	5,000	7.6	0.86	5,900	NA
1-13-59	18,000	200	1,800	500	11,000	2,700	510	5,400	10	0.63	6,500	NA
1-20-59	14,000	150	1,300	140	6,000	1,800	260	2,500	15	1.5	3,600	96
1-27-59	14,000	130	530	360	2,600	560	140	1,300	4.8	0.50	1,800	44
2-3-59	20,000	390	1,300	310	6,000	2,600	310	3,600	5.5	0.77	4,100	174
2-10-59	6,400	17	670	32	4,600	350	170	410	Lost	Lost	2,900	23
2-17-59	15,000	190	1,300	410	11,000	470	180	2,600	7.9	0.56	4,000	200
2-24-59	13,000	320	1,100	320	6,300	1,500	450	2,200	9.6	0.94	3,900	41
3-3-59	12,000	310	910	250	6,400	1,100	420	1,800	6.9	0.88	3,400	220
3-10-59	17,000	470	1,900	320	5,300	2,600	410	2,300	5.5	0.48	3,500	400
3-17-59	11,000	390	1,200	230	6,000	1,500	350	1,100	5.3	0.95	2,800	160
3-24-59	9,700	360	1,400	250	4,400	1,400	380	1,300	4.7	<0.49	2,500	180
3-31-59	7,400	240	870	200	5,400	890	230	890	5.5	0.41	2,300	79
4-7-59	15,000	460	2,600	300	6,900	2,500	390	2,000	5.2	0.46	3,200	290
4-14-59	15,000	450	2,600	230	5,500	2,700	400	2,200	5.8	?	3,000	320
4-21-59	15,000	370	1,800	220	5,100	2,600	330	2,300	4.5	0.36	2,600	330
4-28-59	5,400	140	720	110	2,500	930	220	350	5.3	0.45	1,100	120
5-5-59	9,000	300	1,200	110	3,000	3,000	190	670	6.6	0.36	1,500	210
5-12-59	5,300	130	730	62	1,500	1,000	180	640	4.3	<0.50	880	480
5-19-59	7,900	170	1,200	87	2,400	2,200	180	1,200	2.7	0.96	1,300	130
5-26-59	6,600	210	1,200	64	2,600	2,200	150	950	2.7	<0.95	1,300	170
6-2-59	3,700	150	800	39	1,600	1,400	150	590	3.1	0.45	750	110
6-9-59	3,800	160	800	32	1,300	1,300	130	470	2.4	0.68	740	120
6-16-59	4,100	170	690	18	1,200	1,500	100	400	1.7	0.19	580	87
6-23-59	3,800	140	370	25	970	1,400	86	410	5.4	1.1	580	24
6-30-59	3,100	130	540	21	800	1,100	67	330	2.2	<0.34	690	54
7-7-59	4,700	170	700	22	1,500	1,400	91	490	2.3	<0.67	760	72
7-14-59	4,100	210	340	20	1,700	1,200	55	360	1.9	<0.37	680	43
7-21-59	2,900	100	260	21	1,000	980	59	250	3.0	<0.40	600	22
7-28-59	4,200	130	420	24	2,800	1,100	66	800	2.6	<0.57	620	49
8-4-59	7,500	200	930	43	2,000	1,700	90	930	4.4	0.57	810	59
8-11-59	7,200	190	1,400	48	2,600	2,100	120	820	4.4	0.80	1,100	66
8-18-59	12,000	140	1,300	60	4,000	2,200	130	1,200	4.6	1.0	1,800	81
8-25-59	8,300	190	1,500	78	3,500	1,800	160	1,100	3.2	0.90	1,700	61
9-1-59	8,900	69	1,200	57	3,800	1,700	120	1,300	5.5	1.0	1,800	22
9-8-59	8,900	140	1,400	83	4,700	2,000	120	1,400	4.6	<0.65	2,300	16
9-15-59	7,100	72	1,300	85	3,400	1,800	130	1,100	4.7	0.68	1,700	25
9-22-59	8,400	170	1,400	94	2,700	2,000	150	1,400	4.4	0.58	1,600	40
9-29-59	7,600	58	1,100	140	4,000	1,700	120	1,300	5.9	0.79	2,100	18
10-6-59	8,000	130	1,300	100	3,400	1,800	160	1,300	3.9	0.81	1,800	34
10-13-59	6,500	110	710	140	3,500	910	110	1,200	5.8	0.70	1,900	12
10-20-59	11,000	210	1,500	180	4,300	2,400	160	1,800	6.2	<1.0	2,500	27
10-27-59	8,900	170	1,100	170	4,300	1,700	180	1,300	4.4	0.64	1,900	26
11-3-59	6,000	140	740	110	3,100	970	140	960	4.5	0.71	1,900	19
11-10-59	9,800	190	1,500	150	4,600	2,300	190	1,400	4.2	0.65	2,600	40
11-17-59	13,000	380	1,800	180	6,100	2,800	250	2,000	6.7	0.71	3,800	80
11-24-59	19,000	410	2,100	280	8,700	360	250	2,700	6.7	0.87	4,300	68
12-1-59	5,400	140	290	99	2,800	820	150	510	4.1	0.76	1,300	28
12-8-59	10,000	180	1,300	200	5,800	2,400	270	1,200	4.4	1.1	3,100	36
12-15-59	9,200	380	1,100	230	5,600	1,300	250	1,300	7.4	0.72	3,300	33
avg	9376											

NA - Not Analyzed

TABLE II

CONCENTRATIONS OF SEVERAL SELECTED RADIONUCLIDES IN COLUMBIA RIVER AT VANCOUVER, WASHINGTON - 1959

10^{-9} μc/ml

Date	P^{32}	Cr^{51}	Zn^{65}	Np^{239}
6-23-59	14	710	41	300*
7-28-59	5.3	940	<20	94
8-25-59	9.8	2,300	39	87
9-29-59	19	1,800	<19	120
10-19-59	37	Lost	--	--
11-3-59	39	2,300	<19	160
12-1-59	80	4,000	55	400

* Questionable analytical result

section of the river reduces the gross radioactivity at a much slower rate than is characteristic for upriver areas. Frequent sampling in the lower stretches of the river has not been considered necessary inasmuch as the more intense sampling in the Pasco vicinity has shown that exposure rates are well below the maximum permissible limits at this point and the degree of hazard diminishing with distance.

From the data of Tables I and II and Figure 5, estimates can be made of the total quantities of the various radionuclides which are transported by the river each day. Tables III and IV show the quantities for 1959. Most of the radionuclides have such short lives that they are essentially eliminated by the time they reach the lower streches of the river but, as indicated in Table IV, Cr^{51}, Np^{239}, Zn^{65}, and P^{32} persist in measurable amounts. Small amounts of Co^{60} are also known to be present. The most reliable measurements for this radionuclide, made in connection with a special study[(4)], indicate that less than one curie of Co^{60} is transported each day. Figure 6 shows how radioactive decay would deplete typical quantities of radionuclides measured at Pasco during the last quarter of 1959 as the dilute effluent mixture moves downstream. The length of time required to reach various downstream points is strongly affected by the volume of water moving in the Columbia at different times of the year. Travel times between Pasco and Vancouver may be as short as one week during the spring freshet, but over two weeks during periods of low flow. A somewhat similar figure for radioactive decay was previously presented by Nielsen and Perkins[(4)] and included observed concentrations at various points along the river obtained from special sampling carried out during January, 1957. An outline map of the Pacific Northwest is included as Figure 7 for orientation.

The measured amounts of radionuclides at Vancouver are, for the most part, compatible with the curves of Figure 6. The concentration of Zn^{65} is, however, substantially less than would be anticipated from radioactive decay alone. The lower value probably results from hold-up in the river solids and biota as mentioned above.

