THE UNIVERSITY OF MICHIGAN

Lake Michigan Environmental Survey

JOHN C. AYERS

Special Report No. 49
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Great Lakes Research Division

FINAL REPORT

LAKE MICHIGAN ENVIRONMENTAL SURVEY

by

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PREFACE

STATION LOCATIONS

The 50 lake-sampling stations of the Lake Michigan Environmental Survey followed the lay-out of lake-monitoring stations that the University of Michigan's Great Lakes Research Division has followed fairly consistently since 1962. Of these the A-line (Benton Harbor, Mich., to the Chicago region), the C-line (Holland, Mich., to Racine, Wis.) and the E-line (Frankfort, Mich., to Kewaunee, Wis.) have been occupied most consistently, for experience showed that the B-line and the D-line were not necessary to adequate biological and chemical representation of the lower (southern) two-thirds of the lake.

For the Lake Michigan Environmental Survey all five (A through E) of the original lines of stations were reactivated, with some local changes of station positions, and the following additions were made: F-line from Big Rock near Charlevoix to Manistique, Mich.; EF-line (between the E- and F-lines) from Manitou Passage, Mich., to Porte des Mortes Passage, Wis.; CD-line (between the C- and D-lines) from White Lake, Mich., to Port Washington, Wis.; and the single station AB-1 (between the A- and B-lines) off Glencoe, Ill. The added lines and station were adjudged necessary to provide a suitable coverage of all those waters that are properly Lake Michigan: north of the F-line seiche (wind tide) action can introduce Lake Huron water into what is geographically Lake Michigan.

As mentioned at the beginning of the above paragraph, some stations of the original 5 lines have been relocated within what is functionally the same locality. Such relocated stations carry their original letter and number designation, but the number is primed, i.e.: A-6', B-7'. Each of the nuclear plant sites is considered to be a part of a line of stations, and each bears an unused equivalent station designation: COOK = A-1', BAILLY = A-7', PAL (Palisades) = B-1', ZION = B-8', KEW (Kewaunee) = E-6', PTB (Point Beach) = E-7', and BRK (Big Rock) = F-1'. There are, in these survey stations, no stations A-2 or A-2' nor E-1 or E-1'.

The station relocations reported above have been largely for order and for convenience. It is, however, vital to report the following station relocations that were forced upon us by nature.

Our original plan and proposal envisioned, in front of each nuclear plant,

at 1 mile perpendicular to shore, a station which should be both a part of the lake-wide surveys and a part of the plant's local detailed surveys in order that the local surveys would be tied to the lake-wide conditions.

We were forced, by conditions of no capturable benthos or unsampleable bottom or both, to relocate the following plant-site stations farther off shore: BAILLY, to 2 miles off shore, sediment sampleable but little or no benthos; KEW, to 3-1/2 miles off shore, sediment hard and unsampleable and little or no benthos; PTB, to 4 miles off shore, sediment hard and unsampleable and little or no benthos. At the relocated stations both sediment and benthos can be obtained in the required quantities.

Our present and past evidence indicates that at KEW and PTB the inshore condition consists of migrating gravel bars travelling over a basic bottom of hard red clay. We consider the relocation off shore to be necessary if reliable benthos and sediment samples are to be gotten.

It is here noted for the record that sediment station F-6 is apparently traversed by waves of clean coarse sand (sampled on 1 September) which, when absent, leave cobbles that cannot be adequately sampled (2 November). When sediment samples could be obtained at this station they were taken.

The stations of the survey are tabulated below by station designation, distance off shore (in the cases of the nuclear plant sites), the latitude N and longitude W, and the station type.

Each of the station locations are indicated on the included orientation chart of Lake Michigan.

Stations of Lake Michigan Environmental Survey

Station	Position	Station type
COOK (1 mile off shore)	41°58.3', 86°35.5'	Complete station
A-3	42°05.9', 86°43.5'	Sediment "
A-4	42°03.5', 87°06.5'	Complete "
A-5	41°57.5', 87°19.0'	Sediment "
A-6'	41°48.2', 87°13.0'	Sediment "
BAILLY (2 miles off shore)	41°40.5', 87°08.0'	Complete "
AB-1	42°08.3', 87°33.0'	Complete "
PAL (1 mile off shore)	42°19.3', 86°20.4'	Complete "
B-2	42°24.0', 86°27.0'	Sediment "
B-3	42°24.0', 86°35.5'	Sediment "
B-4	42°23.5', 87°01.5'	Complete "
B-5	42°22.9', 87°21.0'	Sediment "
B-6	42°22.3', 87°30.0'	Sediment "
B-7'	42°24.4', 87°38.0'	Sediment "

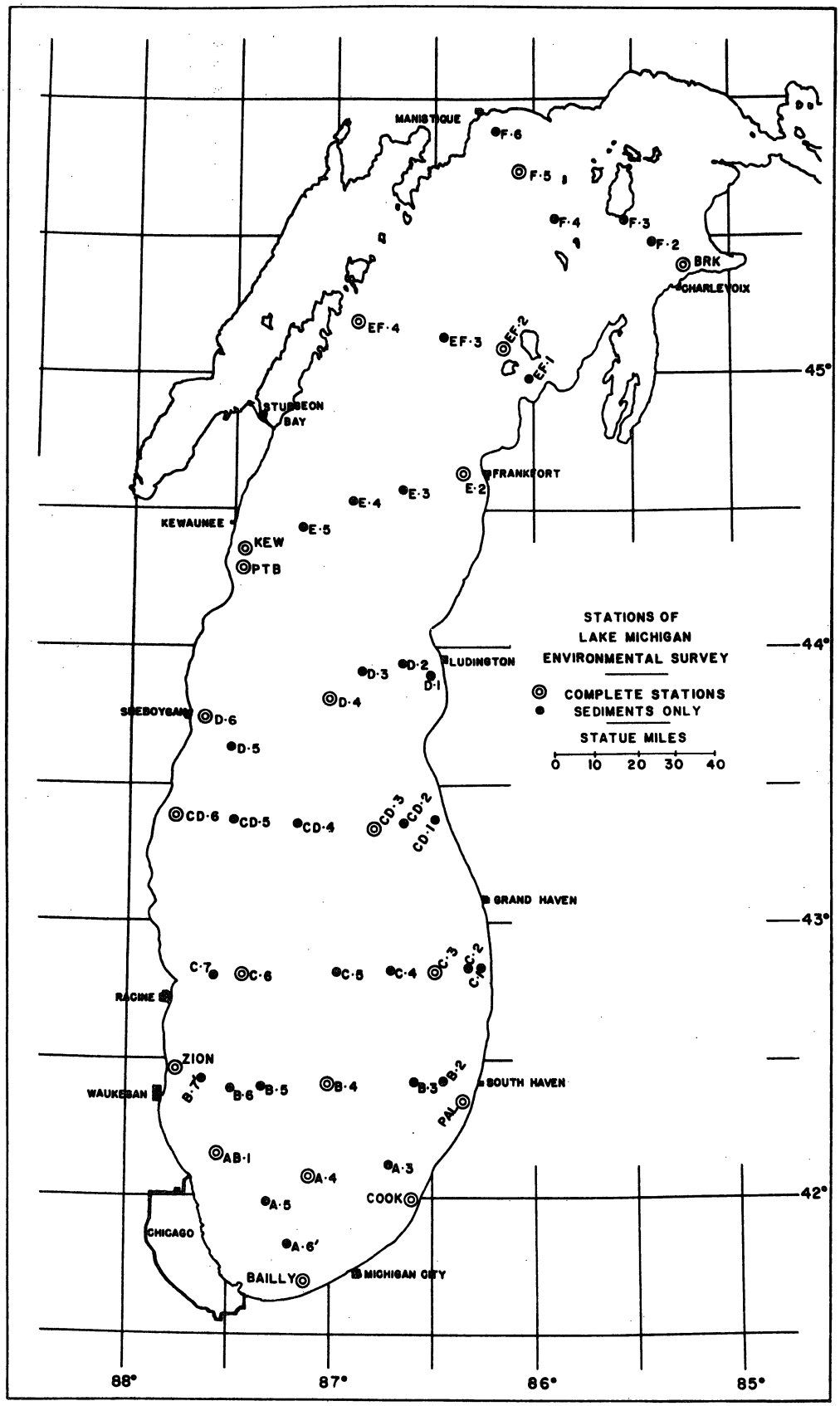
ZION	(1 mile off shore)	42°26.5', 87°46.9'	Complete	"
C-1		42°48.8', 86°15.4'	Sediment	"
C-2		42°48.8', 86°18.8'	Sediment	"
C-3		42°48.6', 86°29.0'	Complete	"
C-4		42°48.4', 86°43.0'	Sediment	"
C-5		42°48.1', 86°59.0'	Sediment	"
C-6		42°47.4', 87°26.8'	Complete	"
C-7		42°47.2', 87°35.0'	Sediment	"
CD-1		43°21.8', 86°29.3'	Sediment	"
CD-2		43°20.9', 86°39.2'	Sediment	"
CD-3		43°29.8', 86°47.7'	Complete	"
CD-4		43°20.7', 87°10.4'	Sediment	"
CD-5		43°21.4', 87°29.5'	Sediment	"
CD-6		43°22.2', 87°46.8'	Complete	"
D-1		43°55.8', 86°30.2'	Complete	"
D-2		43°55.9', 86°38.5'	Sediment	"
D-3		43°54.1', 86°51.2'	Sediment	"
D-4		43°48.0', 87°01.3'	Complete	"
D-5		43°37.5', 87°31.0'	Sediment	"
D-6		43°43.9', 87°39.2'	Complete	"
E-2		44°37.0', 86°20.0'	Complete	"
E-3		44°34.0', 86°39.9'	Sediment	"
E-4		44°31.4', 86°54.8'	Sediment	"
E-5		44°25.4', 87°10.2'	Sediment	"
KEW	(3-1/2 miles off shore)	44°20.3', 87°27.4'	Complete	"
PTB	(4 miles off shore)	44°17.0', 87°27.2'	Complete	"
EF-1		44°58.5', 86°01.5'	Sediment	"
EF-2		45°05.5', 86°09.0'	Complete	"
EF-3		45°07.5', 86°27.0'	Sediment	"
EF-4		45°10.4', 86°51.8'	Complete	"
BRK	(1 mile off shore)	45°22.5', 85°12.2'	Complete	"
F-2		45°28.6', 85°23.3'	Sediment	"
F-3		45°33.6', 85°32.1'	Sediment	"
F-4		45°33.6', 85°53.4'	Sediment	"
F-5		45°44.0', 86°03.2'	Complete	"
F-6		45°52.7', 86°11.8'	Sediment	"

CRUISE DATES

Each survey station was sampled three separate times between 21 August 1969 and 11 June 1970. The dates during which the three sampling cruises were conducted are listed below.

First Cruise (initial sampling)

21-22 August, 1969--outfitted R/V MYSIS.
23 August-10 September, 1969--completed stations on lines CD, D, E, EF, F.
2-18 October, 1969--completed all survey stations not taken between 23 August-10 September with the exception of station C-5.


MANISTIQUE
F·6
F·5
F·4
F·3
F·2
BRK
CHARLEVOIX
EF·4
EF·3
EF·2
EF·1
45°
STURGEON BAY
FRANKFORT
E·2
E·3
E·4
KEWAUNEE
E·5
KEW
PTB
STATIONS OF
LAKE MICHIGAN
ENVIRONMENTAL SURVEY
COMPLETE STATIONS
SEDIMENTS ONLY
STATUE MILES
0 10 20 30 40
44°
D·3
D·2
D·1
LUDINGTON
D·4
SHEBOYGAN
D·6
D·5
CD·6
CD·5
CD·4
CD·3
CD·2
CD·1
GRAND HAVEN
43°
C·7
C·6
C·5
C·4
C·3
C·2
C·1
RACINE
ZION
WAUKEGAN
B·7
B·6
B·5
B·4
B·3
B·2
SOUTH HAVEN
PAL
AB·1
A·4
A·3
A·5
COOK
42°
CHICAGO
A·6'
BAILLY
MICHIGAN CITY
88°
87°
86°
85°

Second sampling cruise

25 October-6 November, 1969--reoccupied all stations in northern portion of lake with the exception of station EF-4.

7-11 November, 1969--completed the second sampling of stations C-5, C-4, C-3, C-2, C-1, B-4, B-3, B-2, and PAL before the end of the 1969 field season.

25 April-4 May, 1970--completed second sampling with the taking of stations A-3, COOK, A-4, A-5, A-6', BAILLY, AB-1, B-5, B-6, B-7', ZION, C-6, and C-7.

Third sampling cruise

7 May-11 June, 1970--all survey stations were reoccupied for the third time.

RESUME OF SAMPLES

Of the 100 stations planned for the summer and fall of 1969, 85 were taken. Of these 85 station samples, 34 were complete stations at which we collected: sediments for radioactivity (R), for neutron activation (NA), and for atomic absorption analysis (AA); water for R, NA, and AA (the NA and AA were Millipore filtered); phytoplankton for R, NA, AA, and for biologic count and identification (Biol.); zooplankton for R, NA, AA, and Biol.; and benthos for R, NA, AA, and Biol. A sediment sample for R was taken at each station with the exception of station F-6 which could not be sampled on one occasion (giving a total of 84 R samples). There would have been 34 samples of each of the remaining samples had bad weather not necessitated the pooling of all but the Biol. samples from stations KEW and PTB (giving a total of 33 samples for each parameter other than the Biol. portion which was collected from both the KEW and PTB locations and therefore totaled 34). One bottle of NA water leaked away reducing this total to 32.

During the spring 1970 cruises the 13 stations not occupied for the second time during the 1969 field season were taken twice to produce the station total of three separate samples.

The remaining 37 stations which had been occupied twice during the 1969 field season were occupied for the third time during the spring 1970 cruise with the exception of stations E-4 and E-5 which were cancelled due to bad weather. This gave a total of 61 sample stations taken during the spring 1970 cruise from which 25 stations supplied a complete spectrum of samples with the exception of station PTB from which no samples of phytoplankton, zooplankton, or benthos were secured for R, NA, and AA analysis (giving a total of 24 samples for these parameters). This portion of the PTB station was again combined with

station KEW for sampling continuity.

Following is a summary of the samples collected during both the 1969 and 1970 field seasons:

Water:

	Stations 1969		1970		Total samples
R	33	+	25	=	58
NA	32	+	25	=	57
AA	33	+	25	=	58

Sediments:

R	84	+	61	=	145
NA	33	+	25	=	58
AA	33	+	25	=	58

Phytoplankton:

R	33	+	24	=	57
NA	33	+	24	=	57
AA	33	+	24	=	57
Biol	34	+	25	=	59

Zooplankton:

	Stations 1969		1970		Total samples
R	33	+	24	=	57
NA	33	+	24	=	57
AA	33	+	24	=	57
Biol	34	+	25	=	59

Benthos:

R	33	+	24	=	57
NA	33	+	24	=	57
AA	33	+	24	=	57
Biol	34	+	25	=	59

Seston (particulate matter) from water (AA analysis):

Millipore filters from 4 liters of water at each station
33 stations (1969) + 25 stations (1970) = 58 total samples

Fish:

6 collections of sculpins R
2 purchases of locally-caught perch fillets R
1 purchase of locally-caught chubs R

Birds:

1 Sea-gull R

Contingency Samples:

2 bags of benthos
33 + 25 = 58 bottles (2-liter) of raw water

Blanks (for controls on analyses):

distilled water
nitric acid

Total collections (exclusive of contingency samples and blanks):

Water	98	+	75	=	173
Sediments	150	+	111	=	261
Seston	33	+	25	=	58
Phytoplankton	133	+	97	=	230
Zooplankton	133	+	97	=	230
Benthos	133	+	97	=	230
Fish	9	+	0	=	9
Birds	1	+	0	=	1
	690				1192

CHAPTER A

LAKE MICHIGAN RADIOLOGICAL SURVEY

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SUMMARY

This chapter describes the history of radioactive materials in Lake Michigan, reports on the present (1969-1970) radioactivity content of the lake, and forecasts the situation in 1975. The primary radionuclides in Lake Michigan are of natural origin and from fallout. The radioactivity contributed so far by Big Rock Nuclear Power Plant is much less than one percent of the total activity in the lake water. The most important natural radionuclides in the water are potassium-40 as a dissolved salt and carbon-14 as the inorganic carbonate ion. In 1970, tritium, cesium-137, strontium-90, and yttrium-90 activity from fallout of nuclear detonations exceeds the activity in water from natural or other man-made sources. Natural radium, thorium, and potassium, and the cesium-137 from fallout are the chief radioelements in the sediment.

The University of Michigan Great Lakes Research Division collected 370 samples of water, sediment, zooplankton, phytoplankton, benthic organisms, and fish for analysis of their radioactivity content. Only 5 of 49 water samples had cesium-137 concentrations greater than the minimum detectable level of 3.5×10^{-9} uCi/ml for a 2000 ml sample. Four of the five water samples with cesium-137 were in the southern part of the lake. Zinc-65 was detected above the minimum detectable level of 8×10^{-9} uCi/ml in 8 water samples out of 49 scattered throughout the lake. The highest concentration of zinc-65, 32×10^{-9} uCi/ml, was at the Big Rock Point sampling station. The average cesium-137 activity in sediment was 1.4×10^{-6} uCi/g dried weight. There is no significant trend of cesium-137 levels with depth of sampling although the levels are somewhat higher at mid-depths (170' to 350') than in shallow or deep regions. The average concentrations of radium-226 (with thorium-232) and potassium-40 in sediment were 1.6×10^{-6} uCi/g and 15×10^{-6} uCi/g dried weight, respectively. Cesium-137 and zinc-65 activities were detected in benthos and

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phytoplankton but not in zooplankton samples. In 7 samples of fish analyzed for their radioactivity content, cesium-137 and zinc-65 were detected at approximately the same concentration, 3×10^{-7} uCi/g wet weight. This indicates that the food chain reconcentration of zinc-65, of which there is so very little in the lake, is much larger than the reconcentration of cesium-137. The present concentrations of zinc-65 and cesium-137 in water are far below their respective public maximum permissible concentrations in water.

In 1975 the amounts of natural radionuclides in water and sediment should be the same as those found at the present time. Similarly the radioactivity in Lake Michigan from fallout will be approximately the same in 1975 as it is now, so long as there are no further atmospheric detonations. There will be additional fallout into the lake but this activity will be offset by radioactive decay of that activity presently there. By the end of 1975, nine power reactors will have generated approximately 1.8×10^{8} MWe-hr electric power on the shore of Lake Michigan. If the rates of release of radioactivity to the hydrosphere from these nine reactors are similar to those reported at the two newest and largest pressurized water reactors, Connecticut Yankee and San Onofre, then an additional 300 curie gross beta-gamma activity and 180,000 curie tritium will be distributed throughout Lake Michigan. These projected releases of radioactivity will increase the radioactivity concentration of Lake Michigan by 0.06×10^{-9} uCi/ml gross beta-gamma activity above an ambient concentration of approximately 3×10^{-9} uCi/ml. The tritium from the reactors will add 4×10^{-8} uCi/ml, to the present of 20×10^{-8} uCi/ml.

In conclusion, man-made radioactivity in Lake Michigan at present is predominantly tritium, strontium-90, yttrium-90, and cesium-137. The tritium and most of the strontium-90 and yttrium-90 are in the water environment. We estimate that two-thirds or more of the cesium-137 is in the sediment. Zinc-65 can be detected in a few samples of fish, water, and other biological organisms, but it is at levels which are several orders of magnitude less than the values which might be harmful to man.

INTRODUCTION

Lake Michigan is the third largest in surface area of the Great Lakes and is the only one that lies wholly in the United States. The bottom of Lake Michigan is divided into five areas: South Basin, Divide, North Basin, Straits Area, and Green Bay.[1]

The South Basin extends from a line connected Milwaukee, Wisconsin, and Grand Haven, Michigan, to the southern tip of the lake.[2] Of the ten reactors scheduled presently for the lake, six will be located within the South Basin.[3,4] The five areas of Lake Michigan and the locations of the ten nuclear power stations are shown in Figure A-1. The Kewaunee Nuclear Power Plant and the two Point Beach units are to be located in the North Basin, whose bottom is irregular in shape and is the deepest area of the lake. Big Rock Nuclear Power Plant, the only operating reactor on the lake, discharges heat and radioactivity into the Straits area of the lake.

The purposes of this chapter are: to describe the history of radioactive materials in Lake Michigan, to report on the present (1969-1970) radioactivity content of the lake, and to estimate what the situation will be by 1975.

RADIOACTIVITY IN LAKE MICHIGAN

Natural Sources

There are a number of natural radionuclides present in Lake Michigan. Eisenbud[5] states that of the 340 natural isotopes, approximately 70 are radioactive. The most abundant primordial radionuclides are K-40, Rb-87, Th-232, U-235 and U-238.[6] Of their daughter products, Ra-226, Rn-222 and Pb-210 have sufficiently long half-lives to have been found in the aquatic environment.[5-9] In addition to the primordial nuclides and their daughters, an important group of natural radionuclides is produced by cosmic ray interaction with the stable nuclides N-14, O-16, and Ar-40 of the atmosphere.[7,9] The most fully studied of these natural activation products are H-3 and C-14.[5,6,7]

The average potassium content of Lake Michigan is 1.3 mg/l.[10] Of the three potassium isotopes, only K-40 is unstable and decays with a half-life of 1.3×10^9 years.[5] The fractional content of K-40 in natural potassium is 0.012 percent.[6] From these figures one finds that the average concentration of K-40 radioactivity in Lake Michigan is 1.1×10^{-9} uCi/ml.[11]

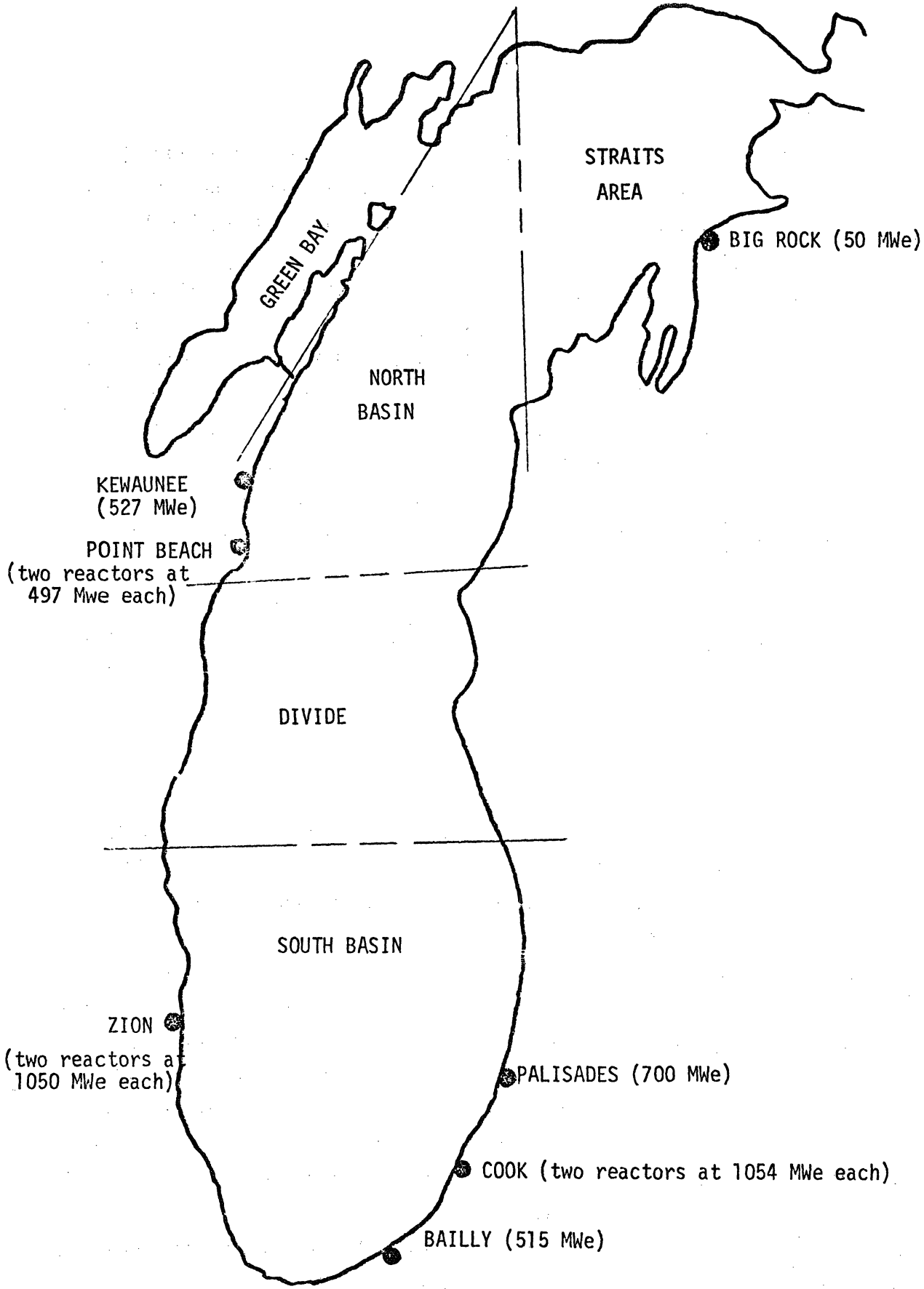


Figure A-1. Lake Michigan showing the locations of ten nuclear power Stations.

Thorium-232, U-235, U-238, Ra-226, and Rn-222 are naturally occurring alpha particle emitters.[7] Risley[12] in 1962 found that 97 percent of the gross alpha analyses of Lake Michigan water contained less than 3×10^{-9} uCi/ml. Eisenbud,[5] in a summary of Ra-226 in public water supplies in the United States, reported that Chicago public drinking water, which is drawn from Lake Michigan, contained 2.4×10^{-11} uCi/ml of Ra-226 in 1953. In 1958, Lucas[13] found that the same water supply contained 3×10^{-11} uCi/ml of Ra-226. Holtzman[8] reported that the Pb-210 content of Lake Michigan was 3×10^{-12} uCi/ml. Data for uranium and Rn-222 in Lake Michigan are not known to us. Radon-222 activity in surface waters is highly variable[5,7] and often unreported. The uranium content of fresh waters generally vary up to 10 parts per billion (10^{-8} g/ml), or 3×10^{-9} uCi/ml.[6]

The principal reactions which produce tritium are high energy (E > 100 Mev) proton spallation reactions, and the N-14 (n,t) C-12 and O-16 (n,t) N-14 reactions with secondary neutrons.[14] The natural concentration of tritium before large scale weapon testing in 1952, was 6 to 20×10^{-10} uCi/ml.[15] In 1953 Kaufman[16] reported that the H-3 concentration in Lake Michigan was 1.7 H-3 atoms per 10^{18} hydrogen atoms. Smith[15] gives 3.3×10^{-9} as the conversion factor from H-3 atoms per 10^{18} H atoms to uCi/ml, so the tritium concentration in Lake Michigan in 1953 was $56. \times 10^{-10}$ uCi/ml.

The natural C-14 content of carbon is reported to be $7.4 \pm 2.7 \times 10^{-6}$ uCi per gram of carbon.[5] Natural C-14 in Lake Michigan therefore depends on the inorganic and organic content of the water. The concentration of inorganic carbon (as CO_2, H_2CO_3, NCO_3^-, CO_3^{2-}) is 24 mg/l[44], this is equivalent to an inorganic C-14 concentration of 1.6×10^{-10} uCi/ml. The average concentrations of suspended and dissolved organics in Lake Michigan are 1.1 mg/l and 4.9 mg/l, respectively.[42] If it is assumed that 50% of the organic matter is carbon,[43] then the organic C-14 concentration is 0.2×10^{-10} uCi/ml.

In summary, the natural radionuclides and their concentrations in the water of Lake Michigan are C-14 (0.2×10^{-9} uCi/ml), K-40 (1.1×10^{-9} uCi/ml), Ra-226 ($.03 \times 10^{-9}$ uCi/ml), Pb-210 ($.003 \times 10^{-9}$ uCi/ml), H-3 (5.6×10^{-9} uCi/ml), and gross alpha activity (less than 3×10^{-9} uCi/ml).

Fallout from Nuclear Detonations

In this section gross beta, Sr-90, Cs-137 and H-3 activity in Lake Michigan from fallout of nuclear detonations will be reviewed.[17-22] Table A-1

Table A-1

Gross Beta Radioactivity in Surface Waters of Great Lakes (excluding tritium)[23]
(10^{-9} uCi/ml)

Year of Measurement	Superior[a]	Michigan	Huron[d]	Erie	Ontario
1959	-	-	-	15.1[e]	-
1960	-	0.6[b]	-	2.7[e]	2.1[g]
1961	-	5.6[b]	-	5.8[e]	5.3[g]
1962	8.0	12.9[c]	14.4	21.7[e]	20.5[g]
1963	10.0	13.4[c]	14.4	28.3[f]	24.6[g]
1964	6.2	-	11.0	7.3[f]	6.4[h],13.5[g]
1965	5.1	-	-	7.3[f]	4.4[h]
1966	3.0	-	-	-	-
1967	2.8	-	-	3.0[f]	-
1968	3.5	-	-	-	-

a. FWPCA, Duluth, Minn.
b. FWPCA, Sault St. Marie, Mich., Gary, Ind., and Milwaukee, Wisc.
c. FWPCA, Gary and Milwaukee.
d. FWPCA, Detroit and Pt. Huron, Mich.
e. FWPCA, Buffalo, N. Y.
f. New York State Surface Water Program, Niagara Falls.
g. NYSW, Oswego, N. Y.
h. NYSW, Messena, N. Y.

summarizes the gross beta radioactivity (excluding tritium) for the surface water of Lakes Superior, Michigan, Huron, Ontario and Erie. The gross beta concentration of natural origin is less than 2×10^{-9} uCi/ml, thus most of the gross beta activity in Table A-1 is from fallout.

