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PLUTONIUM-238 IN SEDIMENT CORES FROM THE MOUND LABORATORY AREA

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ABSTRACT

Plutonium-238 concentrations in 8 sediment cores from water bodies near Mound Laboratory are reported. All have been measurably contaminated and for the most part show concentrations with depth in the sediment suggesting that chemical and/or biological processes may be quite active, and that run-off from nearby contaminated soil is probably continuing. The integrated Pu-238 deposits indicate that these samples essentially represent the complete sediment column.

INTRODUCTION

In July of 1974, a field sampling program was carried out in the vicinity of Mound Laboratory in Miamisburg, Ohio. The objective was to obtain large area, undisturbed sediment cores and water samples from local bodies of water contaminated as a result of a ruptured underground waste line in the laboratory in early 1969.^(1,2) The field work was performed by personnel from the Health and Safety Laboratory (HASL) and Woods Hole Oceanographic Institution (WHOI).

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In all, eight successful cores were obtained and divided into 120 depth increment aliquots ranging from 1 to 4 cm thick. The sampling locations are shown diagrammatically in Fig. 1. Details of the coring equipment, the procedures used, the samples obtained, and the radiochemical methods have all been reported earlier.³⁻⁵ To briefly recap the analytical scheme: initially one half of each incremental sample was dried, weighed and then leached to minimize laboratory contamination which might occur during normal drying, homogenizing and aliquoting. The leach procedure followed was from reference 6, through step 5. The clear filtered solution was then quantitatively aliquoted into appropriate size samples (generally between 2 and 10 ml) depending upon the anticipated concentration of Pu-238. These were analyzed for plutonium by the method in reference 6, starting with step 6.

Most of the samples were analyzed under contract by LFE Environmental Analysis Laboratories, Richmond, California. For purposes of cross checking and intercomparison, a few samples were also analyzed by HASL, WHOI, and Mound Laboratory (ML).

In this report, all of the completed sediment analyses are presented as well as the depth profiles and integrated Pu-238 values at the core locations.

Figure 1. Sampling Locations.

QUALITY CONTROL

The quality of data such as obtained in this study, depends upon a number of often separate and distinct manipulations. To know the quality of obtained results, one must monitor as many steps in the procedure as practical and establish numerical error estimates where possible. In this program the following "quality controls" were applied:

a. Sampling - Sites were chosen which appeared to be undisturbed and the coring and extruding apparatus were thoroughly washed between stations.

b. Sediment Incrementing (in the field) - The core was inverted and then extruded, that is, the deepest, presumably least contaminated part first. As the material emerged from the coring barrel, a 1 to 2 cm thick ring, at the periphery, was cut away and discarded. This is material which is often contaminated as the barrel penetrates through a highly concentrated surface pollutant region, into a much lower concentration material. Additionally, the entire bottom of the sediment, to a thickness of a few cm, was discarded as possibly contaminated by the action of the sphincter closing in the nose cone.

c. Sediment Blanks - Aliquots of a leach solution from a known low activity sediment, prepared identically to the Miamisburg samples were used as blanks. These tests are useful to indicate contamination problems in the entire chemistry scheme, both pre- and post-leaching. It should be pointed out that these samples are submitted to the analytical laboratories "blind", the analysts cannot readily differentiate the controls from the unknowns. For this we used sediment obtained some years ago from Crater Lake, Oregon. Only two tests were run, one by HASL and one by LFE. The results shown in the top section of Table 1 indicate no particular bias between the laboratories, and a median value of 0.14 dpm Pu-238 per sample.

d. Solution Blanks - Two types of solution blanks were employed. With each set of samples sent to LFE for analysis (generally 10 to 15 in number) one "leach" blank was included. This is simply an acid solution at about the same pH as the real leach solutions. Another blank solution, simply an aliquot of distilled water, was added to each batch when the analyses were started. The leach blanks were also sent blind. These solution blanks serve to alert us to possible contamination in the chemistry following the leach, as well as to changes in contamination levels