TABLE III

QUANTITIES OF VARIOUS RADIONUCLIDES IN COLUMBIA RIVER WATER AT PASCO, WASHINGTON - 1959

curies/day

Date	Total Beta	RE+Y	Na^{24}	P^{32}	Cr^{51}	Cu^{64}	Zn^{65}	As^{76}	$Sr^{89}+Sr^{90}$	Sr^{90}	Np^{239}	$Zn^{69}m$
1-6-59	2,600	21	180	76	1,400	250	72	900	1.3	0.15	1,000	NA
1-13-59	3,600	40	360	100	2,200	550	100	1,100	2.0	0.13	1,300	NA
1-20-59	3,400	36	310	34	1,400	430	62	600	3.6	0.36	860	23
1-27-59	3,300	30	120	84	600	130	33	300	1.1	0.12	420	10
2-3-59	5,100	99	460	78	1,500	660	78	910	1.4	0.19	100	44
2-10-59	1,300	3.3	120	6.3	900	69	33	80	Lost	Lost	570	4.5
2-17-59	3,100	40	270	86	2,300	98	38	540	1.7	0.12	840	42
2-24-59	3,100	76	260	76	1,500	360	110	520	2.3	0.22	930	9.7
3-3-59	2,900	75	220	60	1,500	270	100	430	1.7	0.21	820	53
3-10-59	4,400	120	490	82	1,400	670	110	590	1.4	0.12	900	100
3-17-59	2,800	99	300	58	1,500	380	89	280	1.3	0.24	710	41
3-24-59	2,500	91	360	64	1,100	360	97	330	1.2	< 0.12	640	46
3-31-59	1,800	57	210	48	1,300	210	55	210	1.3	0.098	550	19
4-7-59	4,000	120	690	79	1,300	660	100	530	1.4	0.12	850	77
4-14-59	4,300	130	740	66	1,600	770	110	630	1.7	?	860	91
4-21-59	4,900	120	580	71	1,700	840	110	740	1.5	0.12	840	110
4-28-59	2,200	56	290	44	1,000	370	89	140	2.1	0.18	440	48
5-5-59	4,800	160	640	59	1,600	1,100	100	360	3.5	0.19	300	110
5-12-59	3,100	76	430	36	370	580	100	370	2.5	< 0.29	510	280
5-19-59	4,700	100	710	51	1,400	1,300	110	710	1.6	0.57	770	77
5-26-59	4,700	150	860	46	1,900	1,600	110	680	1.9	< 0.68	930	120
6-2-59	3,100	120	660	32	1,300	1,200	120	490	2.6	0.37	620	91
6-9-59	3,400	140	710	28	1,100	1,100	110	410	2.1	0.60	650	110
6-16-59	3,800	160	640	17	1,100	1,400	92	370	1.6	0.18	540	80
6-23-59	3,900	150	380	26	1,000	1,500	89	430	5.6	1.1	600	25
6-30-59	3,200	140	560	22	830	1,100	70	340	2.3	< 0.35	720	56
7-7-59	4,100	150	600	19	1,300	1,200	79	420	2.0	< 0.58	660	62
7-14-59	3,000	150	400	14	1,200	860	40	260	1.4	< 0.27	490	31
7-21-59	2,000	68	180	14	680	660	40	170	2.0	< 0.27	410	15
7-28-59	2,600	79	260	15	1,700	670	40	490	1.6	< 0.35	380	30
8-4-59	3,400	90	420	19	900	760	40	420	2.0	0.26	360	26
8-11-59	2,600	69	510	18	950	770	44	300	1.6	0.29	400	24
8-18-59	3,500	41	380	18	1,200	650	38	350	1.4	0.29	530	24
8-25-59	2,100	48	380	20	890	460	41	280	0.81	0.23	430	15
9-1-59	2,200	17	300	14	940	420	30	320	1.4	0.25	440	5.4
9-8-59	2,200	34	340	20	1,100	480	29	340	1.1	< 0.16	560	3.9
9-15-59	2,000	20	360	24	950	500	36	310	1.3	0.19	470	7.0
9-22-59	3,100	62	510	34	990	730	55	510	1.6	0.21	590	15
9-29-59	2,600	20	380	49	1,400	590	42	450	2.0	0.27	730	6.2
10-6-59	2,200	36	360	28	940	500	44	360	1.1	0.22	500	9.4
10-13-59	1,700	29	190	37	930	240	29	320	1.5	0.19	510	3.2
10-20-59	3,300	64	450	55	1,300	730	48	550	1.9	<0.30	760	8.2
10-27-59	2,900	56	360	56	1,400	790	53	430	1.5	0.21	630	8.6
11-3-59	1,800	43	230	34	950	300	43	300	1.4	0.22	590	5.9
11-10-59	2,900	56	440	44	1,300	670	56	410	1.2	0.19	760	12
11-17-59	2,900	85	400	40	1,400	630	56	450	1.5	0.16	850	18
11-24-59	5,300	110	590	78	2,400	100	70	750	1.9	0.24	1,200	19
12-1-59	1,800	48	99	34	960	280	51	170	1.4	0.26	450	9.6
12-8-59	2,300	42	300	46	1,300	550	62	280	1.0	0.25	720	8.3
12-15-59	2,100	85	250	51	1,200	290	56	290	1.7	0.16	740	7.4
avg	3100											

NA Not Analyzed

TABLE IV

QUANTITIES OF VARIOUS RADIONUCLIDES IN COLUMBIA RIVER WATER AT VANCOUVER, WASHINGTON - 1959

curies/day

Date	P^{32}	Cr^{51}	Zn^{65}	Np^{239}
6-23-59	19	960	55	400*
7-28-59	3.8	670	<14	67
8-25-59	3.2	750	13	28
9-29-59	8.8	830	< 9	55
10-19-59	16	Lost	--	--
11-3-59	17	1,000	< 8	70
12-1-59	39	2,000	27	200

* Questionable analytical result

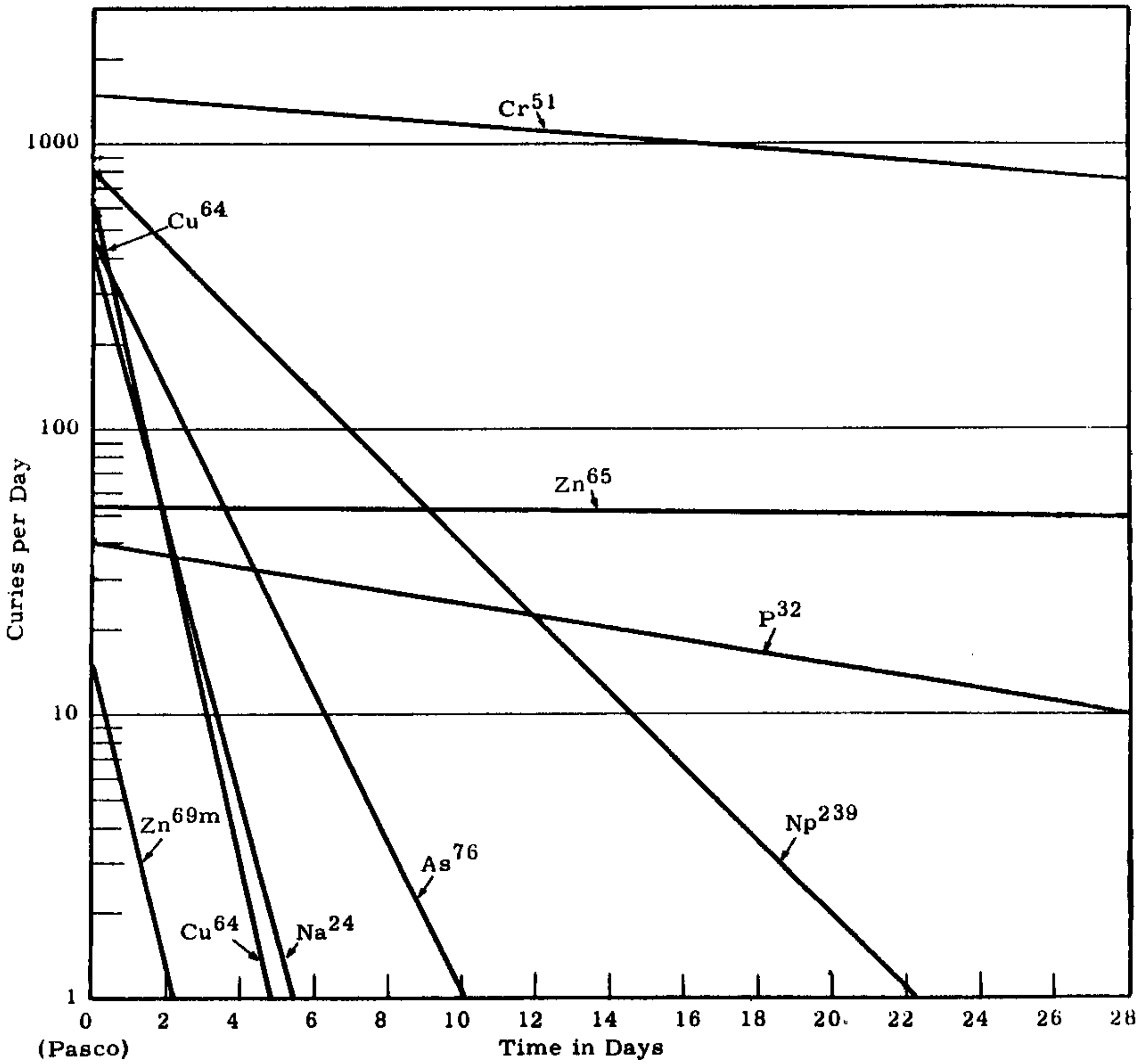


FIGURE 6

Radioactive Decay of Radionuclides
Measured in Columbia River Water at Pasco, Fall, 1959

