Table 193. Concentrations of radionuclides in terrestrial foods.

Food item	Concentration, pCi/g dry[a]											
	Jan. 1, 1974						Jan. 1, 1982					
	^{3}H	^{55}Fe	^{60}Co	^{90}Sr	^{137}Cs	$^{239,240}Pu$	^{3}H	^{55}Fe	^{60}Co	^{90}Sr	^{137}Cs	$^{239,240}Pu$
A. Island group ALICE-IRENE												
Domestic meat				3.08	51.7		← b →					
Pandanus fruit	← Not available →									23.5	221	
Breadfruit	← Not available →									23.5	221	
Wild birds		32.8	0.207	0.040	<0.081	0.0048	← b →					
Bird eggs		13.8	<0.057	0.090	<0.049	0.0015	← b →					
Arrowroot	← Not available →									1.18	1.77	
Coconut meat	← Not available →						0.237	6.64	<0.163	1.35	22.1	0.181
Coconut milk	← Not available →						2.37	66.4	<1.63	13.5	221	1.81
B. Island group BELLE												
Domestic meat				5.04	116		← b →					
Pandanus fruit	← Not available →							0.034	<0.036	38.4	496	<0.24
Breadfruit	← Not available →							0.034	<0.036	38.4	496	
Arrowroot	← Not available →									1.92	3.96	
Coconut meat	← Not available →									2.21	49.6	
Coconut milk	← Not available →									22.1	496	
C. Island group JANET												
Domestic meat				1.80	38.7		← b →					
Pandanus fruit	← Not available →							0.178	<0.031	13.8	165	0.00204
Breadfruit	← Not available →							0.178	<0.031	13.8	165	0.00204
Wild birds		59.9	0.257	0.0076	0.0834	0.0033	← b →					
Bird eggs		34.2	<0.077	0.193	0.114	0.0148	← b →					
Arrowroot	← Not available →									0.687	1.32	
Coconut meat	← Not available →								<0.019	0.790	16.5	
Coconut milk	← Not available →								<0.19	7.90	165	

Table 193 (continued).

Concentration, pCi/g dry[a]

Jan. 1, 1982

Table 193 (continued).

Food item	Jan. 1, 1974 ^{3}H	^{55}Fe	^{60}Co	^{90}Sr	^{137}Cs	$^{239,240}Pu$	Jan. 1, 1982 ^{3}H	^{55}Fe	^{60}Co	^{90}Sr	^{137}Cs	$^{239,240}Pu$
D. Island group KATE-WILMA + LEROY												
Domestic meat				0.79	14.3		← b →					
Pandanus fruit	← Not available →							0.0985	<0.344	6.03	61.9	0.00791
Breadfruit	← Not available →							0.0985	0.344	6.03	61.9	0.00791
Wild birds		54.4	0.406	0.096	0.088	0.0247	← b →					
Bird eggs		22.5	<0.056	0.0040	<0.050	0.0154	← b →					
Arrowroot	← Not available →									0.304	0.495	
Coconut meat	← Not available →						0.190	2.04	0.011	0.347	6.19	0.086
Coconut milk	← Not available →						1.90	20.4	<0.11	3.47	61.9	<0.86
Coconut crabs	0.480		1.03	1.96	7.59	0.0035	← b →					
E. Island group ALVIN-KEITH												
Domestic meat				0.103	0.849		← b →					
Pandanus fruit	← Not available →							0.034	<0.016	0.236	2.14	0.0039
Breadfruit	← Not available →							0.034	<0.016	0.236	2.14	0.0039
Wild birds		56.6	0.214	0.012	0.085	0.0235	← b →					
Bird eggs			0.037	0.0036	0.129	0.00065	← b →					
Arrowroot	← Not available →									0.012	0.017	
Coconut meat	0.293	<0.229	<0.029	0.034	0.687	<0.0026	← b →					
Coconut milk	2.97	<2.29	<0.29	0.335	6.87	<0.026	← b →					
Coconut crabs	0.342		0.498	0.304	1.10	0.0027	← b →					

Concentration, pCi/g dry[a]

[a]Except for domestic meat all the concentrations reported in Table 193 are expressed in pCi/g dry weight. The concentration in domestic meat is expressed in pCi/g fresh weight.

[b]*Jan. 1, 1974 data corrected for radioactive decay only to obtain Jan. 1, 1982 values.*

foods available at the time of return were corrected for decay and listed under the first possible date of return, January 1, 1974. These concentrations are mostly derived from measurements on birds, bird eggs, and coconut crabs, and they do include the concentrations predicted for coconut and coconut milk from the southern islands (Group E, ALVIN-KEITH). Since swine and poultry can be expected to provide meat within a year or two after return, the concentrations of ^{90}Sr and ^{137}Cs predicted in domestic meat are listed under the date of return. The predicted concentrations in pandanus fruit, breadfruit, arrowroot and, except for the southern islands, coconut and coconut milk were decay corrected and listed under January 1, 1982, or 8 yr after return. Eight years has been assumed as the period required for newly planted crops to mature and yield food. Except for coconut on the southern islands, edible plants will have to be reestablished, and hence their radionuclide concentrations are listed under the later date. Actually, 8 yr is rather short for all but tacca. The concentrations of the radionuclides other than ^{90}Sr and ^{137}Cs in pandanus fruit and breadfruit were set equal to the mean of the concentration in pandanus leaves (see Table 139). This procedure enabled us to estimate the maximum contribution of these radionuclides to the dose from terrestrial foods.

The integrated dose via ingestion of terrestrial foods was estimated following the procedure described in the chapter on dose estimates for the marine food chain. Equation (6), the expression for the integrated dose, can be written in the form

$$\text{Dose} = I_o^* \times D_T,$$

where

I_o^* = initial rate of ingestion of a radionuclide, pCi/day

and

D_T = the integrated dose from $t = 0$ to $t = T$ (day) per unit rate of ingestion of activity rem/pCi/day.

Dosages for each island group integrated over 5, 10, 30, and 70 yr were estimated using rates of ingestion computed from the concentrations of Table 193. It is of interest to consider the two basic diets shown in Table 139 in the chapter on dietary and living patterns, one the expected diet at the time of return, and the other the expected diet 10 yr after return. The 5- and 10-yr integral doses were calculated assuming the diet at the time of return. This diet contains only foods that are available on islands of the group at the time of return, i.e., domestic meat, birds, bird eggs, coconut crabs, and only in the case of the southern islands, coconut meat and coconut milk. The initial rates of ingestion of radionuclides for each island group assuming the diet at the time of return are listed in Table 194. These values were compounded according to the post-return diet described in Table 139 from the concentrations listed in the left side of Table 193 under the date of return, January 1, 1974. The 10-yr integral dose also includes a 2-yr contribution from the edible plants that become available for the first time 8 yr after return. The initial rates of ingestion of these foods were calculated according to the 10-yr post-return diet described in

Table

Food i

A. Isl
Pork a
Wild b
Bird e
Total

B. Isl
Pork a
Total

C. Isl
Pork a
Wild b
Bird e
Total

D. Isl
Pork a
Wild b
Bird e
Cocon
Total

E. Isl
Pork a
Wild b
Bird e
Cocon
Cocon
Cocon
Total

Table 104. Rate of ingestion of radionuclides from terrestrial foods assuming diet at time of return (Jan. 1, 1974).

	Ingestion rate, pCi/day					
Food item	^{3}H	^{55}Fe	^{60}Co	^{90}Sr	^{137}Cs	$^{239,240}Pu$
A. Island group ALICE-IRENE						
Pork and chicken				185	3100	
Wild birds		984	6.21	1.21	<2.4	0.143
Bird eggs		69	<0.29	0.45	<0.24	0.0074
Total		1050	6.35	187	3100	0.150
B. Island group BELLE						
Pork and chicken				302	6960	
Total				302	6960	
C. Island group JANET						
Pork and chicken				108	2320	
Wild birds		1800	7.70	0.29	2.5	0.100
Bird eggs		171	<0.39	0.97	0.6	0.074
Total		1970	7.89	109	2320	0.174
D. Island group KATE-WILMA, LEROY						
Pork and chicken				47.4	858	
Wild birds		1800	7.70	0.29	2.50	0.100
Bird eggs		113	<0.28	0.02	<0.25	0.077
Coconut crabs	0.480		1.03	1.96	7.59	0.0035
Total	0.480	1900	8.87	49.7	868	0.180
E. Island group ALVIN-KEITH						
Pork and chicken				6.18	50.9	
Wild birds		1700	6.41	0.37	2.55	0.704
Bird eggs		131	<0.35	0.02	<0.35	0.003
Coconut	29.3	<23	<2.9	3.35	68.7	<0.259
Coconut milk	14.9	<11	<1.42	0.17	3.44	<0.129
Coconut crabs	2.91		4.23	2.58	9.31	0.023
Total	47.1	1850	13.7	12.7	135	0.99

Table 139 from the concentrations listed in the right side of Table 193. The basis of this procedure is described more fully below.

The 30- and 70-yr integral doses were calculated assuming the 10-yr post-return diet. In addition to the foods that are available at the time of return, the 10-yr post-return diet includes pandanus fruit, breadfruit, arrowroot, and for islands other than the southern islands, coconut meat and coconut milk. The initial rates of ingestion for each island group assuming the 10-yr post-return diet are listed in Table 195. These values were compounded according to the 10-yr post-return diet described in Table 139 and are presented in two parts. The rates of ingestion for the foods immediately available were calculated using the concentrations listed on the left side of Table 193, and are presented on the left side of Table 195 under January 1, 1974, the date of return. The rates of ingestion for the foods that are to become available 8 yr after return were calculated using the concentrations on the right side of Table 193. These rates of ingestion are presented on the right side of Table 195 under the 8-yr post-return date, January 1, 1982. In essence, the foods immediately available are assumed to contribute to the diet beginning January 1, 1974, and the edible plants that are yet to be established are assumed to contribute to the diet beginning January 1, 1982.

The values of the dose per unit rate of ingestion D_T that were used to calculate the 5-, 10-, 30-, and 70-yr doses are listed in Table 196. The doses from ^{90}Sr and $^{239,240}Pu$, which can be regarded as bone-seekers, were calcul to bone. The dosage from the other nuclides were calculated to the whole The dose per unit rate of ingestion D, been calculated assuming that the rac nuclide is removed from food and the vironment solely by radioactive deca The origin of D_T is fully discussed ir chapter on dose estimates for the ma environment. Table 196 can be seen include 2-, 22-, and 62-yr values of These values are used to estimate th 10-, 30-, and 70-yr dosages from in tion of the foods that do not contribut the diet until 8 yr after return.

Prediction of the Dosage from Terrestrial Foods by Island Grou

Estimated Dosage Assuming Diet Time of Return — Table 197 presen 5- and 10-yr integral doses calculat assuming the diet at the time of ret (see Table 139). These dosage esti combine the rates of ingestion of Ta 194 and 195 and 2-, 5-, and 10-yr v of the dose per unit rate of ingestio listed in Table 196. The 5- and 10- dosages are useful for examining th situation for the first few years fol return. The total whole-body dose been computed as the sum of the wh body dosages from the non-bone se The total bone dose has been comp the sum of the total whole-body dos the bone doses from ^{90}Sr and ^{239,}

Terrestrial food from BELLE v contribute the greatest dosages, fc from the southern islands ALVIN- would contribute the least. Stront accounts for more than 99.9% of t

Table 195. Rate of ingestion of radionuclides from terrestrial foods assuming 10-yr post-return diet.

	Ingestion rate, pCi/day											
	January 1, 1974						January 1, 1982					
Food item	^{3}H	^{55}Fe	^{60}Co	^{90}Sr	^{137}Cs	^{239,240}Pu	^{3}H	^{55}Fe	^{60}Co	^{90}Sr	^{137}Cs	^{239,240}Pu
A. Island group ALICE-IRENE												
Domestic meat				308	5170							
Pandanus fruit										941	8840	
Breadfruit										807	7570	
Wild birds		197	1.24	0.242	<0.5	0.0286						
Bird eggs		34.5	<0.14	0.226	<0.1	0.0037						
Arrowroot										47	71	
Coconut meat							23.7	664	<16.3	135	2210	18.1
Coconut milk							35.6	<37	<8.5	20	331	<1.7
Total		231	1.31	308	5170	0.0323	59.3	683	12.4	1950	19000	19
B. Island group BELLE												
Domestic meat				504	11600							
Pandanus fruit								1.34	<1.46	1540	19800	<9.5
Breadfruit								1.15	<1.25	1320	17000	<8.1
Arrowroot										77	159	
Coconut meat										221	4960	
Coconut milk										33	743	
Total				504	11600			2.50	1.35	3180	42700	8.8
C. Island group JANET												
Domestic meat				180	3870							
Pandanus fruit								7.12	<1.25	550	6610	0.082
Breadfruit								6.10	<1.07	471	5560	0.071
Wild birds		360	1.54	0.058	0.50	0.020						
Bird eggs		85.5	<0.19	0.482	0.29	0.037						
Arrowroot										28	53	
Coconut meat									<1.85	79	1650	
Coconut milk								<2.54	<2.27	12	248	<1.31
Total		**445**	**1.64**	**181**	**3870**	**0.057**		**14.5**	**3.22**	**1140**	**14100**	**0.81**

Table 195 (continued).

Food item	Ingestion rate, pCi/day											
	January 1, 1974						January 1, 1982					
	^{3}H	^{55}Fe	^{60}Co	^{90}Sr	^{137}Cs	$^{239,240}Pu$	^{3}H	^{55}Fe	^{60}Co	^{90}Sr	^{137}Cs	$^{239,240}Pu$
D. Island group KATE-WILMA + LEROY												
Domestic meat				79	1430							
Pandanus fruit								3.94	<13.8	241	2480	0.316
Breadfruit								3.38	<11.8	207	2120	0.271
Wild birds		360	1.54	0.058	0.50	0.020						
Bird eggs		56	<0.14	0.01	<0.12	0.039						
Arrowroot										12	20	
Coconut meat							19.0	204	<1.05	34.7	619	<8.64
Coconut milk							28.5	<6.44	<2.27	5.2	93	<0.38
Coconut crabs	0.480		1.03	1.96	7.59	0.003						
Total	0.480	416	2.59	81	1440	0.062	47.5	215	14.4	500	5330	5.0
E. Island group ALVIN-KEITH												
Domestic meat				10.3	84.9							
Pandanus fruit								1.33	<0.65	9.44	85.4	0.156
Breadfruit								1.14	<0.56	8.09	73.2	0.134
Wild birds		340	1.28	0.073	0.51	0.141						
Bird eggs		65	<0.17	0.009	<0.17	0.002						
Arrowroot			Not available							0.47	0.68	
Coconut meat	29.3	<23	<2.9	3.35	68.7	<0.259						
Coconut milk	44.6	<33	<4.2	0.50	10.3	<0.386						
Coconut crabs	2.91		4.23	2.58	9.3	0.023						
Total	76.8	433	9.17	16.8	174	0.488		2.48	0.60	18.0	159	0.290

Table 196. Integrated dose per unit rate of ingestion to whole body and bone.

		D_T, rem/pCi/day						
		Period of integration						
Nuclide	Organ	2 yr	5 yr	10 yr	22 yr	30 yr	62 yr	70 yr
^{3}H	Whole body	4.51(-8)[a]	1.05(-7)	1.85(-7)	3.05(-7)	3.51(-7)	4.17(-7)	4.23(-7)
^{55}Fe	Whole body	7.50(-8)	2.35(-7)	3.73(-7)	4.29(-7)	4.32(-7)	4.32(-7)	4.32(-7)
^{60}Co	Whole body	1.27(-5)	2.96(-5)	4.65(-5)	6.09(-5)	6.33(-5)	6.46(-5)	6.46(-5)
^{90}Sr	Bone	2.87(-3)	1.08(-2)	2.39(-2)	4.99(-2)	6.33(-2)	9.70(-2)	1.02(-1)
^{137}Cs	Whole body	3.49(-5)	9.62(-5)	1.89(-4)	3.74(-4)	4.71(-4)	7.22(-4)	7.61(-4)
$^{239,240}Pu$	Bone	1.51(-6)	9.39(-6)	3.71(-5)	1.75(-4)	3.19(-4)	1.27(-3)	1.59(-3)

[a]The number within parentheses denotes the power of 10. Thus, 4.51(-8) is a contraction of 4.51×10^{-8} rem/pCi/day.

Table 197. Prediction of the dosage from ingestion of terrestrial foods assuming diet at the time of return.

	Isotope	5-yr dose, rem Whole body	5-yr dose, rem Bone	10-yr dose, rem Whole body	10-yr dose, rem Bone
A. Island group ALICE-IRENE					
	^{3}H			2.7(-6)	
	^{55}Fe	2.5(-4)[a]		4.4(-4)	
	^{60}Co	1.9(-4)		4.5(-4)	
	^{90}Sr		2.02		10.1
	^{137}Cs	0.298		1.25	
	$^{239,240}Pu$		1.4(-6)		3.4(-5)
	Subtotal	0.298	2.02	1.25	10.1
	Total 5-yr whole-body dose	0.30 rem		Total 10-yr whole-body dose	1.25 rem
	Total 5-yr bone dose	2.32 rem		Total 10-yr bone dose	11.3 rem
B. Island group BELLE					
	^{55}Fe			1.9(-7)	
	^{60}Co			1.7(-5)	
	^{90}Sr		3.26		16.3
	^{137}Cs	0.669		2.81	
	$^{239,240}Pu$				1.3(-5)
	Subtotal	0.67	3.26	2.81	16.3
	Total 5-yr whole-body dose	0.67 rem		Total 10-yr whole-body dose	2.81 rem
	Total 5-yr bone dose	3.93 rem		Total 10-yr bone dose	19.2 rem

Table 197 (Continued).

Isotope	5-yr dose, rem Whole body	5-yr dose, rem Bone	10-yr dose, rem Whole body	10-yr dose, rem Bone
C. Island group JANET				
^{55}Fe	4.6(-4)		7.4(-4)	
^{60}Co	2.3(-4)		4.1(-4)	
^{90}Sr		1.18		5.88
^{137}Cs	0.223		0.831	
^{239,240}Pu		1.6(-6)		7.6(-6)
Subtotal	0.224	1.18	0.932	5.88
Total 5-yr whole-body dose	0.22 rem		Total 10-yr whole-body dose	0.93 rem
Total 5-yr bone dose	1.40 rem		Total 10-yr bone dose	6.82 rem
D. Island group KATE-WILMA + LEROY				
^{3}H	5.0(-8)		2.2(-6)	
^{55}Fe	4.5(-4)		7.3(-4)	
^{60}Co	2.6(-4)		6.0(-4)	
^{90}Sr		0.536		2.62
^{137}Cs	0.0835		0.350	
^{239,240}Pu		1.7(-6)		1.4(-5)
Subtotal	0.0842	0.536	0.351	2.62
Total 5-yr whole-body dose	0.084 rem		Total 10-yr whole-body dose	0.351 rem
Total 5-yr bone dose	0.620 rem		Total 10-yr bone dose	2.97 rem

Table 197 (Continued).