One noticeable trend in gross beta radioactivity in the lakes is the increase in concentration as one moves from Lake Superior to Lake Ontario. Generally, the concentrations in Lake Superior are the lowest, Lakes Ontario and Erie are the highest, and Lakes Michigan and Huron are somewhere in the middle. The concentrations in the lakes are highest in 1963, one year after the United States ceased atmospheric testing.

Estimates of Sr-90 deposition in the Great Lakes region were obtained from soil samples and precipitation collections at various collection stations.[17,18] Table A-2 gives the data for Argonne, Illinois, which were used to estimate Sr-90 deposition in Lake Michigan. In Table A-3 the Sr-90 deposited before 1956 was estimated by subtracting the deposition for 1956-1962 given in Table A-2, from the 43 mCi/km^2 "probable" total deposition to December 31, 1962 reported by the Federal Radiation Council.[24]

The Sr-90 activity in Column 2 of Table A-3 was corrected for decay to 1970 and to 1975. The sums of Columns 3 and 4, respectively, are estimates of the total Sr-90 in Lake Michigan in 1970 (3570 Ci) and 1975 (3330 Ci).

Machta[25] reports that the Sr-90 concentration in the water of Lake Michigan in 1964 and 1965 was approximately 9×10^{-10} uCi/ml and 8×10^{-10} uCi/ml, respectively. Table A-4 shows that the concentration of Sr-90 in lake Michigan in 1965, 8×10^{-10} uCi/ml, accounts for most of the Sr-90 deposited upon the surface of Lake Michigan to that time. Machta also concluded that the tributaries contributed little Sr-90 to the total amount in the lake and that the sediment held little Sr-90. His data also show that thermal stratification of the lake may influence the surface water concentration of Sr-90. (Figure A-2)

In secular equilibrium with Sr-90 in Lake Michigan is its daughter product, Y-90. Both Y-90 and Sr-90 emit beta particles, but no gamma photons. Therefore, the contribution to gross beta activity in the lake from Sr-90 is doubled when one considers its daughter Y-90.

The estimates of Cs-137 deposition were taken from reference 19 for the years 1956 through 1966. In Table A-5, cesium-137 deposition in the years before 1956 and after 1966 were estimated by multiplying the Sr-90 deposition (Table A-3, Column 2) by 1.6, the measured Cs-137/Sr-90 ratio in air.[18] On

Table A-2

Strontium-90 Deposition in Great Lakes Region[17,18]
(mCi/Km^2-yr)

Year of deposition	International Falls, Minn.	Argonne Ill.	Green Bay Wisc.	Pittsburgh Pa.
1956	-	0.50	-	-
1957	-	2.24	-	-
1958	-	4.83	-	0.92
1959	4.08	4.41	4.60	4.91
1960	0.90	1.09	0.95	7.53
1961	1.85	2.18	1.93	1.73
1962	8.04	6.89	7.19	2.80
1963	22.22	14.82	12.78	10.80
1964	8.88	11.02	9.11	9.77
1965	4.56	4.24	4.93	1.24
1966	1.35	1.42	1.70	1.58
1967	0.86	1.17	0.90	9.40
1968	0.87	0.90	1.36	9.08

TABLE A-3

Strontium-90 Deposition on Surface of Lake Michigan[17,18]

Year of deposition	Activity (Ci) in year of deposition	Activity (Ci) corrected for decay to 1970**	Activity (Ci) corrected for decay to 1975***
Before 1956	1220*	785	680
1956	29	20	18
1957	130	94	85
1958	280	209	180
1959	256	195	170
1960	63	49	44
1961	126	101	90
1962	400	327	290
1963	860	725	630
1964	640	550	480
1965	246	217	190
1966	82	74	67
1967	68	63	56
1968	52	50	44
1969	(51)	50	44
1970	(49)	49	43
1971	(48)	-	43
1972	(47)	-	43
1973	(46)	-	43
1974	(45)	-	43
1975	(43)	-	43
Totals	4382	3568	3326

* the difference between the total "probable" deposition in "wet" areas to Dec. 31, 1962[24] [43 mCi/km^2] and the activity in each year from 1956 to 1962.

() Fallout after 1968 assumed to be $D_t = D_{1968} \times e^{-\lambda(t-1968)}$.

** $D = D_t e^{-\lambda (1970-t)}$

*** $D = D_t e^{-\lambda (1975-t)}$ t = 1952 for deposition before 1956.

Table A-4

Inventory of Strontium-90 in Lake Michigan in 1965

A. Sr-90 in hydrosphere = 8×10^{-13} Ci/l x 1.7×10^{14} ft^3 x

$$28.3 \frac{\text{liter}}{ft^3} = 3850 \text{ Ci}$$

B. Sr-90 in precipitation corrected for decay to 1965 (from Table A-2)

	mCi/km^2
before 1956	15.20
1956	0.40
1957	1.83
1958	4.07
1959	3.80
1960	0.96
1961	2.00
1962	6.40
1963	14.10
1964	10.80
1965	4.24

Total 63.80 x 5.8×10^4 km^2 surface area

= 3700 Ci.

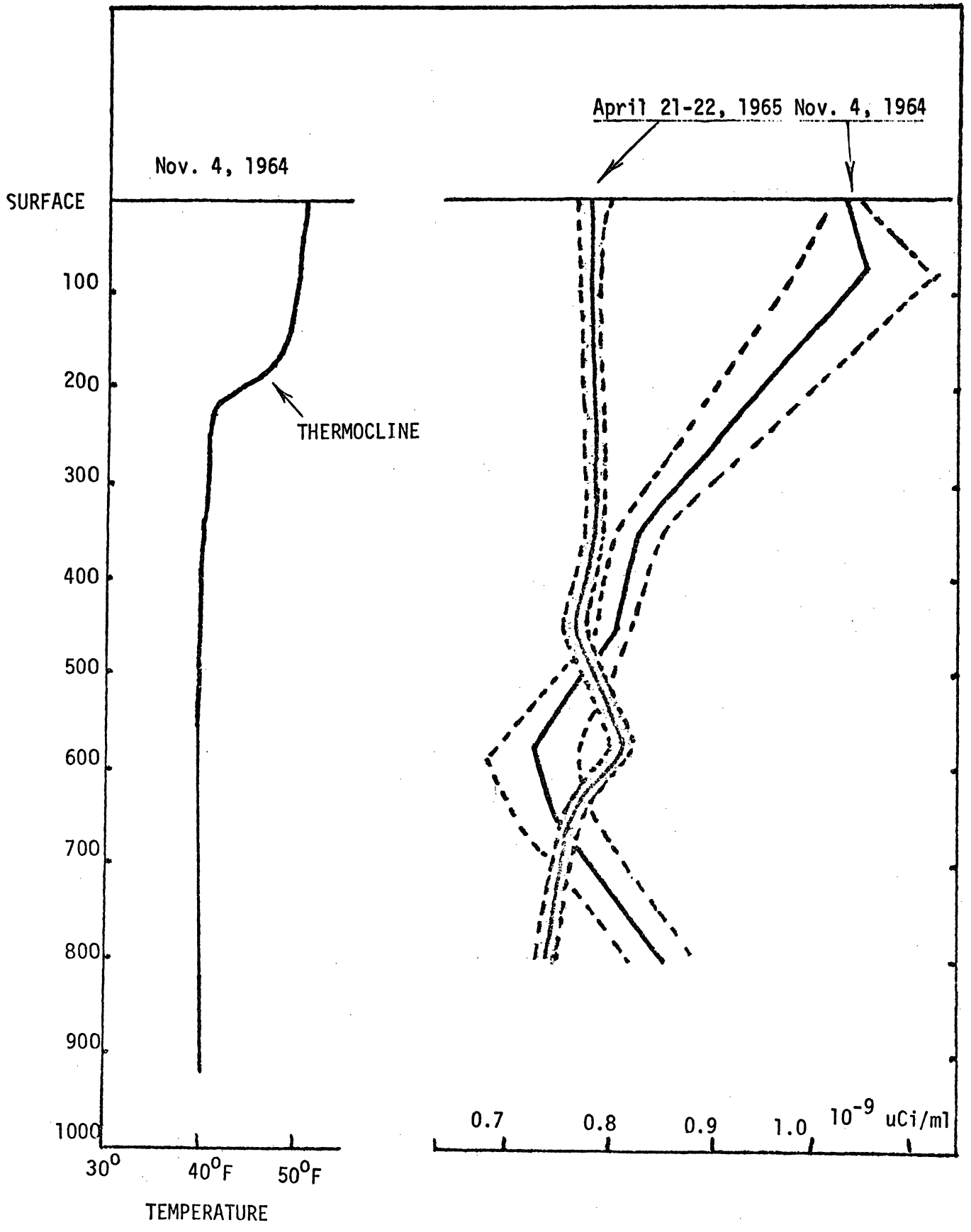


Figure A-2. Vertical Profile of Strontium-90 Concentration in Lake Michigan[25]

Table A-5

Cesium-137 Deposition on Surface of Lake Michigan[19]

Year of deposition	Activity (Ci) in year of deposition	Activity (Ci) corrected for decay to 1970	Activity (Ci) corrected for decay to 1975
before 1956	1950*	1300	1145
1956	172	126	111
1957	250	190	162
1958	450	330	300
1959	580	450	400
1960	116	92	80
1961	185	150	130
1962	750	630	560
1963	1250	1080	950
1964	860	750	650
1965	405	355	320
1966	155	145	128
1967	110*	103	90
1968	82*	79	70
1969	(81)	79	70
1970	(78)	78	70
1971	(77)		70
1972	(76)		70
1973	(73)		70
1974	(72)		70
1975	(70)		70
Totals	7843	5937	5786

* 1.6 x Sr-90 in Table 2.[17]

() Fallout after 1968 assumed to be $D_e = D_{1968} e^{-\lambda (t-1968)}$

this basis, the estimated Cs-137 in Lake Michigan in 1970 is 5940 Ci and in 1975, 5790 Ci. The estimated concentration of Cs-137 in Lake Michigan at the present time is 1.2×10^{-9} uCi/ml (5940 Ci/4.8×10^{18} ml), excluding losses to sediment or to lake outflow.

Tritium is formed from ternary fission in atomic weapons at the rate of 0.7 Ci per kiloton of TNT explosive yield; the yield for fusion weapons is 6,700 Ci/kT.[14] To date, approximately $1,700 \times 10^{6}$ Ci of H-3 have been contributed to the environment from weapon testing.[14] Much of this tritium is oxidized to water and removed from the troposphere by precipitation.[21,22] The concentration of H-3 in precipitation is not constant, but swings from a peak level in the spring to a low level in the winter.[20,22] The maximum H-3 content in precipitation, 3×10^{-5} uCi/ml, occurred in the spring and early summer of 1963 in northwestern Canada.[22] Since then the H-3 concentration has been decreasing continuously. Recently (1968), snow at the Dresden reactor contained 5×10^{-7} uCi/ml.[26]

There are no specific figures for the concentration of tritium in Lake Michigan. The Public Health Service found in 1968 that the H-3 concentrations in water downstream from large nuclear installations ranged between 2×10^{-7} to 10^{-5} uCi/ml.[14,23] Kahn reports that the concentration of H-3 in the Illinois River at the Dresden reactor in 1968 was $2 \pm 2 \times 10^{-7}$ uCi/ml.[26]

Big Rock Nuclear Power Plant

Big Rock Nuclear Power Plant, a boiling water reactor owned and operated by the Consumers Power Company, is the only operating power reactor on Lake Michigan. This plant has released 33.1 Ci of gross beta-gamma radioactivity into Lake Michigan from 1962 to 1968.[30] Occasional analyses have indicated that most of this activity has consisted of Zn-65, Co-58, Cs-137, Ba-140 and La-140. In 1968, 7.5 Ci of gross beta-gamma activity was discharged. If this were also true for 1969 and 1970, the total radioactivity released to date is some 50 Ci gross beta-gamma activity. It is estimated that the maximum quantity of tritium that could have been released during 1968 is 34 Ci.[30] Thus, the H-3 released to Lake Michigan since the plant went critical in 1962 can scarcely exceed 300 Ci.

Reported Concentrations in Tributaries and Biota

Tributaries

A paper by Risley[12] constitutes the only available data on radioactivity in the lake's tributaries. His data, reproduced in Table A-6, show that the total average gross beta radioactivity (suspended plus dissolved solids) in 24 major tributaries in 1963 was 1.5×10^{-8} uCi/ml. This is the average of the last column in Table A-6. Typically, seasonal variations in fallout and water drainage led to a range of concentrations, the highest level often times being 2-3 times the lowest. However, the average concentration of total gross beta activity, 1.5×10^{-8} uCi/ml, compares favorably with the gross beta concentration found in Lake Michigan in 1963 (refer to Table A-1).

Risley also monitored gross alpha radioactivity, reproduced in Table A-7, in the tributaries.[12] Except for seven rivers on the Michigan side of the lake, between Traverse City (Boardman River) and Muskegon (Muskegon River), the gross alpha activity in tributaries reflected lake concentrations (refer to Section II.A of this paper). Risley was not able to explain the higher gross alpha levels in the seven Michigan rivers. He did, however, attribute all the gross alpha activity to natural sources.

Mortimer[31] reports the outflow of water from Lake Michigan is approximately the same as the runoff from its drainage basin. It appears therefore, that the quantity of fallout and natural radioactive materials lost from the lake to Lake Huron is roughly balanced by the gain in fallout and natural activity from the tributaries.

Plankton

Radioactivity levels in plankton were also measured by Risley.[32] In 1962-1964 samples were collected from throughout the lake by towing a 20-mesh plankton net from near the bottom to the surface. His data indicate that most plankton had gross beta levels of less than 2×10^{-4} uCi/g of ash. However, at the entrance to Green Bay and the shoreline of Michigan from Ludington to Frankfort, the gross beta levels in plankton went as high as 5×10^{-4} uCi/g of ash. Isoconcentration contours from Risley[32] for gross beta in plankton are reproduced in Figure A-3.

Fish

The State of Michigan Water Resources Commission, Water Quality Division[28] has measured radioactivity in fish collected near Big Rock Nuclear Power Plant.

Table A-6

Lake Michigan tributaries-1963. Average Gross Beta Radioactivity in 10^{-9} uCi/ml (14)

RIVER	Spring TSβ	Summer TSβ	Fall TSβ	Winter TSβ	Avg SSβ	Avg DSβ	Avg TSβ
Sheboygan		14	13		2	11	13
Manitowoc	26	11	10	18	3	13	16
Branch	27	13	9	37	7	15	21
Duck Creek	18	37	36	66	6	34	39
Oconto		17	11	12	2	12	14
Peshtigo		14	13		1	13	13
Menominee		17			5	12	17
Ford	15	15	6	8	1	10	11
Escanaba	18	14	8	5	3	7	11
Rapid	11	17	16		2	13	14
Whitefish		8	5		1	5	6
Manistique		10	11	11	2	9	11
Black	5	6	2	7	1	4	5
Boardman	10	9	4	6	3	5	7
Manistee	10	10	27	15	8	8	15
Little Manistee	18	8		5	6	4	10
Big Sable	35	8	16	6	12	5	17
Pere Marquette	16	12	10	11	7	6	12
White	10	25	9		9	6	15
Muskegon	64	36	15	11	23	10	32
Grand	20	19	15	13	4	12	17
Kalamazoo	16	16	12	17	6	9	15
St. Joseph	15	12	17		6	8	15
Burns Ditch	11	12	12	15	5	7	12

TS = Total solids

DS = Dissolved solids

SS = Suspended solids.

Table A-7

Lake Michigan tributaries-1963. Average Gross Alpha Radioactivity in 10^{-9} uCi/ml[14]

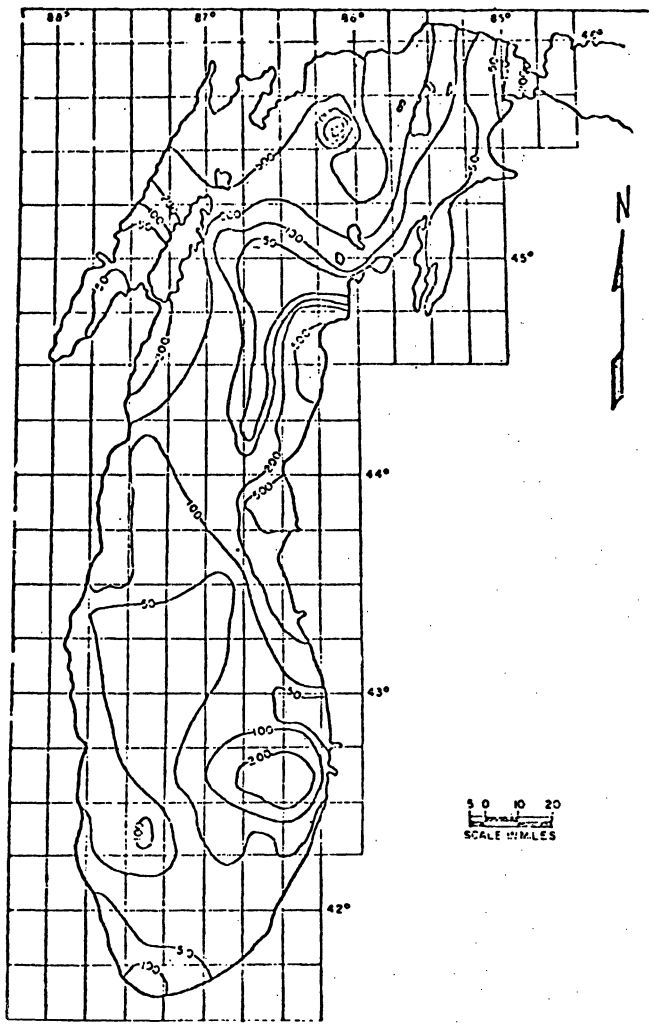
RIVER	Spring TS α	Summer TS α	Fall TS α	Winter TS α	Avg SS α	Avg DS α	Avg TS α
Sheboygan		<1	<1		<1	<1	<1
Manitowoc	<1	<1	<1	<1	<1	<1	<1
Branch	<1	<1	<1	<1	<1	<1	<1
Duck Creek	1.6	<1	1.8	1.3	<1	1.4	1.4
Oconto		<1	<1	<1	<1	<1	<1
Peshtigo		<1	<1		<1	<1	<1
Menominee		<1			<1	<1	<1
Ford	<1	<1	<1	<1	<1	<1	<1
Escanaba	<1	<1	<1	<1	<1	<1	<1
Rapid	<1	<1	<1		<1	<1	<1
Whitefish		<1	<1		<1	<1	<1
Manistique		1.2	<1	<1	<1	<1	<1
Black	<1	<1	2.0	<1	<1	<1	<1
Boardman	3.5	3.9	1.2	<1	2.2	<1	2.2
Manistee	<1	<1	26	4.3	7.6	<1	7.6
Little Manistee	7.8	3.6		<1	3.7	<1	3.9
Big Sable	47	1.3	11	5.1	16	<1	16
Pere Marquette	5.0	4.9	5.9	1.9	4.4	<1	4.4
White	1.7	18	1.8		6.8	<1	7.2
Muskegon	45	22	3.9	<1	18	<1	18
Grand	2.8	<1	<1	<1	<1	<1	<1
Kalamazoo	<1	<1	<1	<1	<1	<1	<1
St. Joseph	<1	<1	<1		<1	<1	<1
Burns Ditch	<1	<1	<1	<1	<1	<1	<1

TS = Total Solids

DS = Dissolved Solids

SS = Suspended solids

Figure A-3



Lake Michigan plankton gross beta radioactivity contours (1962-1964) in 10^{-6} uCi/g of ash.[32]

From 1961 to 1966 the gross beta radioactivity in fish has dropped from $2x10^{-4}$ uCi/g dry weight to approximately $1.2x10^{-4}$ uCi/g. From 1964 to 1966 the gross beta concentration in fish was relatively constant at $1.2x10^{-4}$ uCi/g dry weight.

DESCRIPTION OF THE RADIOLOGICAL SURVEY

Collection of Samples

Three hundred and seventy samples of water, sediment, zooplankton, phytoplankton, benthic organisms, and fish were collected by the University of Michigan Great Lakes Research Division. The distribution of environmental samples by type and year of sampling is given in Table A-8. Fifty sampling

Table A-8

Distribution of Environmental Samples for Radiological Analysis

Year of Collection	Water	Benthos	Phyto-plankton	Zoo-plankton	Sediment	Fish	Total
1969	33	32	32	33	85	7	222
1970	16	26	27	26	53	0	148
Totals	49	58	59	59	138	7	370

stations were located throughout the lake (Figure A-4), thirty of which provided only sediment samples. Three sampling trips were made to Lake Michigan, the first in August, 1969, the second in October, 1969, and the last in April, 1970.

The environmental samples were collected from a research vessel operated by the Great Lakes Research Division. Two-liter water samples were collected by dipping a weighted plastic bottle beneath the surface and removing the cork. Sediment was taken with a Ponar dredge. Phytoplankton and zooplankton were captured with #20 and #5 plankton nets, respectively, towed horizontally under the surface. A sled net towed along the bottom gathered benthos. Fish were either purchased from commercial fishermen or taken from the vessel itself.

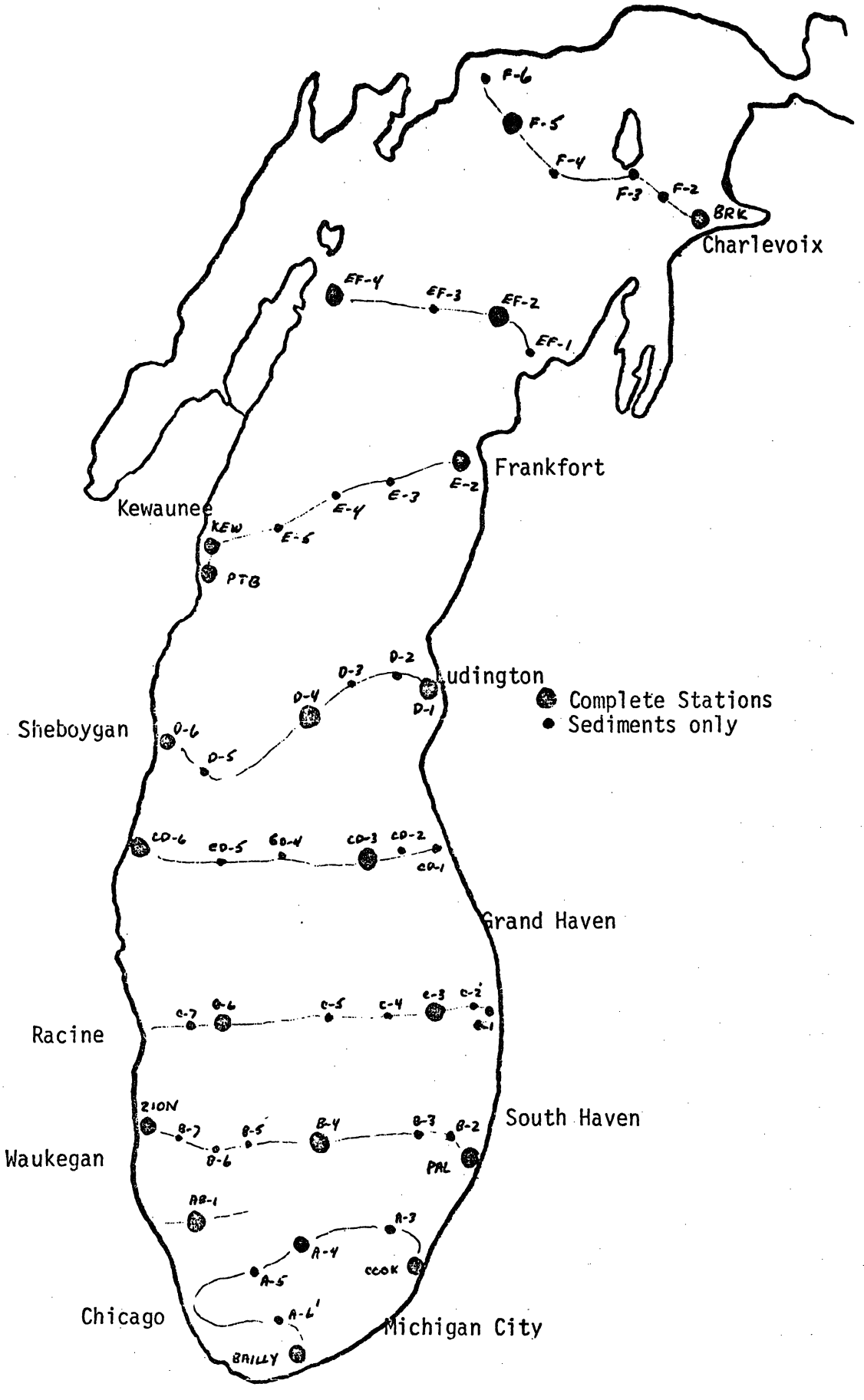


Figure A-4. Stations of Lake Michigan Environmental Survey

Preparation

The biological samples were preserved by freezing. The sediment and water samples were stored in polyethelene bags and bottles, respectively, until analyzed by the Radiological Health Group.

Sediment samples were oven-dried for 48 hours at 110°C. The dried cake was then broken up in a motor-driven mill and the granules were placed in one-pint plastic freezer containers. Each container was filled with 330 cubic centimeters of sediment. The mean density of dried sediments was approximately 1.6 g/cc (range 1.0-2.2 g/cc).

The two-liter water samples were acidified with HCl and evaporated to dryness on 2" diameter planchets. The residue, consisting of dissolved and suspended solids, was then counted for activity.

Samples of phytoplankton, zooplankton and benthos were defrosted and placed on a Whatman No. 1 filter to remove excess water. The organisms were then scraped from the filter, placed in a crucible, weighed, oven dried for 16 hours at 110°C, and then reduced to ash at 550°C. The ash was transferred to planchets, weighed, and counted for radioactivity.

Fish samples were defrosted in a crucible. They were then dried, ashed, and transferred to planchets in the same manner as the other biological samples.

All samples were counted for 8,000 seconds on a 5" x 5" NaI (Tl) scintillation crystal connected to a 256-channel Nuclear Data Series 2200 spectrometer. The gamma-ray spectra were transferred to punched paper tape and then to computer magnetic tape. The radionuclides which could be identified in sediment spectra were Ra-226 and its daughters, natural K-40, and Cs-137. Only Zinc-65 and Cs-137 were observable in water and biological samples.

Gross beta measurements of water and biological specimens were made with a Beckman Low Beta II thin-window (0.5 mg/cm^2) proportional counter. The length of the beta count was 3,000 seconds.

Calibration

Gamma Spectrometer for Planchet Sources

A description of the calibration procedures for planchet sources and a summary of the least squares computer program used to analyze gamma-ray spectra are presented in the Appendix, page A-29.

It is difficult to specify the minimum detectable activity (MDA) of each

radionuclide in a composite spectrum, because each isotope may interfere with all the others. Further, the background, which is subtracted from the gross spectrum, changes from time to time. We have therefore devised the method, explained in the Appendix, page A-36, to determine the minimum detectable activity for Cs-137 and Zn-65.

As a result of the analyses summarized in Table A-9, it appears doubtful

Table A-9

Minimum Detectable Activities and Minimum Detectable Levels in Biological and Water Samples

	MDA (uCi)	MDL Biological*(uCi/g)	Water**(uCi/ml)
Cesium-137	7×10^{-6}	1.0×10^{-6}	3.5×10^{-9}
Zinc-65	16×10^{-6}	2.2×10^{-6}	8.0×10^{-9}

*Weight of heaviest sample 7.2 grams of ash.
**For a sample volume of 2000 ml.

that Cs-137 or Zn-65 could be observed frequently in water samples of 2-liter size from Lake Michigan. In Section II.B. the maximum Cs-137 activity in water from fallout is predicted to be 1.2×10^{-9} uCi/ml, only 1/3 the minimum detectable level of 3.5×10^{-9} uCi/ml. Therefore, water samples would have to be at least three times their present size in order to measure Cs-137 in Lake Michigan. Since the expected Zn-65 activity in water is much less than the MDL is greater than that for Cs-137, Zn-65 should also be observed infrequently.

Gamma Spectrometer for Sediment Containers

The minimum detectable activity for Cs-137 in sediment is 6×10^{-5} uCi and the minimum detectable levle is 1×10^{-7} uCi/g. All Ra-226 and K-40 activities in sediment are very significant so it is neither possible, nor necessary to determine for these radionuclides a minimum detectable activity or level. The Ra-226, K-40 and Cs-137 sediment standards are described in the Appendix, page A-36.