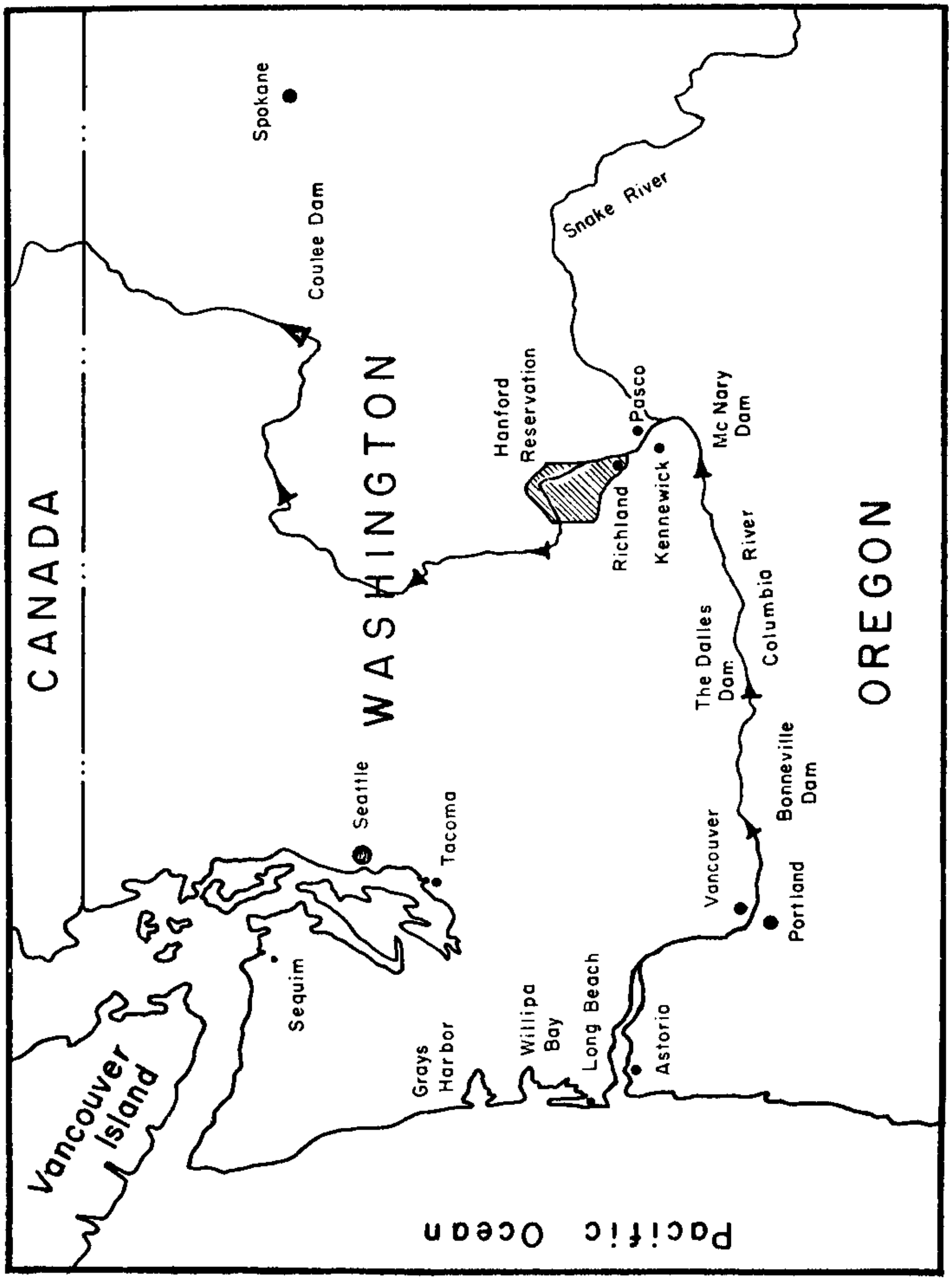


FIGURE 7
Vicinity Map for Pacific Northwest

Although the half lives of Zn^{65} (245 d), Cr^{51} (27 d), and P^{32} (15 d) are long in comparison with most of the other radionuclides of the effluent mixture, they are not so long that the total quantities of these radionuclides in the North Pacific will continue to increase over a period of years. On the basis of the Vancouver measurements the total amount of P^{32} in existence from the reactor effluent amounts to about 400 curies, the amount of Cr^{51} is on the order of 40,000 curies, and the amount of Zn^{65} is about 7,000 curies. The quantities of "fresh" P^{32} and Cr^{51} added to the existing pool now serve only to make up for loss by radioactive decay and there will be no further increase in the total quantities of these radionuclides unless the rate of release in the reactor effluent increases. The equilibrium level for Zn^{65} has also essentially been reached. The Cr^{51}, with a half life of 27 days, is the most abundant isotope downriver from Pasco and, as shown in Figure 6, obviously predominates near the mouth of the river. It should be pointed out, however, that Cr^{51} atoms decay to V^{50} by means of electron capture, a process which releases very little energy. Thus, in spite of its abundance, Cr^{51} contributes very little to the absorbed dose of persons who use the river or its products.

The Np^{239}, which has a relatively high initial abundance, should, perhaps, also be mentioned. Because of its short half life, an equilibrium level is reached in a few days' time and, based on Vancouver measurements, amounts to about 400 curies. Although the Np^{239} decays to Pu^{239}, the half lives of these two nuclides are vastly different (2.3 days versus 24,300 years) and consequently one curie of Np^{239} yields only 0.27 microcurie of Pu^{239}. The potential exposure from Pu^{239} formed in the Columbia River water is thus virtually nil.

EXPOSURE FROM DRINKING COLUMBIA RIVER WATER

As mentioned in the preceding section, the gross quantity of radioactive material in the Columbia should not be taken as an index of the radiation exposure involved. The absorbed dose is dependent not only upon the concentration of particular radionuclides in the water but also upon the energy release of the unstable atoms and upon the uptake and retention of the radionuclides by the body. For the particular mixture of radionuclides in the river at Pasco, estimated exposure from drinking water to the gastrointestinal tract constitutes a greater fraction of the maximum permissible limit than does the calculated exposure to any of the other body organs. The relative contribution to the GI tract dose which is made by individual radionuclides is illustrated in Figure 8. The contributions of the individual radionuclides must, of course, be combined in order to estimate the total dose received. For the twelve-month period shown in Figure 8, the average exposure for anyone who consistently drank untreated water from the river near Pasco would have amounted to about 15 per cent of the maximum permissible exposure for the GI tract (MPE-GI) for persons in the neighborhood of controlled areas. The corresponding calculated rate of intake of the radionuclides contributing exposure to the bone, such as P^{32}, Zn^{65}, and Sr^{89-90}, is about 2 per cent of the maximum permissible rate for persons in the neighborhood of controlled areas.

The concentration of radioelements in the Columbia River, and thus the potential exposure to persons drinking the water, fluctuates seasonally, principally because of variations in river flow. The per cent of the MPE-GI calculated for each month of 1959 is shown in Figure 9. While there are undoubtedly occasions when a few people drink unfiltered water directly from the river, we are not aware of any cases where the raw water is used routinely. A much more realistic approximation of the exposure received by persons who drink water from the river is obtained from measurements made on the sanitary water supplies of Pasco and Kennewick. The effectiveness of the Pasco treatment plant in removing individual radionuclides is indicated in Figure 8,

PERCENT OF MAXIMUM PERMISSIBLE CONCENTRATION
IN COLUMBIA RIVER WATER AND SANITARY WATER
AT PASCO, WASH.

