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Radionuclide Distributions in Sediments
of Marine Areas used for Dumping Solidified Radioactive Wastes

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Abstract

A number of sediment samples, collected both by coring and by grabbing, from the shallow Pacific solid waste radioactive dump site and from the Atlantic dump site, have been analyzed carefully for a number of long-lived radionuclides. Both dump sites yielded samples that were expected to serve as controls, collected at considerable distance from any visually-located waste containers, as well as other samples that were collected close to identified waste drums, some of which showed evidence of physical disintegration. The Atlantic site shows evidence of wide-spread, general contamination, with ^{137}Cs and possibly with ^{241}Am . The Pacific site is perhaps less generally contaminated with ^{137}Cs , but shows evidence of widespread general contamination with several transuranic nuclides. Samples collected near to identified waste containers, at both sites, show that significant portions of leached radioactivity (^{137}Cs , $^{239,240}\text{Pu}$, ^{238}Pu , ^{241}Am , ^{242}Cm and ^{244}Cm) are immobilized by the sediments within very short distances, possibly measured in meters or tens of meters. The data also suggest considerable differences among the horizontal trajectories of the various leached transuranic elements. It is argued that careful study of nuclide distributions around such old waste containers would provide data of great value in helping to predict long-term behaviour of radionuclides released to marine environments.

If we are to be able to make useful predictions of the environmental distributions in, and hence of the environmental effects, on the oceans, of radioactive wastes that may be released during the nuclear fuel cycle, we require many more data than are now available. As Bowen (1), and others (2) have emphasized, it is essential, in pursuit of these needed data, that each identifiable release of radionuclides to saltwater be milked of as much information as it can produce. In this context, it is especially important to study the radionuclide distributions in and about the various sites used by the United States for dumping solidified radioactive wastes. Besides their importance as offering relatively long-term environmental interactions (dumping continued from 1946 to 1962, being sharply reduced thereafter, and stopped by 1970), these sites involve both the Atlantic and Pacific coasts, occupy a range of water depths from about 900 to close to 3000 m, and represent a good deal of difference in biotic regime. In addition, as we show below, they received measurable amounts of some nuclides that are both of considerable interest from the predictive point of view, and not usually found, yet, in the environment.

Dyer (1976) (3) has described these dump sites, and his initial efforts to survey and to sample them; he also presented some rather preliminary radiochemical data concerning samples from these areas. In the present report we present, and discuss, the results of more refined radiochemical analyses of suites of sediment samples from Dyer's (3) collections. Data are now available showing concentrations of iron-55, cesium 137, plutonium 238 and 239,240, americium 241, and

curium 242 and 244.

Materials and Methods

From the Atlantic dump site samples were available from both plastic tubes driven into the sediment, and similar tubes driven, on shipboard, into sediment retrieved with a modified Ekman box corer. As described by Dyer (3), these samples were collected by the Woods Hole Oceanographic Institution manned submersible ALVIN. Although this site is described as a "2800 meter dumpsite" sampling depths, as we show below, covered a rather wide range.

From the two Pacific dump sites samples were available either from small-diameter plastic tubes driven into the sediment, or from Shipek grabs. These samples were collected by the unmanned submersible CURV III, of the U. S. Naval Undersea Center. Most of our samples were from the "900 meter dumpsite" but one core, at 1920 m, is taken to represent the "1700 meter dumpsite".

Of the samples we received, all but one core had been sectioned into subsamples before shipping to us. One core (Core liner 1, from dive 583 in the Atlantic dumpsite) was sent to us whole, and frozen, and we were able to section this to provide a much more detailed profile of the depth distributions of the nuclides.

Another source of concern is that we have no reason to believe that the samples sectioned by others were trimmed of their outer rind. A coring tube usually carries down into the

sediment an appreciable amount of material from the upper, usually more contaminated, layers. Our practice is to trim away, and discard, an outer rind, 0.4 to 1 cm thick, to avoid this source of contamination, and we did so on the one core we sectioned here.