Beckman Low Beta II - Planchet Sources

The chief advantage of gross beta analysis is its relative sensitivity and simplicity in obtaining environmental trends of radioactivity concentrations. In addition, it is useful as a method of choosing samples for specific analysis.

Since a gross beta count does not determine the radionuclides present in a sample, the data are of little use in defining health hazards. Self-absorption further complicates the interpretation of gross beta data. The calibration curve used to convert gross beta counts to activity is given in Figure A-6, page A-38, where the method used to generate this curve is also explained.

RESULTS AND DISCUSSIONS

Water

The measured concentrations of Cs-137, Zn-65 and gross beta radioactivity in Lake Michigan surface waters are presented in Table A-17, page A-39. The data are arranged alphabetically by stations selected by the Great Lakes Research Division. Five of 49 samples had Cs-137 concentrations greater than the MDL of 3.5×10^{-9} uCi/ml. All but one of the five samples with Cs-137 were in the South Basin. Zinc-65 was found in 8 samples out of 49 scattered throughout the lake. The highest levels of Zn-65 were at the Big Rock Point (BRK) sampling station. The average gross beta radioactivity was 3.3×10^{-9} uCi/ml (range 1.3 - 5.9×10^{-9} uCi/ml).

Sediment

One hundred and thirty-eight sediment samples were collected from throughout the lake, 85 samples in 1969, 53 in 1970. The only identifiable radionuclides were Cs-137, K-40, and Ra-226. We do not doubt that Th-232 and its daughters were in the activities reported as Ra-226. Radioactive members of the U-238 and Th-232 series are found extensively in nature.[5] The results of this portion of the study are included in Tables A-18 and A-19, pages A-41 and A-44.

The average Cs-137 activity in sediment was 1.4×10^{-6} uCi/g of dried weight. There was no significant difference between the activities of samples taken in 1969 and those in 1970. The average Cs-137 in Lake Michigan sediment is approximately the same as the 1×10^{-6} uCi/g reported by Eisenbud[34] for the Hudson River and by Kahn[35] for the Deerfield River. There is no significant trend of Cs-137 levels with depth of sampling although the levels are somewhat higher at mid-depths (170' to 350') than in shallow or deep regions. This is shown in Table A-20, page A-46.

The average Ra-226 was 1.6×10^{-6} uCi/g. This is approximately twice the

Ra-226 reported in the Deerfield River but is equal to the combined total of Ra-226 plus Th-232 at that location.[35] Radium-226 does not vary with depth in Lake Michigan (Table A-20).

The average K-40 is 15×10^{-6} uCi/g and ranges from about 5×10^{-6} uCi/g to 30×10^{-6} uCi/g. There is an indication in Table A-20, that K-40 levels increase with depth.

On July 25, 1970 a survey was made near Big Rock Nuclear Point Plant with an underwater gamma probe. Preliminary results of this survey substantiate the findings here that Cs-137 is somewhat higher at mid-depths than in shallow areas. Further, "the only man-made radioisotope seen in any of the spectra was Cs-137, although some spectra were taken within a mile and a half of the reactor."[36] Most spectra showed significant amounts of K-40 and small but detectable amounts of Ra-226.

The sediment samples were classified into textural groups: sand, gravel, silt, and clay. When the samples were arranged in order of increasing depth of collection, the samples classified as sand and gravel came out in the shallower areas, silt in the mid-depths, and clays from the deepest zones (Table A-20). This is in good agreement with the observations by others of sediment textural groups in Lake Michigan.[2]

Benthos

Both Cs-137 and Zn-65 were detected in environmental samples of benthic origin. Refer to Tables A-21 and A-26, pages A-50 and A-58. Noticeable differences between benthos and zooplankton or phytoplankton are: a) the benthos contain slightly more Cs-137, and b) there is approximately twice as much gross beta activity in benthos as there is in zooplankton or phytoplankton.

Zooplankton

There is no indication in Tables A-22 and A-27, pages A-52 and A-60, that Cs-137 or Zn-65 are concentrated in zooplankton. Gross beta levels are much lower than those found by Risley in 1963 (Reference 32 and Figure A-3 of this paper).

Phytoplankton

The concentration of Zn-65 is much higher in phytoplankton (Tables A-23 and A-28, pages A-54 and A-62) than in any of the other environmental medium sampled. Gross beta radioactivity is the same as those for zooplankton.

Fish

Only seven fish samples were analyzed (Table A-24, page A-56) two perch, two sculpin and three chubs. Cesium-137 and Zn-65 were detected in the flesh portion of 6 of the 7 samples. The range of gross beta activities was $0.8\text{-}1.1\text{x}10^{-4}$ uCi/g of ash.

The average Cs-137 activity in the edible flesh is $3.6\text{x}10^{-7}$ uCi/g of wet weight (range 0 to $9.2\text{x}10^{-7}$ uCi/g) as shown in Table 25, page A-57, reported concentrations of Cs-137 in fresh water fish have ranged over three orders of magnitude to as much as $2\text{x}10^{-5}$ uCi/g fresh weight.(37) The average Zn-65 in flesh is $3.3\text{x}10^{-7}$ uCi/g (range 0 to $10.0\text{x}10^{-7}$ uCi/g).

Concentration factors for Cs-137 in fish, the quotient of the average Cs-137 concentration in fish by the Cs-137 concentration in water, are presented in Table A-10. The cesium concentration factor ranges from about 100

Table A-10

Concentration Factors for Cesium-137 and Zinc-65 in Fish

$$CF = \frac{\text{Activity per unit weight of fish}}{\text{Activity per unit volume of water}}$$

	Lower Estimate of CF*	Upper Estimate of CF**
Cesium-137	$\geq$100	900
Zinc-65	$\geq$40	$\geq 3\text{x}10^4$

*Denominator of arithematic expression for concentration factor is the minimum detectable limit given in Table A-9.

**Denominator is our best estimate of the radionuclide concentration in Lake Michigan.

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to 900 and is in good agreement with the cesium concentration factor found elsewhere.(45) The concentration factor in fish for Zn-65 ranges from 40 to $3\text{x}10^4$. The upper estimate of the zinc concentration factor is higher than published values.(45)

PROVISIONAL FORECAST FOR LAKE MICHIGAN IN 1975

Natural Radioactivity

The most significant natural contributors to radioactivity in water are H-3 (5.6×10^{-9} uCi/ml), K-40 (1.1×10^{-9} uCi/ml), and C-14 (0.2×10^{-9} uCi/ml). These concentrations should change very little over the next five years. The radium, thorium, and potassium content of lake sediments should also remain constant through 1975.

Fallout

If there are no further atmospheric detonations, the fallout contribution to total radioactivity in Lake Michigan will not be significantly different in 1975 than it is in 1970. In the interim five years there will be additional fallout into the lake,[29] but this activity will be offset by radioactive decay and run out from the lake of that activity presently there. It is estimated earlier in this paper (Table A-3) that the total Sr-90 in Lake Michigan in 1975 will be approximately 7 percent less than at present. Most of this activity will probably be in the water medium as it was in 1965 (see pages A-5 - A-13).

The amount of Cs-137 in the lake environment in 1975 will be approximately the same as it is now (Table A-5). However, most of this activity is thought to be in the sediment and not in water. In 1970, it is estimated with the following assumptions that there are 4000 Ci of Cs-137 in the sediment environment of Lake Michigan. This is two-thirds of the 6000 Ci of Cs-137 which are thought to be in the lake at this time.

1. The bottom area is twice that of the surface, or 44,800 mi^2.
2. Most of the Cs-137 is in the upper 1.5 cm of sediment (approximately the depth of sampling).
3. The density of sediment is 1.6 g/cc.
4. The average concentration of Cs-137 in sediment is 1.4×10^{-12} Ci/g (see page A-21.).

Reactor Effluents

Currently, nine power reactors are scheduled to be generating electric power before 1975 (Table A-11) but of these units only Big Rock Nuclear Power Station is presently operating. The eight remaining units are expected to

Table A-11

Projected Electric Power Generation by Power Reactors Situated on Lake Michigan[3,4,27] through 1975

Year of start up (t)	Reactor	Power level (MWe)	Type BWR/PWR	Estimated generation through 1975 (MWe-hr)* 0.8xMWe (1976-t)x8766 hr
1962	Big Rock	50	BWR	2.3×10^6 to 1970+2.1×10^6 = 0.44×10^7
1971	Palisades	700	PWR	2.46×10^7
	Point Beach 1	497	PWR	1.74×10^7
	Zion 1	1050	PWR	3.68×10^7
	Z			
1972	Point Beach 2	497	PWF	1.39×10^7
	Cook 1	1054	PWR	2.94×10^7
	Kewaunee	527	PWR	1.47×10^7
1973	Cook 2	1060	PWR	2.22×10^7
	Zion 2	1050	PWR	2.20×10^7
			PWR	18×10^7 MWe-hr
			BWR	0.4×10^7 MWe-hr

*The average generating capacity of each station is assumed to be 80%.

start up within the next three years. They are Palisades, Point Beach 1, and Zion 1 in 1971; Point Beach 2, Cook 1 and Kewaunee in 1972; and Cook 2 and Zion 2 in 1973. The Bailly station is not scheduled for operation until 1976.

The sources of fission and activation product radioactivity in the primary coolant are given in Table A-12.[26,39] The relative influence of each of these sources, the power history of the reactor, and several other factors, determine qualitatively and quantitatively, the radionuclides that will be present in the coolant.[30] Table A-13 lists the fission and activation products with half-lives greater than 3 days which have been identified in primary coolants of operating light-water power reactors.[4,26,27,35,38-40] However, because the waste processing at each facility is unique, it is difficult to anticipate exactly what quantities will be discharged in liquid effluents.

The following estimates are based on approximate discharges of gross activity from presently operating reactor stations. It is reported[30] that the two newest and largest PWRs, Connecticut Yankee and San Onofre, discharge approximately 1.1×10^{-6} Ci of gross beta-gamma activity and 10^{-3} Ci of tritium per MWe-hr of power generation. If these rates of release or radioactivity apply to the reactors on Lake Michigan, then the total electrical energy generation by PWR reactors of 18×10^{7} MWe-hr through 1975, will have released 200 Ci gross beta-gamma activity and 180,000 Ci H-3. The 1962-75 contribution from Big Rock Nuclear Power Plant, a BWR, will be 90 Ci gross beta-gamma and 440 Ci H-3. These projected releases of radioactivity will increase the radioactivity concentration of Lake Michigan by 6×10^{-11} uCi/ml gross beta-gamma activity and 4×10^{-8} uCi/ml of H-3. For purposes of this calculation it is assumed that no radioactive decay of radwaste effluents has occurred and that no activity is lost to sediment or lake outflow. A summary of the inventories of radioactivity in Lake Michigan for 1953, 1963 (the year of heaviest fallout), 1970, and 1975 is given in Table A-14.

Table A-12

Sources of Radioactivity in Reactors[26,28]

Fission Products

1. Fuel pins
2. "Tramp" uranium

Activation Products

1. Corrosion impurities	$^{59}Co(n,\gamma)^{60}Co$
2. Primary coolant water	$^{18}O(p,n)^{18}F$
3. Chemical additives	$^{7}Li(n,n\alpha)^{3}H$
4. Dissolved atmospheric gases	$^{14}N(n,p)^{14}C$
5. Tramp uranium	$^{238}U(n,\gamma\beta)^{239}Np$
6. Stable fission products	$^{133}Cs(n,\gamma)^{134}Cs$
7. Natural impurities	$^{31}P(n,\gamma)^{32}P$

Table A-13

Activation and Fission Products ($T_{1/2}$ > 3 days) Identified in Primary Coolants of Light-water Reactors[4,26,27,35,38-40]

Antimony-124	Neodymium-147
Barium-140	Niobium-95
Carbon-14	Phosphorus-32
Cerium-141,144	Ruthenium-103,106
Cesium-134,136,137	Silver-110m
Chromium-51	Strontium-89,90
Cobalt-57,58,60	Sulfur-35
Curium-242	Tantalum-182,183
Hafnium-181	Tellurium-132
Hydrogen-3	Tin-113
Iodine-131	Tungsten-185
Iron-55,59	Zinc-65
Manganese-54	Zirconium-95

Table A-14

Inventories of Radioactivity in Lake Michigan

	Activities (Ci)			
Water				
Gross Beta (Excluding H-3)	1953	1963	1970	1975
Natural	6,200[a]	6,200	6,200	6,200
Fallout	0	60,000[b]	9,100[c]	8,600[c]
Reactor	0	6[d]	50[e]	300[f]
Tritium				
Natural	27,000[g]	27,000	27,000	27,000
Fallout	0	>960,000	960,000[h]	<960,000
Reactor	0	30[i]	300[j]	180,000[k]
Radium-226	110[l]	110	110	110
Sediment				
Cesium-137	0	no estimate	4,000 [m]	3,900[n]

a) Sum of K-40 at 1.1×10^{-9} uCi/ml, C-14 at 1.8×10^{-10} uCi/ml, and Pb-210 at 3×10^{-12} uCi/ml (pages A-3-5) times 4.8×10^{18} ml.

b) 13.4×10^{-9} uCi/ml (Table A-1)x4.8×10^{18} ml minus 5,300 Ci.

c) Sum of Sr-90, Y-90, and one-third of Cs-137 inventory (Tables A-3 and A-5 and page A-24).

d) 33.1 Ci/6 years for Big Rock Nuclear Plant (page A-13).

e) Refer to page A-13.

f) Refer to page A-24. Sum of BWR plus PWR releases.

g) 5.6×10^{-9} uCi/ml (page A-3) times 4.8×10^{18} ml.

h) $2 \pm 2 \times 10^{-7}$ uCi/ml in Illinois River (page A-5) times 4.8×10^{18} ml.

i) Refer to page A-13.

j) Refer to page A-24. Sum of BWR plus PWR releases.

k) Refer to page A-24.

l) 2.4×10^{-11} uCi/ml (page A-3) times 4.8×10^{18} ml.

m) Refer to page A-24.

n) 4000 Ci x $\exp(-\lambda \times 5 \text{ years})$.

APPENDIX

Calibration of a Gamma Ray Spectrometer - Part 1

Spectrometer Equipment

The gamma ray spectrometer consists of a 5" x 5" NaI crystall connected to a 5" photomultiplier tube, a Nuclear Data Corporation Series 2200 multichannel pulse height analyzer with a 512-channels memory, two preamplifier-amplifier-discriminator modules (to permit two detectors to be used simultaneously), a mixer-rejector module, an input-route module, a punch and reader drive module (to allow the spectra stored in memory to be read out using either a typewriter or a punch paper tape unit), an IBM typewriter, and a Talley punch paper tape unit, Model 420 PR.[41]

The shielding cave is made with lead bricks, 10 cm thick on the sides and 5 cm thick on top and bottom. The inside dimensions of the cave are 30 cm by 30 cm by 61 cm high. A planchet centered on the crystal is 13 cm from each side and 13 cm from the top of the cave.

Standards

The procedures used to calibrate the spectrometer met the following criteria:

1. Calibration sources were prepared so that their physical dimensions were identical to those of the samples to be measured.
2. The activities of the calibration sources were known within specified error limits.
3. The samples were counted under conditions that were identical to the conditions under which the calibration sources were counted. These conditions include shielding, gain and zero settings, temperature, etc.

The Calibration Sources. Small amounts of liquid standards were obtained from the U. S. Public Health Service, which purchases them from the Radiochemical Centre* and transfers them to small polyethylene bottles for distribution to various Federal and State radiological health laboratories. Table A-15 shows the sources received from the Public Health Service

* Radiochemical Centre, Amersham, Buckinghamshire, England.

Table A-15

Liquid Calibration Sources

Isotope	Activity[1] (dpm/gram of solution)	Std. Dev.[1]	Time of calibration[1]	Volume[2]	Solution[2]
Cs-137	45,600	1.0%	0700 EST 1/1/68	6 ml	0.1 N HCl
Co-60	26,500	0.4%	1/1/68	5 ml	0.1 N HCl
Ba+La-140	1,119,000	0.7%	0700 EST 1/6/70	6 ml	0.1 N HCl
Mn-54	280,900	0.5%	0700 EST 5/10/68	6 ml	0.03 N HCl
Zr+Nb-95	2,400,000	0.9%	0700 EST 3/27/69	6 ml	0.5% oxalic acid
Sr-85	61,940	1.3%	0700 EST 12/10/69	6 ml	0.1 N HCl
Ru+Rh-106	2,080,000	2.4%	0500 EST 4/28/69	1 ml	1. N HCl
I-131	4,629,000	1.2%	1200 EST 1/19/70	2 ml	0.1% formalin
Zn-65	275,900	0.9%	0700 EST 5/21/68	6 ml	0.01 N HCl
Ce+Pr-144	74,200	0.9%	0700 EST 7/9/69	6 ml	0.1 N HCl
Sb-125	68,770	1.2%	11/8/67	6 ml	0.6 N HCl

(1) These values were taken from the Calibration Certificates of the original sources provided by the Radiochemical Centre.

(2) These values were taken from the Calibration Certificates supplied by the Public Health Service.

Five planchets were prepared for each of the radioisotopes in Table A-15 with the exception of Cs-137; three Cs-137 planchets were prepared. The calibration planchets were prepared as follows:

1. One milliliter of a wetting agent was placed in the planchet to insure uniform drying. Without the wetting agent the surface tension of any liquid in the planchet would pull the last few drops to the side of the planchet which would result in a ring source instead of a circular source. The wetting agent used was Kodak Photo-Flo 200, diluted 1:100 with water.
2. The standard solutions were transferred by weight from the polyethylene bottles to the planchets. The transfer was done using glass eye droppers which had been treated with Siliclad to minimize adsorption of the radioactive ions on the glass. The planchet was swirled carefully to insure that the radioactivity was dispersed uniformly across the planchet.
3. The planchet was placed under a heat lamp in a hood, and the liquid was evaporated to dryness.
4. One milliliter of a sealer was transferred to the planchet and evaporated to dryness. The sealer consisted of 0.5 grams of plexiglass powder dissolved in 100 milliliters of 1, 2-dichloroethane.

Constant Counting Conditions. It is very important that the calibration planchets be counted under the same conditions as the sample planchets. Parameters such as temperature can be kept constant by following good laboratory practice, e.g. keeping the windows and door to the counting room closed at all times. Contamination of the detector must be avoided. The gain and zero settings of the equipment must be constant while counting calibration planchets. However, the spectrum analysis computer program can make the necessary corrections if the gain and zero settings of an environmental sample differ from the calibration gain and zero settings.

In order to determine how large the activity of a calibration planchet could be before induced gain shifts and live timer errors become significant, two experiments were conducted. In both experiments the percent dead time of the spectrometer was used as a measure of the activity of the sample being counted.

The first experiment determined the effect of sample activity on induced gain shifts. This was done by building a tower of 5 cm diameter, 1.5 cm tall

petri dishes on the 5" x 5" NaI crystal. A point source of Cs-137 containing approximately 3 microcuries was placed at the top of the tower and counted for 100 seconds. The percent dead time and location of the photopeak were recorded. The tower was then shortened by one or more of the petri dishes and another 100 second count taken. In this way the dead time of the spectrometer was increased slowly from 1.2% to 31.1% with a noticeable induced gain shift.

The second experiment determined the effect of sample activity on counting efficiency. Two towers of petri dishes were built on the 5" x 5" NaI crystal. Two point sources of Cs-137 were used, each with an activity of about 3 microcuries. The first source was placed on top of one tower and counted for 100 seconds. Then the first source was removed, and the second source was placed on top of the second tower and counted for 100 seconds. The first source was then replaced on the first tower, and both sources were counted together for 100 seconds. The counts under the photopeak were recorded for the three counts. If the live timer were accurate the counts detected with both sources in place should equal the sum of the counts detected with each source counted individually. The dead time resulting from having both sources in place was also recorded. The towers were then shortened by one or more petri dishes, and another set of measurements was taken.

Figure A-5 shows the data so obtained, and indicates that as dead times exceed about 5% the fraction of counts lost by overloading the live timer increases linearly. Therefore, it would be desirable to keep the activity of the calibration planchets below 5% to insure that no counts will be lost due to the live timer. Figure A-5 also indicates that the gain is not constant with increasing dead time and that the change in gain with dead time is most significant at dead times around 2%.

From the information displayed in Figure A-5 it was decided that calibration planchets could be prepared that had activities which would result in dead times between 4% and 5%. Within this range the spectrometer would not be losing any counts due to overloading the live timer, and the gain shift induced by a sample with 4% dead time would be within 0.1% of the gain shift induced by a sample with a 5% dead time.

Spectrum Analysis Computer Program

A spectrum analysis computer program which uses the least squares method has been developed by Dr. J. I. Trombka of the Goddard Space Flight Center.

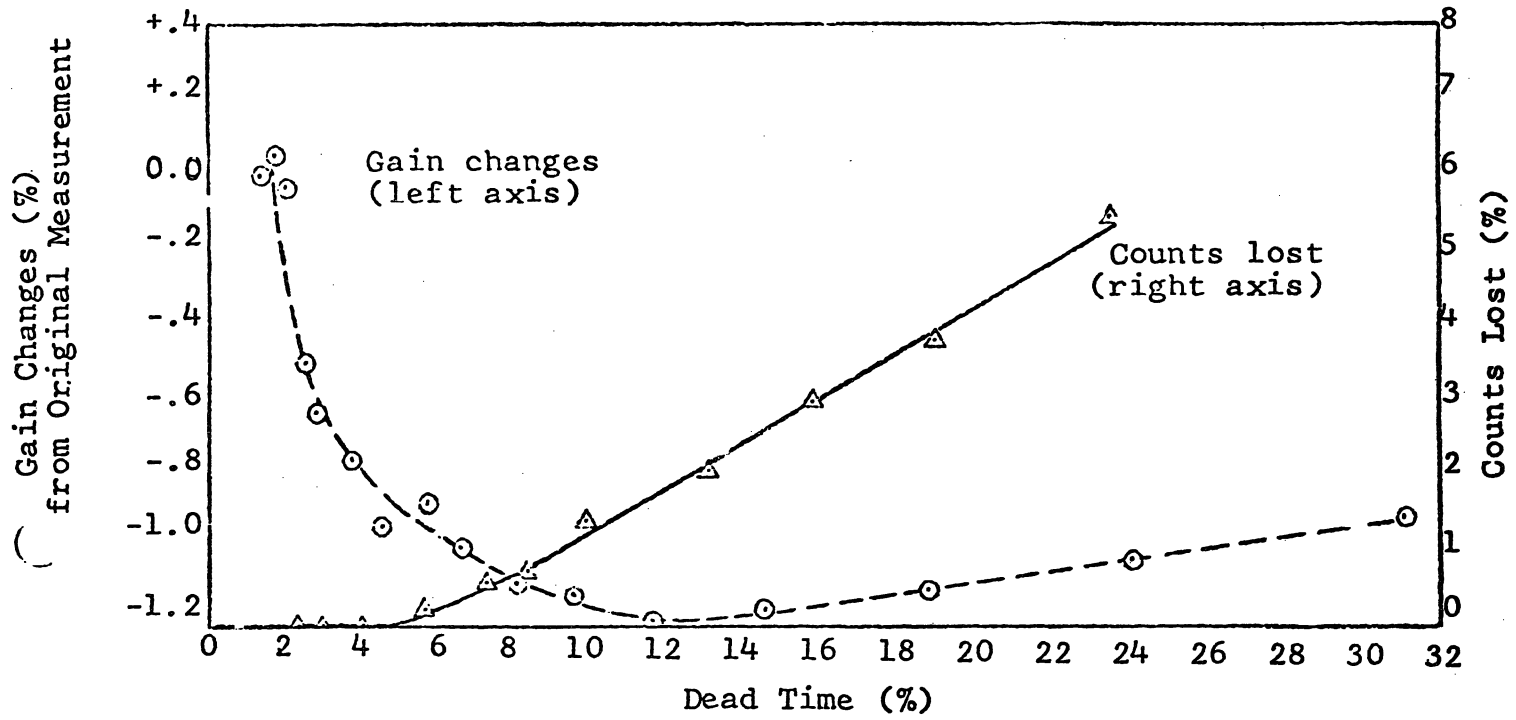

Figure A-5. Induced Gain Changes and Counting Efficiency Changes as a function of Dead Time.

A copy of this program was obtained from Dr. Trombka and substantially revised to fit the needs of this Department. The program is called NASA after its original sponsor.

The NASA program is designed to receive a library of standard spectra. The standard spectra are linear arrays of numbers with dimensions of "cps/channel." The activity which produced each of the library spectra must be known. The program can then receive a sample spectrum and determine how much of each of the library standards is present in the sample spectrum.

In routine operation a set of library reference spectra are transferred by the computer from punched paper tape to the beginning of a reel of magnetic tape. Each spectrum occupies a specific location, called a record, on the magnetic tape. As sample spectra are taken they are transferred to the magnetic tape occupying successively higher record numbers. Any spectrum on the magnetic tape can be recalled and printed or graphed if desired.

The NASA program constructs a spectrum from the library reference spectra to match the sample spectrum. The final results given by the NASA program for each sample are a graph of the spectrum (the net spectrum if background subtraction is requested by the user) and one data sheet which contains the activities of each of the library references that are present in the sample spectrum. The graph of the spectrum is used to detect the presence of any radioisotopes for which the NASA program is not programmed.

The data sheet also includes two error values for the sample spectrum analysed. The chi square value is a measure of how well the entire calculated spectrum matched the entire sample spectrum. The amount of each radioisotope predicted to be in the sample spectrum has associated with it a standard deviation expressed as a percent of the predicted amount. The two error values together with the graph of the spectrum are used to decide the validity of the predicted activities for the given sample spectrum.

Calibration of a Gamma Spectrometer - Part 2

Method for Determining Minimum Detectable Activities and Levels.

1. Arrange numerically all samples on planchets by increasing percent standard deviation of their radioactivity content.
2. Create a frequency distribution such as that given in Table A-16. Activities which are considered significant have a standard deviation

Table A-16

Frequency Distribution of Significant and Non-Significant
Cs-137 and Zn-65 Activities in Biological and Water Samples

Frequency (significant)	0	0	0	0	0	5	5	1	4
Cesium-137 (10^{-6} uCi)	03	04	05	06	07	08	09	10	11
Frequency (non significant)	8	14	10	1	0	0	0	0	1

Minimum detectable activity = 7×10^{-6} uCi

Frequency (significant)	0	0	0	0	0	2	0	1	0	2	2	3	3
Zinc-65 (10^{-6}uCi)	07	08	09	10	11	12	13	14	15	16	17	18	19
Frequency (non sig.)	1	0	2	3	2	5	1	1	2	0	1	1	1

MDA = 16×10^{-6}uCi

of less than 50%, i.e., a 2 sigma counting error of less than 100%. The frequency of occurrence of X picocuries is given above the noted activity. The frequency of occurrence for activities which are not considered significant (50% $\leq \sigma \leq$ 99%), i.e., a 2-sigma counting error greater than 100%, are given below the noted activity.
NOTE: In a frequency distribution such as this, the frequencies of occurrence of all activities considered non-significant should be given. However, it is not necessary to present the frequencies of occurrence for those activities considered significant but of greater activity than the maximum activity in the non-significant group.

3. Choose a minimum detectable activity (MDA) which separates reasonably the significant activity from the non-significant activity. The MDA for Cs-137 by such an analysis is approximately 7×10^{-6} uCi, that for Zn-65, 16×10^{-6} uCi per sample. Notice that statistical fluctuations in the sample activities permit the occurrence of a non-significant activity greater than the MDA as well as a significant activity less than the MDA.
4. Find the minimum detectable level (MDL) in water by dividing the MDA by 2000 milliliters.

$$MDL_W = \frac{MDA}{2000} \quad uCi/ml$$

5. Find the minimum detectable level (MDL) in a biological sample by dividing the minimum detectable activity by the weight of the heaviest sample in the group of samples. The MDA in the heaviest sample represents the lowest concentration of activity that can be measured.

$$MDL_B = \frac{MDA}{\text{weight of heaviest sample}} \quad uCi/g$$

Ra-226, K-40, Cs-137 Sediment Standards

The Cs-137 sediment standard contained $5.1 \pm 0.2 \times 10^{-2}$ uCi (one standard deviation) of added activity. The density of this standard was 1.6 g/cc (330 ml of 0.5 N HCl plus 198 g stable $ZnCl_2$). Sediment samples which have a density greater than 1.6 g/cc would have their Cs-137 concentrations reported incorrectly because of increased scatter of photons. The opposite situation occurs for

samples of density less than the standard. It was necessary therefore to evaluate the magnitude of this error.

The error due to incompatible matching between the densities of the sample and standard was studied by adding different amounts of stable $ZnCl_2$ to acidified Cs-137 solution. The number of counts in the energy region 0.63 to 0.69 Mev was evaluated at densities of 1.98 g/cc and 2.48 g/cc and compared to data at 0.99 g/cc. At 1.98 g/cc there were 9.5% fewer counts in the Cs-137 photopeak, at 2.48 g/cc, 13% fewer counts. Since our Cs-137 standard has a density of 1.6 g/cc, all measurements of Cs-137 in sediment ($1.0 < \rho < 2/2$ g/cc) have a non-reported error resulting from differences of density of approximately ± 5%.