TABLE 1
QUALITY CONTROL - BLANKS

Laboratory	Date	Sample	dpm Pu-238/Sample
<u>SEDIMENT BLANKS</u>			
HASL	11/74	Crater Lake	.15±.02
LFE	↓	↓	.13±.04
<u>SOLUTION BLANKS</u>			
LFE	11/74	"Leach" acid	.18±.04
↓	12/74	↓	.06±.03
	1/75		.20±.10
	3/75		.22±.05
	8/75		.23±.03
	9/75		.03±.06
LFE	11/74	Water	.07±.05
↓	12/74	↓	.02±.02
	1/75		.01±.01
	3/75		.09±.08
	4/75		.08±.08
	9/75		.05±.05

TABLE 2

ALIUQUOTING TEST

Station 5Section ADepth (cm) 0-3

HASL No.	Date	Laboratory	dpm Pu-238/Sample
SE-3	11/74	LFE	119±5
SE-6	"	"	117±5
SE-24	2/75	HASL	116±4
SE-69	8/75	LFE	123±4
SE-84	10/75	"	122±8

as a function of time. The lower part of Table 1 summarizes these tests. The median of all the data is .08 dpm, that of the leach blank is .19 dpm. Whether or not these are significantly different and different from the value for the sediment blank is irrelevant, since they are all trivial in comparison to the activities found in most of the Miamisburg sediment. Hence, except for a very few cases, which will be pointed out later, the blank may be completely neglected.

e. Aliquoting Test - This test was designed to determine whether the final leach solution was in fact homogeneous with respect to Pu-238 concentration, and whether the aliquots, in small plastic bottles, changed with time. Table 2 lists the five results obtained over the course of almost a year for aliquots from the 0 to 3 cm depth at station 5. Note that four of the analyses were performed by LFE, one by HASL. Clearly, within the time span no trends or biases can be seen.

f. Duplicates - This quality check specifically refers to the precision of analysis, within a specific shipment of samples. Time trends, which might have been observed in the previous aliquoting test, are omitted. Five sets of duplicates were submitted to the contractor-analyst in the course of the study. The results are listed in Table 3. Four of the five show a total

TABLE 3

RESULTS OF DUPLICATE ANALYSES (ANALYZED BY LFE)

HASL No.	Sample	dpm Pu-238/Sample	% Difference from mean
SE-3	5A/0-3	119±5	±0.8
SE-6	"	117±5	
SE-19	4A/0-2	30.0±1.8	±0.3
SE-20	"	30.2±1.8	
SE-32	1A/12-13	52.3±3.1	±2.5
SE-36	"	49.7±3.5	
SE-60	5A/9-11	96.1±3.8	±0.8
SE-65	"	97.8±3.9	
SE-75	3A/10-12	2.2±0.2	±16
SE-76	"	1.6±0.2	

difference between duplicates of 5% or less, the other is in excess of 30%. Note, however, that this latter set had total activities of only about 2 dpm per sample and 1 s errors of 10%. At these activity levels, it appears that the variability of the blank (mentioned earlier) and the analytical error may increase the overall uncertainty of any particular result by a substantial amount.

g. Laboratory Intercomparisons - This quality control test serves to pinpoint particular individual laboratory biases. In this program, LFE the contractor group which carried out most of the analyses, was intercalibrated with all three of the other interested laboratories (HASL, WHOI, and ML). These data are summarized in Table 4. In almost every case, the agreement between laboratories is within the 1 s errors reported.

h. Standards - For this program, the accuracy of the analyses was monitored by means of blind known samples added to each batch of samples to be analyzed. These were prepared by adding a weighed amount of Pu-238 standard to an aliquot of a leach blank (see d above). The results displayed in Table 5, are not heartening and have remained to this day inexplicable. In every case, the samples appeared to have measurably more Pu-238 than the amount which was apparently added, by an average of 30%. The laboratories have

TABLE 4
LABORATORY INTERCOMPARISONS

Sample (station/depth)	dpm Pu-238/Sample			
	LFE	HASL	Mound	WHOI
5A/0-3	120± 5*	116± 4	x	Lost
5A/27-29	197±14	x	x	193±28
6A/2-4	214± 8	x	x	188±28
6A/10-12	267±19	247±15	x	x
7A/0-3	97± 4	x	104±1	91±11
7A/3-5	99± 9	x	115±1	x
7A/7-9	182± 5	x	179±1	x
7A/13-15	151± 8	x	150±1	x
7A/17-19	317±13	x	346±1	x