	Isotope	5-yr dose, rem Whole body	5-yr dose, rem Bone	10-yr dose, rem Whole body	10-yr dose, rem Bone
E. Island group ALVIN-KEITH					
	^{3}H	4.9(-6)		8.7(-6)	
	^{55}Fe	4.4(-4)		6.9(-4)	
	^{60}Co	4.1(-4)		6.5(-4)	
	^{90}Sr		0.137		0.355
	^{137}Cs	0.0130		0.0311	
	$^{239,240}Pu$		9.3(-6)	0.0324	3.7(-5)
	Subtotal	0.0138	0.137	0.0324	0.303
	Total 5-yr whole-body dose		0.014 rem	Total 10-yr whole-body dose	0.032 rem
	Total 5-yr bone dose		0.151 rem	Total 10-yr bone dose	0.387 rem

[a]The number within parentheses denotes the power of 10. Thus, 2.5(-4) is a contraction of 2.5×10^{-4}.

dose from the bone-seekers, and ^{137}Cs accounts for greater than 95% of the total whole-body dose. Table 198 presents the relative contributions of the terrestrial foods to the integral 5- and 10-yr dosages from ^{90}Sr and ^{137}Cs. Table 198 indicates that for island group ALVIN-KEITH, domestic meat would contribute about 50% of the 5-yr bone dose from ^{90}Sr, and coconut and coconut crabs would together contribute about 45%. Edible plants are still absent in the remaining island groups at the time of return, and for these islands meat is estimated to contribute 95% or more of the 5-yr bone dose from ^{90}Sr. It should be mentioned that meat has not been noted to be an effective agent for the transfer of ^{90}Sr to man and that prediction of the ^{90}Sr in meat from that in soil is associated with considerable uncertainty, particularly when the concentration in soil is low.

Assessment of the dosage from ingestion of domestic meat has been made considering only the transfer of ^{90}Sr and ^{137}Cs via muscle. Although liver is consumed in the diet as well as muscle, it has not been considered in the predictive approach for meat. Exclusion of liver from consideration does not affect the ^{90}Sr bone dose assessment. Although the ^{90}Sr concentration is more frequently greater in rat liver than in rat muscle, the ^{90}Sr concentrations in the two organs are statistically indistinguishable by the Wilcoxen matched-pairs signed-rank test[11]. As far as the bone dose from other nuclides is concerned, $^{239,240}Pu$ would not be expected to contribute significantly to the bone dose. If the measured concentration of $^{239,240}Pu$ in muscle or liver of rat (see Tables 71 and 72 in the chapter on the terrestrial biota survey) whichever is greater, were used to represent the concentration in meat, the $^{239,240}Pu$ in meat would increase the total bone dose by less than 0.1%.

Cesium-137 accounts for 95% or more of the 5-yr whole-body dosages (see Table 197). For the southern islands (ALVIN-KEITH) coconut would contribute about 50% of the total 5-yr whole-body dosage and meat about 40%. For the remaining island groups domestic meat would contribute over 95% of the 5-yr whole-body doses. Coconut crabs would contribute about 1% of the 5-yr whole-body dose for KATE-WILMA + LEROY and about 7% of the 5-yr whole-body dose for ALVIN-KEITH. Since the concentrations of ^{137}Cs in muscle and liver can be expected to be similar, exclusion of liver from consideration as meat does not substantially influence the prediction of the whole-body dose from meat. The concentrations of ^{137}Cs in rat muscle are significantly greater than those in rat liver (P = 0.02 by the Wilcoxen matched-pairs signed-rank test), but the conversion factor relating the concentrations in the two tissues differs only slightly from unity (see Tables 71 and 72 in the chapter on the terrestrial biota survey). Both ^{55}Fe and ^{60}Co are more concentrated in liver than in muscle. If the measured concentrations of these nuclides in rat liver were used to represent the concentration in meat, the ^{55}Fe and ^{60}Co in meat would increase the total whole-body dose only by 0.1% or less.

Table 197 indicates that for the northern island groups, the 10-yr integral doses

Table 198. Relative contributions of terrestrial foods to the integral dose assuming diet at time of return.

Food item	Percentage of total 5-yr		Percentage of total 10-y	
	^{90}Sr dose to bone	^{137}Cs dose whole body	^{90}Sr dose to bone	^{137}Cs dose whole body
A. Island group ALICE-IRENE				
Domestic meat	98.9	100	43.9	46.9
Pandanus fruit			26.8	24.7
Breadfruit			23.1	21.1
Wild birds	0.65	<0.08	0.29	0.04
Bird eggs	0.24	<0.008	0.11	0.004
Arrowroot			1.3	0.20
Coconut meat			3.9	6.2
Coconut milk			0.57	0.93
B. Island group BELLE				
Domestic meat	100	100	44.2	47.1
Pandanus fruit			27.0	24.6
Breadfruit			23.2	21.1
Arrowroot			1.4	0.20
Coconut meat			3.9	6.2
Coconut milk			0.58	0.92
C. Island group JANET				
Domestic meat	99.1	100	43.9	47.0
Pandanus fruit			26.9	24.8
Breadfruit			22.9	20.8
Wild birds	0.27	0.11	0.12	0.05
Bird eggs	0.89	0.03	0.39	0.01
Arrowroot			1.4	0.20
Coconut meat			3.9	6.2
Coconut milk			0.59	0.93
D. Island group KATE-WILMA + LEROY				
Domestic meat	95.4	98.8	43.1	46.3
Pandanus fruit			26.4	24.7
Breadfruit			22.7	21.1
Wild birds	0.58	0.29	0.26	0.14
Bird eggs	0.04	<0.03	0.02	0.01

Table 198 (continued)

Food item	Percentage of total 5-yr ^{90}Sr dose to bone	Percentage of total 5-yr ^{137}Cs dose whole body	Percentage of total 10-yr ^{90}Sr dose to bone	Percentage of total 10-yr ^{137}Cs dose whole body
D. Island group KATE-WILMA + LEROY (continued)				
Arrowroot			1.3	0.20
Coconut meat			3.8	6.2
Coconut milk			0.57	0.93
Coconut crabs	3.9	0.87	2.4	0.41
E. Island group ALVIN-KEITH				
Domestic meat	48.7	37.7	41.7	30.9
Pandanus fruit			7.6	9.6
Breadfruit			6.5	8.2
Wild birds	2.9	1.9	2.5	1.5
Bird eggs	0.2	<0.26	0.13	0.21
Arrowroot			0.38	0.08
Coconut meat	26.4	50.9	22.6	41.8
Coconut milk	1.4	2.5	1.1	2.1
Coconut crabs	20.3	6.9	17.4	5.6

exceed the 5-yr integral doses by greater than a factor of four. The increase is more than twice the increase in the period of integration. As Table 198 indicates, the pronounced increase in the dosages is primarily due to the 2-yr contribution from pandanus and breadfruit; coconut and arrowroot make smaller contributions to the 10-yr dose. As a consequence, pandanus and breadfruit collectively, and domestic meat each contribute 40-50% of the 10-yr bone dose from ^{90}Sr and 40-50% of the 10-yr whole-body dose from ^{137}Cs for the northern island groups. For the southern islands ALVIN-KEITH, the 10-yr integral dosages are two to three times greater than the 5-yr integral dosages, and pandanus and breadfruit contribute about 15-20% of the 10-yr bone and whole-body dosages from ^{90}Sr and ^{137}Cs.

Estimated Dosage Assuming 10-yr Post-Return Diet — Table 199 presents the 30- and 70-yr integral doses calculated assuming the 10-yr post-return diet. These dosages relate primarily to the conditions that will prevail when normal living patterns have become established.

The estimates incorporate the rates of ingestion of Table 195 and the dose factors (D_T) of Table 196. The 30- and 70-yr dose factors of Table 196 combine with the rates of ingestion on the left side of Table 195 to yield the estimated 30- and 70-yr doses for the foods available at the time of return. These estimates are listed on the left side of Table 199. The 22- and 62-yr dose factors of Table 196 combine with the rates of ingestion in the right side of Table 195 to yield the estimated 22- and 62-yr doses for the foods that are available beginning 8 yr after return. These estimates are listed on the right side of Table 199. The 22- and 30-yr doses are summed to give the total 30-yr dose, and the 62- and 70-yr doses are summed to give the total 70-yr dose. Total whole-body and total bone dosages are compounded in the same manner as for the 5- and 10-yr integral doses, and the total doses are listed at the bottom of the table.

As in the case of the 5- and 10-yr dosages, the greatest total 30- and 70-yr doses are associated with BELLE and the least with the island group ALVIN-KEITH. Also, ^{137}Cs accounts for 99% or more of the total whole-body dose and ^{90}Sr accounts for 99% or more of the total bone dose from bone-seeking nuclides. Table 200 presents the relative contributions of the terrestrial foods to the integral 30- and 70-yr dosages. Except for the southern islands, only a small fraction of the total bone and whole-body dosages is attributable to foods that are available at the time of return. A major fraction of the total dosages, up to 75%, is attributable to pandanus and breadfruit, which would not begin to enter the diet until several years after return. For the southern islands ALVIN-KEITH, pandanus and breadfruit would contribute about 45% of the total bone dose from ^{90}Sr and about 45% of the total whole-body dose from ^{137}Cs.

Interpretation of the Dosage Estimates – Table 201 is a summary which combines the dose predictions of Tables 197 and 199. It indicates that only the average dose rates for the southern island group (ALVIN-KEITH) are less than the 100 mrem/yr normal exposure due to internal and external irradiation from natural sources. From Table 200, it is clear that the dosages from foods obtained on the other island groups could be reduced substantially if the diet were restricted to food items available at the time of return.

Table 202 lists the contributions of each food to the predicted 30-yr dose (shown in Table 199). The table also shows the contributions and the reduced total dosages that could result if steps are taken to modify the diet. The following two examples have been considered: (1) Locally grown pandanus and breadfruit are replaced with pandanus and breadfruit grown on the southern islands, and (2) all foods derived from locally grown plants are replaced with their counterparts grown on the southern islands. Substantial reductions in the total whole-body and bone dosages would be experienced if pandanus and breadfruit are excluded from cultivation on the northern islands and are brought in from the southern islands. Further reductions are possible if the remaining edible plants are also excluded

Table 199. Prediction of the dosage from ingestion of terrestrial foods assuming 10-yr post-return diet.

Isotope	Ingestion rate, pCi/day January 1, 1974	30-yr dose, rem Whole body	30-yr dose, rem Bone	70-yr dose, rem Whole body	70-yr dose, rem Bone	Ingestion rate, pCi/day January 1, 1984	22-yr dose, rem Whole body	22-yr dose, rem Bone	62-yr dose, rem Whole body	62-yr dose, rem Bone
A. Island group										
ALICE-IRENE										
^{3}H						59.3	1.8(-5)		2.5(-5)	
^{55}Fe	231	1.0(-4)[a]		1.0(-4)		683	0.0003		0.0003	
^{60}Co	1.31	8.3(-5)		8.5(-5)		12.4	0.0008		0.0008	
^{90}Sr	308		19.5		31.5	1950		97.3		190
^{137}Cs	5170	2.44		3.93		19,000	7.11		13.7	
$^{239,240}Pu$	0.0323		1.0(-5)		5.1(-5)	19		0.003		0.024
Subtotal		2.44	19.5	3.93	31.5		7.11	97.3	13.7	190
Total 30-yr whole-body dose		9.55 rem				Total 70-yr whole-body dose		17.7 rem		
Total 30-yr bone dose		126 rem				Total 70-yr bone dose		239 rem		
B. Island group										
BELLE										
^{55}Fe						2.50	1.1(-6)		1.1(-6)	
^{60}Co						1.35	8.2(-5)		8.7(-5)	
^{90}Sr	504		31.9		51.4	3180		159		309
^{137}Cs	11,600	5.46		8.83		42,700	16.0		30.8	
$^{239,240}Pu$						8.8		1.5(-3)		1.1(-2)
Subtotal		5.46	31.9	8.83	51.4		16.0	159	30.8	309
Total 30-yr whole-body dose		21.4 rem				Total 70-yr whole-body dose		39.6 rem		
Total 30-yr bone dose		212 rem				Total 70-yr bone dose		400 rem		

Table 199 (continued).

Isotope	Ingestion rate, pCi/day January 1, 1974	30-yr dose, rem Whole body	30-yr dose, rem Bone	70-yr dose, rem Whole body	70-yr dose, rem Bone	Ingestion rate, pCi/day January 1, 1984	22-yr dose, rem Whole body	22-yr dose, rem Bone	62-yr dose, rem Whole body	62-yr dose, rem Bone
C. Island group										
JANET										
^{55}Fe	445	1.9(-4)		1.9(-4)		14.5	6.2(-6)		6.2(-6)	
^{60}Co	1.64	1.0(-4)		1.1(-4)		3.22	2.0(-4)		2.1(-4)	
^{90}Sr	181		11.4		18.4	1140		56.9		111
^{137}Cs	3870	1.82		2.95		14,100	5.28		10.2	
$^{239,240}Pu$	0.057		1.8(-5)		9.1(-5)	0.806		1.4(-4)		1.0(-3)
Subtotal		1.82	11.4	2.95	18.4		5.28	56.9	10.2	111
Total 30-yr whole-body dose		7.10 rem				Total 70-yr whole-body dose		13.1 rem		
Total 30-yr bone dose		75.4 rem				Total 70-yr bone dose		142 rem		
D. Island group										
KATE-WILMA + LEROY										
^{3}H	0.480	2(-7)		2.0(-7)		47.5	1.5(-5)		2.0(-5)	
^{55}Fe	416	1.8(-4)		1.8(-4)		215	9.2(-5)		9.3(-5)	
^{60}Co	2.59	1.6(-4)		1.7(-4)		14.4	8.8(-4)		9.3(-4)	
^{90}Sr	81.0		5.13		8.26	500		24.9		48.5
^{137}Cs	1440	0.677		1.09		5330	1.99		3.85	
$^{239,240}Pu$	0.062		2.0(-5)		9.8(-5)	4.96		8.7(-4)		6.3(-3)
Subtotal		0.677	5.13	1.09	8.26		1.99	24.9	3.85	48.5
Total 30-yr whole-body dose		2.67 rem				Total 70-yr whole-body dose		4.94 rem		
Total 30-yr bone dose		32.7 rem				Total 70-yr bone dose		61.7 rem		

Table 199 (continued).

Isotope	Ingestion rate, pCi/day January 1, 1974	30-yr dose, rem		70-yr dose, rem		Ingestion rate, pCi/day January 1, 1984	22-yr dose, rem		62-yr dose, rem	
		Whole body	Bone	Whole body	Bone		Whole body	Bone	Whole body	Bone
E. Island group										
ALVIN-KEITH										
^{3}H	76.8	1.3(-5)		3.3(-5)						
^{55}Fe	433	1.9(-4)		1.9(-4)		2.48	1.1(-6)		1.1(-6)	
^{60}Co	9.17	5.8(-4)		5.9(-4)		0.60	3.7(-5)		3.9(-5)	
^{90}Sr	16.8		1.07		1.72	18.0		0.898		1.75
^{137}Cs	174	0.0819		0.132		159	0.0596		0.115	
$^{239,240}Pu$	0.49		1.6(-4)		7.8(-4)	0.290		1.8(-4)		1.3(-3)
Subtotal		0.0826	1.07	0.133	1.72		0.0596	0.898	0.115	1.75
Total 30-yr whole-body dose		0.142 rem				Total 70-yr whole-body dose		0.248 rem		
Total 30-yr bone dose		2.11 rem				Total 70-yr bone dose		3.71 rem		

[a]The number within parentheses denotes the power of 10; thus, 1.0(-4) is a contraction of 1.0×10^{-4}.

Table 200. Relative contributions of terrestrial foods to the integral dose assuming 10-yr post-return diet.

Food item	Percentage of total 30-yr dose				Percentage of total 70-yr dose			
	^{90}Sr dose to bone		^{137}Cs dose to whole body		^{90}Sr dose to bone		^{137}Cs dose to whole body	
	Commencement date		Commencement date		Commencement date		Commencement date	
	1/1/74	1/1/82	1/1/74	1/1/82	1/1/74	1/1/82	1/1/74	1/1/82
A. Island group ALICE-IRENE								
Domestic meat	16.7		25.5		14.2		22.3	
Pandanus fruit		40.2		34.7		41.4		36.2
Breadfruit		34.5		29.6		35.5		31.0
Wild birds	0.01		<0.002		0.01		<0.002	
Bird eggs	0.01		<0.0005		0.01		<0.004	
Arrowroot		2.0		0.28		2.1		0.29
Coconut meat		5.8		8.7		5.9		9.1
Coconut milk		0.85		1.3		0.88		1.4
Subtotal	17	83	26	74	14	86	22	78
B. Island group BELLE								
Domestic meat	16.7		25.4		14.3		22.3	
Pandanus fruit		40.2		34.5		41.5		36.1
Breadfruit		34.5		29.6		35.6		31.0
Arrowroot		2.0		0.27		2.1		0.29
Coconut meat		5.8		8.7		6.0		9.0
Coconut milk		0.86		1.3		0.89		1.4
Subtotal	17	83	25	75	14	86	22	78

Table 200 (continued).

	Percentage of total 30-yr dose				Percentage of total 70-yr dose			
	^{90}Sr dose to bone		^{137}Cs dose to whole body		^{90}Sr dose to bone		^{137}Cs dose to whole body	
	Commencement date		Commencement date		Commencement date		Commencement date	
Food item	1/1/74	1/1/82	1/1/74	1/1/82	1/1/74	1/1/82	1/1/74	1/1/82
C. Island group JANET								
Domestic meat	16.7		25.7		14.2		22.6	
Pandanus fruit		39.6		34.8		41.2		36.6
Breadfruit		34.4		29.3		35.3		30.7
Wild birds	0.005		0.003		0.005		0.003	
Bird eggs	0.05		0.002		0.04		0.002	
Arrowroot		2.0		0.28		2.1		0.29
Coconut meat		5.8		8.7		5.9		9.1
Coconut milk		0.88		1.3		0.90		1.4
Subtotal	17	83	26	74	14	86	23	77
D. Island group KATE-WILMA + LEROY								
Domestic meat	16.6		25.2		14.2		22.0	
Pandanus fruit		39.8		34.8		41.2		36.2
Breadfruit		34.2		29.7		35.4		30.9
Wild birds	0.01		0.009		0.01		0.008	
Bird eggs	0.002		0.003		0.002		0.002	
Arrowroot		2.0		0.28		2.0		0.29
Coconut meat		5.7		8.7		5.9		9.0
Coconut milk		0.86		1.3		0.89		1.4
Coconut crabs	0.41		0.13		0.35		0.12	
Subtotal	17	83	25	75	15	85	22	78

Table 200 (continued).

Food item	Percentage of total 30-yr dose: ^{90}Sr dose to bone, Commencement date 1/1/74	1/1/82	^{137}Cs dose to whole body, Commencement date 1/1/74	1/1/82	Percentage of total 70-yr dose: ^{90}Sr dose to bone, Commencement date 1/1/74	1/1/82	^{137}Cs dose to whole body, Commencement date 1/1/74	1/1/82
E. Island group ALVIN-KEITH								
Domestic meat	33.3		28.3		30.3		26.2	
Pandanus fruit		24.1		22.5		26.5		25.0
Breadfruit		20.6		19.4		22.7		21.4
Wild birds	0.24		0.17		0.22		0.16	
Bird eggs	0.03		0.06		0.03		0.05	
Arrowroot		1.2		0.18		1.3		0.20
Coconut meat	10.8		22.9		9.9		21.2	
Coconut milk	1.6		3.4		1.5		3.2	
Coconut crabs	8.3		3.1		7.6		2.9	
Subtotal	54	46	58	42	50	50	54	46

Table 201. Summary of predicted integral dosages from ingestion of terrestrial foods.