The K-40 sediment standard was made from 415.83 g of KCl. This is the equivalent of 0.185 uCi of K-40 activity. The density of the K-40 standard was 1.26 g/cc.

The Ra-226 sediment standard contained $8.0 \pm 0.6 \times 10^{-3}$ uCi. It was made from radium-bearing manganese nodules separated from Lake Michigan sediments. A U.S. Public Health Service calibrated Ra-226 source was used to compute the radium activity of the nodules.

Counting Efficiency for Gross Beta Radioactivity

Figure A-6 is a plot of total counting efficiency for Cs-137 beta emissions (Efficiency = cpm/βpm) versus sample weight in a planchet with 20 cm^2 area. The solids of environmental samples were simulated with NaCl. For each 100 disintegrations of Cs-137 there are 4.7 emissions of 1.180 Mev β, 95.3 emissions of 0.518 Mev β, and 9.4 emissions of internal conversion electrons or a total of 1.094 β per disintegration.[33]

In materials of low atomic number the range of beta particles is, to a first approximation, a function only of the mass interposed in the path of the radiation and the particles energy.[46]

The maximum range of a 0.5 Mev β in 2.2 g/cc concrete is 0.08 cm or 0.176 g/cm^2.[11] In a planchet of 20 cm^2 area, this infinite thickness is equivalent to a maximum sample weight of 3.5 g. Figure A-6 shows that there is little difference in the counting efficiencies for samples with weights greater than 3.5 grams.

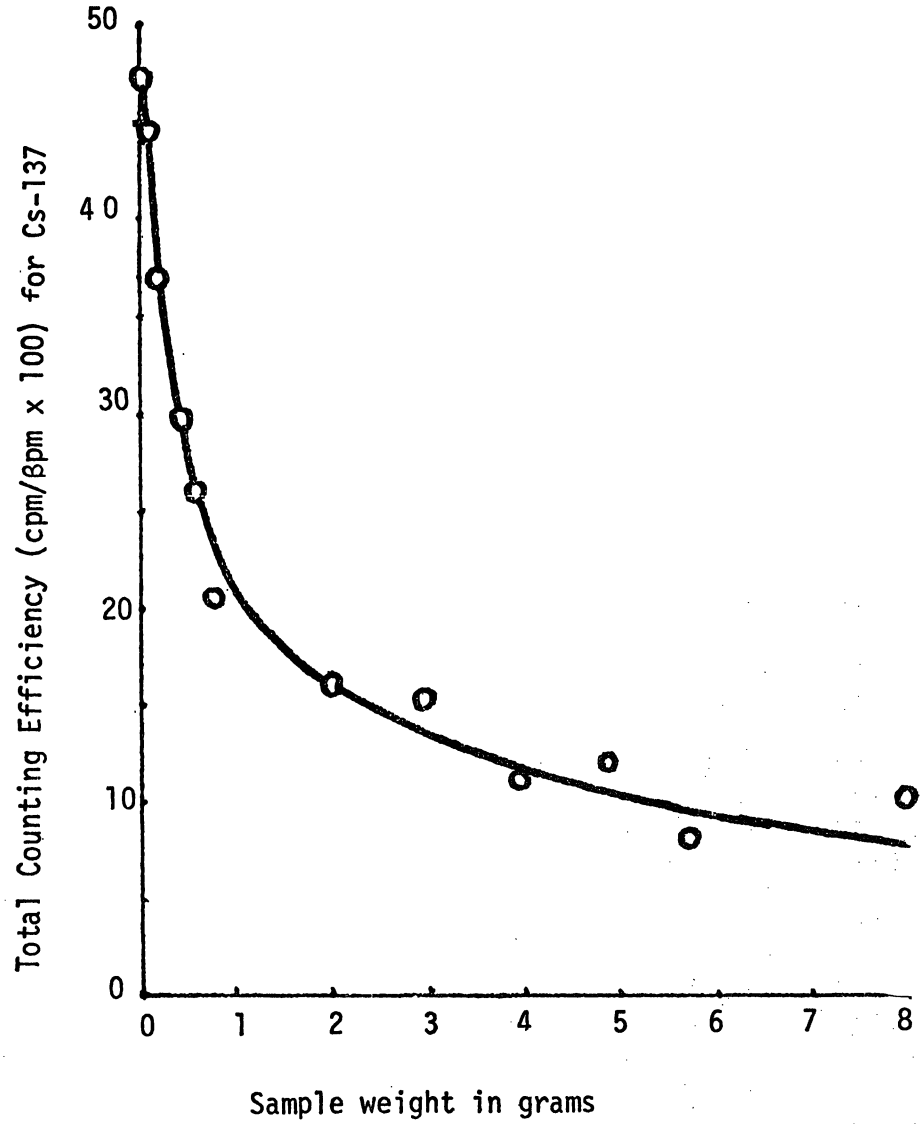

Figure A-6. Gross Beta Efficiency vs. Sample Weight for 2 in. diameter planchet.

********** LAKE MICHIGAN RADIOLOGICAL SURVEY **********

Table A-17

RADIOACTIVITY IN WATER

SAMPLE STATION	SAMPLE NUMBER	WEIGHT[1] (GRAMS)	COLLECTION DATE	ACTIVITY IN PCI/LITER (% ERROR)[2] CESIUM-137	ZINC-65	GROSS BETA[3,4]
A-4***	28	0.5192	10-15-69	7.0 (38%)	9.5 (60%)	3.5 (17%)
A-4***	141	0.5472	04-30-70	0.0 (0%)	0.0 (0%)	3.6 (17%)
AB-1**	25	0.4901	10-10-69	0.0 (0%)	0.0 (0%)	3.2 (18%)
AB-1**	133	0.6863	05-02-70	0.0 (0%)	0.0 (0%)	4.1 (18%)
B-4***	19	0.4572	10-15-69	0.0 (0%)	0.0 (0%)	2.8 (20%)
B-4***	33	0.5152	11-09-69	9.5 (30%)	0.0 (0%)	3.2 (20%)
BAILLY	23	0.4800	10-05-69	0.0 (0%)	0.0 (0%)	3.2 (18%)
BAILLY	131	0.3818	04-28-70	0.0 (0%)	0.0 (0%)	2.3 (22%)
BRK***	1	0.5302	08-29-69	0.0 (0%)	10.5 (66%)	4.3 (15%)
BRK***	13	0.4281	11-01-69	0.0 (0%)	32.5 (24%)	3.2 (17%)
BRK***	136	0.5139	05-17-70	0.0 (0%)	0.0 (0%)	2.7 (21%)
C-3***	20	0.4446	10-03-69	0.0 (0%)	0.0 (0%)	2.9 (19%)
C-3***	27	0.3790	11-08-69	4.5 (62%)	0.0 (0%)	2.9 (18%)
C-3***	132	0.6033	05-07-70	0.0 (0%)	0.0 (0%)	3.2 (19%)
C-6***	146	0.6411	05-04-70	0.0 (0%)	0.0 (0%)	3.5 (21%)
CD-3**	2	0.4671	08-23-69	0.0 (0%)	11.5 (56%)	3.4 (18%)
CD-3**	29	0.5224	10-25-69	5.5 (54%)	0.0 (0%)	4.5 (15%)
CD-6**	7	0.4548	09-10-69	0.0 (0%)	0.0 (0%)	3.3 (18%)
CD-6**	21	0.4613	11-06-69	0.0 (0%)	0.0 (0%)	3.0 (18%)
CD-6**	140	0.5592	06-11-70	0.0 (0%)	0.0 (0%)	3.7 (17%)
COOK**	22	0.3472	10-04-69	0.0 (0%)	0.0 (0%)	1.3 (33%)
COOK**	137	0.5962	04-26-70	0.0 (0%)	0.0 (0%)	3.4 (19%)
D-1***	3	0.4848	08-24-69	0.0 (0%)	0.0 (0%)	3.5 (18%)
D-1***	30	0.7149	10-29-69	0.0 (0%)	0.0 (0%)	3.0 (22%)
D-4***	4	0.7324	08-24-69	0.0 (0%)	0.0 (0%)	3.0 (23%)
D-4***	31	0.7575	10-28-69	0.0 (0%)	0.0 (0%)	2.9 (25%)
D-4***	134	0.5616	05-14-70	0.0 (0%)	0.0 (0%)	2.9 (20%)
D-6***	8	0.3878	09-07-69	0.0 (0%)	0.0 (0%)	2.7 (19%)
D-6***	17	0.3182	11-05-69	0.0 (0%)	9.5 (68%)	1.9 (24%)
D-6***	135	0.4114	05-23-70	0.0 (0%)	0.0 (0%)	2.4 (21%)
E-2***	5	0.4804	08-25-69	0.0 (0%)	0.0 (0%)	3.3 (18%)
E-2***	14	0.3878	10-30-69	0.0 (0%)	0.0 (0%)	3.3 (16%)
E-2***	138	0.5880	05-15-70	0.0 (0%)	0.0 (0%)	3.3 (19%)
EF-2**	6	0.5053	08-26-69	0.0 (0%)	0.0 (0%)	3.2 (19%)
EF-2**	16	0.4020	10-31-69	0.0 (0%)	7.0 (66%)	2.9 (18%)
EF-2**	139	0.8098	05-16-70	0.0 (0%)	0.0 (0%)	5.2 (15%)
EF-4**	9	0.4682	09-02-69	0.0 (0%)	11.0 (68%)	3.1 (19%)
EF-4**	147	0.5998	05-20-70	0.0 (0%)	0.0 (0%)	5.2 (14%)

Table A-17 (Cont'd.)

RADIOACTIVITY IN WATER

SAMPLE STATION	SAMPLE NUMBER	WEIGHT[1] (GRAMS)	COLLECTION DATE	ACTIVITY IN PCI/LITER CESIUM-137	ZINC-65	(% ERROR)[2] GROSS BETA[3,4]
F-5***	10	0.3999	09-01-69	0.0 (0%)	0.0 (0%)	4.1 (14%)
F-5***	18	0.3681	11-02-69	0.0 (0%)	0.0 (0%)	2.7 (18%)
KEW***	11	0.4102	09-06-69	0.0 (0%)	11.5 (60%)	3.1 (18%)
KEW***	15	0.4424	11-04-69	0.0 (0%)	0.0 (0%)	5.9 (12%)
KEW***	142	0.6440	05-22-70	0.0 (0%)	0.0 (0%)	3.3 (20%)
PAL***	24	0.4085	10-04-69	4.5 (62%)	0.0 (0%)	3.3 (17%)
PAL***	26	0.4108	11-10-69	0.0 (0%)	0.0 (0%)	2.9 (19%)
PTB***	12	0.4849	09-07-69	0.0 (0%)	0.0 (0%)	3.5 (17%)
PTB***	148	0.6584	05-22-70	0.0 (0%)	0.0 (0%)	4.2 (16%)
ZION**	32	0.5950	10-14-69	0.0 (0%)	0.0 (0%)	2.8 (23%)
ZION**	143	0.6578	05-03-70	0.0 (0%)	0.0 (0%)	3.8 (19%)

1. Weight of residue after evaporation
2. Number in parentheses is percent error (two standard deviations) of total radioactivity content in a two liter sample.
3. Cesium-137 and Zinc-65 radioactivity were corrected for decay back to the date of collection. Gross beta radioactivity is given for the date of counting (July-August 1970).
4. 0.0 (0%) signifies that the activity in the sample was less than the minimum detectable limit.

Table A-18
RADIOACTIVITY IN SEDIMENT - 1969

SAMPLE STATION	SAMPLE NUMBER	WEIGHT[1] (GRAMS)	COLLECTION DATE	ACTIVITY IN PCI/GRAM (% ERROR)[2] CESIUM-137	RADIUM-226	POTASSIUM-40[3]
A-3***	248	374.0	10-04-69	8.1 (8%)	1.9 (26%)	17.2 (18%)
A-4***	247	332.0	10-15-69	3.4 (10%)	1.8 (22%)	20.3 (16%)
A-5***	243	509.0	10-15-69	1.3 (12%)	1.0 (24%)	9.8 (18%)
A-6'**	277	434.0	10-06-69	2.6 (10%)	1.4 (20%)	14.1 (16%)
AB-1**	276	562.0	10-10-69	0.6 (16%)	1.1 (18%)	7.0 (16%)
B-2***	260	354.0	10-03-69	0.3 (18%)	2.3 (18%)	19.2 (16%)
B-2***	271	424.0	11-09-69	1.5 (24%)	1.9 (30%)	18.0 (22%)
B-3***	255	329.0	10-03-69	2.2 (12%)	2.4 (20%)	19.8 (16%)
B-3***	270	335.0	11-09-69	1.4 (30%)	2.6 (26%)	25.6 (20%)
B-4***	259	332.0	10-15-69	2.9 (14%)	2.5 (22%)	22.6 (18%)
B-4***	269	355.0	11-09-69	2.6 (20%)	2.8 (28%)	29.9 (20%)
B-5***	285	369.0	10-15-69	1.9 (14%)	2.5 (20%)	22.1 (16%)
B-6***	272	430.0	10-15-69	2.2 (20%)	1.5 (38%)	18.6 (24%)
B-7'**	249	480.0	10-14-69	1.0 (12%)	0.9 (22%)	10.5 (16%)
BAILLY	239	610.0	10-05-69	0.1 (64%)	0.6 (20%)	7.2 (14%)
BAILLY	286	507.0	10-05-69	0.7 (14%)	1.1 (20%)	12.3 (14%)
BRK***	174	535.0	08-29-69	1.2 (10%)	1.0 (18%)	10.7 (14%)
BRK***	265	488.0	11-01-69	3.1 (10%)	2.1 (20%)	8.4 (26%)
C-1***	234	584.0	10-02-69	0.2 (28%)	0.5 (24%)	8.4 (14%)
C-1***	281	449.0	11-07-69	0.7 (16%)	1.2 (20%)	16.5 (12%)
C-2***	256	310.0	10-02-69	6.2 (8%)	2.0 (24%)	15.4 (20%)
C-2***	258	332.0	11-07-69	4.2 (10%)	2.2 (22%)	14.7 (22%)
C-3***	245	382.0	10-03-69	0.5 (36%)	2.8 (18%)	20.4 (16%)
C-3***	278	342.0	11-08-69	0.9 (24%)	2.9 (18%)	23.2 (14%)
C-4***	254	342.0	10-02-69	4.1 (8%)	1.8 (22%)	18.0 (16%)
C-4***	257	362.0	11-07-69	3.1 (14%)	1.9 (26%)	10.8 (30%)
C-5***	274	352.0	10-02-69	1.7 (32%)	3.1 (28%)	24.9 (26%)
C-5***	246	357.0	11-07-69	1.1 (20%)	2.7 (18%)	23.1 (16%)
C-7***	244	511.0	10-17-69	1.1 (14%)	1.0 (22%)	8.6 (18%)
CD-1**	168	581.0	08-23-69	0.8 (14%)	1.1 (20%)	12.4 (14%)
CD-1**	262	584.0	10-28-69	1.3 (12%)	1.1 (22%)	13.1 (16%)
CD-2**	202	524.0	08-23-69	0.9 (22%)	0.7 (38%)	9.8 (24%)
CD-2**	253	336.0	10-25-69	2.4 (12%)	3.0 (18%)	23.5 (16%)
CD-3**	177	350.0	08-23-69	1.2 (18%)	2.7 (18%)	23.2 (16%)
CD-3**	251	295.0	10-25-69	1.0 (26%)	3.4 (18%)	28.1 (16%)
CD-4**	170	589.0	09-10-69	1.2 (16%)	1.7 (20%)	14.8 (16%)
CD-4**	233	497.0	11-06-69	1.3 (12%)	1.2 (22%)	17.4 (14%)
CD-5**	166	499.0	09-10-69	1.9 (12%)	1.1 (24%)	14.4 (16%)

Table A-18 (Cont'd.)

RADIOACTIVITY IN SEDIMENT - 1969

SAMPLE STATION	SAMPLE NUMBER	WEIGHT[1] (GRAMS)	COLLECTION DATE	ACTIVITY IN PCI/GRAM (% ERROR)[2] CESIUM-137	RADIUM-226	POTASSIUM-40[3]
CD-5**	232	488.0	11-06-69	3.2 (8%)	1.2 (24%)	15.1 (16%)
CD-6**	165	575.0	09-10-69	0.8 (14%)	0.8 (20%)	12.2 (14%)
CD-6**	231	507.0	11-06-69	1.3 (12%)	0.9 (26%)	12.8 (16%)
COOK**	240	586.0	10-04-69	0.1 (58%)	0.9 (20%)	9.5 (16%)
D-1***	167	642.0	08-24-69	0.1 (32%)	0.5 (22%)	9.4 (12%)
D-1***	261	624.0	10-29-69	0.2 (26%)	0.6 (20%)	13.9 (12%)
D-2***	169	504.0	08-24-69	0.8 (12%)	0.7 (22%)	11.6 (14%)
D-2***	263	540.0	10-28-69	0.8 (14%)	0.7 (26%)	11.4 (14%)
D-3***	175	168.0	08-24-69	5.4 (12%)	4.6 (20%)	44.6 (16%)
D-3***	252	279.0	10-28-69	3.1 (12%)	2.8 (20%)	26.1 (16%)
D-4***	178	363.0	08-24-69	0.9 (24%)	2.8 (18%)	25.6 (14%)
D-4***	273	333.0	10-28-69	1.4 (34%)	3.0 (26%)	26.2 (22%)
D-5***	157	483.0	09-07-69	0.4 (30%)	1.3 (20%)	15.8 (16%)
D-5***	238	396.0	11-06-69	2.1 (16%)	1.5 (30%)	17.9 (20%)
D-6***	156	614.0	09-07-69	0.6 (18%)	0.7 (24%)	7.2 (18%)
D-6***	230	562.0	11-05-69	0.6 (16%)	0.5 (26%)	7.7 (16%)
E-2***	150	362.0	08-25-69	0.6 (32%)	2.6 (18%)	14.1 (18%)
E-2***	264	532.0	10-30-69	0.8 (16%)	0.9 (22%)	11.6 (16%)
E-3***	162	333.0	08-25-69	0.5 (52%)	3.5 (18%)	29.0 (16%)
E-3***	266	306.0	10-29-69	0.0 (0%)	2.9 (22%)	32.5 (16%)
E-4***	163	585.0	09-06-69	0.3 (56%)	1.7 (20%)	15.4 (16%)
E-4***	236	373.0	10-05-69	1.6 (18%)	2.1 (22%)	24.2 (16%)
E-5***	161	358.0	09-03-69	0.0 (0%)	3.0 (18%)	24.1 (16%)
E-5***	237	289.0	10-05-69	0.6 (56%)	3.2 (22%)	29.0 (18%)
EF-1**	164	430.0	08-26-69	0.2 (70%)	2.0 (18%)	16.2 (16%)
EF-1**	283	391.0	10-31-69	1.0 (16%)	1.7 (20%)	16.4 (14%)
EF-2**	153	568.0	08-26-69	0.8 (18%)	0.8 (28%)	8.3 (20%)
EF-2**	279	437.0	10-31-69	1.5 (10%)	0.6 (26%)	9.4 (14%)
EF-3**	179	334.0	08-25-69	0.0 (0%)	3.2 (18%)	28.8 (14%)
EF-3**	250	296.0	10-31-69	0.0 (0%)	3.3 (18%)	28.9 (14%)
EF-4**	160	589.0	09-02-69	1.0 (14%)	1.4 (20%)	9.5 (18%)
F-2***	152	586.0	08-30-69	1.0 (10%)	0.6 (22%)	7.4 (14%)
F-2***	267	430.0	11-02-69	2.8 (12%)	2.1 (20%)	11.3 (20%)
F-3***	155	611.0	09-01-69	0.4 (18%)	0.5 (26%)	5.1 (18%)
F-3***	284	384.0	11-02-69	1.3 (10%)	0.7 (24%)	9.3 (14%)
F-4***	149	535.0	09-01-69	0.2 (76%)	2.0 (22%)	18.8 (18%)
F-4***	275	320.0	11-02-69	1.1 (52%)	2.5 (36%)	14.4 (40%)
F-5***	151	424.0	09-01-69	0.0 (0%)	2.3 (18%)	23.5 (14%)

Table A-18 (Cont'd.)

RADIOACTIVITY IN SEDIMENT - 1969

SAMPLE STATION	SAMPLE NUMBER	WEIGHT[1] (GRAMS)	COLLECTION DATE	ACTIVITY IN PCI/GRAM (% ERROR)[2] CESIUM-137	RADIUM-226	POTASSIUM-40[3]
F-5***	268	366.0	11-02-69	0.2 (90%)	1.7 (22%)	28.3 (16%)
F-6***	154	740.0	09-01-69	0.1 (58%)	0.4 (24%)	4.5 (18%)
KEW***	159	575.0	09-06-69	0.7 (14%)	0.7 (22%)	8.2 (16%)
KEW***	235	609.0	11-04-69	0.2 (38%)	0.6 (22%)	6.2 (16%)
KEW***	282	475.0	11-04-69	0.9 (12%)	0.8 (20%)	9.9 (14%)
PAL***	241	544.0	10-04-69	0.2 (58%)	1.4 (20%)	14.0 (16%)
PAL***	242	576.0	11-10-69	0.1 (56%)	0.5 (22%)	7.1 (14%)
PTB***	158	631.0	09-07-69	0.2 (30%)	0.5 (22%)	5.4 (16%)
ZION**	280	553.0	10-14-69	0.2 (58%)	1.7 (20%)	9.6 (20%)

1. Dried weight.
2. Number in parentheses is percent error (two standard deviations) of total radioactivity content in sample.
3. Radioactivity levels were corrected for decay back to the date of collection.

********** LAKE MICHIGAN RADIOLOGICAL SURVEY **********

Table A-19

RADIOACTIVITY IN SEDIMENT - 1970

SAMPLE STATION	SAMPLE NUMBER	WEIGHT[1] (GRAMS)	COLLECTION DATE	ACTIVITY IN PCI/GRAM (% ERROR[2]) CESIUM-137	RADIUM-226	POTASSIUM-40[3]
A-3***	219	383.0	04-25-70	0.3 (48%)	2.1 (18%)	17.0 (16%)
A-4***	224	391.0	04-30-70	4.1 (10%)	1.3 (28%)	15.9 (18%)
A-5***	186	595.0	04-30-70	1.1 (12%)	1.0 (20%)	8.5 (16%)
A-5***	209	565.0	05-02-70	0.5 (20%)	2.3 (16%)	10.3 (14%)
A-6***	183	536.0	04-28-70	1.0 (12%)	0.9 (22%)	11.2 (14%)
A-6***	211	569.0	06-08-70	0.8 (10%)	0.7 (20%)	10.4 (12%)
AB-1**	182	632.0	05-02-70	0.6 (14%)	1.1 (18%)	6.9 (16%)
AB-1**	215	582.0	06-08-70	0.8 (12%)	0.7 (22%)	8.9 (14%)
B-5***	194	375.0	05-02-70	2.6 (12%)	2.1 (22%)	20.6 (16%)
B-5***	229	282.0	06-09-70	5.9 (8%)	2.2 (24%)	25.4 (16%)
B-6***	197	408.0	05-02-70	4.2 (8%)	1.2 (24%)	14.2 (16%)
B-6***	221	398.0	06-09-70	4.2 (8%)	1.4 (24%)	15.2 (16%)
B-7***	218	488.0	05-02-70	3.8 (8%)	1.2 (22%)	11.1 (16%)
B-7***	189	563.0	06-09-70	1.9 (10%)	1.1 (22%)	9.8 (18%)
BAILLY	214	595.0	04-28-70	0.5 (18%)	0.9 (20%)	11.6 (14%)
BRK***	204	511.0	05-17-70	1.5 (12%)	1.4 (20%)	10.7 (18%)
C-3***	226	376.0	05-07-70	1.7 (16%)	2.4 (20%)	21.4 (16%)
C-4***	227	374.0	05-07-70	4.3 (8%)	1.6 (22%)	17.0 (14%)
C-5***	195	353.0	06-11-70	1.3 (18%)	2.4 (18%)	24.5 (14%)
C-6***	192	487.0	05-04-70	2.6 (10%)	1.1 (22%)	11.4 (16%)
C-6***	216	515.0	06-10-70	1.7 (10%)	1.1 (20%)	12.4 (16%)
C-7***	185	576.0	05-04-70	1.0 (14%)	1.1 (20%)	9.2 (16%)
C-7***	213	550.0	06-10-70	1.4 (10%)	1.0 (20%)	9.1 (16%)
CD-1**	203	555.0	05-11-70	1.1 (24%)	1.2 (32%)	11.1 (26%)
CD-3**	180	418.0	05-11-70	5.4 (8%)	1.4 (22%)	16.4 (14%)
CD-3**	208	318.0	05-23-70	2.7 (12%)	2.3 (20%)	24.6 (14%)
CD-4**	173	576.0	05-23-70	0.5 (12%)	0.5 (22%)	6.9 (14%)
CD-5**	196	416.0	06-11-70	2.7 (10%)	1.0 (26%)	17.6 (14%)
CD-6**	188	577.0	06-11-70	0.7 (14%)	0.9 (20%)	12.3 (14%)
COOK**	212	582.0	04-25-70	0.0 (0%)	2.3 (18%)	12.2 (22%)
D-1***	199	656.0	05-12-70	0.1 (32%)	0.4 (22%)	8.0 (12%)
D-2***	206	357.0	05-14-70	1.4 (18%)	2.4 (20%)	24.1 (16%)
D-3***	228	253.0	05-14-70	3.9 (10%)	2.9 (20%)	28.6 (14%)
D-4***	223	245.0	05-14-70	0.6 (38%)	3.1 (18%)	30.2 (14%)
D-5***	193	398.0	05-23-70	2.4 (10%)	1.1 (24%)	17.3 (14%)
D-6***	172	552.0	05-23-70	1.0 (12%)	1.0 (20%)	8.7 (18%)
E-2***	217	463.0	05-15-70	0.5 (20%)	1.3 (18%)	14.2 (14%)
E-3***	222	239.0	05-16-70	1.0 (24%)	2.8 (20%)	31.6 (14%)

Table A-19 (Cont'd.)

RADIOACTIVITY IN SEDIMENT - 1970

SAMPLE STATION	SAMPLE NUMBER	WEIGHT[1] (GRAMS)	COLLECTION DATE	ACTIVITY IN PCI/GRAM (% ERROR)[2] CESIUM-137	RADIUM-226	POTASSIUM-40[3]
E-4***	176	300.0	05-16-70	0.2 (94%)	3.1 (18%)	30.5 (14%)
E-5***	198	340.0	05-16-70	0.0 (0%)	2.6 (22%)	28.7 (16%)
EF-1**	205	412.0	05-16-70	0.9 (16%)	1.3 (20%)	16.6 (14%)
EF-2**	190	570.0	05-16-70	0.6 (14%)	0.7 (22%)	12.3 (12%)
EF-3**	225	216.0	05-16-70	0.0 (0%)	3.3 (18%)	33.9 (14%)
EF-4**	191	549.0	05-20-70	1.0 (14%)	1.4 (20%)	9.8 (18%)
F-2***	200	560.0	05-19-70	0.7 (22%)	0.6 (38%)	8.2 (22%)
F-3***	201	512.0	05-19-70	0.4 (28%)	0.7 (30%)	5.8 (26%)
F-4***	220	356.0	05-19-70	0.0 (0%)	2.1 (18%)	23.6 (14%)
F-5***	207	349.0	05-19-70	0.1 (88%)	1.9 (18%)	23.0 (14%)
F-6***	184	553.0	05-19-70	0.4 (24%)	1.0 (20%)	11.3 (14%)
KEW***	171	571.0	05-22-70	1.0 (12%)	0.8 (22%)	9.4 (14%)
PTB***	181	535.0	05-22-70	0.3 (22%)	0.6 (20%)	7.7 (14%)
ZION**	187	597.0	05-03-70	0.0 (0%)	2.1 (20%)	8.5 (26%)
ZION**	210	595.0	06-09-70	0.2 (62%)	1.4 (18%)	8.9 (20%)

1. Dried weight.
2. Number in parentheses is percent error (two standard deviations) of total radioactivity content in sample.
3. Radioactivity levels were corrected for decay back to the date of collection.