*Mean of four analyses - see Table 2.

x - no sample submitted.

attempted every conceivable test to resolve this difference, but have been unsuccessful. The notion that the contractor laboratory, LFE, had a calibration bias is refuted by the results in Table 4 and the 18% bias of the HASL result (SE-27) in Table 5. Two different standard solutions were used in preparing the samples for these tests, the first four of Table 5 were from one set and the last two from the other. Both of these were re-checked as far as possible and found to be in good agreement with the original values. It is not inconceivable that a systematic error occurred during the spiking of the leach solution blanks (such as with a balance giving a weighing error in a specific direction), but this has been impossible to confirm.

We are, therefore, left with this apparently insoluble question as to the actual accuracy of the Pu-238 analysis, in this study. Secondary, indirect and intuitive lines of reasoning suggest that the accuracy is much better than reflected in Table 5, and that the problem lies in the preparation of the standard sample. We do, however, acknowledge that unless a better case can be made for this conclusion, all of the Pu-238 data in this program must be suspect to the degree indicated.

TABLE 5
STANDARD SAMPLES

HASL No.	Lab.	dpm Pu-238		<u>Found</u> <u>Added</u>
		Added	Found	
SE-15	LFE	10.3	13.9±0.6	1.35
SE-27	HASL	19.3	22.8±1.1	1.18
SE-40	LFE	22.3	31.1±3.1	1.39
SE-50	LFE	40.0	47.6±1.4	1.19
SE-71	LFE	7.7	10.5±0.3	1.36
SE-78	LFE	7.3	9.6±0.7	1.32

RESULTS AND DISCUSSION

Tables 6 through 12 summarize the analytical results for Pu-238 on the samples from the eight sediment cores. The error terms represent one standard deviation due to counting. The second column "dpm Pu-238/sample" was included to indicate the actual activity levels encountered in the individual aliquots which were processed. It is clear that, as mentioned earlier, in only a very few cases, such as in the deeper sections of stations 2 and 3 (see Table 7), are activities within factors of 2 or 3 of the blank. Note that in the third column of these tables, where the Pu-238 concentrations are listed per gram of dry sediment, the units change by a factor of 10^3 from picocuries (pCi) in the pond and river samples to nanocuries (nCi) in the canal.

a. Great Miami River - The Pu-238 concentrations in the sediment from the Great Miami River (Table 6) indicate no particular depth profile, varying by less than a factor of two over the 10 cm sampled. The mean concentration in the section is 0.44 pCi/g. This value is in good agreement with data reported in a Mound Laboratory study⁽⁷⁾ where samples some distance from the canal outfall varied from 0.3 to 1.6 pCi/g in the top foot of sediment. For comparison with samples believed to be contaminated with Pu-238

TABLE 6

Pu-238 IN SEDIMENT - STATION 4, GREAT MIAMI RIVER

Depth (cm)	dpm Pu-238/Sample	pCi Pu-238/g (dry)
0-2	30.1±1.8	.63±.04
2-4	1.4±0.2	.41±.06
6-8	65.6±1.0	.36±.01
8-10	15.6±0.9	.45±.03

solely from worldwide fallout (including both atmospheric nuclear tests and the SNAP-9A burn-up) both marine sediment and continental soil data may be cited. Sediment from a shallow water core, 6 cm long, from Buzzards Bay, Mass. contained 0.002 pCi/g, while several North Atlantic cores from various depths contained .001 pCi/g or less, generally all within the top 15 cm of the sediment column. ^(8,9) Undisturbed soil samples from the New York City area suggest that in the top 5 cm the concentration is about 0.002 pCi/g. It does appear, therefore, that in the area of the Great Miami River sampled, the sediment was contaminated with Pu-238 by at least two orders of magnitude over the expected global background.

b. North Pond - Two cores were taken from the North Pond, in approximately the center and as close together as practical: probably about 1 meter apart. The data are listed in Table 7 and plotted in Fig. 2. The purpose of taking the two cores was to examine the uniformity of the sediment at this separation distance. Qualitatively, the concentrations indicate a similar variation with depth, but Station 3 has higher values than Station 2 near the surface and lower values deeper in the core. Both cores approach non-detectable activities in the deepest sections.