All samples received were analyzed for ^{137}Cs , $^{239,240}\text{Pu}$, and ^{238}Pu . Most were also analyzed for ^{241}Am , ^{242}Cm and ^{244}Cm , and a few for ^{55}Fe . Our radiochemical methods have been published in references 4, 5 and 6, and our performance in inter-laboratory comparisons, using a variety of samples, in references 7, 8 and 9.

Results

The analytical data, expressed as disintegrations per minute per kilogram of dry sediment, are set out, for the Atlantic samples, in Table 1, and for the Pacific samples, in Table 2. Where a blank appears in a radionuclide column opposite a particular sediment fraction it indicates no data relevant to that nuclide were sought. Where a line appears it indicates the nuclide was sought, but the amount present was below our usual detection limits. The indication ND under the curium isotopes opposite many Pacific samples indicates an especially strong effort was made to detect them, typically these samples were counted for 12 to 14 days and yielded only the rate, about 1 count per day, expected from the ^{244}Cm contamination of our ^{243}Am yield monitor.

Discussion

Most of the information that we now have concerning the movements of artificial radionuclides released to aquatic environments derives from situations like the world-wide fallout experiment in which the radionuclides were rained onto the water surface, or the various waste disposal operations, like Windscale (10), Cap La Hague (11) or Bombay Harbor (12), where the radionuclides have been mixed into the water column. It is not obvious that data from such situations will satisfactorily support prediction of the behavior of radionuclides released at the sediment-water interface. Release at this surface does, however, characterize the situation at solid waste dump sites (13, 3) and prediction of such behavior is of considerable present concern in the context of possible use of the deep ocean for emplacement of high level radioactive waste (14,15). Concern also is raised in this connection by arguments, such as those of Bowen (1), Labeyrie et al (16), Bowen et al (17) or Livingston and Bowen (18), that some radionuclides, after being first rather quickly moved to depth in shallow-water sediments, slowly are moved back up to the sediment-water interface where they may be remobilized. Data of Noshkin et al. (19, 20) show this process is operating at the several United States Pacific Nuclear Test Sites, but it is not clear that those data can be used in very general ways because of the many biogeochemical peculiarities of the coral atoll regimes. The dump sites do, however, present very usual, and hence reasonably generalizable,

oceanographic situations, and it is for this reason incumbent on us to obtain from them as much information as possible. In addition to presenting us with the best examples of radionuclide release at the sediment-water interface, they probably present us with patterns that have had a minimum of 10, and more likely close to 20, years to develop. Thus they represent experiments in an especially valuable stage of development.

The first questions, obviously, to be asked of these data are: have the solidified wastes disposed to these dump sites released artificial radionuclides in measurable amounts, and, if so, what do the distributions in the sediments of the released nuclides tell us about their behavior and trajectories after release? As we have, with various of our colleagues, reported (1, 21, 22, 23, 16, 17, 18) most of the radionuclides for which data appear in Tables 1 and 2 are measurable, as result of their delivery in world-wide fallout, in any marine sediments we have so far studied; curium is the only element discussed here that can be regarded as, quantitatively at least, unique to the dumped wastes. Our first question, then, must be answered by examining the inventories found in the dump site sediments to see whether any nuclides are present in greater amounts than can be explained by fallout, by examining the ratios among the various radionuclides to see whether these differ grossly from those observed in fallout-labelled sediments, and by examining the vertical profiles of nuclide concentrations in the sediments to see whether these differ in interpretable ways from those to be expected as a result of fallout delivery.

Radionuclide Inventories:

To examine first the inventories represented by the various samples, these have been calculated for those cores that penetrated, or came close to penetrating, the whole nuclide-labelled part of the sediment column, and are set out in Table 3. Since the samples did not reach us in condition that permitted satisfactory measurement of the wet weight of the sediment, we have assumed, based on extrapolations from our own data concerning similar sediments, a mean wet to dry weight ratio of 2.0, and a mean dry density of 0.75 g per cm³. In a few instances, shown by asterisks in Table 3, inventory values have been estimated, by reasonable extrapolation from near-by core-profiles, from analytical values representing only the upper layer of sediment. For comparison we have estimated, from a variety of sources, both the total amount of each nuclide expected to have been delivered in fallout to the sea surface at the latitude represented, and the amounts we predict to have reached the sediment. The comparison is striking:

1. At the two Pacific Dump sites ¹³⁷Cs exhibits an inventory higher than expected in all samples but two; ^{239,240}Pu, ²³⁸Pu and ²⁴¹Am are more abundant than expected, although ²⁴¹Am may not be significantly in excess in core 134273.
2. At the Atlantic Dump site ¹³⁷Cs exhibits an inventory higher than expected in all samples but two, although in one other (Dive 585, tube core 6) the excess is only marginally significant; both Pu isotopes and ²⁴¹Am are generally less than expected, ²³⁸Pu in all samples, and ^{239,240}Pu clearly in excess only in Dive 585, Core Liner 4, and ²⁴¹Am clearly in excess only

in Dive 586 Tube Core 3 and in Dive 585 Core Liner 4.

3. Reference to the "Remarks" in Tables 1 and 2 confirms that at both sites substantial inventory excesses of ^{137}Cs were as likely to be found in samples taken as "controls", far from identified waste drums, as they were in samples close to the containers. At the Pacific site this was also true of the transuranium nuclides.

4. At both dump sites, those samples that exhibit less ^{137}Cs than expected appear to be showing the effect of scour removing the surface sediment. It is not, however, possible, as we discuss again below, to be certain whether this is an artifact of sampling or a characteristic of the area sampled. At the Atlantic site, all three samples from Dive 584 show ^{137}Cs deficiency (Core Liner 4 is not represented in Table 3 because too little material was available to allow an inventory estimate), whereas at the Pacific site only two of three samples from station 13A appear affected.

5. It is, however, true that two of the three Pacific samples from the middle of a large cluster of waste drums, show enormous excesses of $^{239,240}\text{Pu}$, ^{238}Pu and ^{241}Am , as well as being the only samples (Table 2) to contain measurable curium isotopes. It is also true that of the four Atlantic samples from close to an end of a waste drum, one shows the largest excess of ^{137}Cs , and of $^{239,240}\text{Pu}$ and ^{241}Am .

In summary, then, the inventory data appear to confirm that the dump sites may be rather generally contaminated by radio-nuclides from other than fallout sources, but that in both Pacific

and Atlantic samples there is good evidence for substantial further contamination of sediments in the immediate neighborhood of waste drums.

Radionuclide Ratios:

As discussed elsewhere (16, 18, 22, 23) a good deal of pattern is discernible in the fallout derived ratios, in marine sediments, of $^{239,240}\text{Pu}$ to ^{137}Cs , of ^{238}Pu to $^{239,240}\text{Pu}$, of ^{241}Am to $^{239,240}\text{Pu}$, and of ^{55}Fe to $^{239,240}\text{Pu}$. Some of these ratios we have found to exhibit correlation with depth of overlying water, and all exhibit some variations, place to place or with depth in the sediment, that we believe are clearly outside of the analytical noise. In Table 4 we have summarized our expectations for these ratios, as well as the actual ratios observed (from Tables 1 and 2) in dump-site samples.

Examination of Table 4 shows that the shallow Pacific Dump site samples are characterized by uniformly high ratios $^{239,240}\text{Pu}$ to ^{137}Cs : Only the "very high inventory" samples of Station 13A exhibit ratios of 238 to 239,240 that are outside of the fallout range, and only these, plus the top of the Station 15 core, exhibit high ratios ^{241}Am to $^{239,240}\text{Pu}$. These latter samples, although they are qualitatively very similar, we believe differ significantly in respect to each of the ratios tabulated; inspection of the data in Table 2 shows also that the ratios of ^{242}Cm and ^{244}Cm to $^{239,240}\text{Pu}$ are different between the core samples and the grab, and that the ratio of the two Cm isotopes may be significantly different. We return to this point below in discussing the overall evidence for the trajectories of the nuclides released.