Table A-20

RADIOACTIVITY IN SEDIMENT
Arranged by Increasing Depth of Sampling

SAMPLE STATION NUMBER	SAMPLE DEPTH (FEET)	TYPE OF SAMPLE	SAMPLE ACTIVITY IN PICOCURIES PER GRAM (PERCENT ERROR)[1,2] CESIUM-137	POTASSIUM-40	RADIUM-226[3]
210 ZION**	30	SAND	0.17 (62%)	8.88 (20%)	1.40 (18%)
187 ZION**	30	SAND	0.0 (0%)	8.49 (26%)	2.06 (20%)
280 ZION**	30	SAND	0.23 (58%)	9.61 (20%)	1.71 (20%)
242 PAL***	45	SAND	0.09 (56%)	7.06 (14%)	0.47 (22%)
241 PAL***	45	SAND	0.20 (58%)	13.97 (16%)	1.40 (20%)
214 BAILLY	50	SILT	0.49 (18%)	11.65 (14%)	0.88 (20%)
212 COOK**	50	SAND	0.0 (0%)	12.16 (22%)	2.32 (18%)
286 BAILLY	50	SILT	0.75 (14%)	12.33 (14%)	1.10 (20%)
239 BAILLY	50	SAND	0.08 (64%)	7.15 (14%)	0.55 (20%)
240 COOK**	50	SAND	0.13 (58%)	9.47 (16%)	0.91 (20%)
199 D-1***	60	SAND	0.12 (32%)	7.96 (12%)	0.39 (22%)
261 D-1***	60	SAND	0.23 (26%)	13.90 (12%)	0.60 (20%)
167 D-1***	60	SAND	0.14 (32%)	9.35 (12%)	0.45 (22%)
181 PTB***	70	SAND	0.25 (22%)	7.67 (14%)	0.60 (20%)
184 F-6***	70	SAND	0.42 (24%)	11.33 (14%)	1.03 (20%)
158 PTB***	70	SAND	0.17 (30%)	5.42 (16%)	0.50 (22%)
154 F-6***	70	SAND	0.09 (58%)	4.46 (18%)	0.40 (24%)
281 C-1***	80	SAND	0.67 (16%)	16.51 (12%)	1.19 (20%)
234 C-1***	80	SAND	0.24 (28%)	8.39 (14%)	0.51 (24%)
277 A-6'**	84	SILT	2.60 (10%)	14.05 (16%)	1.42 (20%)
171 KEW***	85	SAND	1.00 (12%)	9.45 (14%)	0.77 (22%)
282 KEW***	85	SILT	0.85 (12%)	9.88 (14%)	0.81 (20%)
159 KEW***	85	SILT	0.70 (14%)	8.20 (16%)	0.70 (22%)
235 KEW***	85	GRAVEL	0.17 (38%)	6.16 (16%)	0.61 (22%)
215 AB-1**	100	SAND	0.84 (12%)	8.95 (14%)	0.65 (22%)
182 AB-1**	100	GRAVEL	0.62 (14%)	6.87 (16%)	1.10 (18%)
172 D-6***	100	SILT	1.01 (12%)	8.68 (18%)	1.01 (20%)
276 AB-1**	100	GRAVEL	0.56 (16%)	6.99 (16%)	1.09 (18%)
230 D-6***	100	SAND	0.58 (16%)	7.70 (16%)	0.52 (26%)
156 D-6***	100	SAND	0.56 (18%)	7.21 (18%)	0.69 (24%)
211 A-6***	102	SAND	0.83 (10%)	10.38 (12%)	0.73 (20%)
183 A-6***	102	SAND	1.02 (12%)	11.21 (14%)	0.87 (22%)
203 CD-1**	125	SILT	1.13 (24%)	11.13 (26%)	1.17 (32%)
168 CD-1**	125	SILT	0.83 (14%)	12.41 (14%)	1.13 (20%)
262 CD-1**	125	SILT	1.26 (12%)	13.11 (16%)	1.14 (22%)

Table A-20 (Cont'd.)

RADIOACTIVITY IN SEDIMENT
Arranged by Increasing Depth of Sampling

SAMPLE STATION NUMBER	SAMPLE DEPTH (FEET)	TYPE OF SAMPLE	SAMPLE ACTIVITY IN PICOCURIES PER GRAM (PERCENT ERROR)[1,2] CESIUM-137	POTASSIUM-40	RADIUM-226[3]
209 A-5***	132	GRAVEL	0.52 (20%)	10.29 (14%)	2.32 (16%)
186 A-5***	132	SAND	1.12 (12%)	8.48 (16%)	1.03 (20%)
243 A-5***	132	GRAVEL	1.29 (12%)	9.76 (18%)	0.98 (24%)
201 F-3***	150	SILT	0.43 (28%)	5.82 (26%)	0.69 (30%)
284 F-3***	150	SAND	1.34 (10%)	9.29 (14%)	0.66 (24%)
260 B-2***	150	CLAY	0.31 (18%)	19.22 (16%)	2.29 (18%)
155 F-3***	150	SILT	0.42 (18%)	5.12 (18%)	0.45 (26%)
271 B-2***	150	CLAY	1.53 (24%)	18.01 (22%)	1.87 (30%)
213 C-7***	162	SAND	1.36 (10%)	9.07 (16%)	0.95 (20%)
185 C-7***	162	SILT	0.96 (14%)	9.21 (16%)	1.05 (20%)
244 C-7***	162	SILT	1.05 (14%)	8.61 (18%)	1.01 (22%)
191 EF-4**	170	SAND	0.99 (14%)	9.79 (18%)	1.36 (20%)
200 F-2***	170	CLAY	0.66 (22%)	8.16 (22%)	0.55 (38%)
267 F-2***	170	SAND	2.80 (12%)	11.31 (20%)	2.11 (20%)
256 C-2***	170	CLAY	6.18 (8%)	15.43 (20%)	2.03 (24%)
152 F-2***	170	SILT	1.02 (10%)	7.36 (14%)	0.64 (22%)
160 EF-4**	170	CLAY	1.00 (14%)	9.49 (18%)	1.37 (20%)
258 C-2***	170	CLAY	4.17 (10%)	14.70 (22%)	2.17 (22%)
189 B-7'**	175	SILT	1.91 (10%)	9.79 (18%)	1.14 (22%)
190 EF-2**	180	SAND	0.62 (14%)	12.31 (12%)	0.66 (22%)
153 EF-2**	180	SILT	0.84 (18%)	8.27 (20%)	0.75 (28%)
279 EF-2**	180	SILT	1.55 (10%)	9.36 (14%)	0.64 (26%)
188 CD-6**	190	SAND	0.73 (14%)	12.27 (14%)	0.90 (20%)
165 CD-6**	190	SILT	0.79 (14%)	12.22 (14%)	0.84 (20%)
231 CD-6**	190	SAND	1.30 (12%)	12.77 (16%)	0.85 (26%)
173 CD-4**	200	SILT	0.49 (12%)	6.91 (14%)	0.48 (22%)
219 A-3***	200	CLAY	0.29 (48%)	16.95 (16%)	2.05 (18%)
270 B-3***	200	CLAY	1.37 (30%)	25.59 (20%)	2.64 (26%)
233 CD-4**	200	SILT	1.33 (12%)	17.44 (14%)	1.24 (22%)
255 B-3***	200	CLAY	2.20 (12%)	19.78 (16%)	2.41 (20%)
170 CD-4**	200	SILT	1.16 (16%)	14.78 (16%)	1.68 (20%)
249 B-7'**	200	CLAY	0.99 (12%)	10.55 (16%)	0.93 (22%)
248 A-3***	200	CLAY	8.07 (8%)	17.19 (18%)	1.90 (26%)
204 BRK***	210	SAND	1.50 (12%)	10.73 (18%)	1.40 (20%)
174 BRK***	210	SILT	1.21 (10%)	10.74 (14%)	1.02 (18%)

Table A-20 (Cont'd.)

RADIOACTIVITY IN SEDIMENT
Arranged by Increasing Depth of Sampling

SAMPLE STATION NUMBER	SAMPLE DEPTH (FEET)	TYPE OF SAMPLE	SAMPLE ACTIVITY IN PICOCURIES PER GRAM (PERCENT ERROR)[1,2] CESIUM-137	POTASSIUM-40	RADIUM-226[3]
265 BRK***	210	SILT	3.06 (10%)	8.44 (26%)	2.11 (20%)
218 B-7***	216	SILT	3.78 (8%)	11.09 (16%)	1.22 (22%)
224 A-4***	230	CLAY	4.14 (10%)	15.89 (18%)	1.32 (28%)
247 A-4***	230	CLAY	3.44 (10%)	20.27 (16%)	1.82 (22%)
196 CD-5**	250	CLAY	2.75 (10%)	17.62 (14%)	1.05 (26%)
226 C-3***	250	CLAY	1.67 (16%)	21.36 (16%)	2.38 (20%)
206 D-2***	250	CLAY	1.37 (18%)	24.14 (16%)	2.45 (20%)
278 C-3***	250	CLAY	0.88 (24%)	23.15 (14%)	2.92 (18%)
169 D-2***	250	SILT	0.76 (12%)	11.62 (14%)	0.73 (22%)
263 D-2***	250	SILT	0.83 (14%)	11.38 (14%)	0.66 (26%)
245 C-3***	250	CLAY	0.53 (36%)	20.43 (16%)	2.80 (18%)
232 CD-5**	250	SAND	3.20 (8%)	15.11 (16%)	1.20 (24%)
166 CD-5**	250	SILT	1.88 (12%)	14.36 (16%)	1.14 (24%)
197 B-6***	260	CLAY	4.18 (8%)	14.21 (16%)	1.25 (24%)
221 B-6***	260	CLAY	4.19 (8%)	15.21 (16%)	1.40 (24%)
272 B-6***	260	CLAY	2.22 (20%)	18.63 (24%)	1.54 (38%)
205 EF-1**	300	CLAY	0.94 (16%)	16.56 (14%)	1.28 (20%)
283 EF-1**	300	CLAY	1.00 (16%)	16.41 (14%)	1.66 (20%)
164 EF-1**	300	CLAY	0.20 (70%)	16.24 (16%)	2.04 (18%)
194 B-5***	310	CLAY	2.62 (12%)	20.64 (16%)	2.14 (22%)
229 B-5***	310	CLAY	5.86 (8%)	25.40 (16%)	2.23 (24%)
285 B-5***	310	CLAY	1.90 (14%)	22.08 (16%)	2.47 (20%)
216 C-6***	325	SILT	1.66 (10%)	12.39 (16%)	1.15 (20%)
192 C-6***	325	CLAY	2.63 (10%)	11.44 (16%)	1.11 (22%)
207 F-5***	330	CLAY	0.15 (88%)	23.02 (14%)	1.86 (18%)
151 F-5***	330	CLAY	0.0 (0%)	23.46 (14%)	2.28 (18%)
268 F-5***	330	SILT	0.19 (90%)	28.28 (16%)	1.67 (22%)
227 C-4***	340	CLAY	4.29 (8%)	16.99 (14%)	1.59 (22%)
254 C-4***	340	CLAY	4.13 (8%)	18.04 (16%)	1.76 (22%)
257 C-4***	340	CLAY	3.12 (14%)	10.79 (30%)	1.89 (26%)
253 CD-2**	350	CLAY	2.39 (12%)	23.53 (16%)	2.97 (18%)
202 CD-2**	350	SILT	0.93 (22%)	9.84 (24%)	0.74 (38%)
220 F-4***	370	CLAY	0.0 (0%)	23.60 (14%)	2.15 (18%)
275 F-4***	370	CLAY	1.05 (52%)	14.42 (40%)	2.47 (36%)
149 F-4***	370	CLAY	0.25 (76%)	18.83 (18%)	1.97 (22%)

Table A-20 (Cont'd.)

RADIOACTIVITY IN SEDIMENT
Arranged by Increasing Depth of Sampling

SAMPLE STATION NUMBER	SAMPLE DEPTH (FEET)	TYPE OF SAMPLE	SAMPLE ACTIVITY IN PICOCURIES PER GRAM (PERCENT ERROR)[1,2] CESIUM-137	POTASSIUM-40	RADIUM-226[3]
208 CD-3**	390	CLAY	2.75 (12%)	24.57 (14%)	2.33 (20%)
180 CD-3**	390	CLAY	5.41 (8%)	16.43 (14%)	1.39 (22%)
177 CD-3**	390	CLAY	1.23 (18%)	23.17 (16%)	2.68 (18%)
251 CD-3**	390	CLAY	0.98 (26%)	28.07 (16%)	3.36 (18%)
193 D-5***	400	CLAY	2.44 (10%)	17.32 (14%)	1.12 (24%)
238 D-5***	400	CLAY	2.12 (16%)	17.93 (20%)	1.46 (30%)
157 D-5***	400	CLAY	0.44 (30%)	15.75 (16%)	1.32 (20%)
269 B-4***	425	CLAY	2.59 (20%)	29.88 (20%)	2.76 (28%)
259 B-4***	425	CLAY	2.87 (14%)	22.64 (18%)	2.53 (22%)
195 C-5***	500	CLAY	1.31 (18%)	24.51 (14%)	2.40 (18%)
246 C-5***	500	CLAY	1.09 (20%)	23.06 (16%)	2.69 (18%)
274 C-5***	500	CLAY	1.73 (32%)	24.88 (26%)	3.11 (28%)
223 D-4***	540	CLAY	0.61 (38%)	30.20 (14%)	3.11 (18%)
178 D-4***	540	CLAY	0.87 (24%)	25.58 (14%)	2.77 (18%)
273 D-4***	540	CLAY	1.40 (34%)	26.20 (22%)	3.05 (26%)
217 E-2***	550	SILT	0.50 (20%)	14.22 (14%)	1.29 (18%)
228 D-3***	550	CLAY	3.91 (10%)	28.58 (14%)	2.92 (20%)
198 E-5***	550	CLAY	0.0 (0%)	28.68 (16%)	2.59 (22%)
161 E-5***	550	CLAY	0.0 (0%)	24.06 (16%)	2.95 (18%)
175 D-3***	550	CLAY	5.44 (12%)	44.57 (16%)	4.61 (20%)
252 D-3***	550	CLAY	3.10 (12%)	26.06 (16%)	2.84 (20%)
264 E-2***	550	SILT	0.77 (16%)	11.57 (16%)	0.93 (22%)
150 E-2***	550	CLAY	0.60 (32%)	14.12 (18%)	2.56 (18%)
237 E-5***	550	CLAY	0.57 (56%)	29.00 (18%)	3.24 (22%)
225 EF-3**	600	CLAY	0.0 (0%)	33.89 (14%)	3.25 (18%)
250 EF-3**	600	CLAY	0.0 (0%)	28.86 (14%)	3.30 (18%)
179 EF-3**	600	CLAY	0.0 (0%)	28.77 (14%)	3.22 (18%)
176 E-4***	650	CLAY	0.22 (94%)	30.46 (14%)	3.11 (18%)
163 E-4***	650	SILT	0.25 (56%)	15.38 (16%)	1.71 (20%)
236 E-4***	650	CLAY	1.57 (18%)	24.17 (16%)	2.12 (22%)
222 E-3***	800	CLAY	1.02 (24%)	31.57 (14%)	2.82 (20%)
162 E-3***	800	CLAY	0.49 (52%)	28.99 (16%)	3.47 (18%)
266 E-3***	800	CLAY	0.0 (0%)	32.55 (16%)	2.86 (22%)

1. Dried weight.
2. Number in parentheses is percent error (two standard deviations) of total radioactivity content in sample.
3. Radioactivity levels were corrected for decay back to the date of collection.

Table A-21

RADIOACTIVITY IN BENTHOS

SAMPLE STATION	SAMPLE NUMBER	WEIGHT[1] (GRAMS)	COLLECTION DATE	ACTIVITY IN PCI/GRAM CESIUM-137	ZINC-65	(% ERROR[2] GROSS BETA[3,4]
A-4***	57	0.4254	10-15-69	0.0 (0%)	0.0 (0%)	87.1 (6%)
A-4***	291	3.2001	04-30-70	4.4 (40%)	5.6 (66%)	131.9 (2%)
A-4***	310	4.1746	06-05-70	0.0 (0%)	0.0 (0%)	214.1 (1%)
AB-1**	50	7.1313	10-10-69	2.5 (32%)	0.0 (0%)	38.3 (4%)
AB-1**	300	2.2948	05-02-70	4.4 (96%)	0.0 (0%)	113.8 (3%)
AB-1**	311	3.2309	06-08-70	0.0 (0%)	0.0 (0%)	195.7 (2%)
B-4***	56	0.4376	10-15-69	0.0 (0%)	0.0 (0%)	67.1 (6%)
B-4***	64	2.3527	11-09-69	0.0 (0%)	0.0 (0%)	160.8 (2%)
B-4***	295	1.6264	06-04-70	5.5 (68%)	11.1 (76%)	135.8 (3%)
BAILLY	53	4.6116	10-05-69	0.0 (0%)	0.0 (0%)	19.4 (6%)
BAILLY	298	0.2945	04-28-70	0.0 (0%)	0.0 (0%)	24.7 (16%)
BRK***	44	0.1605	08-29-69	0.0 (0%)	0.0 (0%)	99.4 (8%)
BRK***	288	0.7421	05-17-70	20.2 (56%)	51.2 (50%)	138.6 (4%)
BRK***	293	0.8138	05-17-70	13.5 (52%)	0.0 (0%)	158.6 (3%)
C-3***	60	4.5130	10-03-69	4.0 (34%)	0.0 (0%)	186.9 (1%)
C-3***	65	2.1959	11-08-69	6.8 (42%)	0.0 (0%)	151.3 (2%)
C-3***	299	2.3695	05-07-70	5.5 (50%)	0.0 (0%)	95.0 (3%)
C-6***	294	1.3657	05-04-70	6.6 (66%)	0.0 (0%)	173.6 (2%)
C-6***	309	7.1920	06-10-70	5.6 (38%)	0.0 (0%)	76.6 (1%)
CD-3**	45	0.1052	08-23-69	0.0 (0%)	0.0 (0%)	36.8 (20%)
CD-3**	63	2.3393	10-25-69	6.4 (40%)	0.0 (0%)	151.5 (2%)
CD-3**	305	3.3171	05-11-70	7.5 (26%)	10.6 (44%)	146.9 (2%)
CD-6**	40	0.2357	09-10-69	0.0 (0%)	0.0 (0%)	49.1 (10%)
CD-6**	54	0.3629	11-06-69	0.0 (0%)	0.0 (0%)	88.1 (6%)
CD-6**	307	4.0665	06-11-70	8.1 (24%)	8.4 (56%)	191.4 (1%)
COOK**	51	3.6102	10-04-69	0.0 (0%)	0.0 (0%)	19.4 (7%)
COOK**	302	1.6387	04-25-70	0.0 (0%)	0.0 (0%)	36.8 (6%)
COOK**	303	1.5789	04-26-70	0.0 (0%)	0.0 (0%)	54.7 (5%)
COOK**	312	2.2073	06-06-70	0.0 (0%)	0.0 (0%)	174.5 (2%)
D-1***	36	0.4914	08-24-69	0.0 (0%)	0.0 (0%)	15.5 (17%)
D-1***	49	0.7145	10-29-69	0.0 (0%)	0.0 (0%)	37.7 (8%)
D-1***	296	1.8035	05-12-70	0.0 (0%)	0.0 (0%)	129.4 (3%)
D-4***	35	0.0202	08-24-69	0.0 (0%)	1089.1 (54%)	35.1 (81%)
D-4***	59	1.8379	10-28-69	6.0 (56%)	0.0 (0%)	111.3 (3%)
D-4***	306	3.4577	05-14-70	7.2 (26%)	6.7 (68%)	188.2 (2%)
D-6***	38	0.2426	09-07-69	0.0 (0%)	0.0 (0%)	48.6 (10%)
D-6***	62	2.9485	11-05-69	5.1 (40%)	0.0 (0%)	139.4 (2%)
D-6***	290	0.4207	05-23-70	0.0 (0%)	0.0 (0%)	75.0 (6%)

Table A-21 (Cont'd.)

RADIOACTIVITY IN BENTHOS

SAMPLE STATION	SAMPLE NUMBER	WEIGHT[1] (GRAMS)	COLLECTION DATE	ACTIVITY IN PCI/GRAM (% ERROR)[2] CESIUM-137	ZINC-65	GROSS BETA[3,4]
E-2***	41	0.0349	08-25-69	0.0 (0%)	0.0 (0%)	55.5 (30%)
E-2***	58	3.8373	10-30-69	5.0 (34%)	0.0 (0%)	182.0 (2%)
E-2***	287	1.9837	05-15-70	4.0 (62%)	0.0 (0%)	123.2 (3%)
E-4***	304	2.6818	05-16-70	8.9 (30%)	11.9 (50%)	220.0 (2%)
EF-2**	43	0.3063	08-26-69	0.0 (0%)	58.8 (68%)	39.7 (11%)
EF-2**	48	0.6229	10-31-69	0.0 (0%)	0.0 (0%)	81.9 (5%)
EF-2**	297	0.7049	05-16-70	0.0 (0%)	0.0 (0%)	125.8 (4%)
EF-4**	39	0.2581	09-02-69	0.0 (0%)	0.0 (0%)	50.3 (10%)
F-5***	42	0.0264	09-01-69	0.0 (0%)	0.0 (0%)	258.5 (12%)
F-5***	61	3.8336	11-02-69	6.3 (22%)	0.0 (0%)	214.0 (1%)
F-5***	301	2.1045	05-19-70	5.2 (68%)	0.0 (0%)	188.4 (2%)
KEW***	34	0.2970	09-06-69	0.0 (0%)	0.0 (0%)	48.3 (10%)
KEW***	55	1.2250	11-04-69	0.0 (0%)	0.0 (0%)	67.7 (5%)
KEW***	289	1.9398	05-22-70	6.7 (44%)	10.3 (64%)	156.9 (2%)
PAL***	46	0.0396	10-04-69	0.0 (0%)	429.3 (74%)	43.6 (33%)
PAL***	52	1.4152	11-10-69	0.0 (0%)	0.0 (0%)	36.1 (6%)
PTB***	37	0.8863	09-07-69	0.0 (0%)	0.0 (0%)	51.3 (6%)
ZION**	47	4.3584	10-14-69	0.0 (0%)	0.0 (0%)	24.4 (5%)
ZION**	292	1.6252	05-03-70	4.9 (74%)	9.8 (84%)	177.8 (2%)
ZION**	308	4.2351	06-09-70	5.9 (28%)	8.7 (44%)	172.7 (2%)

1. Ash weight.
2. Number in parentheses is percent error (two standard deviations) of total radioactivity content in ash.
3. Cesium-137 and Zinc-65 radioactivity were corrected for decay back to the date of collection. Gross beta radioactivity is given for the date of counting (July-August 1970).
4. 0.0 (0%) signifies that the activity in the sample was less than the minimum detectable limit.

Table A-22
RADIOACTIVITY IN ZOOPLANCTON

SAMPLE STATION	SAMPLE NUMBER	WEIGHT[1] (GRAMS)	COLLECTION DATE	ACTIVITY IN PCI/GRAM CESIUM-137	ZINC-65	(% ERROR)[2] GROSS BETA[3,4]
A-4***	93	0.2201	10-15-69	0.0 (0%)	0.0 (0%)	42.1 (12%)
A-4***	346	0.2728	04-30-70	0.0 (0%)	0.0 (0%)	125.2 (5%)
A-4***	357	0.1297	06-05-70	0.0 (0%)	0.0 (0%)	48.1 (14%)
AB-1**	84	0.4339	10-10-69	0.0 (0%)	0.0 (0%)	5.2 (43%)
AB-1**	341	0.1952	05-02-70	0.0 (0%)	0.0 (0%)	58.9 (11%)
AB-1**	365	0.4402	06-08-70	0.0 (0%)	0.0 (0%)	30.1 (11%)
B-4***	79	0.1462	10-15-69	280.4 (62%)	0.0 (0%)	52.3 (13%)
B-4***	92	0.2711	11-09-69	0.0 (0%)	0.0 (0%)	162.2 (5%)
B-4***	361	0.2781	06-04-70	0.0 (0%)	0.0 (0%)	26.4 (14%)
BAILLY	85	0.2105	10-05-69	0.0 (0%)	0.0 (0%)	11.7 (34%)
BAILLY	342	0.3580	04-28-70	0.0 (0%)	0.0 (0%)	28.2 (13%)
BAILLY	355	0.0711	06-07-70	0.0 (0%)	0.0 (0%)	57.5 (17%)
BRK***	67	0.1807	08-29-69	0.0 (0%)	0.0 (0%)	50.1 (12%)
BRK***	94	0.4114	11-01-69	0.0 (0%)	0.0 (0%)	36.1 (10%)
BRK***	343	0.3172	05-17-70	0.0 (0%)	0.0 (0%)	91.0 (6%)
C-3***	83	0.2552	10-03-69	0.0 (0%)	0.0 (0%)	25.8 (16%)
C-3***	98	1.0638	11-08-69	0.0 (0%)	0.0 (0%)	67.8 (5%)
C-3***	363	0.2946	05-07-70	0.0 (0%)	0.0 (0%)	135.3 (5%)
C-6***	349	0.2826	05-04-70	0.0 (0%)	0.0 (0%)	95.4 (6%)
C-6***	352	0.2076	06-10-70	0.0 (0%)	0.0 (0%)	121.0 (6%)
CD-3**	71	0.0569	08-23-69	0.0 (0%)	0.0 (0%)	128.4 (12%)
CD-3**	86	0.2107	10-25-69	0.0 (0%)	0.0 (0%)	42.6 (13%)
CD-3**	360	0.1653	05-11-70	0.0 (0%)	0.0 (0%)	121.6 (7%)
CD-6**	73	0.0616	09-10-69	0.0 (0%)	0.0 (0%)	42.0 (26%)
CD-6**	78	0.2004	11-06-69	0.0 (0%)	0.0 (0%)	34.3 (15%)
CD-6**	350	0.2732	06-11-70	0.0 (0%)	0.0 (0%)	40.6 (12%)
COOK**	82	0.3449	10-04-69	0.0 (0%)	0.0 (0%)	15.3 (20%)
COOK**	344	0.5210	04-26-70	0.0 (0%)	0.0 (0%)	29.2 (10%)
COOK**	362	0.2500	06-06-70	0.0 (0%)	0.0 (0%)	87.2 (7%)
D-1***	77	0.3611	08-24-69	0.0 (0%)	0.0 (0%)	19.8 (16%)
D-1***	95	0.2777	10-29-69	0.0 (0%)	0.0 (0%)	57.8 (9%)
D-1***	345	0.1775	05-12-70	0.0 (0%)	0.0 (0%)	79.9 (9%)
D-4***	66	0.0565	08-24-69	0.0 (0%)	0.0 (0%)	50.5 (23%)
D-4***	81	0.1779	10-28-69	0.0 (0%)	0.0 (0%)	62.1 (10%)
D-4***	359	0.1274	05-14-70	0.0 (0%)	0.0 (0%)	88.7 (9%)
D-6***	76	0.2278	09-07-69	0.0 (0%)	0.0 (0%)	29.3 (15%)
D-6***	90	0.1961	11-05-69	0.0 (0%)	0.0 (0%)	36.5 (14%)
D-6***	354	0.3055	05-23-70	0.0 (0%)	39.3 (98%)	75.3 (7%)

Table A-22 (Cont'd.)

RADIOACTIVITY IN ZOOPLANCTON

SAMPLE STATION	SAMPLE NUMBER	WEIGHT[1] (GRAMS)	COLLECTION DATE	ACTIVITY IN PCI/GRAM CESIUM-137	ZINC-65	(% ERROR)[2] GROSS BETA[3,4]
E-2***	70	0.2104	08-25-69	0.0 (0%)	0.0 (0%)	36.6 (13%)
E-2***	96	0.1355	10-30-69	0.0 (0%)	0.0 (0%)	28.6 (20%)
E-2***	364	0.1054	05-15-70	0.0 (0%)	0.0 (0%)	73.2 (12%)
EF-2**	75	0.2865	08-26-69	0.0 (0%)	0.0 (0%)	37.8 (11%)
EF-2**	80	0.1780	10-31-69	0.0 (0%)	0.0 (0%)	18.2 (26%)
EF-2**	353	0.1896	05-16-70	0.0 (0%)	0.0 (0%)	64.2 (10%)
EF-4**	68	0.1863	09-02-69	0.0 (0%)	0.0 (0%)	51.3 (11%)
EF-4**	356	0.1650	05-20-70	0.0 (0%)	0.0 (0%)	96.4 (8%)
F-5***	69	0.0850	09-01-69	0.0 (0%)	0.0 (0%)	56.4 (16%)
F-5***	91	0.1590	11-02-69	0.0 (0%)	0.0 (0%)	30.6 (17%)
F-5***	348	0.2539	05-19-70	0.0 (0%)	0.0 (0%)	111.3 (6%)
KEW***	74	0.0448	09-06-69	0.0 (0%)	0.0 (0%)	69.1 (23%)
KEW***	89	0.3627	11-04-69	0.0 (0%)	0.0 (0%)	57.4 (8%)
KEW***	340	0.3104	05-22-70	0.0 (0%)	0.0 (0%)	70.8 (8%)
PAL***	88	0.3635	10-04-69	0.0 (0%)	0.0 (0%)	47.9 (8%)
PAL***	97	0.1892	11-10-69	0.0 (0%)	0.0 (0%)	15.4 (27%)
PAL***	347	1.0808	06-02-70	0.0 (0%)	0.0 (0%)	14.9 (13%)
PTB***	72	0.0851	09-07-69	0.0 (0%)	0.0 (0%)	56.8 (17%)
ZION**	87	0.3364	10-14-69	0.0 (0%)	0.0 (0%)	27.5 (13%)
ZION**	351	0.1256	05-03-70	0.0 (0%)	95.5 (82%)	52.4 (13%)
ZION**	358	0.2366	06-09-70	0.0 (0%)	0.0 (0%)	105.6 (6%)

1. Ash weight.
2. Number in parentheses is percent error (two standard deviations) of total radioactivity content in ash.
3. Cesium-137 and Zinc-65 radioactivity were corrected for decay back to the date of collection. Gross beta radioactivity is given for the date of counting (July-August 1970).
4. 0.0 (0%) signifies that the activity in the sample was less than minimum detectable limit.