TABLE 7

Pu-238 IN SEDIMENT - STATIONS 2 AND 3, NORTH POND

Depth (cm)	dpm Pu-238/Sample		pCi Pu-238/g (dry)	
	Station 2	Station 3	Station 2	Station 3
0-2	14.2±.9	18.1±.9	16.5±1.0	21.0±1.3
4-6	7.4±.4	15.9±.8	10.2± .5	15.6± .8
6-8	6.2±.1	6.9±.3	7.7± .1	9.1± .4
10-12	3.9±.3	2.2±.2	4.4± .4	3.1± .3
14-16	1.0±.1	0.8±.1	1.2± .2	1.2± .1
18-20	0.9±.1	0.1±0*	1.2± .1	0.2± 0*
24-26	0.5±.1	0.2±0*	0.4± 0*	0.3± .1

* ±0 refers to 2 values $\leq .05$

FIG. 2
Pu-238 IN N. POND SEDIMENT CORES

It is noted here, in comparison with later discussion, that these profiles from North Pond show no sub-surface maxima, but decrease quite regularly with depth. This profile does not reflect the contamination event with a peak at depth in the core, and must therefore have been profoundly altered by subsequent effects. The profile could be explained by a combination of a sedimentation rate substantially slower than the rates of chemical movement and/or biological stirring. Superimposed, may be a more or less continuous addition of contaminated soil by wash-in during and after rain storms.

c. South Pond - A single core was obtained from the center area of the northern lobe of the South Pond (refer to Fig. 1). It is immediately evident from Table 8 and Fig. 3 that this area is much more contaminated than the North Pond, ranging from 14 to more than 150 pCi/g. Also, the activity in the deepest part of the core, at about 21 cm, does not approach the background although it is less than half the maximum at about 15 cm. The existence of sub-surface maxima suggests, in this case, a rapid sedimentation rate. If one assumes that the high peak at 14-15 cm depth dates the initial contamination event (early 1969), then a sedimentation rate

TABLE 8

Pu-238 IN SEDIMENT - STATION 1, SOUTH POND

Depth (cm)	dpm Pu-238/Sample	pCi Pu-238/g (dry)
0-2	21.4±1.5	24.8±2.2
2-3	15.6±0.8	48.4±3.1
4-5	12.2±0.7	14.1±0.9
6-7	11.4±0.8	23.0±1.8
8-9	33.9±1.8	40.4±2.3
10-11	32.3±1.6	63.8±3.2
12-13	50.8±3.5	92.3±6.0
14-15	95.0±4.7	166.3±8.3
16-17	50.6±2.5	112.3±5.6
18-19	33.0±1.0	88.5±2.7
20-21	50.3±1.3	70.8±1.8

FIG. 3
Pu-238 IN S. POND SEDIMENT CORE

of about 3 cm per year is indicated. The sloping off of concentration above and below the peak can again be attributed to chemical and/or physical translocation processes. The persistent relatively high contamination levels in the upper sections of the core, and particularly the second maximum at 2-4 cm, can be explained by more or less continuous contamination from surface runoff.

(d) Miami-Erie Canal - The Pu-238 concentrations versus depth, for the four canal cores are shown in Tables 9 through 12 and Fig. 4. From left to right in Fig. 4 (from Station 5 through 8), the traverse is in a general north to south direction (refer to Fig. 1) opposite to the direction of water flow. In these, as in the South Pond profile, sub-surface maxima occur. Note that the concentration units in Fig. 4 are nanocuries per gram (nCi/g) greater by 10^3 than those of the two prior profiles. A more compressed scale for the core depth was also used.