The one core from the deep Pacific dump site shows a clear excess of $^{239,240}\text{Pu}$ over ^{137}Cs , but no evidence that the Pu isotope ratios are abnormal; ^{241}Am is just outside what we

believe is the normal range, but this may not be significant nor as discussed below, can we be certain that, if significant, it is attributable to the dumping.

Of the Atlantic dump site samples only one exhibits an excess of $^{239,240}\text{Pu}$ over ^{137}Cs (the 6-7 cm cut from Dive 583 Core Liner 2), all of the others exhibiting less than the normal range of ratios. A considerable proportion of the 238 to 239,240 ratios, however, are above the expected fallout range, and almost all the samples show higher ^{241}Am to $^{239,240}\text{Pu}$ ratios than those expected.

There appear, then, to be some differences between the evidence of the nuclide inventories and that of the nuclide ratios. In some respects the situation is clarified by the examination of the shapes of the sediment concentration vs depth profiles.

Vertical Profiles of Radionuclide Concentration:

Because of the coarse, 5-cm, interval chosen for sampling most of these cores, there is less information than one might expect to be derived from the shapes of the profiles of nuclide concentrations in the sediments. We have, however, never seen in marine sediments in these water depths, concentration maxima deeper than 5 cm (as shown by core 134274 at the Pacific site 13A, and tube core 3 from Dive 586 in the Atlantic); in fact, we have never seen a core with so much radioactivity in its second 5 cm as shown at site 15 in the Pacific. The first two of these instances must have resulted, we believe, from a more or less catastrophic release by a waste drum soon after its dumping, and the burial of this horizon by sediments contaminated by much slower leaching. These two cores, and that at site 15, must represent rather higher rates of sediment accumulation than do most of the others.

As we pointed out above, in discussing the inventory calculations, a number of these dump site samples exhibit profiles of concentration -- as they do inventories -- that are best explained by the loss of the upper layers of sediment. Among the Atlantic cores, such loss is observed in all Dive 584 samples, while among the Pacific cores it is observed in both from Station 13A, but not in the grab from that station. It is not possible to decide from the data in hand whether the losses of upper sediment layers are most likely to indicate systematic sediment erosion from the area sampled, displacement of sediment, before sampling, by turbulence from

the submersible used, bad coring technique, or loss of the core tops during return of the submersible to the surface. Reasonable arguments can be advanced in support of each of these possibilities, and there is little basis for dismissal of any of them. Possibly the fact that not all the samples from station 13A are affected argues against sediment erosion in that area.

In summary, we believe the evidence of the nuclide inventories, of the nuclide ratios, and of the nuclide concentration versus depth profiles indicates the dump site sediments to have been very generally contaminated by other than worldwide fallout. Our conclusions are set out in Table 5.

Behaviour of Radionuclides after Release from Dumped Solid Waste Drums:

Our conclusion, as summarized in Table 5 is that both solid waste dump sites appear to be rather generally contaminated with radionuclides at higher levels than expected from fallout. At the Atlantic dump site ^{137}Cs appears to be the major component of this general contamination, while at the shallow Pacific dump site, ^{137}Cs , plutonium and americium are present at comparable excesses.

The excess ^{241}Am indicated at the Atlantic dump site largely by high ratios of this nuclide to $^{239,240}\text{Pu}$, presents a difficult question. We have recently shown (23) that the sediments of both the Mediterranean Sea, and the Guianas Coast of South America are characterized by high ratios of ^{241}Am to plutonium, and we believe that these ratios are best explained as the result of the properties of the sediments: that they are rich in terrigenous detritus having a high affinity for Am, but poor in biogenous detritus having a high affinity for Pu. It is perfectly possible that the Atlantic dump site presents another such case, although we would not really have expected this. The generally low inventories of $^{239,240}\text{Pu}$ in these sediments certainly argue in that same direction.