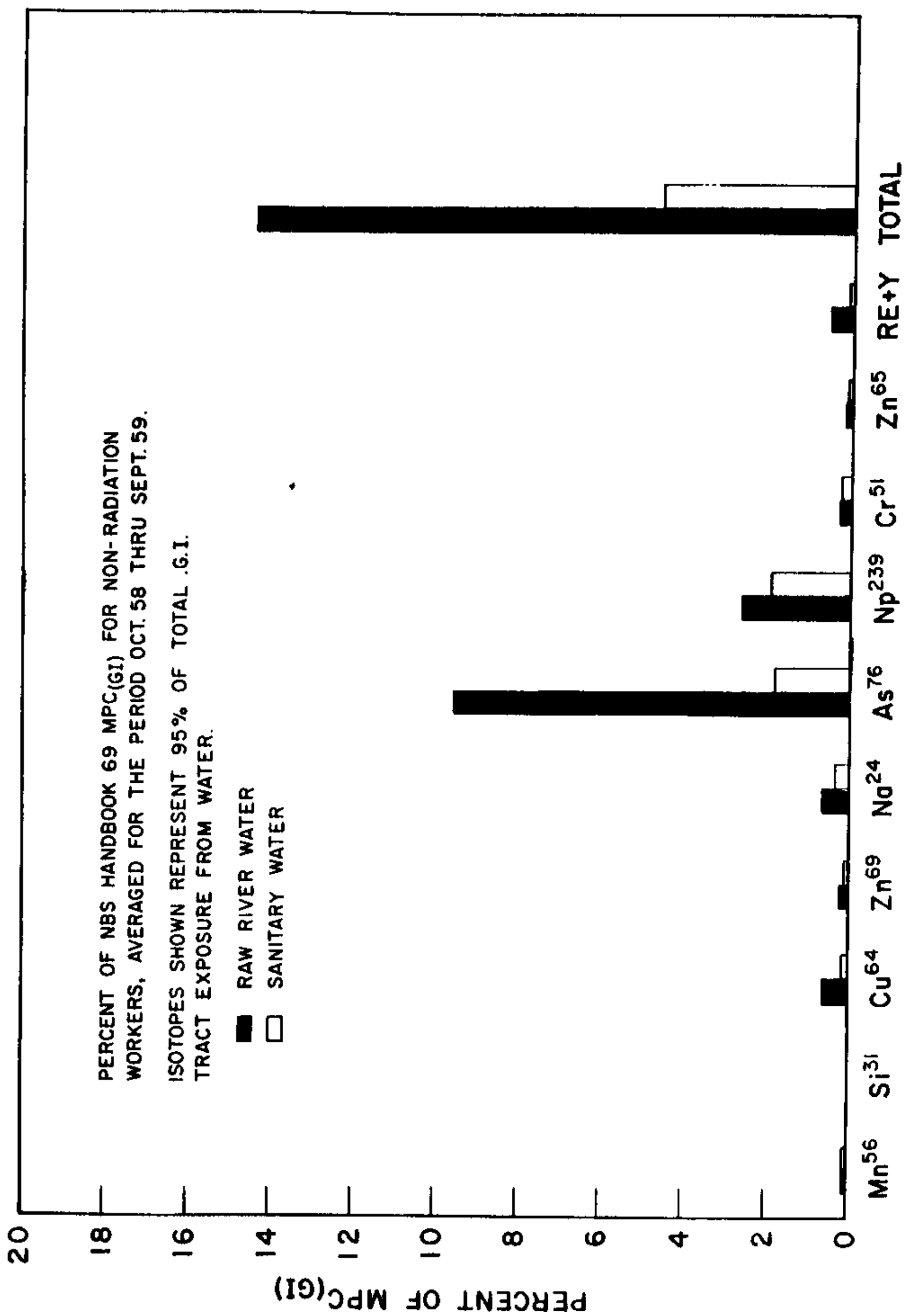


FIGURE 8

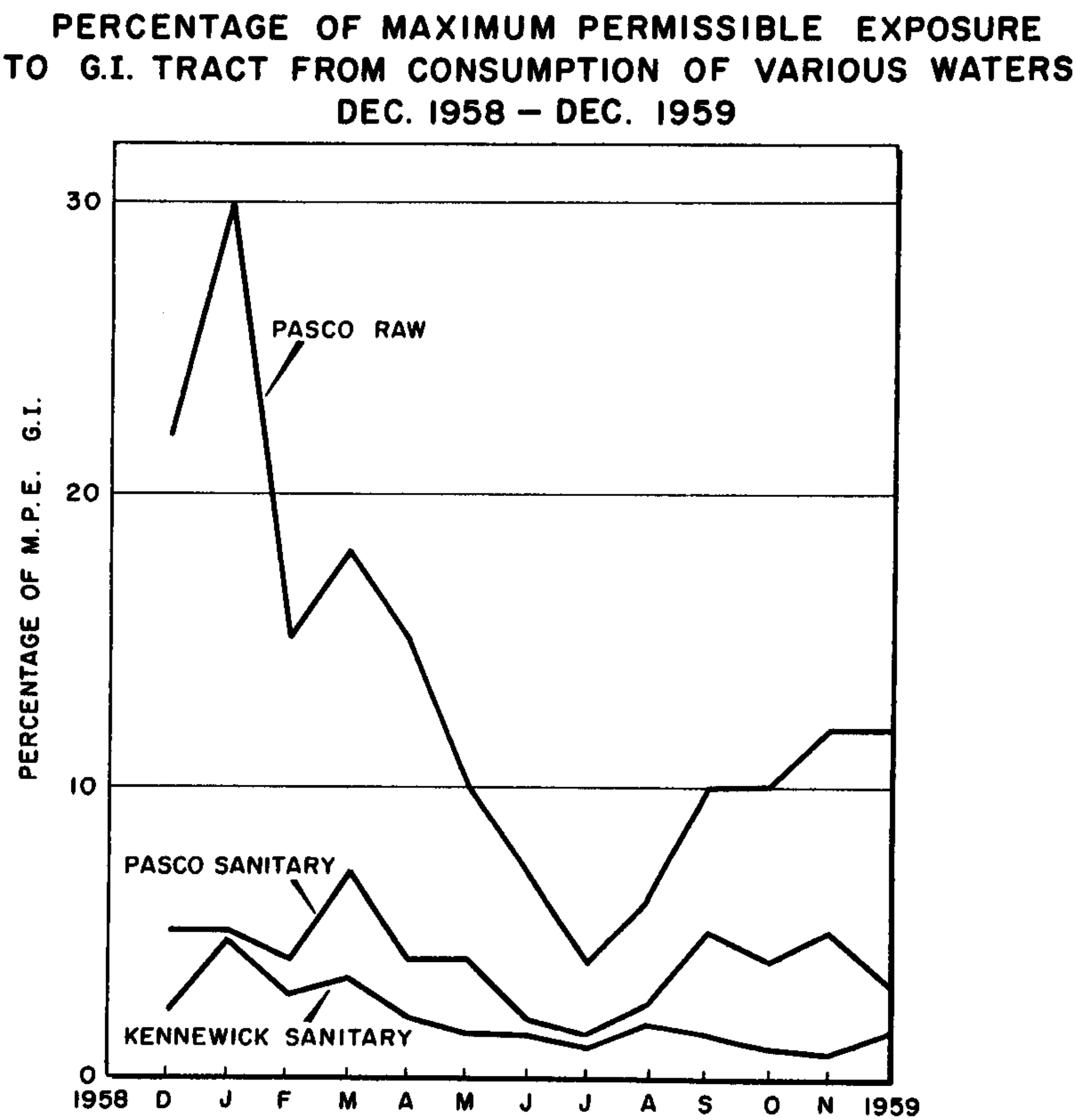

PERCENTAGE OF MAXIMUM PERMISSIBLE EXPOSURE
TO G.I. TRACT FROM CONSUMPTION OF VARIOUS WATERS
DEC. 1958 – DEC. 1959
PERCENTAGE OF M.P.E. G.I.
30
20
10
0
PASCO RAW
PASCO SANITARY
KENNEWICK SANITARY
1958
D
J
F
M
A
M
J
J
A
S
O
N
1959

FIGURE 9

and Figure 9 shows the per cent of the MPE-GI estimated for the sanitary water supplies of Pasco and Kennewick during 1959. For Pasco, the average for the year was about 5 per cent of the MPE-GI. The lower concentrations of radioactive materials in the Kennewick supply reflects lower concentrations of radionuclides in the river water on the Kennewick side of the Columbia attributed to the addition of flow from the Yakima River a few miles upstream. Richland does not obtain its water supply from the Columbia River.