Station 8, the southernmost core, appears to have been most rapidly mixed, almost 80% of the length being within a factor of two in concentration. Whether this is truly a reflection of much faster plutonium translocation by natural means or an artifact of the multiple scientific investigations in the canal, cannot be determined.

TABLE 9

Pu-238 IN SEDIMENT - STATION 5, MIAMI - ERIE CANAL

Depth (cm)	dpm Pu-238/Sample	nCi Pu-238/g (dry)
0-3	117±5	0.23±.01
5-7	114±8	0.26±.02
9-11	97±4	0.62±.03
13-15	122±5	1.08±.04
17-19	308±12	1.71±.07
21-23	246±9	1.20±.05
23-25	267±7	0.67±.02
27-29	197±8	0.47±.03

TABLE 10

Pu-238 IN SEDIMENT - STATION 6, MIAMI - ERIE CANAL

Depth (cm)	dpm Pu-238/Sample	nCi Pu-238/g (dry)
0-2	245±14	0.30±.02
2-4	214± 9	0.38±.02
6-8	224±15	0.18±.01
10-12	257±14	0.26±.02
14-16	210± 6	0.74±.02
18-22	2,671±106	4.47±.18
26-30	3,107±90	4.40±.13
34-38	2,822±84	4.06±.12
42-46	548±18	0.65±.02
50-54	700±28	1.05±.04

TABLE 11

Pu-238 IN SEDIMENT - STATION 7, MIAMI-ERIE CANAL

Depth (cm)	dpm Pu-238/Sample	nCi Pu-238/g (dry)
0-3	97± 4	0.34±.01
3-5	99± 9	0.44±.04
7-9	182± 5	0.59±.02
9-11	526± 26	0.64±.03
13-15	151± 7	0.50±.03
17-19	317± 12	0.68±.03
19-23	2,430± 72	2.69±.08
23-27	3,080±240	3.51±.28
27-31	10,400±400	10.2 ±.41
31-35	568± 95	0.61±.10

TABLE 12

Pu-238 IN SEDIMENT - STATION 8, MIAMI - ERIE CANAL

Depth (cm)	dpm Pu-238/Sample	nCi Pu-238/g (dry)
0-3	788±30	0.43±.02
3-5	558±22	0.56±.02
5-7	775±53	1.81±.13
9-11	671±27	1.47±.06
13-15	1,050±80	0.92±.07
17-19	602±12	1.09±.02
23-27	793±64	1.05±.08
35-39	998±40	1.19±.05
43-47	1,793±36	0.20±.04

FIG. 4
Pu-238 IN MIAMI-ERIE CANAL SEDIMENT CORES

Stations 5, 6 and 7 all follow the same general pattern in their concentration profiles as noted for the South Pond Core, although the maximum at Station 6 is considerably broader than any of the others. Some combination of Pu translocation by chemical and biological means plus continued, lower level contamination with run-off soil from the banks, could explain these profiles. The sedimentation rates of cores 5, 6 and 7, assuming again that the highest value dates the pipeline break, all fall between 3 and 5 cm/year.

e. Total Integrated Deposits - The Pu-238 concentration data in each of the cores was integrated to obtain the total deposit per cm^2 . In these units they are readily comparable to results calculated from data reported by Mound Laboratory⁽¹⁰⁾, and to worldwide fallout from atmospheric tests. The HASL data were graphically integrated by planimeter. For this, the concentrations in activity per gram were converted to units of activity per cubic centimeter utilizing the density of the dry sediment. On 7 randomly chosen samples, a mean density of $1.8 \pm .2$ was measured. The Mound data were integrated simply by multiplying the reported average concentration per foot⁽¹⁰⁾ by the length and density and summing the segment integrals. The same density, 1.8, was assumed for all cases. No attempt was made to integrate or compare

Mound's Miami River results, since so much of their data in the vicinity of the HASL core were essentially below detection limits.

Table 13 summarizes the pertinent results. In the North Pond, the integrals for Stations 2 and 3 are listed separately to indicate the precision of the experiment, at that point. The most obvious conclusion from Table 13 is that all of the sampling sites were substantially contaminated beyond world-wide fallout levels, by a factor of a thousand in the River to as high as about 10^9 in the canal.