Both dump sites present, in addition to the evidence for widespread contamination, instances of only slightly dispersed radionuclides:

- a) In the Atlantic site, core liner 4 of Dive 585, taken at the ruptured end of the same drum near the closed, of which was taken tube core 6 of the same dive, shows elevated inventories of ^{137}Cs , $^{239,240}\text{Pu}$ and ^{238}Pu ; at the other end of the drum little effect of its leakage was evident. Although the two samples do not permit any clear picture of the fate of the leached nuclides, it is certainly suggested that much of the leached radioactivity had a trajectory, in the water column, that was short compared to the length of a 55-gal. oil drum; this conclusion depends on the assumption that the drum did not lie in a current field that was more than strong enough to wipe out the effect of the tidal cycle. Analyses of one core reported by Dyer (3) suggest immobilization of a large amount of ^{137}Cs only a few cm from the cracked end of this drum; unfortunately we had no samples from this core, since the ratio $^{239,240}\text{Pu}$ to ^{137}Cs would have been of great interest.
- b) In the Pacific dump site two of the three samples at site 13A were highly contaminated with transuranic nuclides, including curium, that must have originated from one or more waste drums. These three samples are described as having been taken in the middle of a cluster of 150 waste drums, but unfortunately no distances or dimensions were reached, and we cannot make any assumption whether the source was dispersed or a point, essentially a single drum. It can, however, be concluded from the fact that all three sample depths were recorded as the same, in spite of the rather sharp slope at this site, that the samples were not widely separated, and probably that their separations were tens of meters or even less. That one of these

samples showed so little evidence of transuranic contamination -- reduced certainly by two or more rather than by one order of magnitude versus the other two samples -- suggests that the trajectory in the water column of these elements after leaching must have been very short. We envision a down-current halo only 10 or 20 meters in length. It appears to us also likely that more detailed sampling of this, or a similar situation, would show that the trajectories of plutonium, americium and curium were distinctly different after leaching. Quantitative evidence for such differentiation in marine systems is very hard to come by, although it is obviously much needed for prediction purposes.

TABLE 1

Radionuclide Analyses -- Sediments from Atlantic Dump Site

Collected July, 1975

Dive No.	Identification, Remark, and Position	Depth of Sample m	Depth in Sediment cm	Radionuclides in dpm per kg dry				
				^{137}Cs	^{55}Fe	$^{239,240}\text{Pu}$	^{238}Pu	^{241}Am
583	Core Liner 2 CONTROL 38°33.6'N 72°12.4'W	2790	0- 2	270±34	1460±200	32. ±2	3. ±0.6	11±1
			2- 3	114± 9		9. ±1.1	1.3±0.4	
			3- 4	85± 9		9.7±1.1	0.9±0.3	
			4- 5	43± 7		4.6±0.5	0.3±0.2	
			6- 7	16± 6		4.5±0.4	0.2±0.1	
			8- 9	21± 6		0.9±0.4	---	
			10-11	3± 5		0.8±0.2	---	
584	Tube Core 1 38°30.8'N 72°09'W CONTROL	2820	0- 5	49± 1		3.7±0.4	0.5±0.2	1.7±0.5
			5-10	36± 2		2.5±0.3	0.1±0.1	1.2±0.3
			10-15	11± 3		1.0±0.2	---	0.4±0.1
			15-20	-1± 2		0.5±0.2	---	0.3±0.2
584	Box Core 1 Core Liner 2 38°30.7'N 72°09.4'W New Drum	2829	0- 5	46± 6		3.4±0.4	0.4±0.2	3.1±0.8
			5-10	10± 5		0. ±0.2	---	0.9±0.5
			10-15	7± 5		0.8±0.2	---	0.8±0.4
584	Core Liner 4 38°30.2'N 72°09.4'W New Drum	2827	0-5	14± 5		0.3±0.2	---	0.4±0.5
585	Tube Core 6 38°30.2'N 72°09.4 Near Closed End Drum	2827	0- 7.5	78±10	240± 30	11.1±0.7	1.2±0.2	3.6±0.9
			7.5-15	7±23		0.5±0.2	---	---
			15- 20	8±27		0.1±0.2	---	---
			20- 25	13±20		0. ±0.2	---	---
585	Core Liner 4 38°30.2'N 72°30.6'W Near Open End Same Drum	2827	0- 5	321± 9		34.5±1.7	2.2±0.3	21. ±1.5
586	Tube Core 3 38°45.3'N 72°30.6'W CONTROL	2350	0-10	57±19		8. ±0.6	0.7±0.2	3.4±0.5
			10-15	113±12		10.7±0.8	0.8±0.2	9.4±0.8
			15-20	20±10		2. ±0.3	0.2±0.2	2.7±0.4
590	Tube Core 2 38°56.5'N 72°26.7'W CONTROL	1790	0. - 7.5	109± 6	430±30	17.7±0.9	0.9±0.2	7.2±1
			7.5-17.5	18± 7		0.2±0.1	---	0.8±0.3
			17.5-27.5	2± 5		0. ±0.4	---	