Table A-23

RADIOACTIVITY IN PHYTOPLANCTON

SAMPLE STATION	SAMPLE NUMBER	WEIGHT[1] (GRAMS)	COLLECTION DATE	ACTIVITY IN PCI/GRAM CESIUM-137	ZINC-65	(% ERROR)[2] GROSS BETA[3,4]
A-4***	129	0.9283	10-15-69	0.0 (0%)	0.0 (0%)	36.8 (7%)
A-4***	331	1.8795	04-30-70	0.0 (0%)	0.0 (0%)	29.7 (6%)
A-4***	336	2.1345	06-05-70	0.0 (0%)	0.0 (0%)	45.5 (5%)
AB-1**	118	1.0328	10-10-69	0.0 (0%)	0.0 (0%)	21.4 (10%)
AB-1**	328	1.9784	05-02-70	0.0 (0%)	16.7 (94%)	39.8 (5%)
AB-1**	332	2.2128	06-08-70	0.0 (0%)	0.0 (0%)	39.4 (5%)
B-4***	122	0.1811	10-15-69	0.0 (0%)	0.0 (0%)	119.1 (7%)
B-4***	130	0.1312	11-09-69	0.0 (0%)	122.0 (86%)	54.6 (13%)
B-4***	337	2.3094	06-04-70	0.0 (0%)	0.0 (0%)	28.3 (6%)
BAILLY	329	3.1527	04-28-70	0.0 (0%)	0.0 (0%)	39.2 (4%)
BAILLY	124	1.8466	10-05-69	0.0 (0%)	0.0 (0%)	16.1 (9%)
BAILLY	333	1.8220	06-07-70	0.0 (0%)	0.0 (0%)	41.7 (5%)
BRK***	110	0.1418	08-29-69	0.0 (0%)	0.0 (0%)	45.1 (14%)
BRK***	120	0.6358	11-01-69	0.0 (0%)	0.0 (0%)	28.7 (9%)
BRK***	327	3.3717	05-17-70	2.7 (82%)	0.0 (0%)	31.9 (5%)
C-3***	113	0.5219	10-03-69	0.0 (0%)	0.0 (0%)	16.4 (15%)
C-3***	119	0.6258	11-08-69	0.0 (0%)	33.6 (80%)	42.4 (7%)
C-3***	323	1.2437	05-07-70	6.4 (94%)	29.7 (44%)	26.8 (8%)
C-6***	319	1.4280	05-04-70	0.0 (0%)	0.0 (0%)	24.9 (8%)
C-6***	338	1.9622	06-10-70	0.0 (0%)	0.0 (0%)	51.7 (4%)
CD-3**	106	0.1644	08-23-69	0.0 (0%)	480.5 (30%)	84.7 (9%)
CD-3**	114	0.6160	10-25-69	0.0 (0%)	51.9 (52%)	33.1 (9%)
CD-3**	320	2.4019	05-11-70	3.3 (78%)	0.0 (0%)	33.0 (5%)
CD-6**	109	0.3550	09-10-69	0.0 (0%)	78.9 (62%)	31.1 (12%)
CD-6**	128	0.0760	11-06-69	0.0 (0%)	0.0 (0%)	66.2 (15%)
CD-6**	339	2.2581	06-11-70	0.0 (0%)	0.0 (0%)	38.8 (5%)
COOK**	316	2.3885	04-26-70	0.0 (0%)	0.0 (0%)	38.2 (5%)
COOK**	115	1.7673	10-04-69	0.0 (0%)	0.0 (0%)	17.3 (9%)
COOK**	335	2.2470	06-06-70	0.0 (0%)	0.0 (0%)	22.8 (7%)
D-1***	102	1.5577	08-24-69	0.0 (0%)	0.0 (0%)	34.0 (6%)
D-1***	117	0.8563	10-29-69	0.0 (0%)	19.9 (96%)	35.1 (7%)
D-1***	334	2.0628	05-12-70	0.0 (0%)	0.0 (0%)	17.4 (9%)
D-6***	99	2.0912	09-07-69	0.0 (0%)	0.0 (0%)	34.6 (6%)
D-6***	116	0.9600	11-05-69	0.0 (0%)	0.0 (0%)	58.9 (5%)
D-6***	317	3.3280	05-23-70	0.0 (0%)	0.0 (0%)	27.1 (5%)
D-4***	105	0.0847	08-24-69	0.0 (0%)	566.7 (36%)	63.8 (14%)
D-4***	123	0.5426	10-28-69	0.0 (0%)	0.0 (0%)	33.3 (9%)
D-4***	314	2.3452	05-14-70	0.0 (0%)	0.0 (0%)	23.9 (7%)

Table A-23 (Cont'd.)

RADIOACTIVITY IN PHYTOPLANCTON

SAMPLE STATION	SAMPLE NUMBER	WEIGHT[1] (GRAMS)	COLLECTION DATE	ACTIVITY IN PCI/GRAM (% ERROR)[2] CESIUM-137	ZINC-65	GROSS BETA[3,4]
E-2***	100	0.5503	08-25-69	0.0 (0%)	45.4 (66%)	34.2 (9%)
E-2***	315	0.7258	05-15-70	0.0 (0%)	0.0 (0%)	32.0 (9%)
E-2***	326	2.7979	05-15-70	0.0 (0%)	0.0 (0%)	30.1 (5%)
EF-2**	108	0.2474	08-26-69	0.0 (0%)	165.7 (42%)	28.6 (14%)
EF-2**	127	0.5287	10-31-69	0.0 (0%)	68.1 (48%)	27.6 (10%)
EF-2**	330	2.2995	05-16-70	0.0 (0%)	0.0 (0%)	31.8 (5%)
EF-4**	103	0.1248	08-02-69	0.0 (0%)	0.0 (0%)	81.8 (10%)
EF-4**	318	1.5120	05-20-70	0.0 (0%)	0.0 (0%)	36.3 (6%)
F-5***	101	0.1254	09-01-69	0.0 (0%)	0.0 (0%)	29.1 (20%)
F-5***	126	0.4548	11-02-69	0.0 (0%)	59.4 (66%)	16.5 (15%)
F-5***	321	2.6969	05-19-70	3.0 (86%)	0.0 (0%)	32.5 (5%)
KEW***	104	0.3544	09-06-69	0.0 (0%)	81.8 (62%)	41.2 (9%)
KEW***	111	2.9450	11-04-69	4.1 (40%)	6.5 (60%)	16.7 (4%)
KEW***	325	2.3047	05-22-70	0.0 (0%)	0.0 (0%)	53.2 (4%)
PAL***	121	0.7490	10-04-69	0.0 (0%)	0.0 (0%)	24.2 (10%)
PAL***	125	1.6633	11-10-69	0.0 (0%)	21.0 (52%)	17.3 (9%)
PAL***	324	2.6407	06-02-70	0.0 (0%)	0.0 (0%)	42.2 (5%)
PTP***	107	0.2923	09-07-69	0.0 (0%)	0.0 (0%)	44.1 (10%)
ZION**	112	2.3437	10-14-69	0.0 (0%)	0.0 (0%)	18.1 (8%)
ZION**	313	2.1188	05-03-70	0.0 (0%)	15.1 (44%)	30.9 (6%)
ZION**	322	1.6820	06-09-70	0.0 (0%)	0.0 (0%)	29.0 (7%)

1. Ash weight.
2. Number in parentheses is percent error (two standard deviations) of total radioactivity content in ash.
3. Cesium-137 and Zinc-65 radioactivity were corrected for decay back to the date of collection. Gross beta radioactivity is given for the date of counting (July-August 1970).
4. 0.0 (0%) signifies that the activity in the sample was less than the minimum detectable limit.

Table A-24
RADIOACTIVITY IN FISH

SAMPLE[1] STATION	SAMPLE[2] NUMBER	WEIGHT[3] (GRAMS)	COLLECTION[4] DATE	ACTIVITY IN PCI/GRAM (% ERROR)[5] CESIUM-137	ZINC-65	GROSS BETA[6,7]
BRK***	371	6.2289	06-15-69	29.9 (6%)	7.7 (26%)	103.7 (2%)
C-2***	370	4.8412	06-15-69	1.4 (70%)	7.8 (30%)	81.9 (2%)
CD-3**	369	0.7485	06-15-69	9.4 (78%)	26.7 (58%)	83.0 (5%)
D-4***	367	1.2893	06-15-69	0.0 (0%)	0.0 (0%)	87.7 (4%)
E-2***	366	5.5930	06-15-69	4.3 (24%)	6.6 (32%)	96.4 (2%)
F-5***	368	1.7985	06-15-69	8.9 (36%)	31.7 (22%)	107.3 (3%)
ZION**	372	6.7620	06-15-69	6.7 (14%)	8.9 (20%)	96.9 (2%)

1. Nearest station to point of collection.
2. Type of Fish: perch (370, 371), sculpin (366, 368), chub (367, 369, 372)
3. Ash weight.
4. Exact dates of collection are unknown.
5. Number in parentheses is percent error (two standard deviations) of total radioactivity in ash.
6. Cesium-137 and Zinc-65 radioactivity were corrected for decay back to the date of collection. Gross beta radioactivity is given for the date of counting (July-August 1970).
7. 0.0 (0%) signifies that the activity in the sample was less than the minimum detectable limit.

Table A-25

Lake Michigan Radiological Survey

Cesium-137 and Zinc-65 in Edible Flesh of Fish

Sample Station	Sample Number	Sample Type	Weight (grams)	Activity in 10^{-7}uCi/g of Flesh[2]	
				Cesium-137	Zinc-65
BRK	371	Perch	202.0	9.2	2.4
C-2	370	Perch	134.0	0.5	2.8
CD-3	369	Chub	23.5	3.0	8.5
D-4	367	Chub	36.5	0.0	0.0
E-2	366	Sculpin	141.5	1.7	2.6
F-5	368	Sculpin	57.5	2.8	10.0
Zion	372	Chub	201.0	2.2	3.0

1. Wet weight

2. Cesium-137 and Zinc-65 radioactivity were corrected for decay back to 06-15-69.

Table A-26
RADIOACTIVITY IN PHYTOPLANKTON

(WET WEIGHT)

SAMPLE STATION	SAMPLE NUMBER	WEIGHT (GRAMS)	COLLECTION DATE	ACTIVITY IN PCI/GRAM CESIUM-137	ZINC-65	(% ERROR)[1] GROSS BETA[2,3]
A-4***	129	8.95	10-15-69	0.0 (0%)	0.0 (0%)	3.8 (7%)
A-4***	331	11.26	04-30-70	0.0 (0%)	0.0 (0%)	5.0 (6%)
A-4***	336	25.85	06-05-70	0.0 (0%)	0.0 (0%)	3.8 (5%)
AB-1**	118	20.38	10-10-69	0.0 (0%)	0.0 (0%)	1.1 (10%)
AB-1**	328	41.42	05-02-70	0.0 (0%)	0.8 (94%)	1.9 (5%)
AB-1**	332	25.88	06-08-70	0.0 (0%)	0.0 (0%)	3.4 (5%)
B-4***	122	20.08	10-15-69	0.0 (0%)	0.0 (0%)	1.1 (7%)
B-4***	130	16.88	11-09-69	0.0 (0%)	0.9 (86%)	0.4 (13%)
B-4***	337	45.27	06-04-70	0.0 (0%)	0.0 (0%)	1.4 (6%)
BAILLY	124	18.32	10-05-69	0.0 (0%)	0.0 (0%)	1.6 (9%)
BAILLY	329	43.28	04-28-70	0.0 (0%)	0.0 (0%)	2.9 (4%)
BAILLY	333	23.45	06-07-70	0.0 (0%)	0.0 (0%)	3.2 (5%)
BRK***	110	12.39	08-29-69	0.0 (0%)	0.0 (0%)	0.5 (14%)
BRK***	120	12.24	11-01-69	0.0 (0%)	0.0 (0%)	1.5 (9%)
BRK***	327	23.35	05-17-70	0.4 (82%)	0.0 (0%)	4.6 (5%)
C-3***	113	11.26	10-03-69	0.0 (0%)	0.0 (0%)	0.8 (15%)
C-3***	119	19.60	11-08-69	0.0 (0%)	1.1 (80%)	1.4 (7%)
C-3***	323	18.58	05-07-70	0.4 (94%)	2.0 (44%)	1.8 (8%)
C-6***	319	17.80	05-04-70	0.0 (0%)	0.0 (0%)	2.0 (8%)
C-6***	338	42.77	06-10-70	0.0 (0%)	0.0 (0%)	2.4 (4%)
CD-3**	107	13.34	08-23-69	0.0 (0%)	5.9 (30%)	1.0 (9%)
CD-3**	114	12.49	10-25-69	0.0 (0%)	2.6 (52%)	1.6 (9%)
CD-3**	320	18.20	05-11-70	0.4 (78%)	0.0 (0%)	4.4 (5%)
CD-6**	109	5.49	09-10-69	0.0 (0%)	5.1 (62%)	2.0 (12%)
CD-6**	128	8.66	11-06-69	0.0 (0%)	0.0 (0%)	0.6 (15%)
CD-6**	339	32.72	06-11-70	0.0 (0%)	0.0 (0%)	2.7 (5%)
COOK**	115	38.62	10-04-69	0.0 (0%)	0.0 (0%)	0.8 (9%)
COOK**	316	32.04	04-26-70	0.0 (0%)	0.0 (0%)	2.8 (5%)
COOK**	335	17.87	06-06-70	0.0 (0%)	0.0 (0%)	2.9 (7%)
D-1***	102	7.81	08-24-69	0.0 (0%)	0.0 (0%)	6.8 (6%)
D-1***	117	15.62	10-29-69	0.0 (0%)	1.1 (96%)	1.9 (7%)
D-1***	334	45.25	05-12-70	0.0 (0%)	0.0 (0%)	0.8 (9%)
D-4***	105	11.68	08-24-69	0.0 (0%)	4.1 (36%)	0.5 (14%)
D-4***	123	13.15	10-28-69	0.0 (0%)	0.0 (0%)	1.4 (9%)
D-4***	314	20.17	05-14-70	0.0 (0%)	0.0 (0%)	2.8 (7%)
D-6***	99	26.99	09-07-69	0.0 (0%)	0.0 (0%)	2.7 (6%)
D-6***	116	5.42	11-05-69	0.0 (0%)	0.0 (0%)	10.4 (5%)
D-6***	317	24.17	05-23-70	0.0 (0%)	0.0 (0%)	3.7 (5%)

Table A-26 (cont.)

RADIOACTIVITY IN PHYTOPLANKTON

(WET WEIGHT)

SAMPLE STATION	SAMPLE NUMBER	WEIGHT (GRAMS)	COLLECTION DATE	ACTIVITY IN PCI/GRAM CESIUM-137	ZINC-65	(% ERROR)[1] GROSS BETA[2,3]
E-2***	100	5.38	08-25-69	0.0 (0%)	4.6 (66%)	3.5 (9%)
E-2***	315	14.05	05-15-70	0.0 (0%)	0.0 (0%)	1.7 (9%)
E-2***	326	15.49	05-15-70	0.0 (0%)	0.0 (0%)	5.4 (5%)
EF-2**	108	7.09	08-26-69	0.0 (0%)	5.8 (42%)	1.0 (14%)
EF-2**	127	7.31	10-31-69	0.0 (0%)	4.9 (48%)	2.0 (10%)
EF-2**	330	30.95	05-16-70	0.0 (0%)	0.0 (0%)	2.4 (5%)
EF-4**	103	4.72	08-02-69	0.0 (0%)	0.0 (0%)	2.2 (10%)
EF-4**	318	21.79	05-20-70	0.0 (0%)	0.0 (0%)	2.5 (6%)
F-5***	101	6.76	09-01-69	0.0 (0%)	0.0 (0%)	0.5 (20%)
F-5***	126	4.99	11-02-69	0.0 (0%)	5.4 (66%)	1.5 (15%)
F-5***	321	19.34	05-19-70	0.4 (86%)	0.0 (0%)	4.5 (5%)
KEW***	104	4.29	09-06-69	0.0 (0%)	6.8 (62%)	3.4 (9%)
KEW***	111	16.49	11-04-69	0.7 (40%)	1.2 (60%)	3.0 (4%)
KLW***	325	37.99	05-22-70	0.0 (0%)	0.0 (0%)	3.2 (4%)
PAL***	121	17.88	10-04-69	0.0 (0%)	0.0 (0%)	1.0 (10%)
PAL***	125	10.93	11-10-69	0.0 (0%)	3.2 (52%)	2.6 (9%)
PAL***	324	33.53	06-02-70	0.0 (0%)	0.0 (0%)	3.3 (5%)
PTB***	107	6.12	09-07-69	0.0 (0%)	0.0 (0%)	2.1 (10%)
ZION**	112	30.45	10-14-69	0.0 (0%)	0.0 (0%)	1.4 (8%)
ZION**	313	27.43	05-03-70	0.0 (0%)	1.2 (44%)	2.4 (6%)
ZION**	322	19.50	06-09-70	0.0 (0%)	0.0 (0%)	2.5 (7%)

1. Number in parentheses is percent error (two standard deviations) of total radioactivity content of sample.
2. Cesium-137 and Zinc-65 radioactivity were corrected back to the date of collection. Gross beta radioactivity is given for the date of counting (July-August 1970).
3. 0.0 (0%) signifies that the activity in the sample was less than the minimum detectable limit.

********** LAKE MICHIGAN RADIOLOGICAL SURVEY **********

Table A-27

RADIOACTIVITY IN ZOOPLANCTON

(WET WEIGHT)

SAMPLE STATION	SAMPLE NUMBER	WEIGHT (GRAMS)	COLLECTION DATE	ACTIVITY IN PCI/GRAM CESIUM-137	ZINC-65	(% ERROR)[1] GROSS BETA[2,3]
A-4***	93	29.51	10-15-69	0.0 (0%)	0.0 (0%)	0.3 (12%)
A-4***	346	30.57	04-30-70	0.0 (0%)	0.0 (0%)	1.1 (5%)
A-4***	357	22.41	06-05-70	0.0 (0%)	0.0 (0%)	0.3 (14%)
AB-1**	84	30.71	10-10-69	0.0 (0%)	0.0 (0%)	0.1 (43%)
AB-1**	341	10.52	05-02-70	0.0 (0%)	0.0 (0%)	1.1 (11%)
AB-1**	365	17.62	06-08-70	0.0 (0%)	0.0 (0%)	0.8 (11%)
B-4***	79	12.73	10-15-69	3.2 (62%)	0.0 (0%)	0.6 (13%)
B-4***	92	50.10	11-09-69	0.0 (0%)	0.0 (0%)	0.9 (5%)
B-4***	361	21.79	06-04-70	0.0 (0%)	0.0 (0%)	0.3 (14%)
BAILLY	85	12.36	10-05-69	0.0 (0%)	0.0 (0%)	0.2 (34%)
BAILLY	342	4.41	04-28-70	0.0 (0%)	0.0 (0%)	2.3 (13%)
BAILLY	355	6.06	06-07-70	0.0 (0%)	0.0 (0%)	0.7 (17%)
BRK***	67	25.10	08-29-69	0.0 (0%)	0.0 (0%)	0.4 (12%)
BRK***	94	29.67	11-01-69	0.0 (0%)	0.0 (0%)	0.5 (10%)
BRK***	343	28.64	05-17-70	0.0 (0%)	0.0 (0%)	1.0 (6%)
KEW***	74	25.43	09-06-69	0.0 (0%)	0.0 (0%)	0.1 (23%)
KEW***	89	18.19	11-04-69	0.0 (0%)	0.0 (0%)	1.1 (8%)
KEW***	340	18.38	05-22-70	0.0 (0%)	0.0 (0%)	1.2 (8%)
C-3***	83	28.84	10-03-69	0.0 (0%)	0.0 (0%)	0.2 (16%)
C-3***	98	59.20	11-08-69	0.0 (0%)	0.0 (0%)	1.2 (5%)
C-3***	363	20.61	05-07-70	0.0 (0%)	0.0 (0%)	1.9 (5%)
C-6***	349	30.31	05-04-70	0.0 (0%)	0.0 (0%)	0.9 (6%)
C-6***	352	29.44	06-10-70	0.0 (0%)	0.0 (0%)	0.9 (6%)
CD-3**	71	22.34	08-23-69	0.0 (0%)	0.0 (0%)	0.3 (12%)
CD-3**	86	20.51	10-25-69	0.0 (0%)	0.0 (0%)	0.4 (13%)
CD-3**	360	16.70	05-11-70	0.0 (0%)	0.0 (0%)	1.2 (7%)
CD-6**	73	17.60	09-10-69	0.0 (0%)	0.0 (0%)	0.1 (26%)
CD-6**	78	12.06	11-06-69	0.0 (0%)	0.0 (0%)	0.6 (15%)
CD-6**	350	10.75	06-11-70	0.0 (0%)	0.0 (0%)	1.0 (12%)
COOK**	82	9.63	10-04-69	0.0 (0%)	0.0 (0%)	0.5 (20%)
COOK**	344	14.20	04-26-70	0.0 (0%)	0.0 (0%)	1.1 (10%)
COOK**	362	11.57	06-06-70	0.0 (0%)	0.0 (0%)	1.9 (7%)
D-1***	77	13.02	08-24-69	0.0 (0%)	0.0 (0%)	0.5 (16%)
D-1***	95	36.49	10-29-69	0.0 (0%)	0.0 (0%)	0.4 (9%)
D-1***	345	19.36	05-12-70	0.0 (0%)	0.0 (0%)	0.7 (9%)
D-4***	66	167.70	08-24-69	0.0 (0%)	0.0 (0%)	0.0 (23%)
D-4***	81	20.04	10-28-69	0.0 (0%)	0.0 (0%)	0.6 (10%)
D-4***	359	22.30	05-14-70	0.0 (0%)	0.0 (0%)	0.5 (9%)

Table A-27 (cont.)

RADIOACTIVITY IN ZOOPLANCTON

(WET WEIGHT)

SAMPLE STATION	SAMPLE NUMBER	WEIGHT (GRAMS)	COLLECTION DATE	ACTIVITY IN PCI/GRAM (% ERROR)[1] CESIUM-137	ZINC-65	GROSS BETA[2,3]
D-6***	76	26.08	09-07-69	0.0 (0%)	0.0 (0%)	0.3 (15%)
D-6***	90	8.52	11-05-69	0.0 (0%)	0.0 (0%)	0.8 (14%)
D-6***	354	21.65	05-23-70	0.0 (0%)	0.6 (98%)	1.1 (7%)
E-2***	70	7.67	08-25-69	0.0 (0%)	0.0 (0%)	1.0 (13%)
E-2***	96	10.97	10-30-69	0.0 (0%)	0.0 (0%)	0.4 (20%)
E-2***	364	8.69	05-15-70	0.0 (0%)	0.0 (0%)	0.9 (12%)
EF-2**	75	32.00	08-26-69	0.0 (0%)	0.0 (0%)	0.3 (11%)
EF-2**	80	12.57	10-31-69	0.0 (0%)	0.0 (0%)	0.3 (26%)
EF-2**	353	17.73	05-16-70	0.0 (0%)	0.0 (0%)	0.7 (10%)
EF-4**	68	24.70	09-02-69	0.0 (0%)	0.0 (0%)	0.4 (11%)
EF-4**	356	32.22	05-20-70	0.0 (0%)	0.0 (0%)	0.5 (8%)
F-5***	69	24.50	09-01-69	0.0 (0%)	0.0 (0%)	0.2 (16%)
F-5***	91	8.52	11-02-69	0.0 (0%)	0.0 (0%)	0.6 (17%)
F-5***	348	29.52	05-19-70	0.0 (0%)	0.0 (0%)	1.0 (6%)
PAL***	68	33.78	10-04-69	0.0 (0%)	0.0 (0%)	0.5 (8%)
PAL***	97	30.37	11-10-69	0.0 (0%)	0.0 (0%)	0.1 (27%)
PAL***	347	10.34	06-02-70	0.0 (0%)	0.0 (0%)	1.6 (13%)
PTB***	72	15.40	09-07-69	0.0 (0%)	0.0 (0%)	0.3 (17%)
ZION**	87	28.40	10-14-69	0.0 (0%)	0.0 (0%)	0.3 (13%)
ZION**	351	10.11	05-03-70	0.0 (0%)	1.2 (82%)	0.7 (13%)
ZION**	358	8.74	06-09-70	0.0 (0%)	0.0 (0%)	2.9 (6%)

1. Number in parentheses is percent error (two standard deviations) of total radioactivity content of sample.

2. Cesium-137 and Zinc-65 radioactivity were corrected back to the date of collection. Gross beta radioactivity is given for the date of counting (July-August 1970).

3. 0.0 (0%) signifies that the activity in the sample was less than the minimum detectable limit.

Table A-28
RADIOACTIVITY IN BENTHOS

(WET WEIGHT)

SAMPLE STATION	SAMPLE NUMBER	WEIGHT (GRAMS)	COLLECTION DATE	ACTIVITY IN PCI/GRAM (% ERROR)[1] CESIUM-137	ZINC-65	GROSS BETA[2,3]
A-4***	57	30.08	10-15-69	0.0 (0%)	0.0 (0%)	1.2 (6%)
A-4***	291	78.40	04-30-70	0.2 (40%)	0.2 (66%)	5.4 (2%)
A-4***	310	22.50	06-05-70	0.0 (0%)	0.0 (0%)	39.7 (1%)
AB-1**	50	36.96	10-10-69	0.5 (32%)	0.0 (0%)	7.4 (4%)
AB-1**	300	60.35	05-02-70	0.2 (96%)	0.0 (0%)	4.3 (3%)
AB-1**	311	141.20	06-08-70	0.0 (0%)	0.0 (0%)	4.5 (2%)
B-4***	56	36.47	10-15-69	0.0 (0%)	0.0 (0%)	0.8 (6%)
B-4***	64	158.30	11-09-69	0.0 (0%)	0.0 (0%)	2.4 (2%)
B-4***	295	50.31	06-04-70	0.2 (68%)	0.4 (76%)	4.4 (3%)
BAILLY	53	17.57	10-05-69	0.0 (0%)	0.0 (0%)	5.1 (6%)
BAILLY	298	6.75	04-28-70	0.0 (0%)	0.0 (0%)	1.1 (16%)
BRK***	44	6.57	08-29-69	0.0 (0%)	0.0 (0%)	2.4 (8%)
BRK***	288	32.66	05-17-70	0.5 (56%)	1.2 (50%)	3.1 (4%)
BRK***	293	39.99	05-17-70	0.3 (52%)	0.0 (0%)	3.2 (3%)
KEW***	34	13.05	09-06-69	0.0 (0%)	0.0 (0%)	1.1 (10%)
KEW***	55	32.60	11-04-69	0.0 (0%)	0.0 (0%)	2.5 (5%)
KEW***	289	67.45	05-22-70	0.2 (44%)	0.3 (64%)	4.5 (2%)
C-3***	60	272.50	10-03-69	0.1 (34%)	0.0 (0%)	3.1 (1%)
C-3***	65	159.00	11-08-69	0.1 (42%)	0.0 (0%)	2.1 (2%)
C-3***	299	59.15	05-07-70	0.2 (50%)	0.0 (0%)	3.8 (3%)
C-6***	294	55.08	05-04-70	0.2 (66%)	0.0 (0%)	4.3 (2%)
C-6***	309	241.80	06-10-70	0.2 (38%)	0.0 (0%)	2.3 (1%)
CD-3**	45	3.84	08-23-69	0.0 (0%)	0.0 (0%)	1.0 (20%)
CD-3**	63	165.60	10-25-69	0.1 (40%)	0.0 (0%)	2.1 (2%)
CD-3**	305	136.85	05-11-70	0.2 (26%)	0.3 (44%)	3.6 (2%)
CD-6**	40	11.24	09-10-69	0.0 (0%)	0.0 (0%)	1.0 (10%)
CD-6**	54	30.31	11-06-69	0.0 (0%)	0.0 (0%)	1.1 (6%)
CD-6**	307	165.50	06-11-70	0.2 (24%)	0.2 (56%)	4.7 (1%)
COOK**	51	19.20	10-04-69	0.0 (0%)	0.0 (0%)	3.6 (7%)
COOK**	302	13.20	04-25-70	0.0 (0%)	0.0 (0%)	4.6 (6%)
COOK**	303	36.93	04-26-70	0.0 (0%)	0.0 (0%)	2.3 (5%)
COOK**	312	177.70	06-06-70	0.0 (0%)	0.0 (0%)	2.2 (2%)
D-1***	36	6.41	08-24-69	0.0 (0%)	0.0 (0%)	1.2 (17%)
D-1***	49	14.82	10-29-69	0.0 (0%)	0.0 (0%)	1.8 (8%)
D-1***	296	57.71	05-12-70	0.0 (0%)	0.0 (0%)	4.0 (3%)
D-4***	35	0.79	08-24-69	0.0 (0%)	27.8 (54%)	0.9 (81%)
D-4***	59	64.80	10-28-69	0.2 (56%)	0.0 (0%)	3.2 (3%)
D-4***	306	163.80	05-14-70	0.2 (26%)	0.1 (68%)	4.0 (2%)

Table A-28 (cont.)