The agreement between integrals based on Mound and HASL programs, from neighboring stations is almost better than could have been hoped for; all comparisons being within a factor of two, and four of the six being within 40%. Note, too, that in the worst two cases, HASL's stations 6 and 7, it is the HASL integral which is higher. We believe that the HASL profiles (in Figs. 2-4), and the agreement in the integrals strongly suggest that our sampling procedure did in fact obtain essentially all of the contaminated sediment column from the pond and canal sites. This conclusion does not address either the question of Pu-238 availability in the aquatic food chain, or the ultimate hazard of

TABLE 13
Pu-238 INTEGRALS

	Station	Core Length (cm)	Pu-238 (nCi/cm ²)
<u>North Pond</u>			
Mound data*	HA, HB	152	.36
HASL data	2	26	.22
" "	3	26	.25
<u>South Pond</u>			
Mound data*	KA, KB	152	1.8
HASL data	1	22	2.6
<u>Miami-Erie Canal</u>			
Mound data*	EE, EF	152	43
HASL data	5	31	41
Mound data*	YK	152	93
HASL data	6	54	198
Mound data*	YE	183	81†
HASL data	7	35	134
Mound data*	8	305	82†
HASL data	U	47	83
<u>Great Miami River</u>			
HASL data	4	10	9×10^{-3}
<u>Worldwide Fallout</u>			
30-50° N	-	-	$8 \times 10^{-6} \pm$

*Based upon data from Ref. 10.

†Interpolated missing segment of core.

*Reference 11.

these materials to man. These are beyond the scope of this study. It does not seem unreasonable, however, to suggest that if these water bodies can be sufficiently sequestered from non-natural disturbances, they could serve as ecological "laboratories" in which long term biological effects of Pu-238 exposure may be studied.

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REFERENCES

1. Numerous public announcements referring to the contamination incident were made, e.g.: Ohio News, October 3, 1974, Cincinnati Post, October 3, 1974.
2. Farmer, B. M., Robinson, B. and Carfagno, D. G.
Annual Environmental Monitoring Report - Calendar year 1975
Mound Laboratory, Monsanto Research Corp. Report MLM-2317,
April (1976)
3. Burke, J. C.
A Sediment Coring Device of 21 cm Diameter with Sphincter
Core Retainer
Limnology and Oceanography 13, 714-718 (1968)
4. Volchok, H. L.
Sediment Sampling Near Mound Laboratory - July 1974
USAEC Report HASL-286, p. I-71, October (1974)
5. Volchok, H. L.
Analysis of Environmental Samples from the Mound Area
USERDA Report HASL-291, April (1975)
6. Radiochemical Determination of Plutonium in Soil by Leaching
John H. Harley (Editor)
HASL-Procedures Manual, USERDA Report HASL-300, p. E-Pu-06-01
(1976)
7. Rogers, D. R.
Mound Laboratory Environmental Plutonium Study - 1974
Mound Laboratory, Monsanto Research Corp. Report MLM-2249,
September (1975)
8. Livingston, H. D., Mann, D. R. and Bowen, V. T.
Analytical Procedures for Transuranic Elements in Seawater
and Marine Sediments
Advances in Chemistry Series, No. 147, Analytical Methods
in Oceanography
American Chemical Society (1975)
9. Livingston, H. D. and Bowen, V. T.
Plutonium and Cesium-137 Distribution Patterns in Coastal
Sediments of the Northwest Atlantic Ocean
Presented at: Symposium on Environmental Chemistry and
Cycling Processes, Atlanta, Georgia, April 28-30, (1976)

10. Robinson, B., Rogers, D. R., Westendorf, W. H. and
Black, H. A.
Mound Laboratory Pu-238 Study, Off Site Analytical Data,
May-December 1974
Mound Laboratory, Monsanto Research Corp. Report MLM-MV-74-
72-0001, (1976)
11. Hardy, E. P., Krey, P. W. and Volchok, H. L.
Global Inventory and Distribution of Pu-238 from SNAP-9A
USAEC Report HASL-250, March (1972)