- Notes: 1) All samples analyzed for ^{241}Am were carefully scanned for ^{242}Cm or ^{244}Cm ; in no case did either of these exceed the blank from our ^{243}Am yield monitor, about one count per day per sample.
- 2) 583 probably contaminated with ^{137}Cs , ^{55}Fe , Pu.
- 3) 584 Core Liner 4 probably contaminated with ^{241}Am .
- 4) 585 samples at opposite ends of same waste drum; Tube Core 6 probably only fallout levels, but Core Liner 4 certainly shows contamination with ^{137}Cs , Pu and ^{241}Am .
- 5) 586 and 590 probably both contaminated with ^{137}Cs , Pu and ^{241}Am ; 590 shows high ^{55}Fe .

Table 2
Radionuclide Analyses -- Sediments from "Pacific Farallon" Dump Sites

Station No., Remark, and Position	Depth	Collection Number	Sample Depth in Sediment cm	Radionuclides in dpm per kg dry						
				¹³⁷ Cs	⁵⁵ Fe	^{239,240} Pu	²³⁸ Pu	²⁴¹ Am	²⁴² Cm	²⁴⁴ Cm
38°17'N, 118°10'W Control	800m	132963 Core	0- 5	158±11		110 ±5	4.8±0.7			
			5-10	57± 9		24 ±2	0.7±0.3			
			10-15	4± 6		4 ±0.8	---			
			15-20	2± 7		4 ±0.8	---			
13A 37°38'N, 123°08'W Amid Drum Cluster	976m	134273 Core	0- 5	109±18		102 ±9	8.3±2	37± 2	ND	ND
			5-10	13±33		Lost	---			
			10-15	16± 8		2 ±0.4	---			
			15-20	2± 8		1.2±0.3	---			
13A 37°38'N, 123°08'W Amid Drum Cluster	976m	134274 Core	0-5	39±15	630±35	1060 ±106	321 ±32	439± 70	6±1	28 ±4
			5-10	11±11	460±50	1170 ±170	496 ±50	700±100	14±2	50 ±1
			10-15	3± 6		8.7± 1.2	4.4± 0.8	5± 0.5	ND	0.4±0.1
			15-20	-4± 7		3.2± 0.9	---	---	---	---
13A 37°38'N, 123°08'W Amid Drum Cluster	976m	134277 Grab	0-15	63± 4	1300±40	873 ± 87	271 ±27	414±14	2±0.2	11±0.6
15 37°36'N, 123°06'W Control	930m	134270 Core	0- 5	243±21	1700±90	176 ± 19	13 ± 4.3	90±6		
			5-10	169±18		137 ± 9	5 ± 1.2	44±3		
			10-15	13±17		34 ± 9	---			
			15-20	-3±20		1.4± 0.6	---			
6 37°38'N, 123°05'W Control	945m	134275 Grab	0-15	91± 6		85.5± 3	3.2± 0.3	30±2	ND	ND
33°39'N, 119°28'W Santa Cruz Basin	1920m	132961 Core	0- 5	218±12		92 ±7	4.2± 1.2	33±3	ND	ND
			5-10	31±11		9.4±1.5				
			10-15	4±11		1.6±0.7				
			15-20	2±13		5.6±1.3				

Notes: 1) ND = Carefully sought, but not found.

2) Site 13A was located among about 150 waste containers, and near several that were visibly imploded. Core 134273 shows just about fallout levels, while core 134274 and grab 134277 are highly contaminated. All ²⁴²Cm in these is supported by ^{242m}Am.