Island group	Integral dose, rem							
	5 yr		10 yr		30 yr		70 yr	
	Whole body	Bone	Whole body	Bone	Whole body	Bone	Whole body	Bone
A. ALICE-IRENE	0.30	2.32	1.25	11.3	9.55	126	17.7	239
B. BELLE	0.67	3.93	2.81	19.2	21.4	212	39.6	400
C. JANET	0.22	1.40	0.93	6.82	7.10	75.4	13.1	142
D. KATE-WILMA + LEROY	0.084	0.62	0.35	2.97	2.67	32.7	4.94	61.7
E. ALVIN-KEITH	0.014	0.15	0.032	0.39	0.14	2.11	0.25	3.71

from cultivation in the north and have to originate in the south. If locally grown edible plants are excluded from the diet, but livestock is permitted to graze freely and provide meat, domestic meat becomes the most significant contributor to the whole-body and bone dosages. Thus further substantial reductions in the dosages for the northern islands would be possible if meat and poultry are also excluded from the diet. The implications of these predicted dosages to the projected living patterns are discussed in the summary section of this chapter.

Comparison with Other Locations

Table 203 presents data on ^{90}Sr and ^{137}Cs concentrations in soil and terrestrial foods from selected locations for which the levels generally can be attributed solely to world-wide fallout. The table provides a means for gaining perspective on the current levels of ^{90}Sr and ^{137}Cs in Enewetak soils and foods, particularly on those from the southern islands.

As Table 203 suggests, the ^{90}Sr concentrations in soil from the southern islands of Enewetak are greater than those in soils from Midway, Livermore, and Argonne. The concentrations exceed those from Argonne, which better typifies the United States than Livermore, by about a factor of two. The concentrations of ^{137}Cs in soils from the southern islands compare well with those from Ujilang and Livermore and are a factor of four lower than those from Brownsville, Nebraska. Thus the ^{90}Sr in soils from the southern islands is enhanced over the levels that would be expected from world-wide fallout alone, and ^{137}Cs at present levels in soil is indistinguishable from that attributable to world-wide fallout. The concentrations of ^{90}Sr and ^{137}Cs in Bikini soils far exceed those in soils from the southern islands of Enewetak.

The predicted concentration of ^{90}Sr in meat and poultry from the southern islands ALVIN-KEITH, is 0.10 pCi/g, a value comparable within a factor of two to the average concentration measured in coconut crabs, to the peak levels measured in meat and whole-grain products from New York, and to the peak levels measured

Table 202. Contributions of terrestrial foods to the predicted 30-yr integral dose.

Food item	Integral 30-yr dose, rem					
	Unmodified diet		Modified diet I[a]		Modified diet II[b]	
	Whole body	Bone	Whole body	Bone	Whole body	Bone
A. Island group ALICE-IRENE						
Domestic meat	2.4	21.9	2.4	21.9	2.4	21.9
Pandanus fruit	3.3	50.3	0.032	0.50	0.032	0.50
Breadfruit	2.8	43.1	0.027	0.43	0.027	0.43
Wild birds	<0.0002	0.015	<0.0002	0.015	<0.0002	0.015
Bird eggs	<0.00005	0.014	<0.00005	0.014	<0.00005	0.014
Arrowroot	0.027	2.4	0.027	2.4	0.0003	0.024
Coconut meat	0.83	7.5	0.83	7.5	0.032	0.24
Coconut milk	0.12	1.1	0.12	1.1	0.005	0.037
Total	9.5	126.	3.4	33.9	2.5	23.2
B. Island group BELLE						
Domestic meat	5.6	37.5	5.6	37.5	5.6	37.5
Pandanus fruit	7.4	84.2	0.032	0.50	0.032	0.50
Breadfruit	6.4	72.3	0.027	0.43	0.027	0.43
Arrowroot	0.060	3.9	0.060	3.9	0.0003	0.024
Coconut meat	1.9	12.9	1.9	12.9	0.032	0.24
Coconut milk	0.28	2.0	0.28	2.0	0.005	0.037
Total	21.4	212.	7.9	57.2	5.7	38.7
C. Island group JANET						
Domestic meat	1.8	13.2	1.8	13.2	1.8	13.2
Pandanus fruit	2.5	29.9	0.032	0.50	0.032	0.50
Breadfruit	2.1	25.6	0.027	0.43	0.027	0.43
Wild birds	0.0002	0.004	0.0002	0.004	0.0002	0.004
Bird eggs	0.0001	0.031	0.0001	0.031	0.0001	0.031
Arrowroot	0.020	1.4	0.020	1.4	0.0003	0.024
Coconut meat	0.62	4.5	0.62	4.5	0.032	0.24
Coconut milk	0.093	0.69	0.093	0.69	0.005	0.037
Total	7.1	75.4	2.6	20.8	1.9	14.8

Table 202 (continued)

Food item	Integral 30-yr dose, rem					
	Unmodified diet		Modified diet I[a]		Modified diet II[b]	
	Whole body	Bone	Whole body	Bone	Whole body	Bone
D. Island group KATE-WILMA + LEROY						
Domestic meat	0.67	5.7	0.67	5.7	0.67	5.7
Pandanus fruit	0.93	12.9	0.032	0.50	0.032	0.50
Breadfruit	0.79	11.1	0.027	0.43	0.027	0.43
Wild birds	0.0002	0.004	0.0002	0.004	0.0002	0.004
Bird eggs	<0.00006	0.0006	<0.00006	0.0006	<0.00006	0.0006
Arrowroot	0.0075	0.60	0.0075	0.60	0.0003	0.024
Coconut meat	0.23	1.9	0.23	1.9	0.032	0.24
Coconut milk	0.035	0.30	0.035	0.30	0.005	0.037
Coconut crabs	0.0036	0.12	0.0036	0.12	0.0036	0.12
Total	2.0	32.7	1.0	9.6	0.77	7.1
E. Island group ALVIN-KEITH						
Domestic meat	0.040	0.69	Same as unmodified diet		Same as unmodified diet	
Pandanus fruit	0.032	0.05				
Breadfruit	0.027	0.43				
Wild birds	0.0002	0.005				
Bird eggs	<0.00008	0.0001				
Arrowroot	0.0003	0.024				
Coconut meat	0.032	0.24				
Coconut milk	0.005	0.037				
Coconut crabs	0.004	0.16				
Total	0.14	2.1				

[a]In modified diet I, pandanus fruit and breadfruit are replaced with pandanus and breadfruit grown on the southern islands.
[b]In modified diet II, all edible plants, i.e., pandanus, breadfruit, tacca, and coconut are replaced with foods grown on the southern islands.

in caribou flesh from Alaska. The levels are comparable to the concentrations measured in birds from Bikini in 1967 and are well below the 19 pCi/g measured in coconut crab from Bikini.

The concentrations of ^{90}Sr in birds from ALVIN-KEITH (and from the other islands of the Atoll) are lower by an order of magnitude or more, and the concentrations in bird eggs are lower still. The predicted concentration of ^{137}Cs in meat and poultry from ALVIN-KEITH is two to

Table 203. Comparison of ^{90}Sr and ^{137}Cs concentrations in soils and terrestrial foods from Enewetak and other locations.

Soil sample	Location	Concentration, pCi/g dry soil ^{90}Sr	^{137}Cs	Reference
Soil				
Top 15 cm	Brownsville, Nebr., 1973		0.63(7)[a]	34
Top 15 cm	Argonne, Ill., 1973	0.28[b]		18
Top 15 cm	Livermore, Calif., 1972	0.09(26)[c,d]	0.16[c,d]	35
Top 15 cm	ALVIN-KEITH, Enewetak, 1972-1973	0.50	0.15	This study
Top 15 cm	Ujilang Is., Ujilang, 1972-1973		0.18(4)	This study
Top 15 cm	Midway Is., 1972-1973	0.11(8)		This study
Top 15 cm	Bikini Is., Bikini, 1969	12[f]	40[b,e]	7

Terrestrial foods sample	Location	Concentration, pCi/g fresh weight ^{90}Sr	^{137}Cs	Reference
Animal flesh				
Meat	Chicago, Ill., Nov. 1963		0.27	18
Meat	Chicago, Ill., 1972 (av)		0.017	18
Meat	New York, N.Y., May 1965	0.055[g]		18
Meat	New York, N.Y., 1972(av)	0.0004[g]		18
Caribou flesh	Alaska, May 1966	0.077	56	36
Meat and poultry	ALVIN-KEITH, 1974 (prediction)	0.10	0.85	This study
Coconut crab	Bikini, 1967	19	72	9
	ALVIN-KEITH, Enewetak, 1972-1973	0.10	0.38	This study
Poultry	Chicago, Ill., April 1964		0.12	18
Poultry	Chicago, Ill., 1972(av)		0.014	18
Poultry	New York, N.Y., 1972(av)	0.0005		18
Wild birds	Bikini, 1967	0.13	26	9
Wild birds	ALVIN-KEITH, Enewetak, 1972-1973	0.0036	0.026	This study
Eggs	Chicago, Ill., Jan. 1964		0.045	18
	Chicago, Ill., 1972(av)		0.005	18
	New York, N.Y., 1963(av)	0.011		18
Bird eggs	ALVIN-KEITH, Enewetak, 1972-1973	0.0009	0.032	This study

Table 203 (continued)

Terrestrial foods sample	Location	Concentration, pCi/g fresh weight		
		^{90}Sr	^{137}Cs	Reference
Fruit				
Fresh fruit	Chicago, Ill., Oct. 1962		0.11	18
	Chicago, Ill., 1972(av)		0.006	18
	Chicago, Ill., Jan. 1965	0.020		18
	New York, N.Y., 1968(av)	0.016		18
	New York, N.Y., 1972(av)	0.010		18
Pandanus	Bikini, 1967	19	52	9
Pandanus	Bikini Is., Bikini, 1969	28	130	7
	Enyu Is., Bikini, 1969		87	7
Pandanus	KEITH, Enewetak, 1972-1973	2.6	0.17	This study
Pandanus	ALVIN-KEITH 1982 (prediction)	0.047	0.43	This study
Breadfruit	ALVIN-KEITH 1982 (prediction)	0.071	0.64	This study
Coconut meat	Bikini, 1967	0.19	110	9
	ALVIN-KEITH, 1972-1973	<0.034	0.65	This study
	ALVIN-KEITH, 1974 (prediction)	0.017	0.34	This study
	Bikini Is., Bikini, 1969	0.31	120	7
	Enyu Is., Bikini, 1969	0.08	21	7
Coconut milk	Bikini Is., Bikini, 1969		130	7
	Enyu Is., Bikini, 1969		23	7
	DAVID, 1972-1973	<0.024	1.2	This study
	ALVIN-KEITH 1974 (prediction)	0.017	0.34	This study
Arrowroot[h]	Bikini Is., Bikini, 1969	2.4	0.6	7
	Enyu Is., Bikini, 1969	0.4	0.7	7
	ALVIN-KEITH, 1982 (prediction)	0.012[i]	0.018[i]	This study
Vegetables				
Root vegetables	Chicago, Ill., July 1962		0.089	18
Root vegetables	Chicago, Ill., 1972(av)		0.004	18
Fresh vegetables	New York, N.Y., 1967(av)	0.024		18
	New York, N.Y., 1972(av)	0.014		18

Table 203 (continued)

Terrestrial foods sample	Location	Concentration, pCi/g fresh weight ^{90}Sr	^{137}Cs	Reference
Grains				
Whole-wheat bread	Chicago, Ill., April 1964		0.61	18
	Chicago, Ill., 1972(av)		0.028	18
Whole-grain products	New York, N.Y., Feb. 1964	0.10		18
	New York, N.Y., 1972(av)	0.011		18

[a]The number within parentheses is the number of samples.
[b]The cumulative deposit was assumed to be confined to the top 15 cm. Soil density was assumed to be 1.6 g/cm^3.
[c]Estimated from concentrations in profiles extending to 25 cm.
[d]Median value.
[e]Estimated by the method of Beck, DeCampo, and Gogolak[37] from the mean exposure rate at proposed village area. The relaxation length in soil was assumed to be 2.5 cm and the entire exposure rate was attributed to ^{137}Cs[7].
[f] The ^{90}Sr concentration was assumed to be 30% of the ^{137}Cs concentration[7].
[g]Composite of meat, fish, poultry, shellfish, and eggs.
[h]Processed Marshallese style.
[i] Dry-wt concentration.

three times greater than the concentration measured in coconut crab and the maximum concentration reported for meat from Chicago. On the other hand, the predicted ^{137}Cs concentrations in domestic meat are 10 to 100 times lower than the concentrations reported in coconut crab and wild birds from Bikini and the maximum concentration in caribou flesh from Alaska. The predicted 0.85 pCi/g concentration of ^{137}Cs in meat and poultry is comparable to the 0.61 pCi/g measured in whole-wheat bread from Chicago, the maximum measured in the U.S. foods, except for caribou.

The predicted concentrations of ^{90}Sr and ^{137}Cs in edible plants from the southern islands are greater than the maximum measured in fruits and vegetables from the United States. The predicted ^{90}Sr concentrations are less than the maximum measured in whole grain, and the predicted ^{137}Cs concentrations are less than or comparable to the maximum measured in whole-wheat bread. The ^{90}Sr and ^{137}Cs concentrations measured in pandanus from Bikini are 100 times greater than those predicted in pandanus from VAN-KEITH, and the ^{137}Cs concentrations measured in coconut from Bikini are 100 times greater than those measured or predicted in coconut from VAN-ALVIN. The concentration of ^{90}Sr in the pandanus fruit sample from KEITH is inexplicably high. Unfortunately, the aliquot of the pandanus leaves sample taken for ^{90}Sr analysis was lost during analysis.

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Summary of Dose Assessment

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The anticipated population doses for six living patterns are determined as the sum of the contributions from four exposure pathways (inhalation, external gamma-rays, marine foods, and terrestrial foods).

Six living patterns were chosen in order to evaluate the range of predicted doses from plausible cases of island habitation. Of the six, two patterns of habitation are most probable (living patterns I and III), while one pattern was chosen to be representative of an upper-limit unmodified environment (living pattern IV). A diet based upon past native habits is included in the dose assessment via the food chains. If an imported diet is adopted by the returning population, the total doses listed in this report are significantly overestimated.

Dose Assessment

The total 30-yr integral dose predicted for whole body and for bone for the six living patterns is listed in Table 204. This table includes the contributions from each pathway and, for the external dose assessment, is based upon the unmodified conditions for the village island. The largest contribution to the whole body and bone doses comes from the terrestrial food chain; the external dose pathway is the next highest contributor, while the marine food chain and inhalation pathway contribute the least.

The whole-body and bone doses range from 1.0 and 3.8 rem, respectively for living pattern I (where the village is on Enewetak-Parry, and agriculture is conducted on southern islands), to 11 rem whole body and 80 rem bone for living pattern III (where the village and agriculture are on JANET), to 31 rem whole body and 220 rem bone for living pattern IV (where the village and agriculture are confined to BELLE). The latter living pattern is not one the people have used in the past nor that they have requested upon return; however, it represents a possible extreme exposure situation and is included for comparative purposes.

In general, living on JANET, visiting northern islands, and maintaining agriculture on northern islands (living patterns III, V, and VI) lead to significantly higher doses than if the village and agriculture are located on islands in the southern half of the Atoll (living pattern I). Doses for the same living patterns and conditions have also been calculated for 5, 10, and 70 yr and are shown in Table 205.

Table 206 shows the effect of plowing the village island and graveling the village area, i. e., the "modified" case. For example, for living pattern III where the village is on JANET, the 30 yr integrated external exposure is reduced from 4.0 to 1.7 rem. This comparison indicates that modifying the village island and village area by plowing and graveling does produce a significant reduction in the external exposure dose. The effect on the 5-, 10-, and 70-yr doses from modifying the village island is shown in Table 207.

The most significant contribution via the terrestrial food chain is the dose to

Table 204. The 30-yr integral dose for the six living patterns assuming unmodified conditions.

Table 204. The 30-yr integral dose for the six living patterns assuming unmodified conditions.

30-yr integral dose, rem
Unmodified conditions

Living pattern	Inhalation			External	Terrestrial[b]		Marine[b]		Total	
	Bone	Lung	Liver	Bone,[a] W.B.	W.B.	Bone	W.B.	Bone	W.B.	Bone
I	7(-4)	9(-4)	4(-4)	0.83	0.14	2.1	0.053	0.84	1.0	3.8
II	0.029	0.036	0.016	1.6	2.7	33	0.053	0.84	4.4	35
III	0.10	0.13	0.056	4.0	7.1	75	0.053	0.84	11	80
IV	0.47	0.59	0.25	10	21	210	0.053	0.84	31	220
V	0.11	0.13	0.058	2.9	2.7	33	0.053	0.84	5.7	37
VI	0.090	0.11	0.049	4.4	9.6	130	0.053	0.84	14	135

Living pattern	Village island	Agriculture	Visitation
I	Enewetak-Parry	ALVIN-KEITH	Southern Is.
II	Enewetak-Parry	KATE-WILMA + LEROY	Northern Is.
III	JANET	JANET	Northern Is.
IV	BELLE	BELLE	Northern Is.
V	JANET	KATE-WILMA + LEROY	Northern Is.
VI	JANET	ALICE-IRENE	Northern Is.

[a]Taken from the chapter on external dose estimates, Table 22.
[b]Based upon diet 10 yr after return, as described in the dietary and living patterns chapter.

Table 205. The 5-, 10-, 30-, and 70-yr doses for the six living patterns assuming unmodified conditions.

Living pattern	Total integral dose, rem Unmodified conditions[a] 5 yr[b] W. B.	Bone	10 yr[b] W. B.	Bone	30 yr[c] W. B.	Bone	70 yr[c] W. B.	Bone
I	0.17	0.58	0.35	1.4	1.0	3.8	2.3	8.5
II	0.48	1.3	1.1	4.3	4.4	35	8.0	68
III	1.2	2.6	2.7	9.2	11	80	20	150
IV	3.4	6.9	7.6	25	31	220	56	420
V	0.81	1.6	1.7	4.9	5.7	37	10	71
VI	1.5	3.8	3.3	14	14	135	25	250

[a]Taken from discussion on external dose estimates, Table 22.
[b]Based upon diet at time of return described in the dietary and living patterns chapter.
[c]Based upon diet 10 yr after return described in the dietary and living patterns chapter.

bone resulting from ^{90}Sr uptake via pandanus fruit, breadfruit, and coconut. For living pattern III (Table 206) for example, the total bone dose is 75 rem, of which 80% is derived from the estimated intake of breadfruit, pandanus, and coconut. It is important to note, however, that the large contribution to the bone dose via these fruits only occurs when they are grown on northern islands. Pandanus, breadfruit, and coconut grown on the less contaminated southern islands lead to much lower dose commitments. A comparison of the dose contribution via pandanus, breadfruit, and coconut from the northern and southern half of the Atoll is shown in Table 208; predicted doses via consumption of these food items are higher by a factor of 50 when they are grown in the northern half of the Atoll. Table 209 shows the 30-yr integral dose for the six living patterns for the modified condition and with pandanus, breadfruit, and coconut grown on the southern islands; the effect of the combination of these preventive measures reduces the dose for living pattern III from 11 to 3.7 rem for the whole body and from 80 to 18 rem for bone (compare Tables 204 and 209). If all agriculture is confined to the southern islands then the whole-body dose is further reduced to 1.9 rem and the bone dose is 4.7 rem (see Table 210 and compare with Table 204).