The quantities of short-lived radionuclides which contribute most of the exposure to the GI tract in the vicinity of Pasco diminish rapidly as the river flows toward the Pacific. Applying correction factors for radioacive decay and for dilution to the Pasco measurements for the last half of 1959, one would anticipate that raw river water in the vicinity of Vancouver might contain enough radionuclides to furnish on the order of 1 to 3 per cent of the MPE-GI. Analyses of river water collected at Vancouver during this period (see Table II) indicate that a better estimate would be between 0.2 and 0.5 per cent of the MPE-GI, however. The relative decrease between Pasco and Vancouver for potential exposure to the bone is not as great as in the case of the GI tract because of the longer half lives of radionuclides which contribute to the bone dose. For the second half of 1959 the calculated rate of intake for the radionuclides contributing to the bone dose which might have resulted from consistent drinking of untreated river water at Vancouver amounts to less than 0.8 per cent of the MPC for persons in the neighborhood of controlled areas. Treatment of river water for sanitary use would further reduce the concentration of these radioisotopes.

DIRECT EXPOSURE FROM THE COLUMBIA RIVER

The presence of radioactive materials, particularly gamma emitters, in the Columbia makes the river a low-level source of radiation which provides a slight exposure to persons who spend appreciable time in or near the water, including those engaged in the operation of boats, swimmers, water skiers, and fishermen. Estimates of the exposure which results from such activities are derived with reasonable confidence from measurements made with small ionization chambers which are placed in the river and on boats.

For off-project personnel, maximum external exposure from the river is received in the vicinity of Richland since the major contributors to the dose (Na^{24} is the most important) are short-lived and decay rapidly with time and distance. Measurements indicate an annual exposure of about 60 milliroentgens for persons whose occupations require that they spend about one-third of their time on the water. At least half as much exposure would have been received in a like period of time had the persons been over land rather than the river. The enthusiastic swimmer who spends about 240 hours a year in the water would receive an exposure of about 6 milliroentgens. If the applicable limit for persons in the neighborhood of controlled areas is taken as 500 millirem per year, then these exposures amount to approximately ten per cent and one per cent of the limit respectively.

EXPOSURE FROM THE CONSUMPTION OF FOODS

There are two principal pathways through which radionuclides present in Columbia River water may become incorporated into foods eaten by man. One involves the uptake of certain radionuclides by fish and waterfowl which are harvested by sportsmen and the other the irrigation of farm crops with water pumped from the river. In each case, evaluation of the exposure is not straightforward with respect to maximum permissible concentrations because of the wide variation in diet between individuals and the small fraction of the population involved.

Fish and Waterfowl

The species of fish which are most popular with sportsmen in the vicinity of the Hanford project include: steelhead trout, bass, Rocky Mountain whitefish, salmon, crappie, and sturgeon. Some individuals also fish for suckers and carp. The quantities of the various radionuclides which accumulate in the different species is dependent not so much on their abundance in the water as on the feeding habits of the fish and the utilization of particular radionuclides. The adult salmon, which do not feed after leaving the ocean on their spawning migration, remain virtually uncontaminated. Suckers, which feed directly upon the algae that grows on the rocks of the river bottom, usually contain higher concentrations of radionuclides than species such as bass which obtain the isotopes third or fourth hand via other food organisms. The whitefish is currently considered to be the species which may contribute most to human exposure because of its relatively high accumulation of radionuclides (only slightly less than suckers), and because it is easily caught during the fall at a time when its content of radioactive materials is maximum.

Radionuclides which have been found in Columbia River fish include, in diminishing order of abundance, P^{32}, Na^{24}, Zn^{65}, Mn^{56}, As^{76}, Cu^{64}, Sr^{90}, and Cs^{137} (5, 6, 7). Over 90 per cent of the radioactive material is P^{32} which deposits principally in the hard tissues, such as bone and scales, but is also abundant in visceral organs. Flesh, which is used for food is among the least contaminated parts. Table V shows the concentration of radionuclides which predominate in the flesh of whitefish caught in the Columbia immediately below the reactors at a time when near maximum values occurred.

Marked fluctuations occur in the concentrations of radionuclides in the fish between summer and winter, largely because of changes in the fish's rate of feeding which is related to temperature. Measurements made during the past four years on fish sampled at Ringold are summarized in Figure 10. Ringold is the closest fishing area open to the general public downriver from the reactors. Some whitefish which have accumulated P^{32} within the reservation migrate upstream during the fall and are harvested by fishermen in the vicinity of Priest Rapids. Average concentrations in fish caught in this area are much less than for Ringold, however. Since 1957, samples have been collected at Ringold only during the last quarter

TABLE V

CONCENTRATION OF RADIONUCLIDES IN FLESH OF WHITEFISH COLLECTED NEAR HANFORD - AUGUST, 1957

Isotope	Concentration in $\mu c/g$ wet weight
P^{32}	1×10^{-3}
Na^{24}	1×10^{-4}
Zn^{65}	5×10^{-5}
Co^{60}	1×10^{-6}
Cs^{137}	1×10^{-6}

Data furnished by J. J. Davis; see also reference (7)