RADIOACTIVITY IN BENTHOS

(WET WEIGHT)

SAMPLE STATION	SAMPLE NUMBER	WEIGHT (GRAMS)	COLLECTION DATE	ACTIVITY IN PCI/GRAM (% ERROR)[1] CESIUM-137	ZINC-65	GROSS BETA[2,3]
D-6***	38	11.14	09-07-69	0.0 (0%)	0.0 (0%)	1.1 (10%)
D-6***	62	310.50	11-05-69	0.0 (40%)	0.0 (0%)	1.3 (2%)
D-6***	290	13.00	05-23-70	0.0 (0%)	0.0 (0%)	2.4 (6%)
E-2***	41	1.93	08-25-69	0.0 (0%)	0.0 (0%)	1.0 (30%)
E-2***	58	289.00	10-30-69	0.1 (34%)	0.0 (0%)	2.4 (2%)
E-2***	287	55.80	05-15-70	0.1 (62%)	0.0 (0%)	4.4 (3%)
E-4***	304	136.30	05-16-70	0.2 (30%)	0.2 (50%)	4.3 (2%)
EF-2**	43	0.90	08-26-69	0.0 (0%)	20.0 (68%)	13.5 (11%)
EF-2**	48	35.80	10-31-69	0.0 (0%)	0.0 (0%)	1.4 (5%)
EF-2**	297	34.85	05-16-70	0.0 (0%)	0.0 (0%)	2.5 (4%)
EF-4**	39	11.17	09-02-69	0.0 (0%)	0.0 (0%)	1.2 (10%)
F-5***	42	0.60	09-01-69	0.0 (0%)	0.0 (0%)	11.4 (12%)
F-5***	61	177.10	11-02-69	0.1 (22%)	0.0 (0%)	4.6 (1%)
F-5***	301	138.30	05-19-70	0.1 (68%)	0.0 (0%)	2.9 (2%)
PAL***	46	23.77	10-04-69	0.0 (0%)	0.7 (74%)	0.1 (33%)
PAL***	52	15.77	11-10-69	0.0 (0%)	0.0 (0%)	3.2 (6%)
PTB***	37	20.95	09-07-69	0.0 (0%)	0.0 (0%)	2.2 (6%)
ZION**	47	38.51	10-14-69	0.0 (0%)	0.0 (0%)	2.8 (5%)
ZION**	292	88.45	05-03-70	0.1 (74%)	0.2 (84%)	3.3 (2%)
ZION**	308	265.60	06-09-70	0.1 (28%)	0.1 (44%)	2.8 (2%)

1. Number in parentheses is percent error (two standard deviations) of total radioactivity content of sample.

2. Cesium-137 and Zinc-65 radioactivity were corrected back to the date of collection. Gross beta radioactivity is given for the date of counting (July-August 1970).

3. 0.0 (0%) signifies that the activity in the sample was less than the minimum detectable limit.

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CHAPTER B

NEUTRON ACTIVATION AND ATOMIC ABSORPTION ANALYSIS

Richard Copeland and Ronald Rossmann

FIELD METHODS

Metal-free collecting techniques were employed during the cruises of 1969 and 1970. Metal-free techniques are a prerequisite to the subsequent analysis of trace elements. The samples taken by the metal-free methods were water, bottom sediments, benthos, phytoplankton, and zooplankton.

The equipment used for metal-free collection included water sampling apparatus rigged on the ship's bowsprit, a ponar dredge, # 000, # 5, # 20 plankton nets, synthetic line, assorted pieces of nylon stocking, large and small plastic spoons, plastic funnels, plastic bags, plastic bottles, plastic buckets, large plastic garbage pails, plastic mats, plastic bottles filled with sand for use as weights, a metal-free pump and hoses, fiberglass tubs, and a plastic coated underwater sled.

The water sampling apparatus consisted of a plastic pulley mounted on the forward end of the bowsprit and several yards of light synthetic line running around the pulley and back to the bow of the ship. A water sampling bottle and a metal-free weight were attached to the line and heaved forward. Manipulation of the line maintained the sampling bottle at the proper depth (ca. 2 ft) and at maximum distance from the ship's hull. The forward position of the sampling rig permitted collection of water which had not come in contact with the ship's hull.

Water sampling commenced immediately upon arrival at a station. The sampling bottles were filled and taken to the ship's lab where the water was filtered using glass and plastic apparatus and the filtered water was acidified and stored in plastic bottles. The filters were handled with plastic forceps. After each filtration, the filters were placed in a plastic bag and frozen and the filtering apparatus was rinsed with concentrated nitric acid.

Sediment samples were taken with a ponar dredge. The sediments were deposited on a large plastic mat and samples from the center portion that had not touched the dredge were transferred to plastic bags with a plastic spoon.

The samples were then dried or frozen, depending upon the intended method of analysis.

Benthos samples were obtained in one of two ways, depending upon the species of organisms present, water depth, and type of bottom. The preferred method was to tow a sled net along the bottom. The sled carried a # 000 net which trapped the benthic organisms but allowed the fine stirred-up sediment to pass through. Exclusion of sediment was important to avoid contamination of the sample. Metal-free samples were insured by covering all parts of the sled around the mouth of the net with plastic tape and plastic spray coating. A towing harness of synthetic line was used between the sled and the steel towing cable. The organisms collected in the glass jar at the end of the net were then concentrated by straining the excess water off through a piece of nylon stocking stretched over a large plastic funnel. The organisms were then rinsed lightly with distilled water and transferred by plastic spoons to plastic bags for freezing.

The second method involved collecting sediments with the ponar dredge and separating the benthos from the sediment on board ship. Each dredge sample was placed in a plastic bucket or fiber-glass tub and thoroughly agitated with lake water provided by the metal-free pump. The dense sediment would settle out while the less dense benthos remained in suspension. The water was then poured through the nylon stocking-plastic funnel strainer. The benthos collected on the stocking was placed in a plastic bag with a plastic spoon, rinsed lightly with distilled water, and frozen.

The metal net hoops on both the phytoplankton and zooplankton nets were covered with plastic tape. When it was necessary to use a steel towing cable, about 20 feet of synthetic line was used as a buffer between the net and the cable. Whenever possible the nets were towed with synthetic line.

Phytoplankton samples were collected with a # 20 plankton net. After being towed, the phytoplankton net was suspended from the towing boom and the sample concentrated in the bottom of the net by rinsing the sides of the net with lake water provided by the metal-free pump. The concentrated phytoplankton sample was strained through a # 5 net into a # 20 net placed inside a large plastic garbage pail. The garbage pail supported the # 20 net and prevented metal contamination of the sample. By trapping the zooplankton in the # 5 net, this method prevented contamination of the phytoplankton sample by zooplankton caught in the phytoplankton tow. The net where the phytoplankton sample had

collected after straining was wrung* to remove excess water, turned inside out and the concentrated sample scraped off with plastic spoons and placed in plastic bags and frozen.

Zooplankton samples were collected with # 5 plankton nets. After a sample had been taken, the net was suspended from the towing boom and rinsed down with lake water provided by the metal-free pump. The part of the net which contained the concentrated zooplankton was scrubbed* and rinsed with lake water several times to remove phytoplankton which could contaminate the zooplankton sample. The scrubbed concentrated zooplankton sample was placed on a piece of fine mesh plankton netting stretched over a plastic funnel, rinsed lightly with distilled water and allowed to drain for a minute. The sample was removed from the netting with a plastic spoon, placed in a plastic bag and frozen.

NEUTRON ACTIVATION ANALYSIS

Introduction

The neutron activation analysis work of the Lake Michigan environmental survey began with the arrival of Richard Copeland at the University of Michigan in November 1969.

The first few months were spent developing a suitable analytical technique which would maximize the results obtainable. During this time we experienced great difficulty in packaging multiple samples for long in-core irradiations. These problems were brought to the attention of The Group in March 1970, along with a prediction that only 50 samples (16% of the total) would be completely analyzed by 25 September 1970. A copy of this letter is enclosed as Appendix A. We are pleased to report that we overestimated the demand by others on the counting equipment and that we have completed approximately 40% of the analyses. Of these, seven are presented as examples.

Analytical Procedure

Our prime concern has been to develop a procedure which would maximize the amount of data that could be obtained from the very limited amount of dry sample that was normally available (.5 grams). This precluded the use of any destructive analytical technique. There was not enough sample available to destructively analyze for such diverse elements as ruthenium, tellurium, silver, sodium, iron, phosphorus, etc.

The analytical method we have developed enables us to analyze for most of the elements listed in the original proposal in addition to about 15 other

*Plastic gloves were worn.

elements not listed. We have not been able to analyze routinely for ruthenium, tellurium, molybdenum and phosphorus. Their concentrations are too low to detect nondestructively in .5 gram samples. It is our hope that when all the analyses are completed there may be some sample material from certain stations left over. If this is the case we will attempt to do destructive analyses on them for these four elements. Our analytical procedure is as follows.

The samples, frozen on board ship, are dried in the laboratory overnight at 80°C. One half gram, or whatever is available, is weighed into a polyethylene vial which is then heat sealed. A standard reference solution containing all the elements of interest is sealed in a similar vial. The sample and standard are irradiated together for two minutes in a thermal neutron flux of 3×10^{12} neutrons/cm^2-sec. The standard is then counted immediately for 200 seconds on a 35cc Ge(Li) crystal and the data accumulated in a Nuclear Data 4096 memory. After counting, the data are transferred to magnetic tape and the sample counted for 400 seconds. These data are also stored on tape and the standard recounted for 400 seconds and the sample again for 2000 seconds.

The first set of counts enables us to obtain aluminum and vanadium and occasionally copper and titanium. The second counts give us calcium, magnesium, chlorine, iodine, manganese, dysprosium and in sediment, strontium.

We then irradiate the sample and standard for 10 minutes at a thermal neutron flux of 1.5×10^{13} neutrons/cm^2-sec. The sample and standard are allowed to decay for 24 hours and are counted for several hours. We obtain bromine, sodium, potassium, arsenic, lanthanum and occasionally molybdenum at this time.

The samples are repackaged in aluminum foil as are the standards. Approximately 15-20 of these standards and samples are packaged in an aluminum holder and irradiated for 50 hours at a thermal flux of 10^{13} neutrons/cm^2-sec. The samples are allowed to decay for 5 days and are repackaged to remove the aluminum foil and counted for several hours. Concentrations of lanthanum, gold, samarium, ytterbium and lutetium can usually be obtained.

The samples are allowed to decay for three to five weeks and are counted 12 hours for the final results. Here we obtain rubidium, zinc, mercury, iron, antimony, cobalt, chromium, silver, thorium, selenium, scandium, neodymium, europium, terbium, cesium, and barium.

All of the data are stored on seven-track magnetic tape and analyzed by the University of Michigan IBM 360 computers.

Results

The results were generally encouraging in that usually we were able to analyze routinely for 30-35 elements nondestructively. We were discouraged, however, by the results of the work which seemed to indicate that most of the organic samples are heavily contaminated with sediment. We began to notice very early in the work that there existed a wide variation in trace elements between samples that were collected fairly near one another. When these data were plotted on a base map of Lake Michigan it was apparent that no logical pattern existed by which these wide variations in trace elements could be explained by river or airborne inputs of trace elements into Lake Michigan.

Further examination of the data showed that almost all the elements tended to increase as a group rather than independently. This led us to suspect that some additional physical component was being taken with the biological samples in varying amounts. On the basis of the rare-earth concentration and distribution of those samples which were contaminated, we feel certain that the contaminant is sediment which has been collected with the biological samples.

Because of this problem we do not feel that the data we have obtained represent, in their present form, concentrations of trace elements which are directly connected with the organic phases. Typical analyses of organic phases showing one "lightly contaminated" and one "heavily contaminated" analysis of benthos, phytoplankton, and zooplankton are included with this report (Tables B-1-7). Note especially the differences in iron, aluminum and scandium.

With effort, the sediment contribution to the organic analyses can probably be corrected for and reconcentration factors and other environmental parameters calculated.

The Great Lakes Research Division has proposed to The Group that the funding be continued to complete the neutron activation analysis work. We feel that the remaining 60% of the analyses can be completed by 1 October 1971.

ATOMIC ABSORPTION AND FLAME EMISSION

Ninety percent of the elemental analyses are complete on benthos, zooplankton, phytoplankton, sediment and water samples. The elements determined are Ca, Mg, K, Na, Mn, Fe, Zn, P, Cu, Co, Ni, Mo, Ba, Sr, Cr, and Li. Though only a small portion of the raw data is tabulated, 80% of it is available as computer output. Benthos, zooplankton, phytoplankton and sediment samples

TABLE B-1.* Sample EF-2 Phytoplankton Analysis, P.P.M. Cruise One.

Au	.32±.05	Dy	ND
Mo	ND	Yb	.005±.004
Rb	12.7±.4	Lu	ND
Zn	88.4±50	Cs	4.4±.126
Hg	4.0±.2	Ba	25.5±6
Fe	259±3.6	Al	861±53
Sb	.087±.004	V	.64±.3
Co	.353±.05	Ca	5646±497
Cr	6.2±.1	Mg	<1000
Ag	.084±.02	Cl	133,000±6000
Th	.042±.006	I	32±11
Se	ND	Mn	11.9±.35
Sc	.070±.001	Sr	ND
La	.414±.011	Br	208±24
Nd	ND	K	14349±1828
Sm	.385±.02	Na	9337±265
Eu	.01±.001	As	present
Tb	.045±.02		

*"Lightly contaminated."

TABLE B-2.* Sample Cook Phytoplankton Analysis, P.P.M. Cruise One.

Au	.57±.02	Dy	.19±.03
Mo	ND	Yb	ND
Rb	8.5±4	Lu	.033±.002
Zn	240±100	Cs	.278±.020
Hg	7.6±2	Ba	71±17
Fe	2755±34	Al	10510±613
Sb	.223±.01	V	3.15±.6
Co	.905±.01	Ca	14700±900
Cr	14.3±.3	Mg	1492±400
Ag	ND	Cl	14160±500
Th	.72±.03	I	39±12
Se	1.05±.2	Mn	69±1.0
Sc	.874±.005	Sr	ND
La	2.4±.026	Br	19.9±.335
Nd	ND	K	1238±22
Sm	2.4±.05	Na	238.6±.9
Eu	.064±.002	As	2.1±.1
Tb	.055±.03		

*"Heavily contaminated."

TABLE B-3.* Sample C-3 Benthos Analysis, P.P.M. Cruise One.

Au	ND	Dy	ND
Mo	5±3	Yb	ND
Rb	7.4±.4	Lu	ND
Zn	122±50	Cs	.052±.007
Hg	2.1±.5	Ba	44±23
Fe	157±4.5	Al	454±40
Sb	.02±.004	V	<.3
Co	.15±.004	Ca	12265±740
Cr	3.2±.16	Mg	1361±700
Ag	.051±.03	Cl	120,000±3000
Th	.02±.001	I	40±14
Se	2.8±.15	Mn	9.1±.1
Sc	.039±.001	Sr	ND
La	.17±.01	Br	170±21
Nd	ND	K	10521±1629
Sm	ND	Na	8668±360
Eu	.005±.001	As	2.2±1
Tb	.0145±.007		

*"Lightly contaminated."

TABLE B-4.* Sample CD-3 Benthos Analysis, P.P.M. Cruise Two.

Au	.026±.01	Dy	.328±.1
Mo	ND	Yb	.005±.003
Rb	17±.4	Lu	ND
Zn	73.3±50	Cs	.639±.01
Hg	13±5	Ba	97.9±31
Fe	3866±29	Al	8075±444
Sb	.072±.004	V	2.97±.63
Co	.935±.008	Ca	15243±1424
Cr	6.7±.17	Mg	1142±1000
Ag	.071±.04	Cl	175,000±8000
Th	.266±.011	I	60±37
Se	3.1±.5	Mn	99.3±9.7
Sc	.332±.001	Sr	ND
La	1.013±.025	Br	208±18
Nd	ND	K	14499±1765
Sm	.185±.05	Na	8610±200
Eu	.030±.001	As	9.52±4
Tb	.0175±.005		

*"Heavily contaminated."

TABLE B-5.* Sample AB-1 Zooplankton Analysis, P.P.M. Cruise One.

Au	ND	Dy	present
Mo	ND	Yb	ND
Rb	2.7±.2	Lu	ND
Zn	195±50	Cs	.033±.008
Hg	.81±.4	Ba	38±15
Fe	189±5	Al	792±40
Sb	.408±.012	V	.54±.17
Co	.2±.005	Ca	17645±968
Cr	1.7±.1	Mg	1493±344
Ag	.025±.01	Cl	7550±262
Th	.016±.011	I	ND
Se	3.9±.5	Mn	11.7±.2
Sc	.043±.001	Sr	35±13
La	.09±.004	Br	404±22
Nd	ND	K	4095±300
Sm	.041±.004	Na	1039±17
Eu	.005±.001	As	5.6±3
Tb	.006±.003		

*"Lightly contaminated."

TABLE B-6.* Sample D-6 Zooplankton Analysis, P.P.M. Cruise One.

Au	<.05	Dy	.38±.1
Mo	ND	Yb	.040±.01
Rb	11.3±.3	Lu	.032±.005
Zn	166±50	Cs	.18±.014
Hg	1.2±.5	Ba	206±34
Fe	2294±18	Al	15946±527
Sb	.08±.004	V	3.4±.6
Co	1.07±.01	Ca	34196±2000
Cr	7.6±.15	Mg	2800±700
Ag	.125±.05	Cl	6868±354
Th	1.001±.028	I	ND
Se	.86±.2	Mn	65.1±1.0
Sc	.713±.002	Sr	ND
La	3.28±.03	Br	296±23
Nd	ND	K	7785±874
Sm	ND	Na	3613±90
Eu	.131±.002	As	17±8
Tb	.067±.03		

*"Heavily contaminated."

TABLE B-7. Sample EF-2 Sediment Analysis, P.P.M. Cruise One.

Au	.008±.004	Dy	.801±.2
Mo	ND	Yb	.083±.003
Rb	9.8±.4	Lu	.044±.002
Zn	6.77±5	Cs	.270±.008
Hg	1.18±.08	Ba	98.9±27
Fe	1315±11	Al	29150±1391
Sb	.103±.004	V	5.88±2.14
Co	.770±.007	Ca	4988±831
Cr	2.58±.11	Mg	5263±1648
Ag	.179±.05	Cl	5604±990
Th	1.287±.04	I	ND
Se	<.1	Mn	155.5±2.8
Sc	.337±.001	Sr	ND
La	5.18±.056	Br	21±4
Nd	5.3±2.5	K	11994±705
Sm	1.225±.2	Na	2045±22
Eu	.124±.002	As	3.88±2
Tb	.179±.003		

were dissolved in a concentrated nitric acid - 3% hydrogen peroxide solution. Water samples were freeze-dried to concentrate trace elements 100-fold. Because a large portion of benthos, zooplankton, and phytoplankton samples was sediment contaminated, conclusions from these data should not be attempted. Water and sediment data are ready for interpretation.

Phytoplankton, benthos, zooplankton and sediment samples were digested in a concentrated nitric acid - 3% hydrogen peroxide mixture at approximately 90°C three to four hours. They were then centrifuged and decanted to separate the soluble and insoluble phases. Originally filtration through either glass fiber filters or membrane filters was attempted, but associated with this method is a leaching of trace metals from both the filters and filtration equipment and this technique was abandoned.

Fats of the various organisms did not go into solution. Collection and processing of them yielded no significant amounts of the elements sought.

Being high enough in lake water, concentrations of Ca, Mg, Na, K, Zn and Sr were measured directly. All other elements must be concentrated. Concentration was accomplished by low temperature and low pressure sublimation of the sample. This was done with a freeze-drying unit. One liter of acidified (approximately 2% nitric acid), filtered (0.45 μ membrane filter) lake water was freeze-dried to dryness; the residue was dissolved in ten milliliters of 10% nitric acid, giving a final 100-fold concentration. Concentration by boiling could accomplish the same result, but we feared that the more volatile elements would be lost to the atmosphere.

For analyses of the trace metals Co, Ni, Cu, Mn, and Fe in lake water, a modification of an APDC-MIBK solvent extraction technique was tried.[1] Both non-reproducibility and a need to concentrate barium and molybdenum warranted abandoning this method.

All analyses were performed using either Perkin Elmer and Jarrel Ash atomic absorption units or a Beckman DU flame emission unit. Those done, at least partly, by flame emission were Na, K, and Li.

Except for Sr, Ba, Ca, and P, all elements were measured directly or after

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[1] Brooks, R. R., B. J. Preselay, and I. R. Kaplan. 1967. The APDC-MIBK extraction system for the determination of trace elements in saline waters by atomic absorption spectrophotometry. Talanta 14: 809-816.

dilution on the prepared samples. To suppress ionization effects while measuring Sr and Ba, enough sodium chloride was added to bring the final alkali concentration to 2000 ppm. While measuring Ca, suppression of phosphate interferences was accomplished by lanthanum addition. To bring the final lanthanum concentration to one percent, lanthanum nitrate, lanthanum chloride or lanthanum oxide was added.

With addition of ammonium molybdate, phosphorus is quantitatively converted to phosphomolybdic acid. After extraction of the acid into iso-butyl acetate, phosphorus was measured as molybdenum.[2]

For the various categories of Lake Michigan and Lake Erie samples, Table B-8 presents the percent completed. Examples of the data are found in Table B-9.

TABLE B-8. Atomic Absorption and Flame Emission Progress (Percent Completed).

Category	Lake Erie	Cruise I	Cruise II	Cruise III
Phytoplankton	90	89	94	90
Zooplankton	90	90	94	90
Benthos	90	88	90	90
Sediment	90	93	90	0
Water	90	95	90	0

Representing the degree of accuracy to which atomic absorption and flame emission results can be read, error limits are equal to background noise levels divided by the actual sample reading times the concentration that the sample reading represents. Those analyses listed as not detectable (ND) have elemental concentrations roughly below those listed in Table B-10.

Because of the amount of time required for a phosphorus analysis, few are completed. Phosphorus is not done on lake water. Long periods of storage allow loss of phosphate to a polyethylene storage container's walls.

[2] Ramakrishna, T. V., J. W. Robinson, and P. W. West. 1969. Determination of phosphorus, arsenic, or silicon by atomic absorption spectrometry of molybdenum heteropoly acids. Anal. Chim. Acta 45: 43-49.

TABLE B-9. Examples of Atomic Abosrption and Flame Emission Results.*

Element	Benthos (ppm) ZION I H	Benthos (ppm) C-3 II L	Phytoplankton (ppm) A-4 II H	Phytoplankton (ppm) A-4 I L	Zooplankton (ppm) D-6 I H	Zooplankton (ppm) D-6 III L	Sediment (ppm) CD-3 I	Sediment (ppm) CD-3 II	Water (ppb) B-4 I	Water (ppb) B-4 II
Li							47.2±3.8	54.3±3.9		
Na	3900±180	6190±210	813±7	3360±	492±24	3300±60		210±13	4640±450	4530±530
Mg	13200±100	1450±20	1700±10	1210±120	1680±20	1110±10	10100±200	13700±200	11500±100	12100±100
P	5510±70	9910±120		8830±300	9310±140					
K	6860±90	13200±300		15100±300	2020±90		1150±20	2830±20	1500±50	1450±50
Ca	110000±180	18200±200	5750±60	10800±200	40700±1400	2020±60	14100±200	30000±200	34000±500	34000±500
Cr	11.0±1.2	2.51±1.26	11.3±2.8	2.36±1.18	6.19±1.24	5.88±2.61	25.0±2.5	25.4±1.6		
Mn	119±7	13.7±0.6	65.4±0.7	10.6±0.6	92.1±1.3	17.0±0.4	421±3	901±14	0.669±0.167	0.509±0.169
Fe	4760±110	112±7	1790±50	166±6	1070±10	110±5	8440±70	12900±200	6.58±0.11	5.24±0.11
Co	ND	ND	ND	ND	ND	ND	8.44±2.11	9.68±1.94	1.65±0.08	1.31±0.08
Ni	8.65±4.33	ND	ND	ND	ND	ND	22.3±1.6	30.2±1.2	2.56±1.4	19.5±1.4
Cu	84.3±1.4	24.0±1.5	42.1±0.5	28.1±1.5	8.80±0.4	28.8±0.4	22.0±1.0	42.3±1.6	1.64±0.16	2.24±0.16
Zn	144±6	66.9±6.1	203±3	88.4±5.9	68.1±5.2	104±3	977±46	32.9±3.6	12.2±1.5	19.8±1.6
Sr	116±1	49.5±1.3		15.1±1.4	75.2±1.4		37.6±7.5	32.9±3.6		112±12
Mo	ND	ND		ND	ND		ND	ND	1.5±0.13	1.5±0.13
Ba	21.6±8.6	20.3±1.7		ND	14.5±2.1		ND	ND	31.4±2.8	20.0±2.5

*Roman numerals next to station numbers identify the cruise during which the sample was taken.
H = "Heavily contaminated"
L = "Lightly contaminated"

TABLE B-10. Limits of Detectability.

Elements	Water ppb	Sediment, Phytoplankton, Zooplankton and Benthos[1] ppm
Li	2.0	----
Na	2.0	0.2
Mg	0.5	0.05
P	----	?
K	7.0	0.7
Ca	5.0	0.5
Cr	----	2.5
Mn	0.1[3]	1.0
Fe	0.25[3]	2.5
Co	0.5[3]	5.0
Ni	0.5[3]	5.0
Cu	0.1[3]	1.0
Zn	5.0	0.5
Sr	5.0	0.5
Mo	1.0[3]	10.0
Ba[2]	0.25[3]	2.5

[1]Based on 0.5 gm of sample dissolved in 50 ml of solvent.

[2]The greater the amount of Ca in a sample the higher the limit of detectability.

[3]Analyses done on freeze dried samples taken from one liter original volume to 10 ml final volume.

Due to high concentrations of calcium in samples, potassium values may be slightly high.

In many cases, barium is listed as not detectable (ND) or the results have large error limits. This problem is directly related to increasing noise levels as calcium concentrations increase. We now believe that the problem is nearly solved. Instead of atomic absorption, flame emission is used alleviating the Ca problem. However, this new method promises to be somewhat time consuming.

In its present form, interpretation of benthos, zooplankton and phytoplankton raw data is impossible. A fair number of these samples are believed to be contaminated with sediment associated with them at the time of sampling. "Lightly and heavily contaminated" examples are presented in Table B-10. Sediment contamination is marked by generally higher Fe, Mn, Mg, Cr, and perhaps higher Ca, Cu, Zn, and Sr results. Samples believed to be "lightly contaminated" are marked by higher Na and perhaps P and K values. Though the data consist of "bad" numbers, we believe that these numbers can be quantitatively corrected.

Water data are ready for interpretation. Data represent not only the dissolved fraction but also particulate matter less than 0.45 microns. This particulate matter is what passed through the 0.45 micron membrane filters used for filtering before the addition of nitric acid for preservation.

Sediment data are also ready to interpret. Data do not represent total analysis of a sediment sample, but that portion soluble in concentrated nitric acid. Normally the insolubles are clays, feldspars and quartz. These data probably do not represent concentrations of elements that can be exchanged within an organism's gut.

In summary, and illustrative of the difficulties presented by sediment contamination of biological materials, we present in Table B-11 biological reconcentration factors for several trace elements as computed against the levels of these elements in Lake Michigan water. We emphasize the following points about these numbers:

1) THESE ARE UNCORRECTED FIGURES.
2) THESE FIGURES RANGE FROM GROSSLY TOO HIGH (IN THE CASES OF HEAVILY CONTAMINATED SAMPLES) TO TOO HIGH IN SMALLER BUT UNKNOWN DEGREE (IN THE CASES OF THE "LIGHTLY CONTMAINATED" SAMPLES).

TABLE B-11. Illustrative Reconcentration Factors (in comparison to Lake Michigan water) of Some Trace Elements in Lightly Contaminated and Heavily Contaminated Samples of Lake Michigan Organisms.