A comparison of the 30-yr integral dose for living patterns I and III relative to the average United States external background dose over 30 yr is shown in Table 211. In living pattern I for whole-body exposure the integrated 30-yr dose from all pathways is less than that resulting from external U. S. background. The bone dose would be only slightly higher than U. S. background doses. For the modified case for living

Table 206. The 30-yr integral dose for the six living patterns assuming modified conditions.

	30-yr integral dose, rem Modified conditions[a]									
	Inhalation			External	Terrestrial[c]		Marine[c]		Total	
Living pattern	Bone	Lung	Liver	Bone,[b] W.B.	W.B.	Bone	W.B.	Bone	W.B.	Bone
I	3(-4)	4(-4)	2(-4)	0.83	0.14	2.1	0.053	0.84	1.0	3.8
II	0.012	0.015	6.6(-3)	1.1	2.7	33	0.053	0.84	3.9	35
III	0.045	0.056	0.024	1.7	7.1	75	0.053	0.84	8.9	78
IV	0.092	0.11	0.050	3.3	21	210	0.053	0.84	24	215
V	0.045	0.056	0.024	1.6	2.7	33	0.053	0.84	4.4	35
VI	0.058	0.072	0.031	3.1	9.6	130	0.053	0.84	13	135

[a] Modified by graveling the village area and by plowing the village island.
[b] Taken from chapter on external dose estimates, Table 22.
[c] Based upon diet 10 yr after return described in the dietary and living patterns chapter.

Table 207. The 5-, 10-, 30-, and 70-yr doses for the six living patterns assuming modified conditions.

	Total integral dose, rem Modified conditions[a]							
Living pattern	5 yr[b]		10 yr[b]		30 yr[c]		70 yr[c]	
	W. B.	Bone	W. B.	Bone	W. B.	Bone	W. B.	Bone
I	0.17	0.58	0.35	1.4	1.0	3.8	2.3	8.5
II	0.48	1.3	1.1	4.3	3.9	35	8.0	68
III	0.60	2.1	1.7	8.2	8.9	78	16	150
IV	1.5	5.0	4.3	22	24	215	46	410
V	0.46	1.3	1.0	4.3	4.4	35	8.0	68
VI	1.1	3.4	2.7	13	13	135	23	250

[a]Taken from discussion on external dose estimates, Table 22.
[b]Based upon diet at time of return described in the dietary and living patterns chapter.
[c]Based upon diet 10 yr after return described in the dietary and living patterns chapter.

Table 208. Bone dose from ^{90}Sr via pandanus, breadfruit, and coconut.

Location	30-yr integral dose, rem[a] Intake of pandanus, breadfruit, and coconut.
Southern islands	1.2
Northern islands[b]	63

[a]Based upon diet 10 yr after return discussed in dietary and living patterns chapter.
[b]Average of northern island groups I, II, and III.

pattern III, with agriculture conducted on northern islands, the 30-yr integrated dose from all pathways is higher than U. S. background by a factor of three for whole body and by nearly a factor of 26 for bone. However, if for living pattern III the modified case is considered and agriculture is confined to southern islands, then the whole body dose is 1.9 rem, less than U. S. background, and the bone dose in 4.7 rem, which is approximately 1.5 times the U. S. external background dose.

Of the three pathways contributing to whole body-exposure, the marine pathway contributes the least. Tables 204 and 206 indicate the relative importance. As was mentioned in the discussion of the marine pathway dose assessment, the fish from the island group ALICE through IRENE have a higher concentration of ^{137}Cs and ^{60}Co than fish from the rest of the Atoll, but the men would not fish exclusively off these islands. However, if such a practice were adopted, the whole-body dose via

Table 209. The 30-yr integral dose for the six living patterns assuming modified conditions and agriculture on the southern islands.

	30-yr integral dose, rem									
	Modified conditions[a] and pandanus, breadfruit, coconut, and tacca grown on southern islands									
	Inhalation			External	Terrestrial[c]		Marine[c]		Total	
Living pattern	Bone	Lung	Liver	Bone,[b] W.B.	W.B.	Bone	W.B.	Bone	W.B.	Bone
I	3(-4)	4(-4)	2(-4)	0.83	0.14	2.1	0.053	0.84	1.0	3.8
II	0.012	0.015	0.0066	1.1	0.77	7.1	0.053	0.84	1.9	9.1
III	0.045	0.056	0.024	1.7	1.9	15	0.053	0.84	3.7	18
IV	0.092	0.11	0.050	3.3	5.7	39	0.053	0.84	9.1	43
V	0.045	0.056	0.024	1.6	0.77	7.1	0.053	0.84	2.4	9.6
VI	0.058	0.072	0.031	3.1	2.5	23	0.053	0.84	5.7	27

[a]Modified by graveling the village area and by plowing the village island.
[b]Taken from chapter on external dose estimates, Table 22.
[c]Based upon diet 10 yr after return described in dietary and living patterns chapter.

Table 210. The 30-yr integral dose for the six living patterns assuming modified conditions and agriculture on the southern islands.

	30-yr integral dose, rem Modified conditions[a] and agriculture on southern islands									
	Inhalation			External	Terrestrial[c]		Marine[c]		Total	
Living pattern	Bone	Lung	Liver	Bone,[b] W.B.	W.B.	Bone	W.B.	Bone	W.B.	Bone
I	3(-4)	4(-4)	2(-4)	0.83	0.14	2.1	0.053	0.84	1.0	3.8
II	0.012	0.015	0.0066	1.1	0.14	2.1	0.053	0.84	1.3	4.1
III	0.045	0.056	0.024	1.7	0.14	2.1	0.053	0.84	1.9	4.7
IV	0.092	0.11	0.050	3.3	0.14	2.1	0.053	0.84	3.5	6.3
V	0.045	0.056	0.024	1.6	0.14	2.1	0.053	0.84	1.8	4.6
VI	0.058	0.072	0.031	3.1	0.14	2.1	0.053	0.84	3.3	6.1

[a]Modified by graveling the village area and by plowing the village island.
[b]Taken from chapter on external dose estimates, Table 22.
[c]Based upon diet 10 yr after return described in dietary and living patterns chapter.

Table 211. The 30-yr integral dose from all pathways compared to U. S. external background dose.

Location	30-yr integral dose,[a] rem			
	Unmodified case		Modified case	
	Whole body	Bone	Whole body	Bone
Enewetak Atoll Living pattern I	1.0	3.8	1.0	3.8
Enewetak Atoll Living pattern III	11	80	8.9	78
Enewetak Atoll Living pattern III, agriculture confined to southern islands	4.2	7.0	1.9	4.7
U. S. background only[b]	3.0	3.0	3.0	3.0

[a]Sum of all pathways for the Enewetak living patterns (i.e., external, inhalation, marine, and terrestrial).
[b]Based upon background of 100 mrem/yr at sea level.

the marine pathway would increase by nearly a factor of five, while the bone dose would increase by nearly a factor of two. This would still make the whole-body dose contributions via the marine pathway much less significant than the external and the terrestrial pathways.

The major concern via the inhalation pathway is the absorption of plutonium into the lung and subsequently into the liver and bone. The lung, bone, and liver doses for the six living patterns are listed in Table 204 for the unmodified case and in Table 206 for modified conditions. This pathway contributes the least of all pathways to the bone dose. For living pattern I and unmodified conditions, the 30-yr integral dose to the lung is less than 1 mrem. The lung, bone, and liver doses via the inhalation pathway increase if residence, agriculture, and visitation occur primarily on the northern islands. For living pattern III, for example, the lung, bone, and liver, 30-yr integral doses are 0.13, 0.10, and 0.056 rem, respectively.

For the modified case, shown in Table 206, the northern islands still predominate over the southern islands as potential contributors via the inhalation pathway; however, for living pattern III the 30-yr doses are nearly an order of magnitude lower than in the unmodified case (lung = 0.056 rem, bone = 0.045 rem, and liver - 0.024 rem).

Plutonium isotopes, because of their long half-life, will still be present when the other major isotopes observed at the Atoll have decayed away. Therefore, Tables 212 and 213 are included to show the predicted doses from plutonium to the three major receptor organs (lung, liver and bone) via the three relevant exposure pathways. It is clear, accepting the assumptions made in assessing the pathways, that the potential dose from plutonium is low via all pathways.

Discussion

It is appropriate to briefly examine the major components of most significance to the radiological dose assessment of the Atoll. They are:

- The significant radionuclides.
- The relative importance of each pathway.
- The ensemble of living patterns.
- Remedial action.

Significant Radionuclides — While there are a large number of radionuclides present in the Enewetak environment, four radionuclides (^{90}Sr, ^{137}Cs, ^{60}Co, and ^{239}Pu contribute nearly all of the population dose. This is the result of the combination of long half-life, large inventory, and relative importance of the radionuclides in the four pathways.

^{137}Cs and ^{60}Co are the major contributions to the external gamma dose, but both also contribute to the total dose via the food chains. The 5-, 10-, 30- and 70-yr doses via all pathways are calculated assuming that disappearance of the nuclides from the Atoll environment is by radioactive decay only. The possibility of the rate of removal being more rapid due to other processes such as penetration of the soil surface with time and runoff into the lagoon and ocean is not accounted for in the dose codes. Thus, to the extent that such time-dependent processes are important in increasing the rate disappearance of radionuclides from the environment, the dose estimates are upper limits.

^{90}Sr is of major importance in the food chains. In particular, it contributes the major portion of the bone dose via the terrestrial and marine food chains and is the limiting isotope for the terrestrial food chain and the Atoll. Observations from both soil data and marine data collected during the survey indicate that ^{90}Sr is turning over more slowly in the Atoll environment than is ^{137}Cs.

Plutonium is present in substantial amounts in the northern part of the Atoll and in the lagoon. In the southern half of the Atoll the concentration levels are essentially that of world-wide background. ^{239}Pu is the dominant nuclide, with ^{238}Pu accounting for 10% of the total plutonium. The major pathway for plutonium is the inhalation pathway for living patterns involving northern islands, while for the southern islands plutonium contributes similarly through all pathways. Over 70 yr, however, the dose contribution from plutonium is very small relative to ^{90}Sr, ^{60}Co, and ^{137}Cs.

Relative Importance of Pathways — The relative ranking of the pathways in their contribution to the total dose for most living patterns is as follows:

(1) Terrestrial food chain
(2) External gamma
(3) Marine food chain
(4) Inhalation

The terrestrial food chain can potentially contribute far greater doses than the other three pathways.

The Ensemble of Living Patterns — Two living patterns (I and II) have been requested by the returning population. For living pattern I (village and agriculture on the southern islands) the 30-yr

Table 212. The plutonium 30-yr integral dose to bone, liver, and lung via the three exposure pathways. This table assumes modified conditions.

	Plutonium 30-yr integral dose, rem Modified conditions											
	Marine			Terrestrial[a]			Inhalation			Total		
Living pattern	Bone	Liver	Lung	Bone	Liver	Lung	Bone	Liver	Lung	Bone	Liver	Lung
I	0.018	0.047	-	5.0(-5)	1.8(-4)	-	3(-4)	2(-4)	4(-4)	0.018	0.047	4(-4)
II	0.018	0.047	-	1.5(-3)	5.0(-3)	-	0.012	0.0066	0.015	0.032	0.057	0.015
III	0.018	0.047	-	6.9(-3)	5.3(-3)	-	0.045	0.024	0.056	0.070	0.076	0.056
IV	0.018	0.047	-	3.0(-3)	0.010	-	0.092	0.050	0.11	0.11	0.11	0.11
V	0.018	0.047	-	5.0(-5)	1.8(-4)	-	0.045	0.024	0.056	0.063	0.071	0.056
VI	0.018	0.047	-	3.0(-3)	0.010	-	0.058	0.031	0.072	0.079	0.088	0.072

[a]Based upon diet 10 yr after return discussed in chapter on dietary and living patterns.

Table 213. The plutonium 30-yr integral dose to bone, liver, and lung via the three exposure pathways. This table assumes unmodified conditions on the village island.

Living pattern	Plutonium 30-yr integral dose, rem Unmodified conditions											
	Marine			Terrestrial[a]			Inhalation			Total		
	Bone	Liver	Lung	Bone	Liver	Lung	Bone	Liver	Lung	Bone	Liver	Lung
I	0.018	0.047	-	5.0(-5)	1.8(-4)	-	7(-4)	4(-4)	9(-4)	0.018	0.048	9(-4)
II	0.018	0.047	-	1.5(-3)	5.0(-3)	-	0.029	0.016	0.036	0.049	0.068	0.036
III	0.018	0.047	-	6.9(-3)	5.3(-3)	-	0.10	0.056	0.13	0.12	0.11	0.13
IV	0.018	0.047	-	3.0(-3)	0.010	-	0.47	0.25	0.59	0.49	0.31	0.59
V	0.018	0.047	-	5.0(-5)	1.8(-4)	-	0.11	0.058	0.13	0.13	0.11	0.13
VI	0.018	0.047	-	3.0(-3)	0.010	-	0.090	0.049	0.11	0.11	0.11	0.11

[a]Based upon diet 10 yr after return discussed in chapter on dietary and living patterns.

integral whole-body and bone doses from all pathways are 1.0 and 3.8 rem respectively, comparable to average United States 30-yr integral external background doses for 3 rem. For living pattern III (village on Engebi and agriculture on northern islands) without any modification, the 30-yr integral whole-body dose is 11 rem and the bone dose 80 rem. Other living patterns involving northern islands and without modification have 30-yr, whole-body doses ranging from 4 to 30 rem and bone doses ranging from 35 to 220 rem.

Remedial Action

Terrestrial Food Chain — The doses estimated for the various living patterns indicate that careful assessment and design of an agricultural plan must be an integral part of the program plan for returning people to the Atoll. For example, the southern half of the Atoll has sufficient land area to supply pandanus, breadfruit, and coconut for the entire returning population; therefore, even if people were to live on Engebi, the dose commitment could be greatly reduced by confining agriculture to the southern half of the Atoll. This one restriction, expecially for pandanus, breadfruit, and coconut would be the single most effective preventive measure for reducing the dose commitment. The combination of modifying the village island and living area and, confining the agriculture to the southern islands, both relatively easy to implement, have a very large impact on reducing the dose (compare Tables 204 and 210).

There are, of course, other options for reducing the dose via the terrestrial pathway. One option would be to dig large area pits on all islands which would be filled with "clean" soil from another source; pandanus, breadfruit, coconut and other plants could then be grown and harvested from these "clean" soil areas throughout the Atoll. The subsequent reduction in dose would lead to doses from ^{90}Sr equivalent to or less than those predicted for the southern islands. Another option would include removing the surface layer of soil (0-20 cm) from the northern islands and replacing it with uncontaminated topsoil. This approach should also lead to doses equal to or less than those predicted for the southern islands. This form of remedial action would in the process reduce the dose via the inhalation pathway. This alternative, of course, requires the removal and disposition of an enormous amount of soil, and ocean dumping, which would provide the large reservoir needed and minimize the potential man-rem, would probably be the best and easiest method of disposal. This approach is certainly not one of the easier alternatives.

Efforts to maintain a high calcium diet could also be implemented to reduce the uptake of ^{90}Sr; however, remedial measures to reduce the uptake in the plants or food product would be more effective and desirable as the primary preventive measure.

Of course, the dose commitment would be largely eliminated if no pandanus, breadfruit, or coconut were planted on the Atoll for another 20 to 30 yr and if the diet were to consist of predominantly imported food. As was discussed in the chapter on dietary and living patterns, imported foods are very likely to form a significant fraction of the diet (possibly 85% or more) and, if so, a plan to control the production of pandanus and breadfruit, or at least the location of production, could essentially reduce dose commitments to levels near U. S. external background.

External Dose — The integral 30 yr external dose is reduced between 30 and 70% for living patterns III, IV, V, and VI as a result of plowing the village island and graveling the village area where people will spend a majority of their time. These procedures are fairly straightforward, relatively easy to implement, and lead to the largest percentage reduction in external dose. An additional reduction in external dose of approximately 16% could be attained if all islands were plowed; however, implementing such a program in order to achieve the additional slight reduction is certainly another order-of-magnitude problem. In any case, any plan to plow all islands would have to receive careful scrutiny to determine the possible effects upon the island and Atoll ecology.

Marine Food Chain — The marine food chain would appear to require no remedial action (see marine food chain chapter). The marine pathway contribution to the 30-yr integral dose for the modified case and for agriculture on southern islands (Table 210) is less than 4% for whole unmodified conditions the percentage is far less than these. The concentration of radionuclides in fish muscle is higher in fish around the ALICE-to-IRENE complex, but even if the fishing were confined to these islands, a completely unrealistic fishing pattern, the resulting 30-yr, whole-body and bone doses would still be less significant than the other pathways and less than the 30 yr integral U. S. background dose.

Inhalation Pathway — The dose commitment via the inhalation pathway is due to the presence of plutonium throughout the soil in all of the northern islands. It is not generally localized sufficiently to consider "spot" cleanup. Anything short of removing the top layer of soil and replacing it with uncontaminated soil, or of simply covering existing soil with new soil, or of restricting living on northern islands will have little effect on the dose commitments via the inhalation pathway presented in this chapter. However, it should be noted that the plutonium concentrations on the southern islands are world-wide background levels, and the corresponding dose via the inhalation pathway is less than 1 mrem over 30 yr. This is the same level of exposure one would expect if new soil were brought in to the northern islands. The doses via inhalation on the northern islands is also insignificant relative to other pathways, where remedial action would be far more productive. (See Tables 204 and 206).

Summary of Remedial Action — In summary, the greatest reduction in dose commitment can be realized by developing a carefully designed agricultural plan and limiting the dose via the terrestrial food chains. The next most effective measure would be directed at the external dose commitment by plowing the village island and graveling the village area. Other remedial measures for reducing the dose commitment via the different pathways are possible but reduce the potential dose commitment by far lesser amounts.

YVONNE (Runit) — The island of YVONNE (Runit) is a unique situation among all of the Atoll islands. "Hot spots" of nearly pure plutonium exist throughout the northern part of the island; milligram-size plutonium particles are present and presumably inhalable micron-size particles are also present. The potential health hazard via the inhalation pathway due to the large plutonium inventory is sufficiently great to dictate two basic alternatives for remedial action for this island: (1) make the entire island an exclusion area — off limits to all people, or (2) conduct a cleanup campaign which will eliminate the "hot-spot" plutonium problem and remove whatever amount of soil is necessary to reduce the soil plutonium concentration to a level comparable to the southern half of the island which has soil concentrations similar to other northern islands. If the latter action were taken, the island could be considered in the overall design for remedial action for the northern islands.