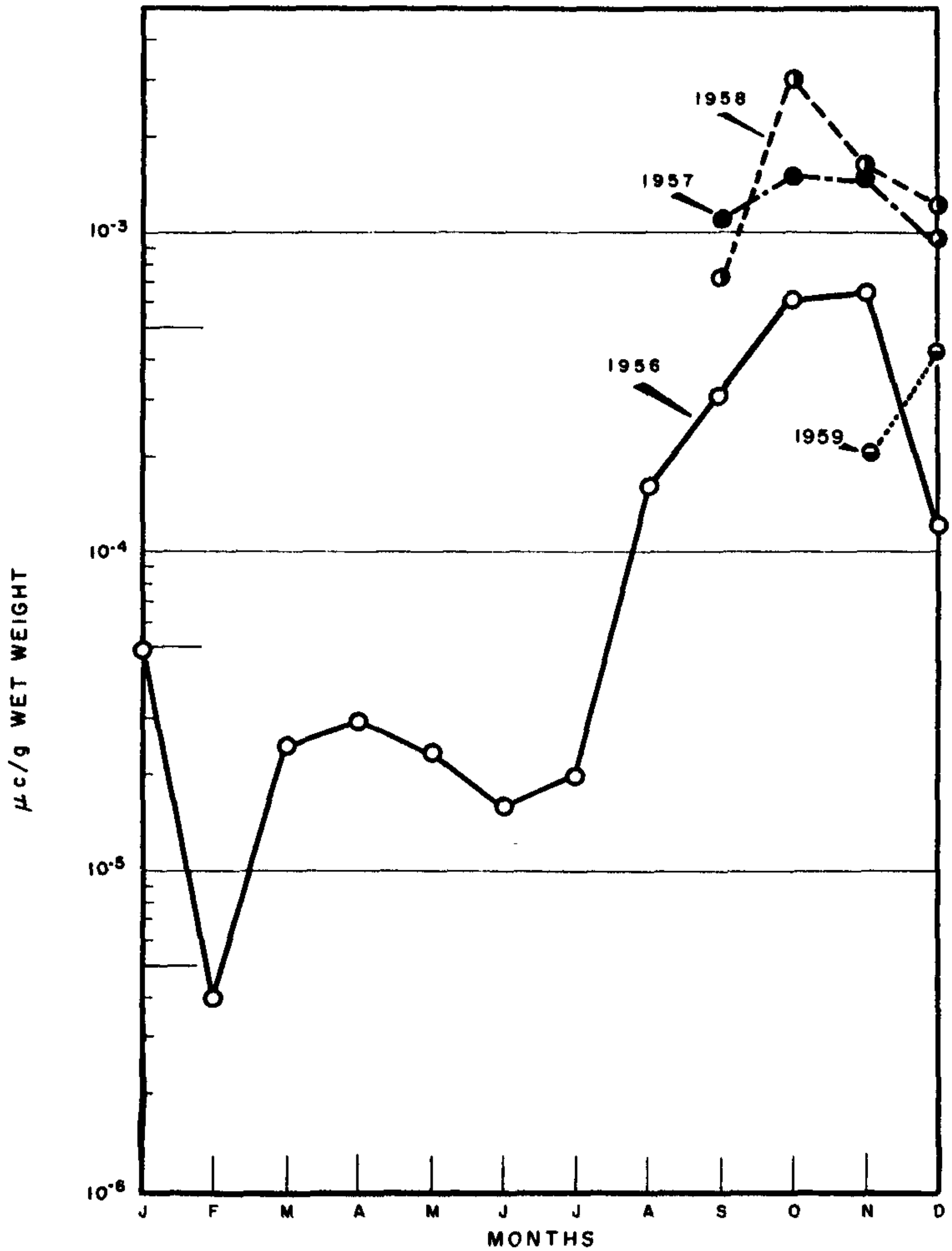


FIGURE 10

Concentrations of Beta Emitters in Muscle of Whitefish at Ringold

[Reproduced with additions from Reference (16)] of the year. Values for 1959 were substantially lower than in the two previous years because of an unusually high flow rate in the Columbia during the last quarter which aided dilution of the effluent. Values for earlier years have been reported by Watson and Davis[5].

In order to estimate the quantity of whitefish flesh which could be consumed repeatedly by a single individual without his body burden of P^{32} exceeding maximum permissible levels, several assumptions are necessary. For the purposes of this report the following assumptions are made for the 1957-58 conditions shown in Figure 10:

(a) That the activity density of the fish followed the expected seasonal trends for the portions of the year when samples were not collected.

(b) That all of the radioactive material emitting beta particles was P^{32}.

(c) That the individual ate only freshly caught fish from the Ringold area and that the same quantity of fish was eaten every week for the entire year.

and (d) That the exposure to the individual from consuming P^{32} contained in fish flesh is equivalent to that received from a like quantity of P^{32} in drinking water.

The maximum permissible concentration for P^{32} in drinking water "for persons in the neighborhood of controlled areas" derived from NBS Handbook 69[8] is 2×10^{-5} $\mu c/cc$ which is equivalent to a daily intake of 4.4×10^{-2} $\mu c/day$. This amounts to about 0.3 μc per week or about 16 μc per year. On the basis of the above assumptions and with averaging over a year's period, this quantity of P^{32} could be obtained from the consumption of about one pound of whitefish flesh each week in years when the average concentration of P^{32} in the fish reaches about 2×10^{-3} $\mu c/g$ of flesh during the late summer or early fall months.

It is considered quite unlikely, but not entirely improbable, that any one person would consume as much as 50 pounds of whitefish caught from the Ringold area during a single year. A reasonable estimate of the average burden of P^{32} in the bodies of individuals who eat whitefish caught at Ringold is probably on the order of ten per cent of the limit.

The concentration of Zn^{65} in the whitefish during the late summer is only about 1/20 of the observed level for P^{32} (Table V). Further, the maximum permissible intake rate for Zn^{65} is 5-fold greater than for P^{32} (Handbook 69). The Zn^{65} thus contributes only a relatively small fraction of the exposure received from the consumption of fish.

The P^{32} content of the flesh of some ducks which are killed along the river within the Hanford reservation is similar to that found in the fish. A comparatively few ducks remain on the river throughout the year so that the accumulation of P^{32} and a few other radionuclides builds up to a level which is in equilibrium with their environment. These ducks are not available to off-project hunters until the fall hunting season at which time their number is diluted 200 to 1000-fold by flocks of ducks which are migrating through the region.

Farm Produce

A few small farms in the Ringold area have irrigation pumps which draw water from the Columbia River. The most significant use of river water for irrigation down-stream from the reactors, however, is a relatively small (about 5,000 acres) district situated just upriver from Pasco and known as Riverview. The occurrence of low concentrations of reactor effluent radionuclides, notably Zn^{65}, in produce of the Riverview district was reported in the 1958 Geneva Conference [7] and more recently by Perkins and Nielsen [9]. Current measurements for this district are summarized in Table VI. Of the ten artificial radionuclides shown in the table, Cr^{51}, Zn^{65}, and Sc^{46} are believed to come principally from the Columbia River water used for irrigation, and the others (fission products)

TABLE VI

MAXIMUM CONCENTRATIONS OF RADIONUCLIDES IN FARM CROPS OF THE COLUMBIA BASIN - 1959

(Units of 10^{-6} μc/gram Raw Weight)

Location			Crop	Reactor Effluent			Fallout and Gaseous Effluents						
				Sc^{46}	Zn^{65}	Cr^{51}	$Zr\text{-}Nb^{95}$	Cs^{137}	$Ru^{103-106}$	I^{131}	$Ce^{141+144}$	Sr^{89}	Sr^{90}
Estimated Detection Limit				0.1	0.1	0.5	0.1	0.05	0.5	0.1	0.5	0.01	0.006
Irrigated with Columbia River Water		Riverview	Cereal	--	2	2	1	--	1	--	4	0.08	0.04
			Vegetables	--	0.9	2	0.1	1.0	0.6	0.1	1	0.03	0.03
			Fruits	--	0.2	0.9	0.2	0.06	--	--	2	0.02	0.007
			Alfalfa-Hay	0.3	8.0	30	9	0.05	3	1	7	0.2	0.03
		Ringold	Cereal	--	4	--	0.9	0.2	1	--	3	0.05	--
			Vegetables	0.2	2	2	0.2	--	0.8	0.6	2	--	--
			Fruits	--	0.1	--	0.1	--	2	--	1	--	0.02
			Alfalfa-Hay	0.2	2	7	0.2	0.2	1	0.6	4	0.07	0.02
Not Irrigated with Columbia River Water	Nearby	Finley	Cereal	--	--	0.8	0.2	0.08	--	--	1.0	*	*
			Vegetables	--	--	--	0.3	--	--	0.3	--	0.02	0.02
			Fruits	--	--	--	0.1	0.07	--	0.2	1.5	--	--
			Alfalfa-Hay	0.2	--	1.2	6.0	0.9	2	4	6	0.07	0.3
		Benton City	Cereal	--	--	--	0.4	0.07	--	--	0.8	0.02	0.03
			Vegetables	--	0.4	--	--	--	--	--	--	--	0.008
			Fruits	--	--	--	0.2	--	--	--	--	0.01	0.008
			Alfalfa-Hay	20	0.2	1	4	0.3	3	0.3	6	0.2	0.1
	Distant	Walla Walla, Spokane, Pendleton, Umatilla	Cereal	--	--	2	1	0.4	3	--	4	*	*
			Vegetables	--	--	0.5	--	--	--	--	--	*	*
			Fruits	--	--	--	--	--	--	--	--	*	*
			Alfalfa-Hay	--	--	--	1	0.3	3	0.5	4	*	*

(--) Indicates no samples above detection limit

* Analyses not completed

originate principally from world-wide fallout with minor contributions from the gaseous effluent of the separations plants. Because of the wide range of values in comparison to the number of samples analyzed, the extremes rather than averages are shown. For virtually every crop and locality, the isotopic content of some samples was below the detection limit. The range is thus between the detection limit and the maximum value shown on Table VI. Zinc-65 and chromium-51 were present in low concentrations in the crops irrigated with Columbia River water but were not detected in significant amounts elsewhere. Cereals and hay (mostly alfalfa) contained larger amounts of Zn^{65} than did the fruits or vegetables. Chromium-51 was higher in alfalfa and hay than in any other type of sample. Irrigation methods are believed to have considerable bearing on the observed concentrations. Some of the Zn^{65} accumulated on the pastures of Riverview and Ringold farms is consumed by cows and appears in their milk. Maximum concentrations in the milk are in the range of 5 to 7×10^{-6} $\mu c/cc$.

The quantities of fission products measured on crops sampled from Riverview and other farming areas near the Hanford project are about the same as in similar crops grown in more remote locations. The radiological characteristics and wide-spread occurrence of these fission products indicates that their principal source is fallout from weapons testing.

The exposure to persons who eat produce from the irrigated farms is difficult to estimate from available information partly because of the variability of the diet between individuals and the wide-spread distribution and seasonal nature of the foods. The Zn^{65} content of a few persons selected from this region has been measured in the new Shielded Personnel Monitoring Station, however. The few results to date suggest that the body burden of most individuals will be considerably less than one per cent of the applicable limit, but that in rare cases the quantity may approach 2 per cent of the limit.