	Phytoplankton		Zooplankton		Benthos	
Element	Lightly Contaminated	Heavily Contaminated	Lightly Contaminated	Heavily Contaminated	Lightly Contaminated	Heavily Contaminated
Ca	161	420	795	975	600	435
Fe	36,000	383,000	26,800	319,000	20,100	537,000
Mn	14,100	82,000	11,900	77,300	31,100	118,000
Zn	2,710	7,400	3,550	5,125	3,670	2,160
Co	207	530	123	630	109	550
Mg	85	127	194	239	145	98
Ba	937	2,730	473	7,925	985	3,760
K	8,950	775	6,360	4,860	10,250	9,050
Na	2,030	52	1,275	785	1,900	1,870
V	2,200	10,800	860	11,700	<1,000	10,200
Br	4,730	4,550	6,630	6,720	5,000	4,720
As	-----	1,230	3,510	10,000	-----	5,600
Al	15,200	185,000	6,700	281,000	9,700	143,000

Appendix A

GREAT LAKES RESEARCH DIVISION

THE UNIVERSITY OF MICHIGAN
1077 NORTH UNIVERSITY BUILDING
ANN ARBOR, MICHIGAN 48104
313/764-2420

March 13, 1970

From: John C. Ayers and Richard Copeland

To: Thomas F. Madigan and LMUSG

Subject: Status of LMUSG sample analyses

We regret to have to inform you that unforeseeable circumstances are going to prevent our being able to carry out the full number of neutron activation analyses indicated in our contract with the LMUSG.

Because we had had no experience with activation of biological materials and since the published data is so sparse, we started with the most unknown of them (phytoplankton). It quickly developed that their primarily carbohydrate composition could not be adequately analyzed by employing irradiation and counting times similar to those employed for non-biological samples. By trial we have concluded that irradiation in the core of the reactor for a minimum of 50 hours is necessary, if the low levels of trace elements in plankton are to be sufficiently activated to be measured.

Fifty-hour irradiations decompose the polyethylene vials which are commonly used as containers during non-biological irradiations. Some samples were lost here.

Packaging in sealed quartz tubes was tried. This is a common encapsulating material for long irradiations of rock and other inorganic materials in small amounts. We found, however, that the stresses built up in the quartz while the ends of the tube were heat sealed (annealing was impossible since biological materials within would vaporize), coupled with further stresses developed by intense gamma ray bombardment, made the quartz so sensitive it exploded at the slightest shock. Some loss occurred in learning this, too. We have now gone to packaging in aluminum tubes which are sealed by aluminum Swedgelok fittings. This appears to work.

The long period of irradiation needed has both slowed our progress and run up our reactor fees beyond expectations.

Unexpectedly high demand by others for use of the counting equipment has limited our use of the equipment. This has delayed progress significantly. Because these other counting demands could not be foreseen, funds for needed additional equipment were not requested.

The long irradiation needed, the divided use of counting equipment, and our packaging problems have together cut down the numbers of samples that we will be able to put through complete neutron activation analysts before September. We envision only 50 samples completely analyzed by then. These will comprise 10 complete stations selectively chosen to be as representative of the lake as is possible.

We are, of course, sorry to have to report thus. Man proposes and God disposes.

Analyses by atomic absorption are going well.

Whipple and Plato are standardizing and calibrating prior to running radioactivity analyses. They anticipate no difficulty in turning out numbers rapidly in a month or so.

J. C. Ayers and R. Copeland

JCA:RC:jf

CHAPTER C

ESTIMATES OF THE RADIOLOGICAL AND CHEMICAL WASTES TO BE RELEASED TO THE LAKE

John C. Ayers

INTRODUCTION

The information presented in this section represents an attempt to accumulate and summarize available data necessary to determine the quantities of wastes, chemicals, and other solutes or suspended materials that arrive in and depart from Lake Michigan. There was, and still is, little hope that present information will be adequate for meaningful materials-balance studies. However, efforts to locate all available data were needed to fully define those areas from which information was partially or entirely lacking.

As was expected, the information that exists is scattered, buried, fragmentary, and often weak. Undoubtedly there exist data that we have not found; what we have unearthed is reported here.

RADIOACTIVE INFLUENTS

A single paper by Risley constitutes the only significant available data on radioactivity in the lake and entering the lake via tributaries.[1] This material is covered in Chapter A.

The states around Lake Michigan all appear to be maintaining radioactivity monitoring programs of greater or less extent. While these data are undoubtedly available from the individual states, they are not summarized in any convenient form or place that we have discovered.

CHEMICAL INFLUENTS

The single best available set of data on chemical influents that has yet come to light is contained in "Water Quality Investigations, Lake Michigan Basin, Physical and Chemical Quality Conditions, Federal Water Pollution Control Administration, Great Lakes Region, Chicago, Illinois. January 1968." In this publication, Tables 3 through 7, 9, and 10 (with errata corrected) present the results of surveys during 1962-64 in Lake Michigan and its major tributaries

[1] Risley, Clifford Jr. 1965. Radioactivity in Lake Michigan and its tributaries. Proc. 8th Conf. Great Lakes Res., p. 160-167.

carried out by the then U. S. Public Health Service.

The USPHS worked from river flows of 1963-64 and average concentrations of solutes to arrive at each river's loadings of solutes that were supplied to the lake in 1963-64. Their results are given in Tables C-1 through C-6. The only thing we have done is to sum in these tables the pounds per day of loadings delivered to the lake from these 19 tributaries in 1963-64. These sums are presented in Table C-7. The inputs to the lake in Table C-7 are given as actual sums of the USPHS findings and as accepted values, which are the sums rounded to the nearest 1,000 lb. per day. They are conservatively low because these tributaries do not drain all of the watershed which discharges into Lake Michigan, and comparisons of total long-term mean flows of 15 of these 19 tributaries to the total 1963-64 mean flows of the same 15 as recorded by USPHS indicate that the flows of 1963-64 were about 19999/25501 of long-term mean flows.

Of the 41,041 square miles of the Lake Michigan watershed only 31,940 square miles have gaged drainage. We have assumed that the inputs summarized in Table C-7 represent practically all the gaged drainage, and multiplied by 41041/31940 to correct for ungaged drainage. We have further multiplied by 25501/19999 to correct the 1963-64 flows of Table C-1 to the long-term flow. The resulting estimates of total inputs into the lake are given in the first column of Table C-8.

The same FWPCA publication already referenced also gives in its Tables 10 and 12 analyses of water of Lake Michigan adjacent to Grand Traverse Bay and at Chicago. Figure C-1 presents our present best idea of the "normal" (prevailing wind) circulation of Lake Michigan. In this figure is summarized our evidence that water from off the mouth of Grand Traverse Bay departs quite directly to the Straits of Mackinac and hence to outflow to Lake Huron. To use the analyses of water adjacent to Grand Traverse Bay as measures of the water outflowing into Lake Huron appears to be justified. These analyses, together with mean outflow through the Straits of Mackinac, and the withdrawal of water at Chicago permit estimates of the amounts of some solutes being removed from the lake.

The USPHS[1] derived the mean outflow through the Straits of Mackinac as 1500 m^3/sec (53,000 cfs) and water is diverted at Chicago at a mean rate of

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1. Lake Michigan Basin, Lake Currents. FWPCA, Great Lakes Region, Chicago, Illinois. November 1967.

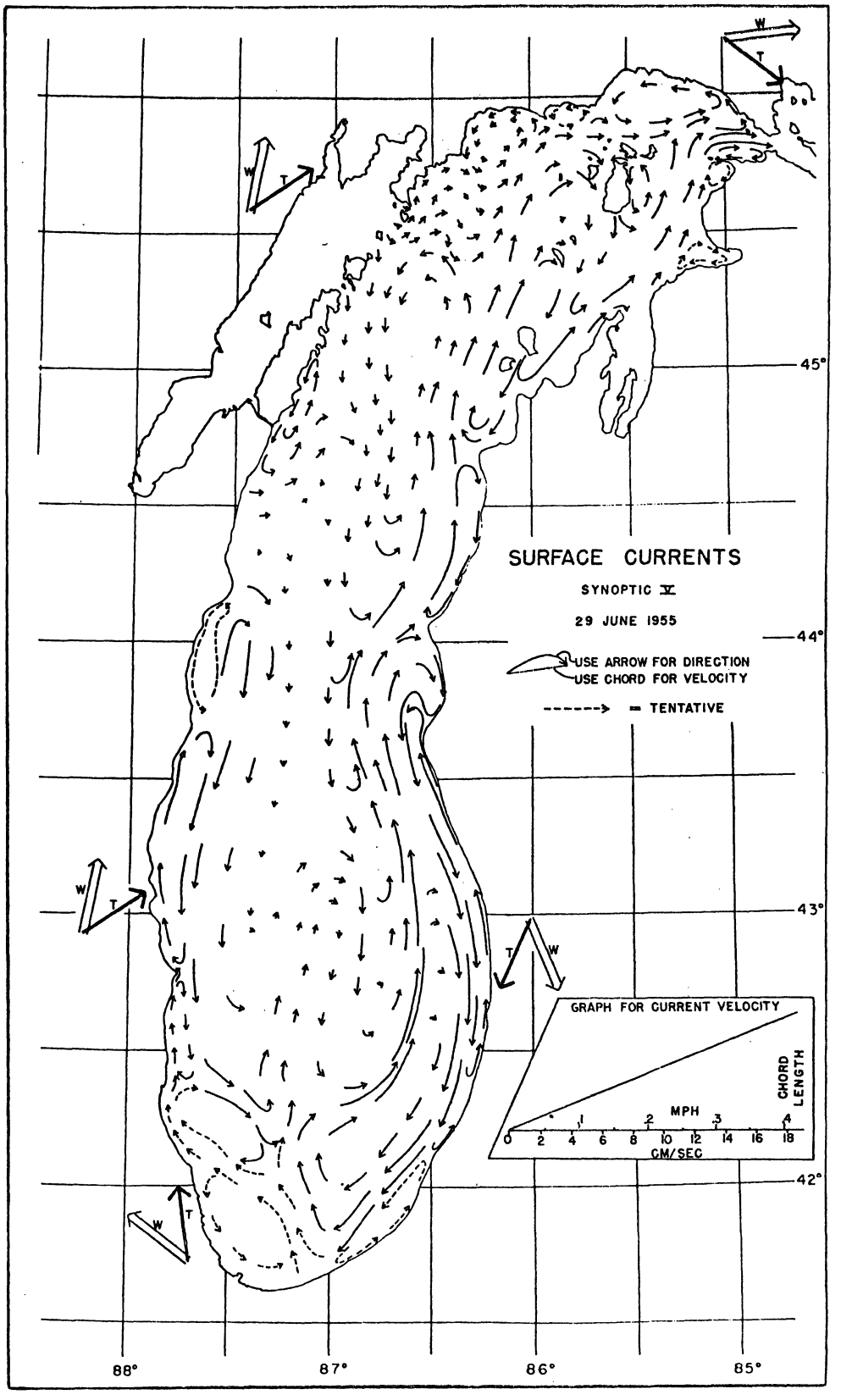

Figure C-1. From Ayers et al. 1958. Currents and Water Masses of Lake Michigan. Pub. No. 3, Great Lakes Research Institute, The University of Michigan, Ann Arbor, Mich.

TABLE C-1. Contributions to Lake Michigan through 19 tributaries. Mean flows (1963-64) and ammonia, nitrate, and organic nitrogen. Data of USPHS.

River	Mean Flow, cfs	Mean Concentration, mg/l			Loading, lb/day		
		NH_3-N	NO_3-N	Org-N	NH_3-N	NO_3-N	Org-N
Boardman	186	0.29	0.44	NS	399	606	---
Manistique	845	0.21	0.26	0.19	957	1180	865
Manitowoc	83	0.38	0.31	0.40	170	139	179
Sheboygan	132	0.63	0.87	0.69	448	619	491
Milwaukee	191	1.5	0.80	0.66	1545	824	680
Burns Ditch	150	1.4	0.72	0.89	1130	582	720
St. Joseph	2060	0.53	0.59	0.53	5890	6550	5890
Kalamazoo	1140	0.46	0.58	0.80	2830	3560	4920
Grand	1900	0.68	0.72	0.77	6970	7370	7890
Muskegon	1731	0.17	0.24	0.33	1590	2240	3080
Pere Marquette	570	0.19	0.16	0.17	584	492	522
Fox	4420	1.6	0.10	0.48	37200	2380	11400
Oconto	790	2.3	0.20	0.92	9840	852	3920
Peshtigo	890	0.14	0.15	0.45	672	720	2159
Menominee	3250	0.24	1.7	0.39	4200	29300	6833
Ford	337	0.12	0.40	0.45	218	727	818
Escanaba	1017	0.11	0.10	0.41	60	548	2248
Rapid	80	0.62	0.24	0.89	267	103	384
Whitefish	227	0.11	0.14	0.25	135	171	306
Sums					75,105	58,963	53,305

TABLE C-2. Contributions of total soluble PO_4 and silica to Lake Michigan by 19 tributaries (1963-64). Data of USPHS.

River	Mean Concentrations, mg/l		Loading, lbs/day	
	Total Soluble PO_4	SiO_2	Total Soluble PO_4	SiO_2
Boardman	0.20	7.5	275	10328
Manistique	0.04	5.8	182	26400
Manitowoc	0.62	5.7	277	2550
Sheboygan	0.40	3.9	285	2780
Milwaukee	0.61	2.8	628	2880
Burns Ditch	1.8	10.	1456	8090
St. Joseph	0.24	6.4	2670	71000
Kalamazoo	0.21	5.9	1290	36300
Grand	0.52	5.3	5330	54300
Muskegon	0.06	5.6	560	52300
Pere Marquette	0.03	7.8	92	24000
Fox	0.28	9.4	6670	224000
Oconto	0.17	9.2	724	39200
Peshtigo	0.08	9.8	384	47000
Menominee	0.11	4.4	1930	77100
Ford	0.04	7.0	73	12700
Escanaba	0.06	7.0	329	38400
Rapid	1.59	3.1	686	1340
Whitefish	0.18	5.7	220	6980
Sums			24,061	737,648

TABLE C-3. Contributions of total dissolved solids, total suspended solids, and calcium to Lake Michigan by 19 tributaries (1963-64). Data of USPHS.

River	Mean Concentration, mg/l			Loading, lbs/day		
	Total Dissolved Solids	Total Suspended Solids	Calcium	Total Dissolved Solids	Total Suspended Solids	Calcium
Boardman	222	NS	47	305694	----	64719
Manistique	170	9.1	29	774000	41500	132000
Manitowoc	260	29	42	116000	13000	18800
Sheboygan	310	26	50	221000	18500	35600
Milwaukee	365	24	49	376000	24700	50500
Burns Ditch	445	21	84	360000	17000	68000
St. Joseph	310	21	62	3440000	233000	688000
Kalamazoo	360	20	71	2210000	123000	436000
Grand	350	24	72	3580000	246000	737000
Muskegon	235	10	30	2190000	93000	280000
Pere Marquette	215	11	40	661000	33800	123000
Fox	271	25	40	6460000	596000	953000
Oconto	262	14	39	1120000	60000	166000
Peshtigo	281	15	33	1350000	72000	158000
Menominee	154	13	28	2700000	228000	491000
Ford	203	7.1	40	369000	12900	72700
Escanaba	166	16	28	910000	87700	154000
Rapid	240	18	35	103000	7760	15100
Whitefish	196	5	34	240000	6120	41600
Sums				27,485,694	1,913,980	4,685,019

TABLE C-4. Contributions of chloride, sulphate, and sodium to Lake Michigan by 19 tributaries (1963-64). Data of USPHS.

River	Mean Concentration, mg/l			Loading, lbs/day		
	Chloride	Sulphate	Sodium	Chloride	Sulphate	Sodium
Boardman	6.7	18	4.5	9226	17901	6197
Manistique	3.3	26	2.1	15000	118000	9570
Manitowoc	12	36	11	5360	16100	4920
Sheboygan	21	48	17	15000	34200	12100
Milwaukee	26	72	23	26800	76200	23700
Burns Ditch	38	87	23	30700	70400	18600
St. Joseph	16	59	9.2	178000	655000	102000
Kalamazoo	34	70	22	209000	430000	135000
Grand	42	74	28	430000	758000	287000
Muskegon	21	24	9.4	196000	224000	87700
Pere Marquette	14	23	9.8	43000	70700	30100
Fox	21	52	14	500000	1240000	334000
Oconto	15	22	3.8	63900	93700	16200
Peshtigo	11	24	2.5	52800	15200	12000
Menominee	7.3	17	2.7	128000	299000	47300
Ford	2.7	20	1.8	4906	36300	3270
Escanaba	2.8	20	2.9	15400	110000	15900
Rapid	5.5	4	1.8	2370	1770	776
Whitefish	2.0	20	3.4	2450	24500	4160
Sums				1,927,912	4,290,971	1,150,493

TABLE C-5. Contributions of potassium, magnesium, and methylene blue active substances to Lake Michigan by 19 tributaries (1963-64). Data of USPHS.

River	Mean Concentrations, mg/l			Loading, lbs/day		
	Potassium	Magnesium	MBAS	Potassium	Magnesium	MBAS
Boardman	0.8	13	0.07	1101	17901	96
Manistique	0.8	7.6	0.08	3640	34600	364
Manitowoc	3.1	18	0.09	1390	8050	40
Sheboygan	3.2	24	0.18	2280	17100	128
Milwaukee	3.0	18	0.24	3090	69000	247
Burns Ditch	3.8	22	0.28	3070	17800	227
St. Joseph	1.9	21	0.12	21100	233000	1330
Kalamazoo	2.1	22	0.14	12900	135000	860
Grand	2.8	26	0.28	28700	266000	2870
Muskegon	1.1	14	0.12	10300	131000	1120
Pere Marquette	0.8	14	0.08	2460	43000	246
Fox	3.8	14	NS	91000	334000	----
Oconto	1.8	14	0.10	7670	60000	426
Peshtigo	1.3	12	0.12	6240	57600	576
Menominee	1.2	11	0.09	21000	19300	1577
Ford	1.1	20	0.18	2000	36300	327
Escanaba	1.1	9.0	0.21	6030	49300	1151
Rapid	1.5	12	0.14	646	5170	60
Whitefish	0.7	14	0.10	86	17100	122
Sums				224,703	1,551,221	11,767

TABLE C-6. Contributions of copper, nickel, and zinc to Lake Michigan by 19 tributaries (1963-64). Data of USPHS.

River	Mean Concentration, mg/l			Loading, lbs/day		
	Copper	Nickel	Zinc	Copper	Nickel	Zinc
Boardman	NS	NS	NS	--	--	--
Manistique	0.08	0.02	0.02	364	91	91
Manitowoc	0.11	0.03	0.03	49	13	13
Sheboygan	0.09	0.14	0.11	64	100	78
Milwaukee	0.11	0.04	0.06	113	41	62
Burns Ditch	0.07	0.03	ND	57	24	--
St. Joseph	0.08	0.01	0.03	888	111	333
Kalamazoo	0.07	0.03	ND	430	184	--
Grand	0.14	0.04	ND	1440	410	--
Muskegon	0.11	0.03	ND	1030	280	--
Pere Marquette	0.12	0.05	0.03	369	154	92
Fox	0.09	0.02	ND	2140	476	--
Oconto	0.01	0.03	0.03	43	128	128
Peshtigo	0.15	0.03	0.04	720	144	192
Menominee	NS	NS	NS	---	---	--
Ford	0.06	0.03	0.03	109	55	55
Escanaba	0.09	0.03	0.03	493	164	164
Rapid	NS	NS	NS	---	---	--
Whitefish	NS	NS	NS	---	---	--
Sums				8,309	2,375	1,208

Table C-7

SUMMARY TABLE

Inputs, via 19 major tributaries in 1963-64, of materials into Lake Michigan. Inputs in pounds per day. Data of USPHS.

	Actual Sum	Accepted Value
Ammonia-Nitrogen	75,105	75,000
Nitrate-Nitrogen	58,963	59,000
Organic-Nitrogen	53,305	53,000
Total Soluble PO_4	24,061	24,000
Silica (SiO_2)	737,648	738,000
Total Dissolved Solids	27,485,694	27,486,000
Total Suspended Solids	1,913,980	1,914,000
Calcium	4,685,019	4,685,000
Chloride	1,927,912	1,928,000
Sulphate	4,290,971	4,291,000
Sodium	1,150,493	1,150,000
Potassium	224,703	225,000
Magnesium	1,551,221	1,551,000
MBAS (detergents)	11,767	12,000
Copper	8,309	8,000
Nickel	2,375	2,000
Zinc	1,208	1,000

TABLE C-8. Comparison of estimated long-term-flow inputs to and outputs from Lake Michigan.

	Total lb/day input to Lake Michigan	Lb/day outputs from Lake Michigan		
		Total	Straits (53,000 cfs)	Chicago (3,200 cfs)
NH_3-N	123,000	10,000	9,000	1,000
NO_3-N	97,000	50,000	48,000	2,000
Org-N	87,000	----	ND	3,000
Tot. Sol. PO_4	39,000	7,000	6,000	1,000
SiO_2	1,210,000	437,000	416,000	21,000
Tot. Dis. Solids	45,077,000	50,360,000*	50,101,000	259,000
Tot. Susp. Solids	3,139,000	----	ND	ND
Ca	7,683,000	10,573,000*	10,020,000	553,000
Cl	3,162,000	2,041,000	1,918,000	123,000
SO_4	7,037,000	5,820,000	5,440,000	380,000
Na	1,887,000	----	1,202,000	ND
K	369,000	----	343,000	ND
Mg	2,544,000	3,643,000*	3,436,000	207,000
MBAS	19,000	----	9,000	ND
Cu	14,000	----	ND	ND
Ni	4,000	----	ND	ND
Zn	2,000	----	ND	ND

*See text

3200 cfs.

From these data the rates of removal of materials have been computed. The resulting estimates are given in the last three columns of Table C-8. The Lake Michigan outflow values for the Straits and the Chicago outlet are listed as a total and separately.

By comparing the total output with the accepted input in this table it should be possible to estimate the lake's accumulation of each parameter. However, as indicated by those values marked with an asterisk, the output in three cases exceeds the input. This may be real, but much more likely it should only be interpreted as an indication of the poor quality of either the input or output estimates or both.

PESTICIDE INFLUENTS

Despite considerable search we have been unable to find any better information than that given by Dr. Donald I. Mount of the Duluth Laboratory of the FWQA in testimony before the February 25, 1969 Conference on Pollution of Lake Michigan and its Tributary Basin (D. I. Mount, pp. 693-761 in "Proceedings, Conference on Pollution of Lake Michigan and its Tributary Basin, Illinois, Indiana, Michigan and Wisconsin. Volume 2, Second Session, February 25, 1969, Chicago, Illinois. U. S. Dept. of the Interior, FWPCA"). In this testimony Dr. Mount says bluntly (pp. 729-731), "The Committee (Pesticide Committee, FWQA, Duluth) has exerted effort to compile information on types, amounts, and distribution of insecticides applied in the Lake Michigan drainage basin, and has learned that there are no accurate, consistent compilations of such information. Fragmentary figures are available for some areas and for some insecticides, but extrapolation of these figures into realistic totals for the drainage basin appears impossible at the present time. Even the following general statements on usage are subject to great error; the values are only general indications and should be used cautiously."

"In 1964 approximately 3.8 million pounds of insecticides were used on crops in the three lake States of Minnesota, Michigan and Wisconsin (U.S.D.A., 1968). It is not known what portion of this was applied in the Lake Michigan watershed. In the lake States the greatest amounts of the insecticides were used on apples and other deciduous fruits. Aldrin (that converts to dieldrin), used on the largest acreage on corn, totalled 761,000 pounds on approximately

1.2 million acres. DDT was applied to about 150,000 acres and accounted for 511,000 pounds.

The State of Wisconsin estimates that in its segment of the Lake Michigan drainage basin approximately 150,000 acres of farm lands received 500,000 pounds of technical insecticides in 1967. Of this 86,600 pounds was DDT, 4,200 pounds was dieldrin, 103,800 pounds was chlordane, and 28,000 pounds was toxaphene. Most of the remainder was composed of non-persistent insecticides."

MANUFACTURING-INDUSTRIAL WASTES

In our experience, this group does not fall into Dr. Mount's (above) categorization that fragmentary figures are available for some areas and for some (wastes). We find in FWPCA publications actual lists, by states, of major industries with their flows of waste discharges and notes as to the compositions of their wastes BUT NO INDICATIONS OF THE ACTUAL QUANTITIES OF WASTE MATERIALS DELIVERED TO LAKE MICHIGAN VIA INDUSTRIAL WASTE. These figures may exist but we have been unable to locate them. It is possible that lack of adequate analyses of wastes does not permit the derivation of the total input that we wish to have.

SEWAGE WASTES

There are lists, by states, of communities (down to miniscule size) and of the quantities of waste-water that they discharge. Biological oxygen demand (BOD) figures are relatively easily obtained, but generally nothing else is to be found. There must be average values of solutes in sewage, by which discharges of waste-water could be multiplied to yield probable summations of materials delivered to the lake via the sewage route. We have found such figures for Lake Erie (Table 4-11, p. 63. "Lake Erie Report. A Plan for Water Pollution Control." U. S. Dept. Interior, FWPCA, Great Lakes Region, Chicago, Illinois) but to our present knowledge none exist for Lake Michigan.

AGRICULTURAL RUNOFF

Our findings in this category have been zero for Lake Michigan, yet the fact that they have been produced for Lake Erie (reference above) indicates that attention has been paid to this category of information. While we do not think so, we may have missed a report on these findings.

MANUFACTURED PRODUCTS, ETC.

We have been unable to find any information that would allow an estimate of departure of solute material from Lake Michigan via Lake Michigan water incorporated into manufactured, canned, processed, etc. products that are exported from the area.

SUMMARY AND CONCLUSIONS

Though we firmly believe that this effort had to be made, we have been forced to the conclusion that there presently do not exist suitable sorts or sources of data from which to make materials-balance studies of the water of Lake Michigan.

We believe that the then U. S. Public Health Service's 1962-64 Great Lakes-Illinois River Basins Project achieved a near-miss sufficiently close to indicate that with a more substantial expenditure of monies and effort there may be possible a meaningful materials-balance analysis of the more conventional chemical parameters of the lake. We do not consider it to be possible at the present time.

There are, at present, no available data sufficient to make possible materials-balance studies on pesticides, manufacturing-industrial wastes, sewage wastes, agricultural runoff, nor departures of material from the lake through manufactured or processed products.

Meaningful materials-balance studies of Lake Michigan are at present impossible.

CHAPTER D

EPILOGUE

John C. Ayers

In this contract the University of Michigan undertook the task of devising, proving out, and evaluating several sorts of collection, preservation, and analysis techniques related to determining whether: 1) the ability of Lake Michigan to safely accept radioactive wastes could be predicted; and 2) whether biological reconcentration of radionuclides up through the food chain could be demonstrated and computed.

The University has developed, tested, and shown to be satisfactory, metal-free techniques for collecting, preserving, transporting, and analysing comparatively massive samples of phytoplankton, zooplankton, and benthos. To our knowledge these things have not previously been done.

The University has adapted and modified older techniques for collection of water and sediment samples, and has demonstrated that they, too, can be collected, preserved, transported, and analysed without contact with foreign metal.

The suite of samples collected for the Lake Michigan Utilities Study Group is not only unusual in its massiveness, it is absolutely unique in its freedom from contamination by contact with foreign metals. It is, in a word, the only existing set of samples adequate to be the departure point in approaching the goals set out in the first paragraph above.

The University has devised, tested, and proven out analysis techniques abundantly adequate for the purposes set forth in the first paragraph above. There have been difficulties encountered, and overcome, and new knowledge has been acquired in so doing.

Analyses for radioactivity have encountered fewest problems, have lost least time, and are virtually 100% accomplished. They, and the conclusions drawn from them, are reported in Chapter A.

Analyses for stable elements by atomic absorption techniques have encountered some problems and lost some time. These analyses are about 85% finished. The problems encountered in atomic absorption analyses are tied in with those

found in neutron activation analyses for stable trace elements. The two analysis methods are complementary and are discussed together in Chapter B.

Although we knew that biological samples were predominantly composed of carbohydrates, we had to find means by which to compensate for the fact that billions of plankton (collected during as much as eight hours on one station) could still yield as little as 0.5 grams dry weight, as compared to a cow's liver which dried to tens or hundreds of grams. The answer, for neutron activation, was of course longer radiation in order to produce measurable activity. About four months were lost in developing suitable radiation and counting times, and in developing packaging methods suited to extremely long radiation times (see Appendix A of Chapter B). Analyses by neutron activation are about 40% complete. Thirty-five elements, instead of the contracted 32, are being analysed for.

Analyses for stable elements (particularly metals) in biological samples, by both atomic absorption and neutron activation, is in many samples complicated by the presence of sediment in the gut of the organisms or adhering to the outside of the organisms. A means of mathematically removing the errors due to incidental sediment contamination has been developed; its application, and the completion of the remaining 60% of neutron activation analysis samples and 15% of atomic abosrption analyses constitute the proposal for continuation of the present contract.

Two sets of biological reconcentration factors, computed from heavily contaminated and relatively uncontaminated samples, are given in the conclusion of Chapter B. These must be treated as, respectively, grossly upper and mildly upper limits of reconcentration factors. The lower of these may be treated as the presently best available figures. The difference between the higher and lower is the measure of the unexpected, but very real, effect of sediment contamination in the biological samples.

Antecedent to whether the ability of Lake Michigan to safely accept radioactive waste could be determined was, and is, the question of whether there is sufficient evidence that a materials-balance study of the lake can be made.

This question is investigated in Chapter C. The results are not encouraging. We foresee no hope of improvement in our ability to do materials-balance studies of Lake Michigan in the immediate future.