Dose Estimates for Other Assumed Living Patterns --- The tables in each section of this chapter describing the dose via a specific pathway (i. e., external, terrestrial, and marine) are presented in a manner in which any combination of living pattern, time distribution, diet, and agricultural pattern can be assumed, and the corresponding dose predicted. We have chosen for dose assessment and presentation in this report the most likely living patterns (I, II, III, V), the most likely distribution of time, the most likely use of islands for agriculture, and the most likely fishing practices. We have also presented two living patterns which represent more extreme possibilities (living patterns IV and VI), although neither has been used in the past nor requested presently by the potential returning population. However, any other desired combination of living pattern and living habits could be assessed from data presented in the report.

IV. Summary of Findings

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INTRODUCTION

It has been the purpose of this survey to gain a sufficient understanding of the total radiological environment of Enewetak Atoll to permit judgments as to whether or not all or any part of the Atoll can safely be reinhabited and, if so, what preliminary steps toward cleanup should be taken and what post-rehabilitation constraints must be imposed.

Enewetak Atoll has an extremely broad range of radiological conditions in a small land mass. To gain an understanding of the details of this range of conditions, it has been necessary to obtain and analyze a very large number of samples from all components of the environment. To gain an equivalent understanding of the implications of this range of conditions for rehabilitation of the Enewetak people, it has been necessary to postulate population distributions, life styles, and dietary habits – an endeavor fraught with uncertainties under the best of circumstances, but particularly so for the current, rapidly changing Marshallese culture.

This section is a summary of the data obtained from the Survey, the postulates used, and the population dose assessments derived from data plus postulates. The reader is cautioned against expecting or using a "simple" description of the radiological condition of Enewetak Atoll, because no single value of any component of the radiological condition is applicable to the entire Atoll without being misleading.

CURRENT RADIOLOGICAL CONDITION OF THE ATOLL

External Gamma Radiation Levels

Three independent techniques were used to measure external gamma radiation levels on the Atoll:

- LiF and CaF_2 thermoluminescent dosimeters (TLDs) were exposed for $3\frac{1}{2}$ months on seven of the northern islands.
- A measurement using a Baird-Atomic survey instrument was made at each soil-sampling location on each island.
- An aerial survey with NaI detectors was conducted over the entire surface area of every island.

All three techniques yield results which agree to within about 10%. ^{60}Co and ^{137}Cs contribute most of the total external gamma radiation, with the remainder due to small amounts of other gamma emitters such as ^{125}Sb, ^{155}Eu, and ^{241}Am. The amount of ^{60}Co relative to ^{137}Cs varies throughout the Atoll, with a range of values from about 0.5 on JANET to greater than 14 on JAMES. Average values for each isotope on each island are given in Table 214. For reference, a map of the Atoll is shown in Fig. 146.

Southern islands (SAM to KEITH) are characterized by low and more or less uniformly distributed gamma-radiation levels over the area of each island. As exposure levels increase, exposure gradients become severe, with beaches

Table 214. Summary of average exposure rates for islands in Enewetak Atoll.

Island	Average exposure rate, μR/hr at 1 m[a]			
	^{137}Cs	^{60}Co	Total γ (0-3 MeV)	Range[b]
ALICE	42	36	81	4-170
BELLE	61	50	115	5-200
CLARA	20	19	42	5-100
DAISY	6.8	14.4	21.3	5-140
EDNA	2.8	2.4	6	5-8
IRENE	14	63	80	3-560
JANET	25	13	40	2-150
KATE	11	7	19	3-22
LUCY	6	7	14	1-20
PERCY	2	2	5	2-11
MARY	5.5	4	10	2-12
NANCY	6	5	12	1-50
OLIVE	6.5	4.5	11	1-15
PEARL	12	45	70	1-400
RUBY	2	12	14	1-42
SALLY	3.5	3	7	3-110
TILDA	4	2	6	2-11
URSULA	3	1.8	5	1-7
VERA	2.8	2	5	1-6
WILMA	1	1	2	1-3
YVONNE	5.6	22.4	33	1-750
SAM	<0.3 (0.20)	<0.6 (0.11)	10.9	0-1
TOM	<0.3 (0.18)	<0.6 (0.13)	<0.9	0-1
URIAH	<0.3 (0.06)	<0.6 (0.43)	<0.9	0-1
VAN	<0.3 (0.08)	<0.6 (0.25)	<0.9	0-1
ALVIN	N.D. (0.06)	<0.6 (0.25)	<0.9	0-1
BRUCE	0.4 (0.22)	0.8 (0.34)	1.2	0-1
CLYDE	<0.3 (0.04)	<0.6 (0.11)	<0.9	0-1
DAVID	N.D. (0.21)	N.D. (0.10)	<0.9	0-5
REX	<0.3 (0.28)	<0.6 (0.25)	<0.9	0-1
ELMER	N.D. (0.19)	N.D. (0.12)	<0.09	0-2
WALT	<0.3 (0.08)	<0.6 (0.10)	<0.9	0-1
FRED	N.D. (0.14)	N.D. (0.12)	<0.9	0-1
GLENN	0.4 (0.33)	<0.6 (0.20)	<0.9	0-1
HENRY	<0.3 (0.14)	<0.6 (0.20)	<0.9	0-1
IRWIN	<0.3 (0.08)	<0.6 (0.46)	<0.9	0-1
JAMES	<0.3 (0.05)	2.8	3.0	0-5
KEITH	<0.3 (0.15)	<0.6 (0.49)	<0.9	0-2
LEROY	2.8	4.8	7.6	3-8

[a]Average dose rates given are derived from aerial survey data. On islands where activity levels are at the lower limit of sensitivity of the aerial survey equipment, dose rates derived from the soil sample data are given in parentheses.

[b]As measured with the Baird-Atomic instrument.

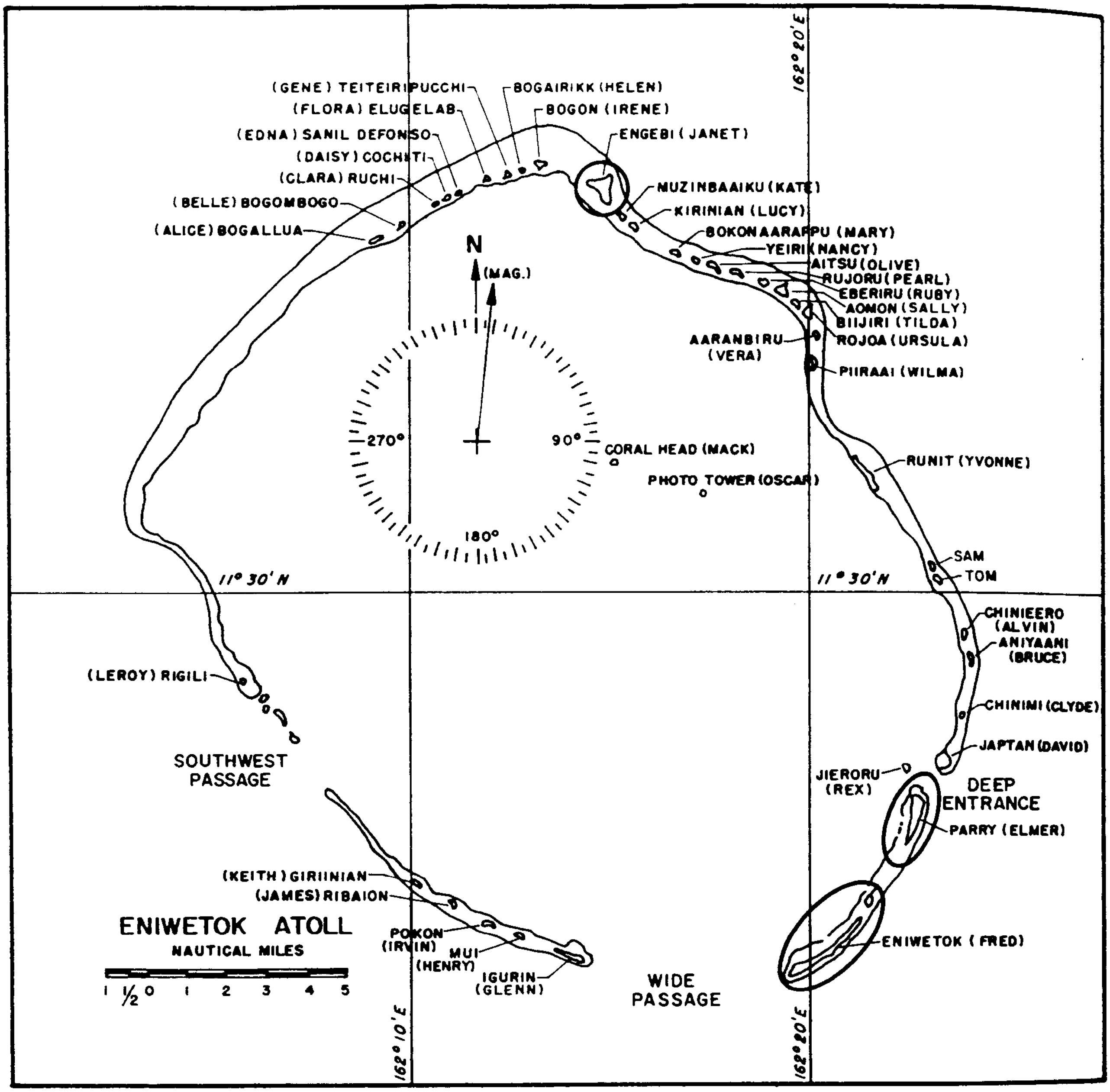

Fig. 146. Islands (those circled) requested as village locations by the Enewetak people.

generally at or very near expected background levels; the highest levels are found in heavy vegetation at island centers or near ground zero sites. "Average" values for islands with relatively high dose levels include a broad range of values for specific areas and should therefore be used with caution.

Radioactivity Levels in Enewetak Soil

Approximately 3000 samples of Enewetak soil were analyzed by germanium gamma-spectroscopic (GeLi) and wet-chemistry techniques to determine the distribution of radioactive species on islands in the Atoll. Samples were taken on every island, but emphasis was given to – and proportionately larger numbers of samples taken on – those islands which were known to have been sites for nuclear testing activity or to have been subjected to large amounts of fallout from such activity.

Two types of soil samples were taken on each island: "surface" and "profile." At "surface" sampling locations, two samples were taken – one a 30-cm^2 × 15-cm-deep core, and the second a composite of two 30-cm^2 × 5-cm-deep cores. At "profile" sampling locations, 100-cm^2 samples were taken from the side wall of a trench dug for the purpose. Nominal depth increments for the profile samples were 0 to 2, 2 to 5, 5 to 10, 10 to 15, 15 to 25, and 25 to 35 cm, and at 10-cm increments to total depth. Total depth for profile samples varied from 35 to 185 cm, depending on the distribution expected from the testing history of the island being sampled.

In general, the predominant species found in the soil samples are ^{90}Sr, ^{137}Cs, ^{239}Pu, and ^{60}Co. ^{40}K, ^{55}Fe, ^{101}Rh, ^{102m}Rh, ^{125}Sb, ^{133}Ba, ^{134}Cs, ^{152}Eu, ^{154}Eu, ^{155}Eu, ^{207}Bi, ^{226}Ra, ^{235}U, ^{238}Pu, and ^{241}Am are also present in some or all of the samples. As was the case for external gamma levels, small amounts of radioactive species on the southern islands (SAM to KEITH) are distributed more or less uniformly over the entire land area. On islands where larger amounts of activity are present, the highest levels of all species are found at the island centers or in proximity to ground-zero sites, usually related in a direct way to the vegetation density in the immediate area. As an example of the kind of data obtained for each of the predominant isotopes on each of the islands, ^{90}Sr values for 0-15 cm core samples on JANET are plotted in Fig. 147.

Table 215 presents geometric mean values and ranges for the four predominant radionuclides on islands from ALICE through WILMA. On islands where there are significant differences in activity levels between densely and sparsely vegetated areas, data for both are given. Similar data for groups of southern islands are shown in Table 216.

"Profile" samples showed a wide range of activity distributions as a function of depth on different parts of the Atoll. Examples of the types found are given in Figs. 148-151. Although generalizations in this area are not very meaningful, Fig. 148 shows the profile distribution normally found on the southern islands. Here the activity levels are usually low through the full range of depths sampled. Some sampling locations show concentrations decreasing somewhat from the surface through the first 10 or 20 cm of soil. Figure 149 shows the type of distribution often found inland on islands subjected to fallout but not to construction or other ground-zero earthmoving activities – i. e., a rapid and fairly steady decrease of activity levels from the surface to total depth. Figure 150 shows the distribution found on beaches and exposed areas on these same islands – i. e., uniform or slowly decreasing activity levels from the surface to total depth. Figure 151 shows a distribution pattern found occasionally on islands which have been the sites for tests or have been subjected to construction and earthmoving activities (primarily IRENE, JANET, PEARL,

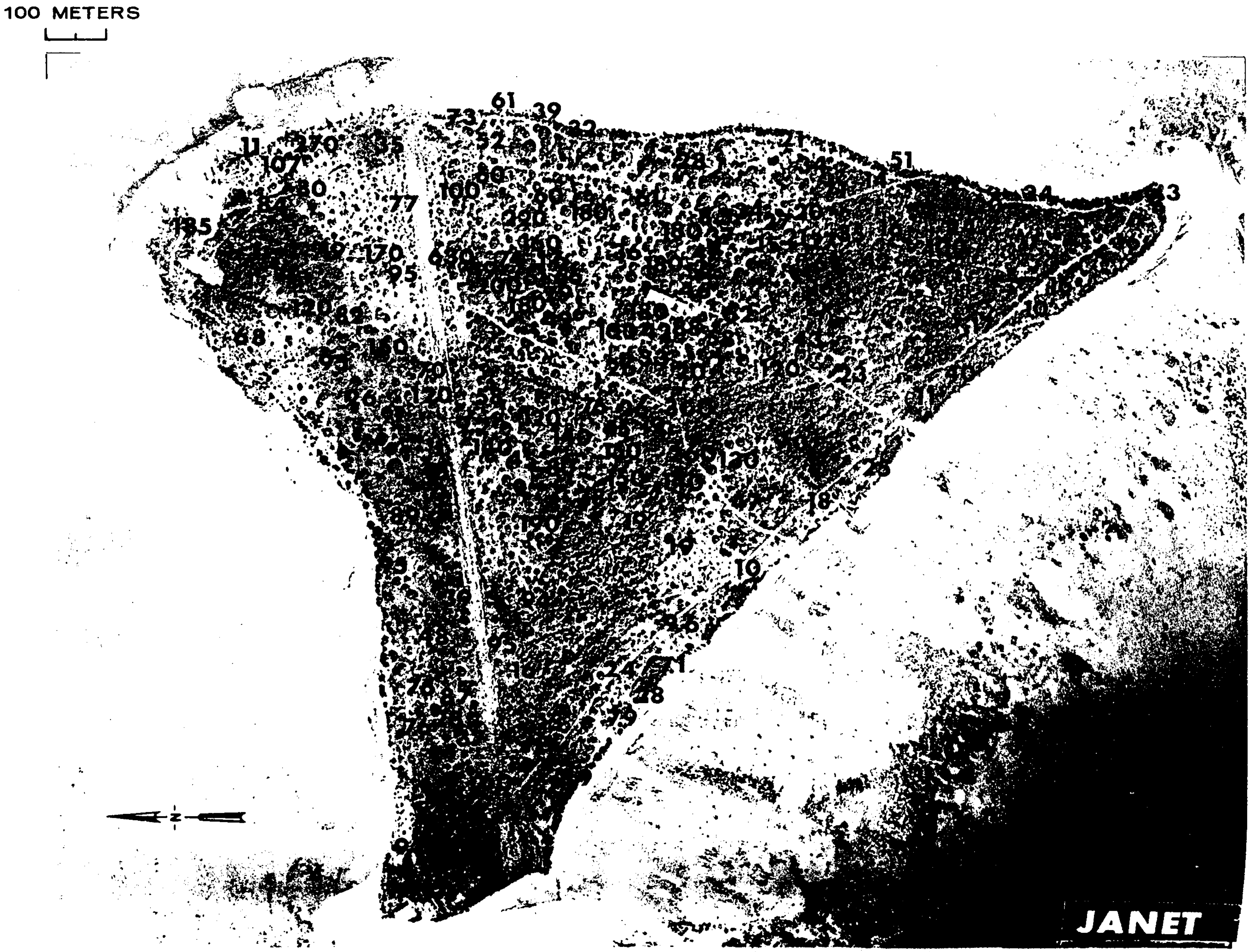

Fig. 147. The average ^{90}Sr activities (pCi/gm) in soil samples collected to a depth of 15 cm.

Table 215. Enewetak soil data, "northern islands" (pCi/g in top 15 cm).

		^{90}Sr		^{137}Cs		^{239}Pu		^{60}Co	
		Mean	Range	Mean	Range	Mean	Range	Mean	Range
ALICE		80	14-430	36	5.6-141	12	3.9-68	5.9	1.4-33
BELLE	Dense	123	14-670	48	14-170	26	7.2-130	10	3.1-30
	Sparse	44	35-130	8.6	3.3-44	11	5.8-26	4.6	2.4-9.6
CLARA		65	13-310	26	5.6-110	22	3.5-88	6.4	0.91-20
DAISY	Dense	190	100-380	11	3.4-33	41	22-98	11	6.4-26
	Sparse	32	16-120	3.8	0.86-9.0	15	3.8-33	0.85	0.37-7.4
EDNA		46	30-220	4.2	2.7-6.4	18	13-24	0.43	0.33-0.63
IRENE		30	5.9-570	3.2	0.22-41	11	2.4-280	5.4	0.12-520
JANET		44	1.6-630	16	0.57-180	8.5	0.08-170	1.9	0.02-33
KATE	Dense	67	37-200	24	18-37	17	8.6-50	2.7	1.6-5.8
	Sparse	11	1.6-49	4.8	1.8-16	2.3	0.17-14	0.46	0.03-3.5
LUCY		32	10-83	11	2.2-25	7.7	2.4-22	1.5	0.26-3.8
MARY		29	11-140	9.9	5.6-26	8.0	2.0-35	1.5	0.74-4.8
NANCY		36	16-110	12	6.0-28	9.1	2.3-28	1.6	0.56-5.3
PERCY		13	3.6-73	0.94	0.12-17	3.5	1.5-23	0.47	0.08-2.9
OLIVE	Dense	22	4.6-70	8.5	3.5-28	7.7	2.2-30	1.5	0.65-4.1
	Sparse	4.5	2.0-11	0.16	0.07-11	2.8	1.9-4.1	0.11	0.05-0.31
PEARL	Hot spot	62	35-140	19	7.4-55	51	15-530	12	3.6-70
	Remainder	17	3.2-61	7.6	1.2-34	11	0.85-100	4.1	0.49-49
RUBY		12	7.1-63	1.4	0.71-7.2	7.3	3.0-24	0.93	0.29-16
SALLY		8.4	0.87-140	3.0	0.03-30	4.3	0.21-130	0.54	0.05-69
TILDA	Dense	27	17-54	8.4	3.5-20	7.6	1.4-17	1.2	0.61-1.9
	Sparse	8.7	2.2-47	1.0	0.04-5.3	2.5	1.1-34	0.37	0.21-1.7
URSULA		6.8	2.0-19	1.7	0.13-7.8	1.3	0.26-7.3	0.31	0.05-1.7
VERA		6.3	1.1-68	2.0	0.03-12	2.5	0.60-25	0.30	0.02-2.2
WILMA		3.3	0.26-13	1.3	0.31-7.2	1.1	0.1-5.3	0.12	0.01-0.7
Southern YVONNE		1.7	0.09-20	0.40	0.02-3.6	3.2	0.02-50	0.64	0.01-20
Northern Beaches		6.4	1.2-30	0.30	0.03-9.0	2.7	0.34-18	0.13	0.03-1.6

YVONNE - Because of the complex distribution of activities on Northern YVONNE no single mean value for an isotope can be used for the island as a whole without being misleading. Readers should consult the YVONNE discussion in this section and the detailed data in Appendix II for information pertinent to their interests.