DISTRIBUTION IN THE OCEAN

Some oceanographic study has been made of the circulation of ocean water off the mouth of the Columbia River by the University of Washington, Department of Oceanography [10]. Available information on the dispersion of Columbia River water is perhaps best summarized in the words of Professor Clifford A. Barnes*, of the University of Washington, who states:

> As shown in Figure 7 (reproduced as Figure 11) the effluent of the Columbia in summer extends as a plume southwest of the river mouth and may be detected at distances up to 200 miles or more. South of the mouth of the Columbia at that season upwelled water is present inshore along the Oregon coast. Measurement in other summers, support the picture given as the general summer situation. Strong southerly winds can change this picture, however, and push the effluent water north along the Washington coast. There is some evidence of a northward displacement in the inshore portion of the plume.
>
> The low salinities along the coast from the Strait of Juan de Fuca to the Columbia River I believe to stem in part from both of these sources as well as the local runoff between these two sources. We have not made detailed observations close inshore that would serve to establish the amounts of fresh water contributed by the different sources.
>
> The winter picture I believe to differ significantly from that in summer. In winter southerly winds prevail rather than northerly, such as are found for a good portion of the summer. This would favor transport of an appreciable amount of the Columbia effluent towards the north, close along shore. Although the positive head of the local runoff at that season would tend to keep it out of the bays, the mixing and return flow on flood tide would carry some of the Columbia effluent into the bays. I can put no figure on the amount.

The long-lived radionuclides which have not been depleted from the river water will undoubtedly be dispersed in the ocean in much the same manner as the river water, although the pattern may be altered to some extent by

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* Personal communication to R. F. Foster, dated January 30, 1960.

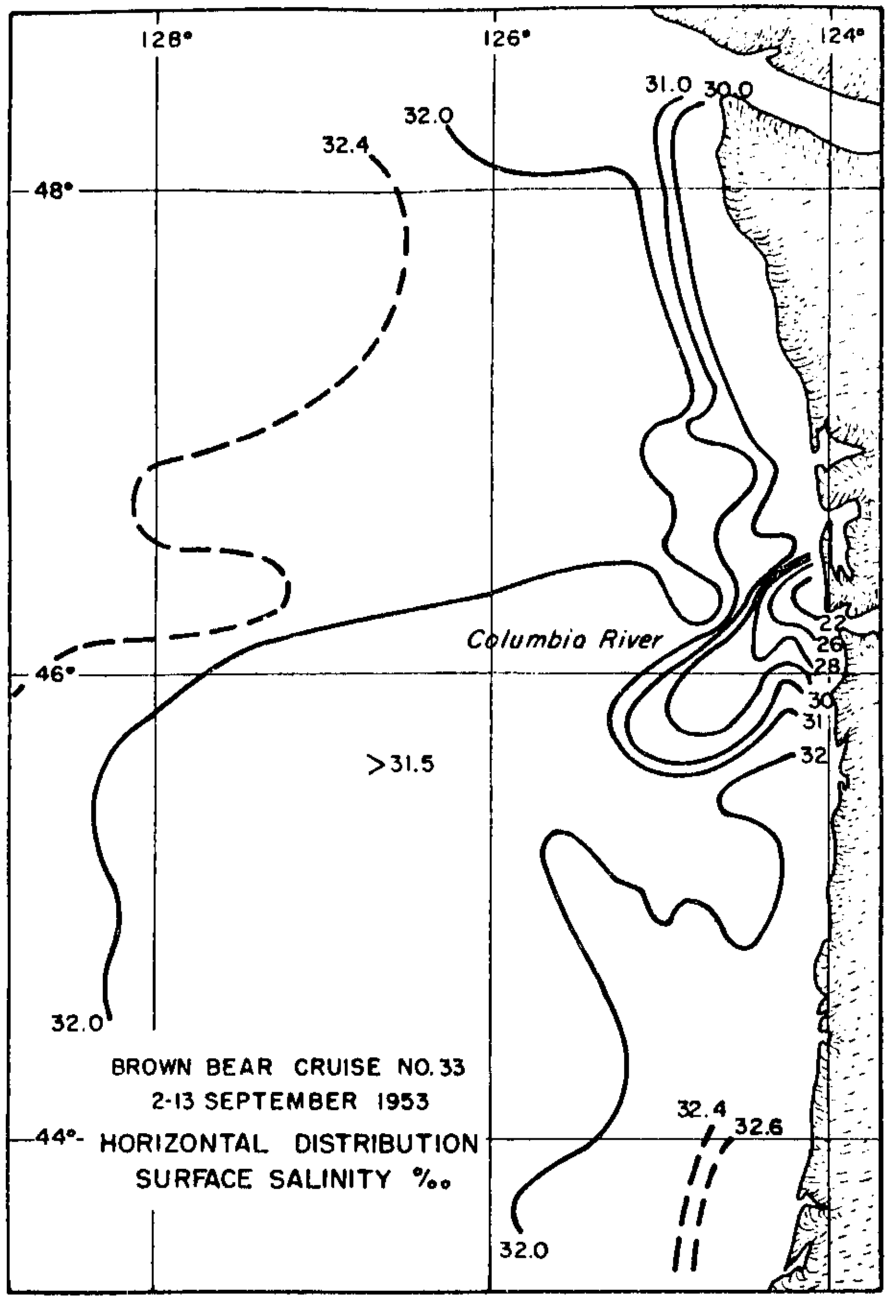

FIGURE 11

Influence of Columbia River Water on Surface Salinity
Near the Washington and Oregon Coasts

[Reproduced from Reference (10)]

removal of the radionuclides from solution by physical, chemical, and biological processes. Once the remaining radionuclides have reached the salt water the most apparent way in which they may contribute further to human exposure is through uptake and concentration in edible marine products.

The possibility of radionuclides from reactor effluent being concentrated by marine organisms has been considered for several years. Limited sampling of fish, shellfish, and other biological materials was carried out near the mouth of the river in the fall of 1953, 1954, 1955, 1956, 1957, and in the spring of 1959. Prior to 1957, the samples were analyzed only for gross beta activity since counting rates were not substantially above the detection limits of equipment on hand. With the availability of gamma-ray spectroscopy, isotopic analyses were made on the samples collected in 1957 and 1959. A detailed report of these measurements is being prepared by the Radioecology Operation* but some of the more pertinent results are included in Table VII.

A major part of the gross beta emitters detected in the organisms collected near the mouth of the river appears to be P^{32}, but this is probably not the case in more remote locations. As one might expect, the Cr^{51} was found only at or near the river mouth and in low concentrations. The Zn^{65} is the radionuclide which has been detected in greatest amounts in marine organisms, particularly oysters, at considerable distances from the river mouth.

The occurrence of Zn^{65} in marine organisms of the Pacific is not a new observation. Following Operation Castle, Zn^{65} formed a high percentage of the activity in fish collected in the vicinity of Bikini and Eniwetok for at least two years(11), and was identified by the Japanese as a principal contaminant in skipjack and other pelagic fish(12). The marked uptake of Zn^{65} by marine plankton, fish, oysters, and other shellfish has also been measured under laboratory conditions(13, 14). More recently(15) Zn^{65} has been reported

* This is to be issued as Document HW-63402, "Gamma Emitting Radioelements in Marine Organisms from the Coasts of Washington and Oregon," by D. G. Watson, J. J. Davis, and W. C. Hanson.

TABLE VII

REPRESENTATIVE CONCENTRATIONS OF RADIOISOTOPES IN MARINE ORGANISMS ALONG THE WASHINGTON COAST - SPRING, 1959

Location	Organism	Gross Beta (Concentration in $\mu c/g$)	Cr^{51} (Concentration in $\mu c/g$)	Zn^{65} (Concentration in $\mu c/g$)
Mouth of Columbia	Salmon (entire)	7×10^{-5}	1×10^{-6}	2×10^{-7}
	Flounder (entire)	5×10^{-5}	--	1×10^{-7}
	Crab (flesh)	1×10^{-4}	1×10^{-7}	1×10^{-5}
Long Beach	Razor clam (soft parts)	*	1×10^{-7}	1×10^{-6}
Willapa Bay	Oyster (soft parts)	2×10^{-5}	--	5×10^{-5}
Sequim (near entrance to Puget Sound)	Oyster (soft parts)	2×10^{-5}	--	4×10^{-6}
	Clams (soft parts)	1×10^{-5}	--	1×10^{-6}
	Crab (entire)	2×10^{-6}	--	3×10^{-7}

(--) indicates below detectable limit.