3) Sites 15 and 6 were planned as controls, but 15 shows excess ¹³⁷Cs, ⁵⁵Fe, Pu and Am, while 6 shows excess Pu and Am.

TABLE 3

NUCLIDE INVENTORIES IN DUMP SITE SEDIMENTS
COMPARED TO THOSE EXPECTED FROM FALLOUT

		INVENTORIES IN MCi per km ²				
		137 Cs	239,240 Pu	238 Pu	241 Am	
<u>PACIFIC DUMPSITE:</u>						
38°17'N;118°10'W		800	3.6	2.4	0.09	---
13A	Core 134273	976	1.8	1.8	0.14	0.63
13A	" 134274	976	0.81	38	14	19
13A	Grab 134277	976	3.2	44	14	21
15	Core 134270	930	7.2	5.9	0.3	2.5
6	Grab 134275	945	4.6	4.3	0.16	1.5
	Core 132961	1920	4.2	1.8	0.08	0.6
<u>ATLANTIC DUMP SITE:</u>						
590	Tube Core 2	1790	3.4	0.46	0.02*	0.21
586	" " 3	2350	4.2	0.49	0.04	0.32
584	" " 1	2820	1.6	0.13	---	0.06
584	Box Core 1	2829	1.1	0.07	---	0.08
585	Tube Core 6	2827	2.2	0.30	0.03*	0.07*
585	Core Liner 4	2827	5.4	0.58	0.04*	0.35*
583	Core Liner 2	2790	3.0	0.34	0.03	0.11*
ESTIMATED Delivery to 30° to 40°						
N. Latitude BAND:		61±10 ¹	1.9 ± 0.4 ²	0.067±0.014 ³	0.475±0.10 ⁴	
SEDIMENT INVENTORY EXPECTED						
1. AT WATER DEPTH 800-1000m:		2.4±0.4 ⁵	1.5 ± 0.3 ²	0.054±0.011 ³	0.57 ± 0.1 ⁶	
2. AT WATER DEPTH 1800-2400m:		2.1±0.4 ⁵	0.80±0.16 ²	0.028±0.006 ³	0.24 ± 0.048 ⁶	
3. AT WATER DEPTH 2800-2900m:		1.9±0.4 ⁵	0.44±0.1 ²	0.015±0.003 ³	0.13 ± 0.03 ⁶	

Notes: *Extrapolated from surface sediment concentration.

¹From Volchok and Toonkel (1974)

²From Noshkin and Bowen (1973)

³Using ratio 238Pu to 239,240Pu = 0.035

⁴Using ratio 241Am to 239,240Pu = 0.25

⁵Taking 3.5% as the 900m sedimented fraction of the inventory, from Noshkin & Bowen (1973)

⁶Taking 0.30 as the sediment ratio 241Am:239,240Pu from Livingston, Bowen, Burke (1976)