SALLY, and YVONNE). In these locations, activity levels below ground level are significantly higher than at the surface. Because of the observed variety of profile distributions, no "average vertical distribution" can be formulated which is applicable to the Atoll as a whole.

The land area which has the most severely nonuniform distribution of radioactive species on the Atoll is that

Table 216. Enewetak soil data, southern islands (pCi/g in top 15 cm).

	^{90}Sr		^{137}Cs		^{239}Pu		^{60}Co	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Group A (DAVID, ELMER, FRED)	0.41	0.02-4.8	0.21	0.01-2.1	0.04	0.004-0.31	0.03	0.01-0.15
Group B (All others except LEROY)[a]	0.52	0.03-3.9	0.14	0.004-1.8	0.07	0.004-1.1	0.06	0.007-63
Group C (LEROY)	11	1.6-34	3.2	0.5-10	0.63	0.02-2.0	0.58	0.04-5.0

[a]SAM, TOM, URIAH, VAN, ALVIN, BRUCE, CLYDE, REX, WALT, GLENN, HENRY, IRWIN, JAMES and KEITH.

part of YVONNE which lies north of the tower (Sta. 1310). This area includes the highest external gamma levels found on the Atoll, with levels of 500-750 μR/hr found over a five-acre site just south of the CACTUS crater. In addition, pieces of plutonium metal weighing as much as several milligrams are randomly scattered on or near the ground surface over most of the area from CACTUS crater to a line drawn across the island, about 60 m north of the tower. Construction and earthmoving activities during the testing period, for which we have no reliable record, served to redistribute the radioactivity in such a way that it is essentially impossible to get an accurate, detailed, three-dimensional survey of radioactive species present in this area now. Four hundred meters north of the tower, for about 100 m along the ocean-side embankment, for example, there is a visible layer of dark soil roughly 20 cm thick, 10 to 20 cm below the surface, which contains high concentrations of plutonium (3200 pCi/g in one sample).

In an effort to obtain a reasonable estimate of the three-dimensional distribution of radioactive material in this area, 45 profile locations (shown in Fig. 152) were sampled to 150-cm depths. Plutonium data for the profiles along the center of the island, and across the island at the position of the plutonium-bearing layer, are shown in Figs. 153-156. Data from all of the profile samples lead to the following observations:

- There were no large plutonium particles analyzed in any of these samples since the maximum specific activity found was ~800 pCi/g.
- **Except for the area in the general vicinity of the exposed plutonium layer, there were few profile sampling locations where plutonium concentrations exceeded 100 pCi/g at <u>any</u> depth. Of the four that did, two had the high concentration in the top 10 cm of soil. Profile sampling locations where plutonium concentrations greater than 100**

pCi/g were found at any depth are enclosed in cross-hatched areas in Fig. 152.

Thus it seems likely that soil bearing high concentrations of plutonium – as opposed to pieces of plutonium – is largely limited to a band roughly 350 m wide across the island, centered on the visible plutonium soil layer. Within this band, plutonium concentrations are greatest on the ocean side, less on the lagoon side, and least in the island center – a finding consistent with historical data which indicate that debris was bulldozed away from the shot point toward both shorelines after the event which produced these plutonium particles.

Except for this band across the island, there is no evidence which indicates that plutonium particles on or near the ground surface in the larger area shown in Fig. 152 are also found at any significant depth below the surface. Because of the discrete nature and random distribution of these particles, of course, the only way that their distribution could be further established would be by analysis of very large volumes of soil.

Radioactivity Levels in Enewetak Lagoon

Approximately 858 samples taken from the Enewetak lagoon environment were analyzed by germanium gamma-spectroscopic (GeLi) and wet-chemistry techniques to determine the distribution of radioactive species in the lagoon, including 345 sediment and bottom cores, 82 seawater and seawater filters, 21 algae, plankton, or coral, and 410 fish samples. Figure 157 shows the major sampling locations for this marine program.

Analysis of the sediment and core samples indicates the presence of ^{40}K, ^{60}Co, ^{90}Sr, ^{101}Rh, ^{102m}Rh, ^{106}Ru, ^{127}Sb, ^{137}Cs, ^{152}Eu, ^{154}Eu, ^{155}Eu, ^{207}Bi, ^{235}U, ^{238}Pu, ^{239,240}Pu, and ^{241}Am in some, but not necessarily all of the samples. Each nuclide is non-uniformly distributed over the lagoon floor, with the highest levels generally found in the northwest part of the lagoon, 2-3 km southeast of the islands ALICE through IRENE; the next highest levels are found in the area southwest of YVONNE; and the lowest levels are found south of a line extending across the lagoon from the Southwest Passage to TOM. Figure 158, for example, shows the distribution pattern for ^{90}Sr. Similar figures have been prepared for each of the predominant species found.

Many of the radionuclides found in the marine sediment and core samples were not detected in the water samples, including ^{102m}Rh, ^{106}Ru, ^{125}Sb, ^{152}Eu, and ^{235}U. In only 15 samples from the northern part of the lagoon were ^{60}Co, ^{155}Eu, ^{207}Bi, and ^{241}Am detected. ^{137}Cs and ^{239,240}Pu were positively identified in all samples. Table 217 gives the mean surface water concentration of ^{137}Cs and ^{239,240}Pu in the four quadrants of the lagoon, in the ocean close to the east side of the lagoon, and for several areas in other parts of the world for comparative purposes.

In the plankton samples, the most abundant isotopes observed were ^{90}Sr (av 0.86 pCi/g, wet wt) and ^{207}Bi (0.83 pCi/g), followed in decreasing order of abundance by ^{60}Co (0.68 pCi/g), ^{239,240}Pu (0.39 pCi/g), ^{155}Eu (0.24 pCi/g), ^{241}Am (0.23 pCi/g), and ^{137}Cs

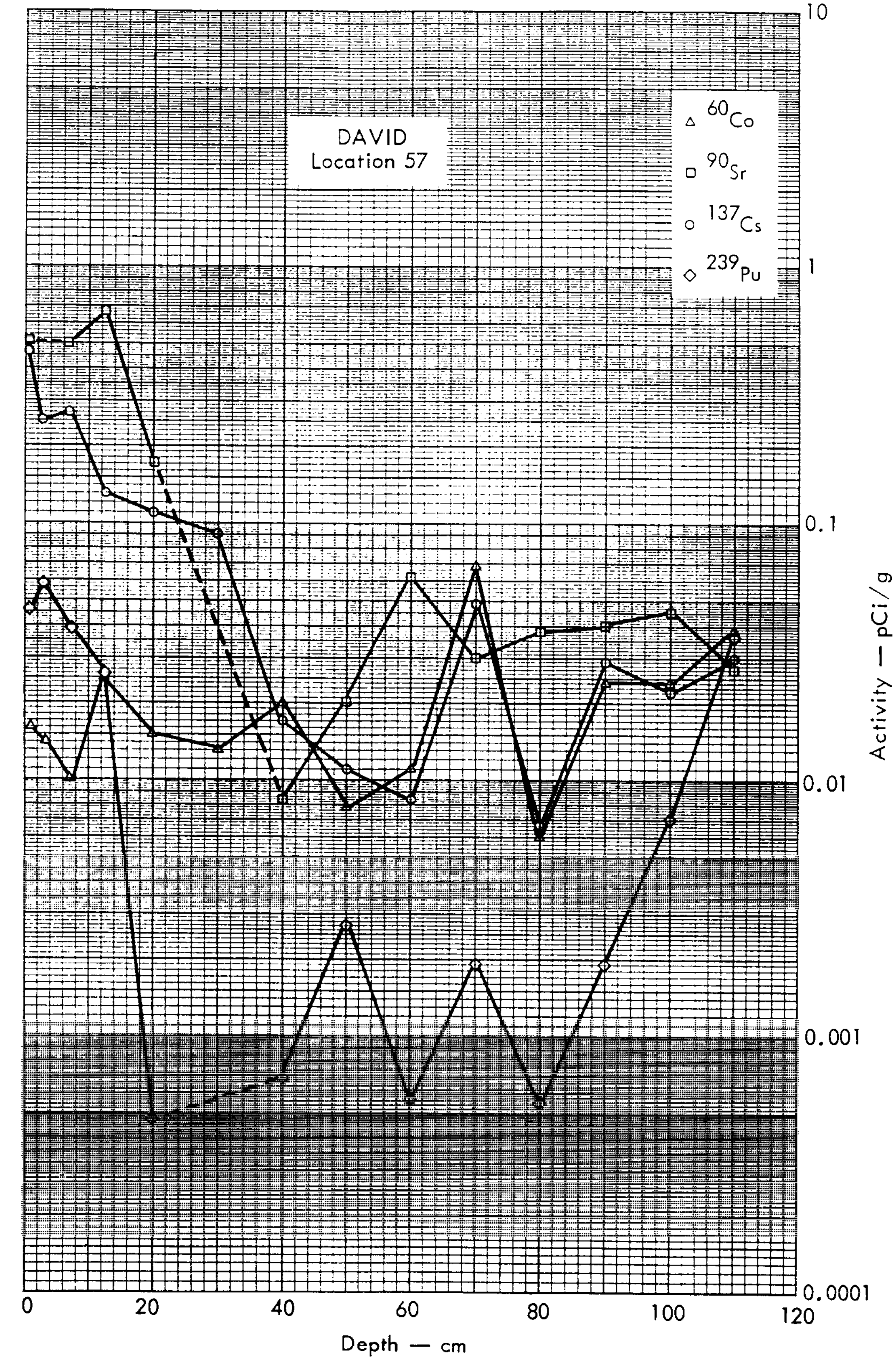

Fig. 148. Activities of selected radionuclides as a function of soil depth.

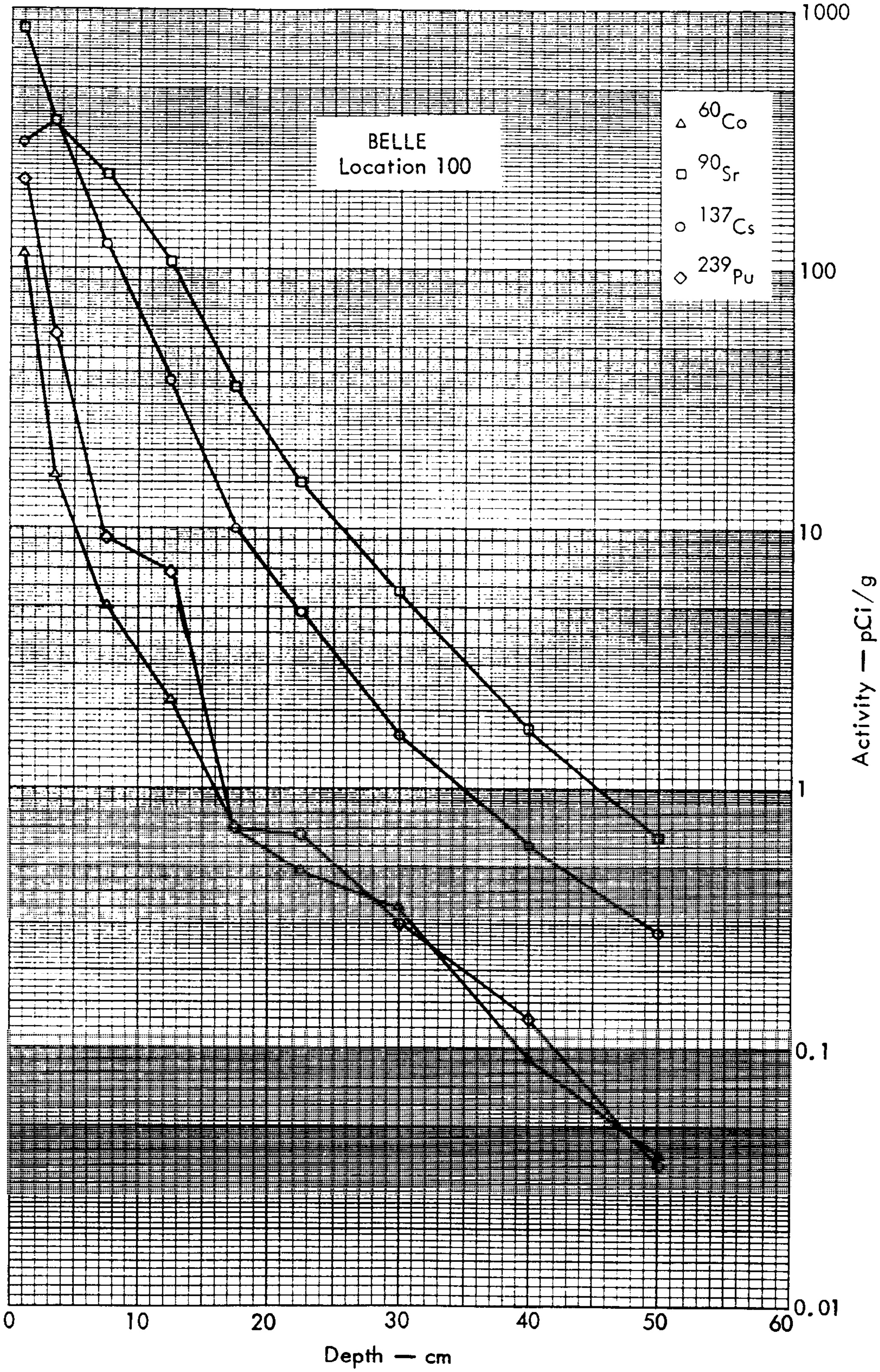

Fig. 149. Activities of selected radionuclides as a function of soil depth.

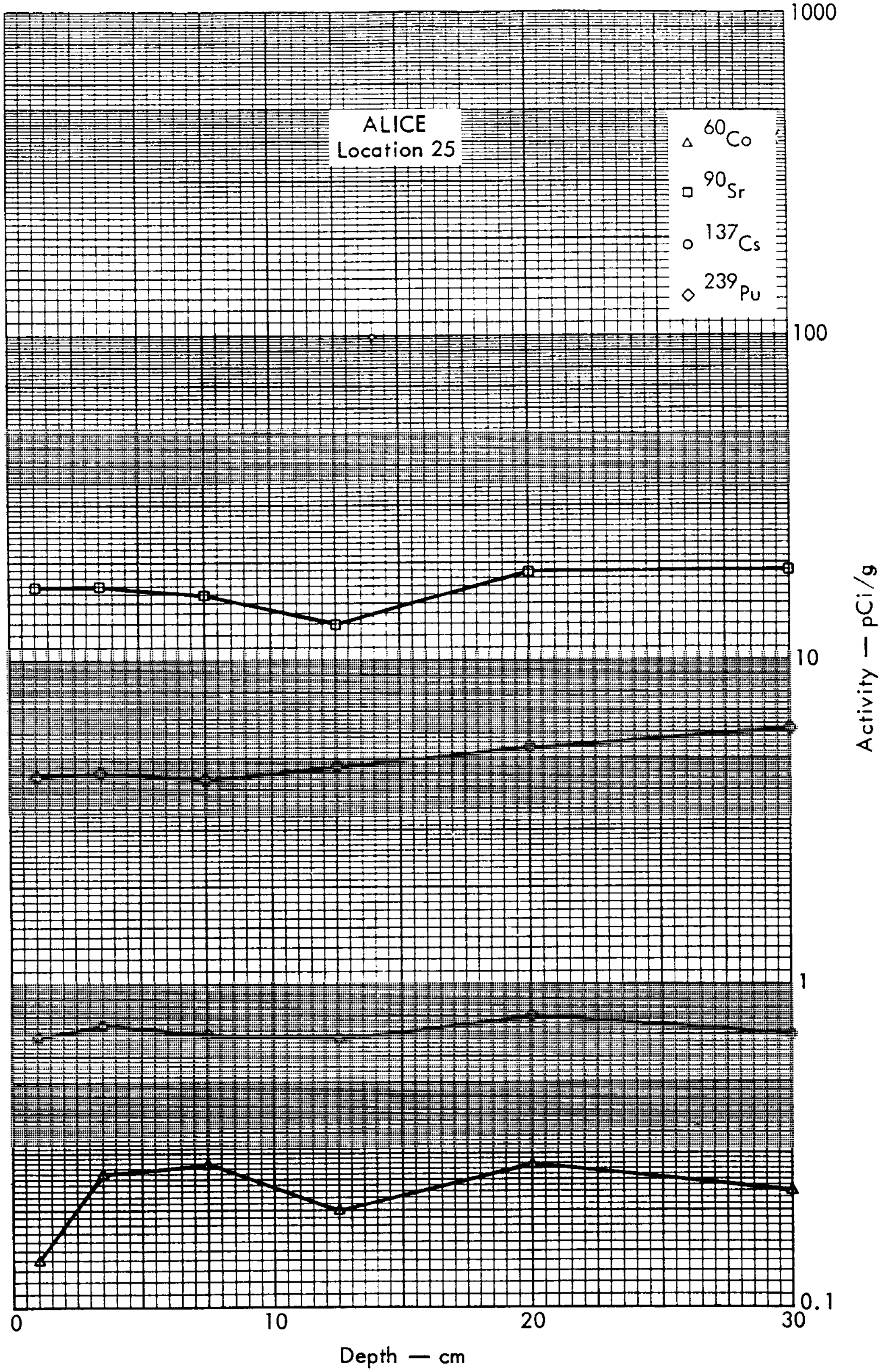

Fig. 150. Activities of selected radionuclides as a function of soil depth.