* indicates no measurement.

Data supplied by J. J. Davis of the Radioecology Operation in oysters of Chesapeake Bay and in other food products of the eastern part of the United States. Nevertheless, the concentration of Zn^{65} in oysters grown in Willapa Bay (about 5×10^{-5} $\mu c/g$) would appear to be substantially higher than in oysters of Chesapeake Bay (about 2×10^{-7} $\mu c/g$) or in other oyster producing areas remote from the Columbia River*.

Since Willapa Bay is the closest commercial oyster-producing area north of the Columbia River, the Zn^{65} content of shellfish grown in this area may be of some interest in reference to various standards. NBS Handbook 69 recommends 10^{-3} $\mu c/cc$ as the maximum permissible concentration of Zn^{65} in drinking water for occupational exposure, which is equivalent to a sustained intake of about 2.2 $\mu c/day$. Using this and an average concentration of 5×10^{-5} μc Zn^{65} per gram of oyster as a basis for computation, the following relationships are derived:

Premise	Sustained consumption rate to give exposure of premise
Occupational Exposure - Handbook 69	700 pounds/week
Persons in the neighborhood of controlled areas(1)	70 pounds/week
Suggested ICRP apportionment for genetic dose(2)	7 pounds/week
Doubling of natural background(3)	14 pounds/week

It should be stressed that these values are for sustained consumption and that the maximum permissible body burden associated with these rates will be reached only if intake is continuous for three years or more.

(1) Taken as 0.1 of values recommended in Handbook 69.

(2) Taking 0.01 of the Handbook 69 value as equivalent to an exposure of 1.5 rem to the gonads in 30 years. It should be noted that the ICRP apportionment for genetic reasons assumes that the entire population is exposed at this level. The oysters in this case contribute to only a very small fraction of the total population.

(3) Assumes that a continuous intake rate of 2.2 $\mu c/day$ results in 5 rem/year to the body and that the natural background is 100 mrem/year.

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* A very few samples of commercially packed oysters from the Pacific Coast, the Gulf of Mexico, and Japan have recently been analyzed by J. M. Nielsen and R. W. Perkins of the Radiological Chemistry Operation.

The accumulation of radionuclides in edible marine products has received considerable attention by the National Academy of Sciences Committee on Biological Effects of Atomic Radiation on Oceanography and Fisheries. Such accumulation has been taken into account by special working groups of this committee which have been concerned with "Radioactive Waste Disposal from Nuclear-Powered Ships" [18] and "The Disposal of Radioactive Wastes into the Atlantic and Gulf of Mexico Coastal Waters of the United States"[19]. A third working group is preparing a report which deals with the disposal of radioactive wastes into the waters of the Pacific Coast of the United States. In order to estimate the rates of disposal of radionuclides which would be appropriate for various marine environments, the working groups have found it necessary to make certain assumptions concerning the fraction of the total exposure to populations which might reasonably be apportioned to marine products, the consumption rate of marine products by persons dependent upon the sea for their protein, and the concentration of various radionuclides in marine products which might result from lower concentrations in the sea water. In the absence of direct measurements on the radionuclide of interest, estimates of its concentration factor between the sea water and the organism have been based on the ratio of the concentration of the stable element in the organism to that in the sea derived from published data.

The lowest values for the concentration of Zn^{65} and P^{32} to be derived from tables published thus far by this committee [18, 19] are 2×10^{-7} μc Zn^{65}/ml and 5×10^{-9} μc P^{32}/ml. This committee is currently considering an alternate method for estimating the concentrations of radionuclides in sea water which might result in maximum permissible concentrations in marine products. Use of the alternate method would lead to a considerably lower concentration of Zn^{65} in sea water than shown above. If such an approach receives wide acceptance and results in the adoption of limits for sea water, then the emphasis on sampling may need to be switched from the marine products which are consumed by man, to the sea water which serves only as an intermediate step in transport of the radionuclides to the organisms. It should be noted that the concentration of Zn^{65} and P^{32} in the Columbia River water in the vicinity of Vancouver, Washington, is currently on the order of 5×10^{-8} $\mu c/ml$ and that this has not resulted in important concentrations in river organisms.

RECOMMENDATIONS FOR ADDITIONAL STUDIES

A critical review of the status of our knowledge on possible exposure to populations or ocean contamination indicates the desirability of obtaining additional information on several facets. One must bear in mind that all sources of exposure must be considered in order to evaluate the significance of the contribution from any particular source. The presence of reactor effluent in the Columbia River cannot, therefore, be considered independently of the other sources in any complete appraisal. The over-all environmental monitoring program at Hanford is presently being reviewed in relation to current needs and recommendations for revisions will be made separately. Because this report relates only to exposures which may result from the effluent, the recommendations presented below are confined to this specific area and are not intended to cover other sources of radiation.

In the Tri-City area, the local fish and waterfowl are the materials which are most apt to provide off-project exposures approaching permissible limits. Since the exposures which result from the consumption of these materials is dependent not only upon the contamination levels, but also upon the amount eaten, the dietary habits of persons eating local fish must also be known in order to use this method of estimating the dose received. No information on the quantities eaten has been obtained for the residents of the Tri-City area and thus, this facet of the evaluation is based largely on personal conjecture. A survey of the eating habits of persons who obtain fish and waterfowl from this section of the Columbia River should be undertaken in order to firm up our present estimates of exposure from this source. The collection of such information might well be included in a much broader survey of the dietary habits of persons in this region designed to improve evaluation of exposure received not only from fish but other food products grown in the region as well. The participation of other qualified governmental agencies or institutions in the conduct of such a survey is believed desirable.

Direct measurement of the burden of radionuclides in the bodies of persons who eat large amounts of locally harvested fish and produce would be preferable to estimates made indirectly from assumed consumption rates. The new Shielded Personnel Monitoring Station can provide excellent estimates of the body burdens of some isotopes, particularly the gamma emitters, and persons of the Tri-City area who are apt to have obtained higher-than-average burdens of isotopes from Columbia River water should be scheduled for measurement in this faciltiy. For direct estimates of the body burdens of beta emitters, such as P^{32}, assay of body structures or products would appear to offer greater promise of definitive results and should be further explored.

Of the few long-lived isotopes which are present in sufficient quantity at the mouth of the river to warrant special attention, Zn^{65} would appear to be the most important because of its marked uptake by shellfish. At the present time, our knowledge of the retention of this (and other isotopes) in the river is known only in a general way. More precise information is needed on the fraction released from the reactors which reaches the river mouth, the travel times involved, and the sites of accumulation in river sediments, if this proves important.

Precise information is not available on the extent of mixing of river water with the sea water at the mouth of the river or the fraction of the Zn^{65} entering the Pacific which may be transported close to shore along the Washington and Oregon coasts and thus available to marine products harvested in these areas. A short-term study should be made of this region by an oceanographic group adequately equipped with the survey vessels and gear necessary for such work.

More complete monitoring of oysters and other edible marine products harvested in the vicinity of the river mouth should be carried out in order to define seasonal fluctuations in contamination levels and variations between the principal areas of production. Sampling of oysters over a wide geographical area should be continued in an effort to appraise the significance of the Columbia River to the Zn^{65} content of the marine products along the Washington and Oregon Coasts. There is also need for more identification of the beta emitters detected in the marine products near the river mouth, and a special search made for Co^{60}.

Special sampling of shellfish, sea, and brackish water should be carried out in selected areas over a period of several months in order to attempt to establish a relationship between the Zn^{65} content of the water and the shellfish. Use should be made of the Shielded Personnel Monitoring Station to measure the Zn^{65} content of a few persons known to be heavy consumers of marine products harvested from near the mouth of the river. Such measurements would obviate the use of multiple assumptions which can lead to overstatement of the exposure.

With the exceptions of the oceanographic survey and the dietary survey which might reasonably be assigned to other qualified institutions or agencies, the Hanford Laboratories organization is not only well equipped to carry out the work outlined in this report but is much interested in doing this as a logical part of the radiological program associated with the operation of the plant. It should be possible to obtain the needed information with only minor additions to our existing work force.

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