Table 4

NUCLIDE RATIOS IN MARINE SEDIMENTS
COMPARING RATIOS EXPECTED FROM FALLOUT TO THOSE OBSERVED IN DUMPSITES

A. WATER DEPTH RANGE 700 to 1100 m:				$^{239,240}\text{Pu}/^{137}\text{Cs}$	$^{238}\text{Pu}/^{239,240}\text{Pu}$	$^{241}\text{Am}/^{239,240}\text{Pu}$
FALLOUT EXPECTATION - RANGE				0.18-0.30	0.04-0.07	0.25-0.35
Dump Site Observed: PACIFIC						
38°17'N;118°10'W	800m	0-5	cm	0.70	0.044	---
		5-10	cm	0.42	0.029	---
13A 37°38'N;123°08'W	976m	0-5	cm	0.94	0.081	0.36
13A 37°38'N;123°08'W	976m	0-5	cm	27.1	0.30	0.41
		5-10	cm	106.	0.42	0.60
		10-15	cm	2.9	0.51	0.58
37°38'N;123°08'W	976m	0-15	cm	13.8	0.31	0.47
15 37°36'N;123°06'W	930m	0-5	cm	0.73	0.074	0.51
		5-10	cm	0.81	0.036	0.32
6 37°38'N;123°05'W	945m	0-15	cm	0.94	0.038	0.35
B. WATER DEPTH RANGE 1800 to 2800 m:						
FALLOUT EXPECTATION - RANGE				0.10-0.16	0.04-0.09	0.25-0.35
Dump Site Observed: PACIFIC:						
33°39'N;119°28'W	1920m	0-5	cm	0.42	0.046	0.36
		5-10	cm	0.30	---	---
ATLANTIC:						
590 38°56.5'N;72°26.7'W	1790m	0-7.5	cm	0.16	0.051	0.41
586 38°45.3'N;72°30.6'W	235m	0-10	cm	0.14	0.088	0.43
		10-15	cm	0.095	0.075	0.88
		15-20	cm	0.10	0.10	1.35
584 TUBE CORE 1	2820m	0-5	cm	0.075	0.135	0.46
		5-10	cm	0.070	0.04	0.48
		10-15	cm	0.091	---	0.40
584 Box Core 1	2829m	0-5	cm	0.074	0.117	0.91
584 Core Liner 4	2827m	0-5	cm	0.021	---	1.33
585 Tube Core 6	2827m	0-7.5	cm	0.14	0.108	0.32
585 Core Liner 4	2827m	0-5	cm	0.107	0.064	0.61
583 Core Liner 2	2790m	0-2	cm	0.12	0.094	0.34
		2-3	cm	0.079	0.145	---
		3-4	cm	0.114	0.093	---
		4-5	cm	0.107	0.065	---
		6-7	cm	0.28	0.044	---
		8-9	cm	0.043	---	---

TABLE 5

NON-FALLOUT CONTAMINATION OF DUMP SITE SAMPLES CONCLUDED FROM VARIOUS LINES OF EVIDENCE

SAMPLE	DEPTH-m	REMARK	NUCLIDE INVENTORY 1				NUCLIDE RATIOS 2			NUCLIDE CONC. PROFILE
			137Cs	239Pu	238Pu	241Am	239,240Pu: 137Cs	238Pu: 239,240Pu	241Am: 239,240Pu	
PACIFIC:										
38°17'N 118°10'W	800	Control	1.5X	1.5X	1.5X	---	2X	1X	---	normal
13A Core 134273	976	Drum Cluster	1	1	3X	1	4X	1.5X	1.2X	normal
13A " 134274	976	" "	0.3X	25X	260X	33X	188X	8X	2X	abnormal
13A Grab 134277	976	" "	1.3X	29X	260X	37X	57.5X	6X	1.6X	---
15	930	Control	3X	4X	5.5X	4.4X	3.2X	1	1.4X	normal
6	945	Control	2X	3X	3X	2.6X	4X	1	1	---
Core 132961	1920	Santa Cruz Basin	2.0X	2.2X	2.8X	2.5X	2.8X	1	1.2	normal
ATLANTIC:										
590	1790	Control	1.6X	0.6X	1	1	1.2	1	1.3	normal
586	2350	Control	2X	0.6X	1	1.3X	1	1	2.6	abnormal
584 Tube Core 1	2820	Control	0.8X	0.3X	---	0.5X	0.6	1.6	1.5	abnormal
584 Box Core 1	2829	Near Drum	0.6X	0.16X	---	0.6X	0.6	1.8	3	abnormal
584 Core liner 4	2827	" "	Very Low				0.2	---	4.5	abnormal
585 Tube Core 6	2827	Near Drum	1.1X	0.7X	2X	1.2X	1	2	1	normal
585 Core liner 4	2827	" "	2.8X	1.3X	3X	3X	0.8	1	2	---
583 Core liner 2	2790	Control	1.6X	0.8X	2X	0.8X	0.8	2	1	normal

¹INVENTORY EXPRESSED AS MULTIPLE OF EXPECTATION - SEE TABLE 3.

²RATIO EXPRESSED AS MULTIPLE OF MIDPOINT OF EXPECTED RANGE - SEE TABLE 4.