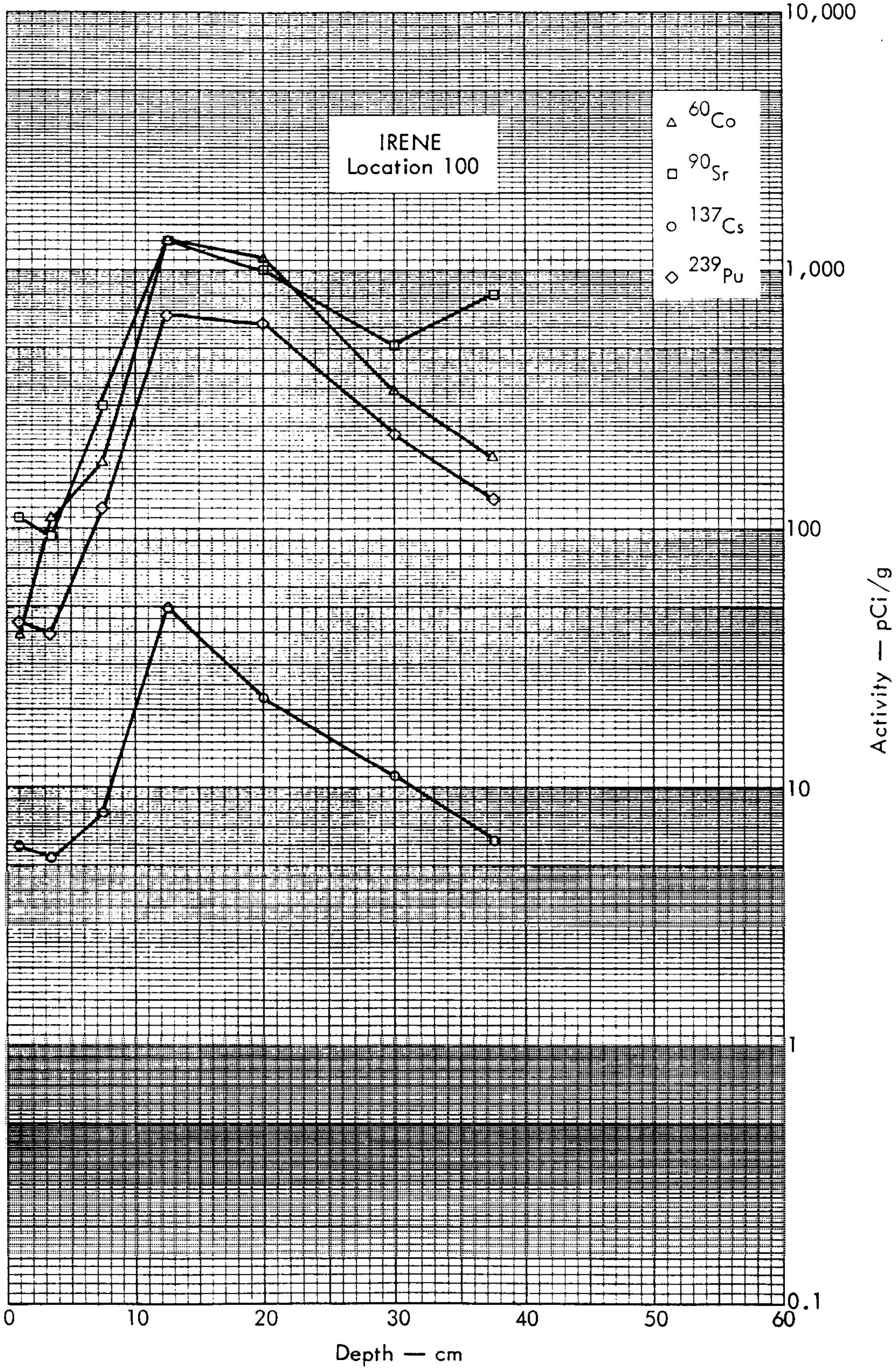

Fig. 151. Activities of selected radionuclides as a function of soil depth.

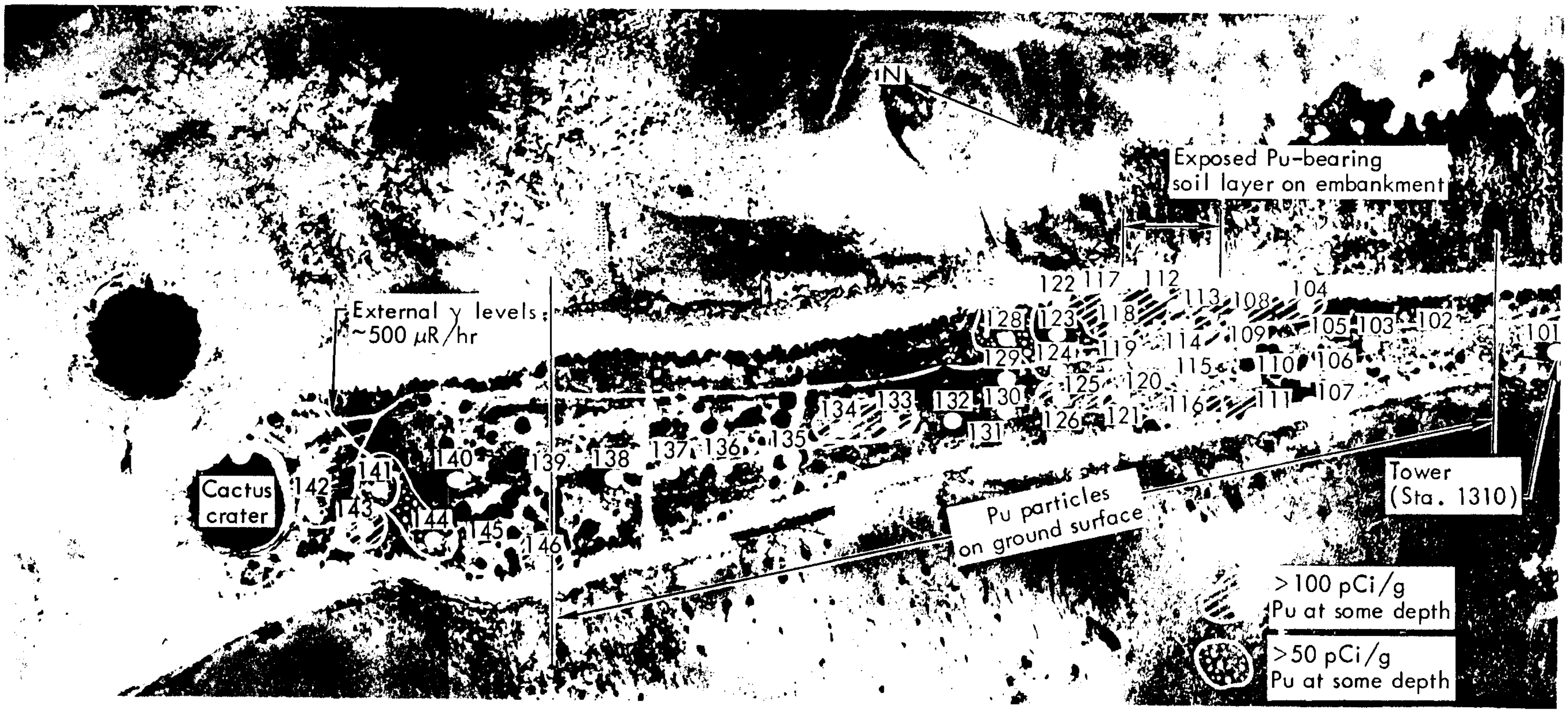

Fig. 152. Soil-profile locations which were sampled to 150-cm depths, YVONNE.

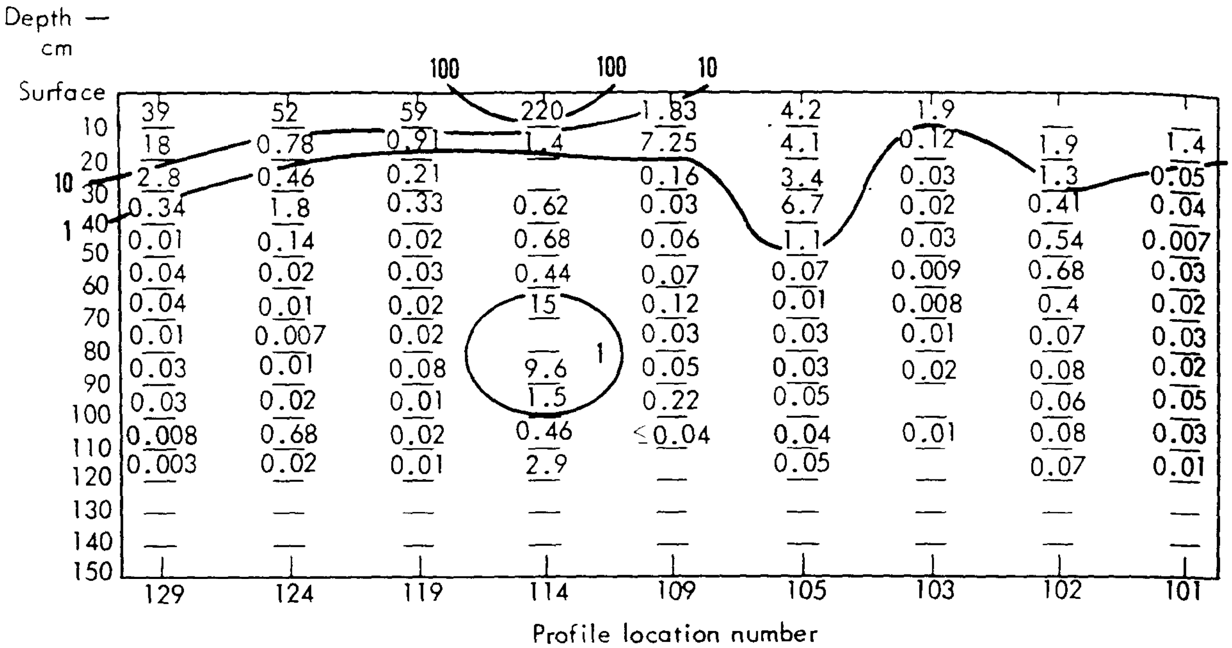

Fig. 153. Plutonium profile data, Locations 101-103, 105, 109, 114, 119, 124, and 129, YVONNE.

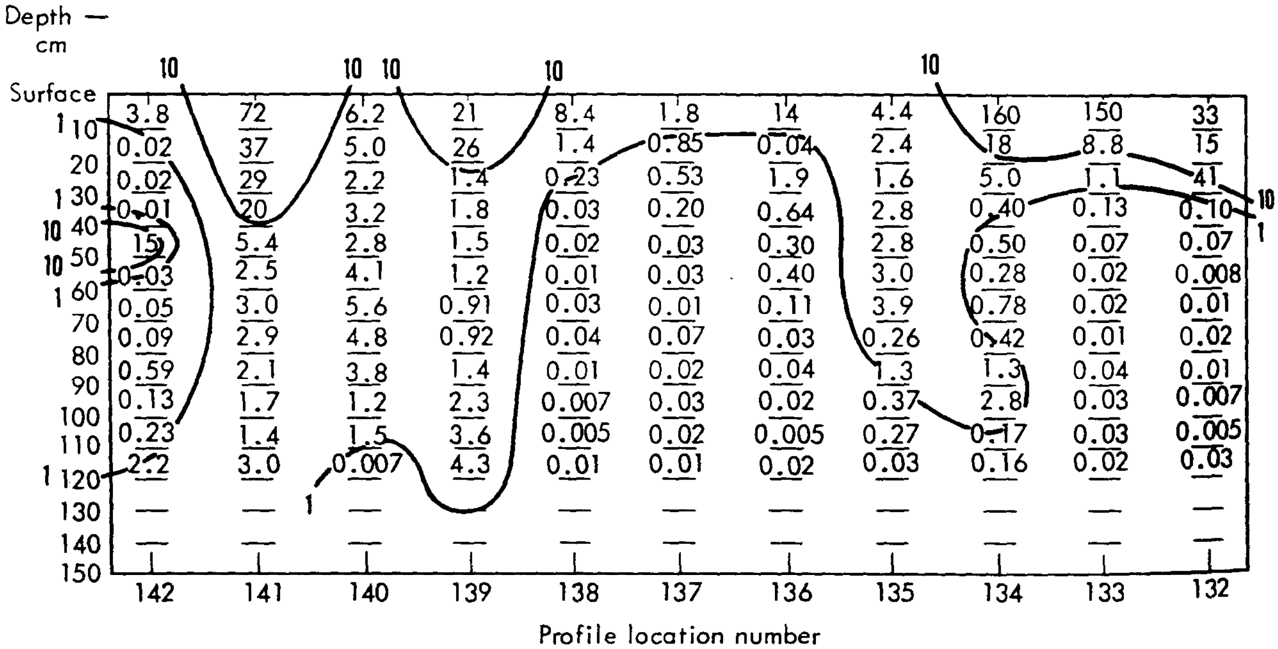

Fig. 154. Plutonium profile data, Locations 132-142, YVONNE.

(0.07 pCi/g). Comparison of these data with similar data obtained in 1964 indicates that, in addition to physical decay, ^{60}Co and ^{137}Cs are being lost from the lagoon with mean residence half-times of 3.3 and 4.1 yr, respectively, while ^{207}Bi appears to be decreasing at approximately its radioactive decay rate. ^{90}Sr,

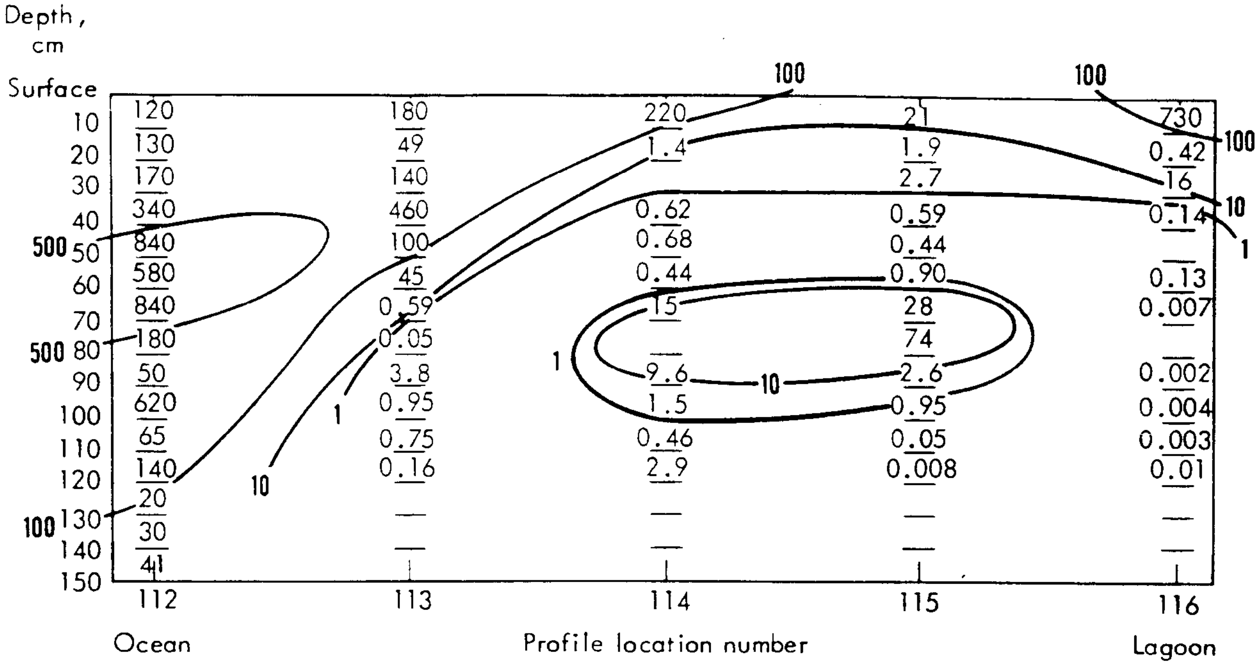

Fig. 155. Plutonium profile data, Locations 112-116, YVONNE.

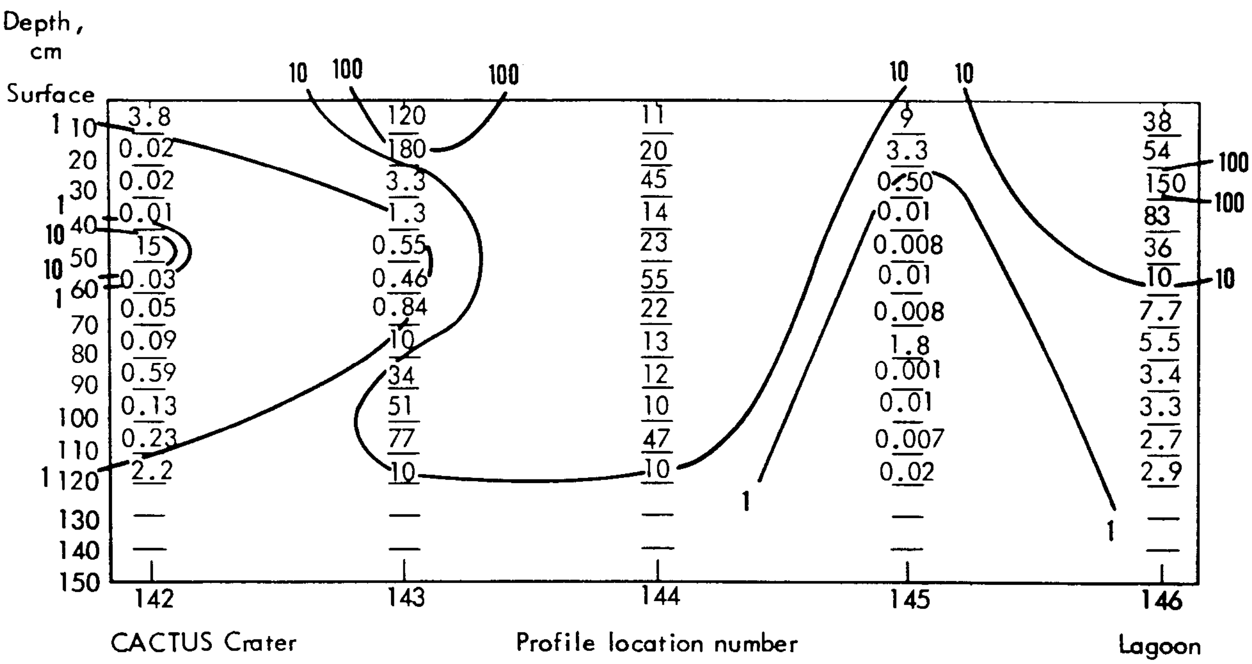

Fig. 156. Plutonium profile data, Locations 142-146, YVONNE.

$^{239,240}Pu$, ^{155}Eu, and ^{241}Am were not reported in 1964.

Of the more than 700 species of fish at Enewetak Atoll, the species selected for this survey were chosen for one or more of the following reasons: (1) They are commonly eaten by the Marshallese; (2) they are relatively abundant at most of the

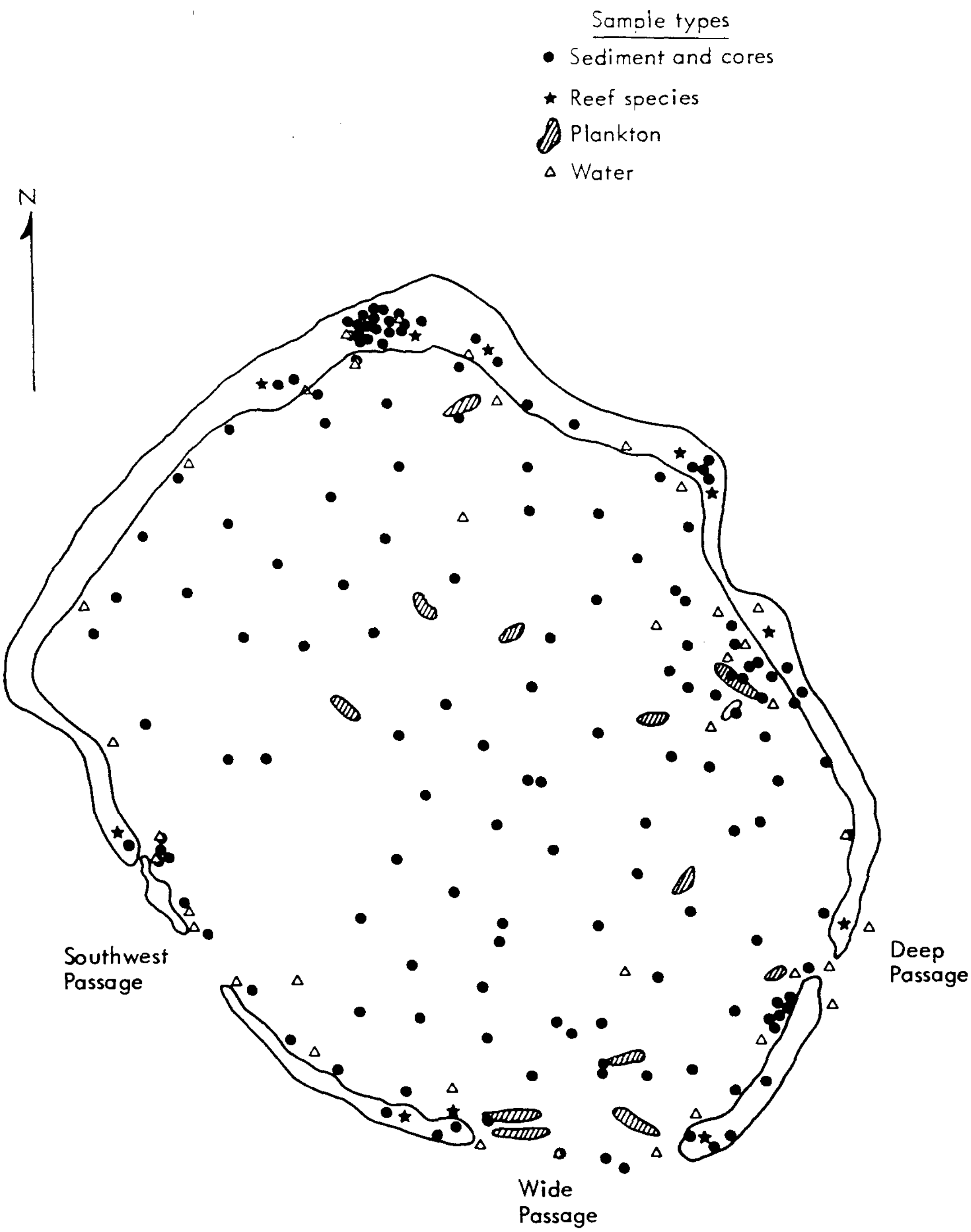

Fig. 157. Enewetak marine program sampling locations.

collection sites; (3) they are representative of a feeding habit; or (4) there is previous relevant radiometric information about the species. The species of reef fishes selected as being representative of feeding habits include the mullet (a plankton and detritus feeder), convict surgeon (a grazing herbivore), goatfish (a bottom-feeding carnivore), and parrotfish (a coral eater). The tunas, jacks, and dolphins – pelagic fish – and the snappers and groupers – benthic fish – which were also

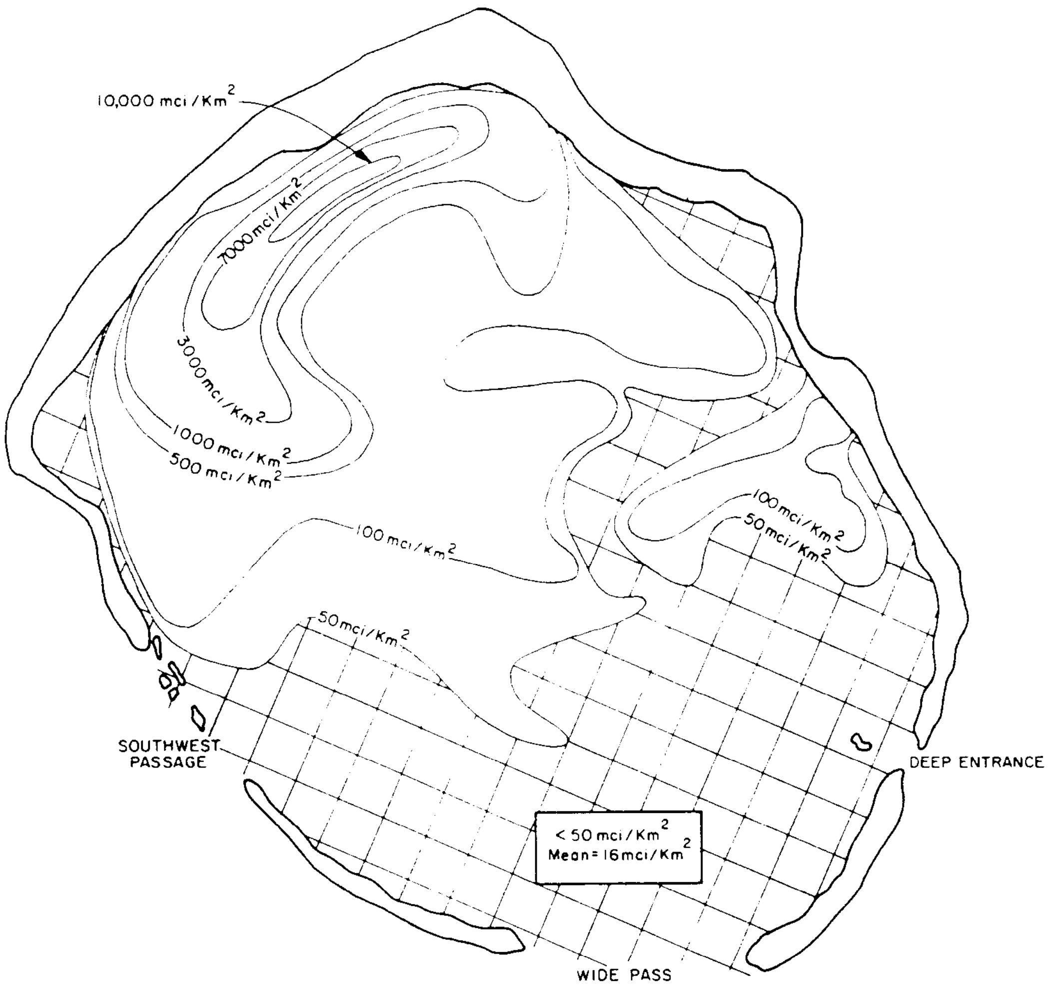

Fig. 158. Activity levels of ^{90}Sr deposited in the sediments of Enewetak Lagoon.

collected are carnivores of high order in the food chain leading to man.

The number and kind of marine organisms collected at near-shore sites at Enewetak Atoll and at Kwajalein Atoll, where "control" samples were taken, are shown in Table 218. Similar information for the carnivorous fish is given in Table 219.

^{40}K, ^{55}Fe, and ^{60}Co were the predominant radioactive nuclides found in all fish, although ^{65}Zn, ^{90}Sr, ^{101}Rh, ^{102m}Rh, ^{108m}Ag, ^{125}Sb, ^{137}Cs, ^{152}Eu, ^{155}Eu, ^{207}Bi, ^{239,240}Pu, and ^{241}Am were also present in some or all samples.

Table 217. Concentration of ^{137}Cs and ^{239}Pu in comparative, surface water samples.

Location	Concentration, fCi/liter ^{137}Cs	Concentration, fCi/liter ^{239}Pu
Enewetak Lagoon		
SE quadrant	226	9.1
NE quadrant	334	42.6
NW quadrant	579	33.4
SW quadrant	332	21.6
Ocean, east of Enewetak Atoll	89	0.3
Lake Michigan (1971)	88	1.1
Humboldt Bay, Calif. (1973)	300	
14°N 180°W (1972)	143	0.44
12°N 170°E (1972)	170	0.35
Windscale vicinity (1969)	105,000	
Mean surface, Atlantic 0-31°N (1968)		0.7

Table 218. Number of organisms collected at Enewetak Atoll and Kwajalein Atoll near-shore sites, October to December 1972.

Collection site	Organism								
	Mullet	Goatfish	Convict surgeon	Parrot-fish	Other reef fish	Tridacna	Sea cucumber[a]	Other inverte-brates	Approx total
Enewetak Atoll									
GLENN-HENRY	~25	11	~50	2	10	6	4	6[b]	114
LEROY	~50	9	34	3	1	1	0	~10[c]	108
FRED	0	~20	~50	[illegible]	7	3	2		91
DAVID	0	25	~50	12	2	4	1		94
BELLE	~50	3	30	1	3	10	0		97
IRENE	2	3	12	0	8	0	0		25
JANET	~50	3	~40	1	0	1	0		98
TILDA-URSULA	~35	11	~50	2	3	[illegible]	[illegible]		107
YVONNE	10	~15	~55	10	3	0	3	9[d]	105
Kwajalein Atoll	–	–	~30	1	5	5			41
Approximate Total	~220	~100	~400	41	42	36	13	25	870

[a]The number given is the number of collections from a given site.
[b]Pencil urchins.
[c]Top snails.
[d]Spiny lobster.

Table 219. Number of carnivorous fish collected from the Enewetak and Kwajalein off-shore lagoon sites, October to December 1972.

Collection site	Yellowfin tuna	Organism						Total
		Skipjack	Mackerel	Dolphin	Snapper	Grouper	Ulua	
Enewetak	2	9	3	2	8	8	8	40
Kwajalein	3	1				2		6
Total	5	10	3	2	8	10	8	46

Figures 159-161 show the average concentrations of predominant radionuclides found in convict surgeon samples taken at each of the collection sites around the lagoon. Similar data were obtained from the mullet, goatfish, and parrotfish samples.

Average radionuclide content of light muscle, dark muscle, and liver of skipjack collected in Enewetak lagoon are shown in Fig. 162. In general, ^{55}Fe levels in the large pelagic fish were higher than levels found in other fish types, while other nuclides were present at levels comparable to or lower than those found in the reef fish.

Of the samples collected at Kwajalein, ^{40}K was present at normal background

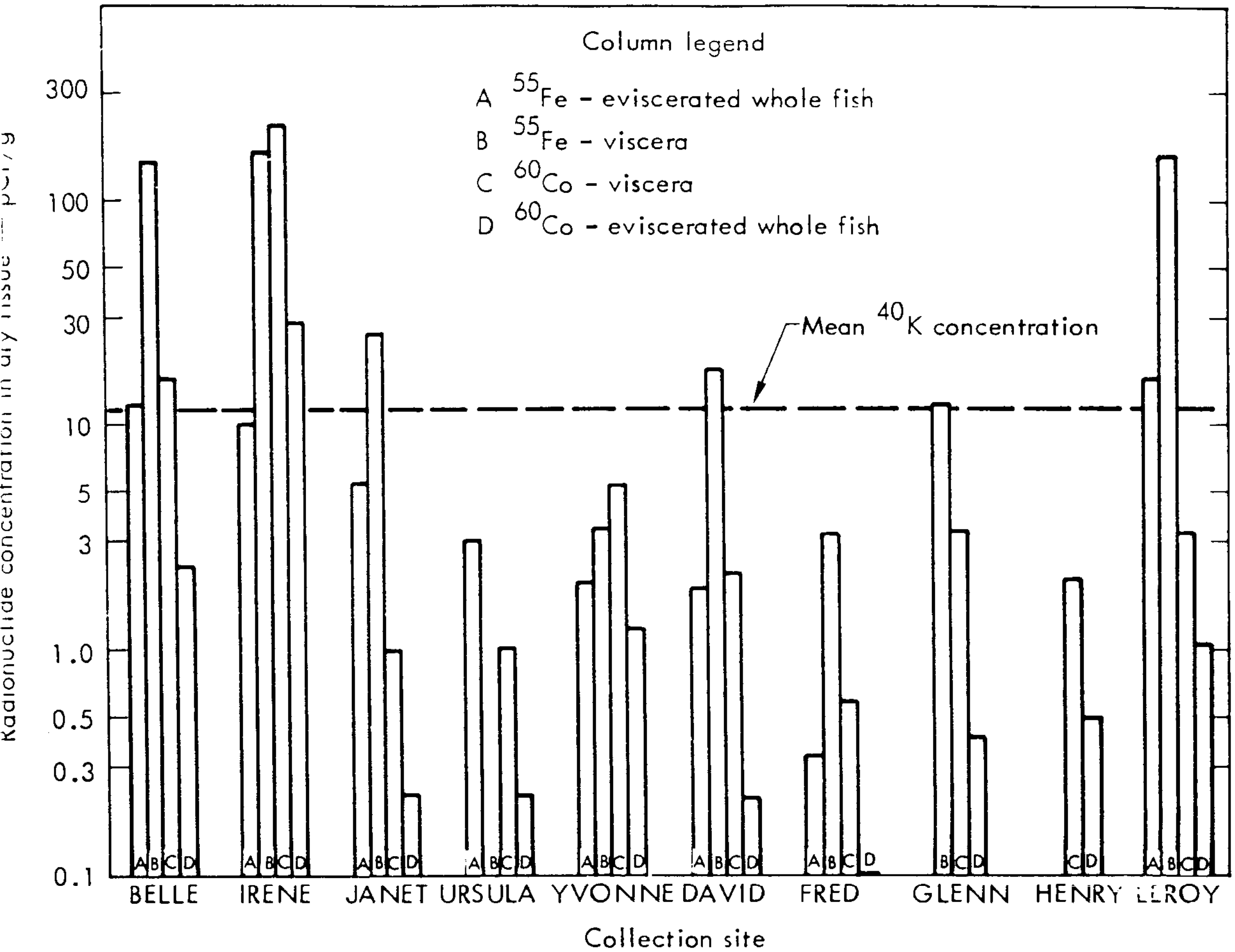

Fig. 159. Average ^{40}K, ^{55}Fe, ^{60}Co concentration in convict surgeon from Enewetak Atoll, October to December, 1972. The ^{40}K value is the mean for all convict surgeon samples.

Table 220. Comparison of ^{60}Co and ^{207}Bi in the viscera of convict surgeon collected in 1964 and 1972.

	^{60}Co in pCi/g, dry			^{207}Bi in pCi/g, dry		
Island	1964	1972	Fraction remaining	1964	1972	Fraction remaining
BELLE	120	16	0.13	8.0	2.0	0.25
JANET	8.3	0.96	0.12	1.2	0.2	0.17
GLENN	19	3.3	0.17	2.6	0.7	0.27
LEROY	56	3.4	0.06	5.2	3.1	0.59
YVONNE	64	5.2	0.08	–	–	–
Average			0.11			0.32

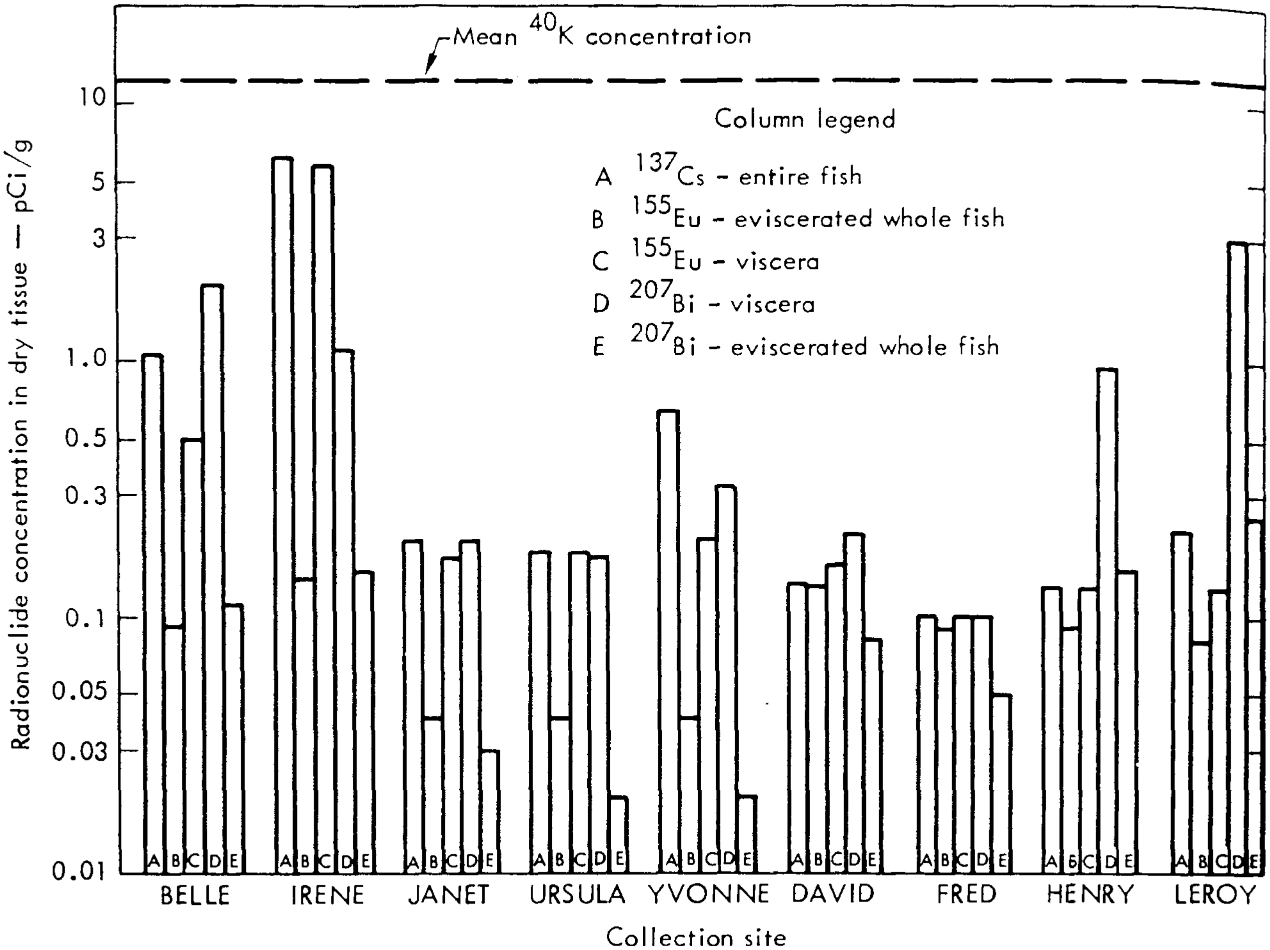

Fig. 160. Average ^{137}Cs, ^{155}Eu, and ^{207}Bi concentration in convict surgeon from Enewetak Atoll, October to December, 1972. The ^{40}K value is the mean for all convict surgeon samples.

levels (av 15 pCi/g). No ^{60}Co, ^{207}Bi, or ^{155}Eu were observed, but ^{55}Fe, ^{137}Cs, ^{90}Sr, and ^{239,240}Pu were found in some or all of the samples, usually at levels comparable to the lower values found at Enewetak.

As with the plankton, comparison of data obtained from this survey with similar data from samples taken in 1964 indicates that, for some nuclides at least, there are processes operating to reduce concentrations in the lagoon faster than is expected from radioactive decay alone. Table 220, for example, presents a comparison of ^{60}Co and ^{207}Bi data for the two collection periods. The effective half-life of 2.7 yr for ^{60}Co (radioactive decay half-life 5.24 yr) and 5.1 yr for ^{207}Bi (radioactive decay half-life 30 yr) implies an effective half-life in the ecosystem for both isotopes of about 5-6 yr.

Of the marine invertebrates present at Enewetak, tridacna clams, sea cucumbers, spiny lobster, and top snails were collected and analyzed. In the tridacna, ^{60}Co was the most abundant radioisotope found, and it was present in higher amounts in the kidney than in the viscera,

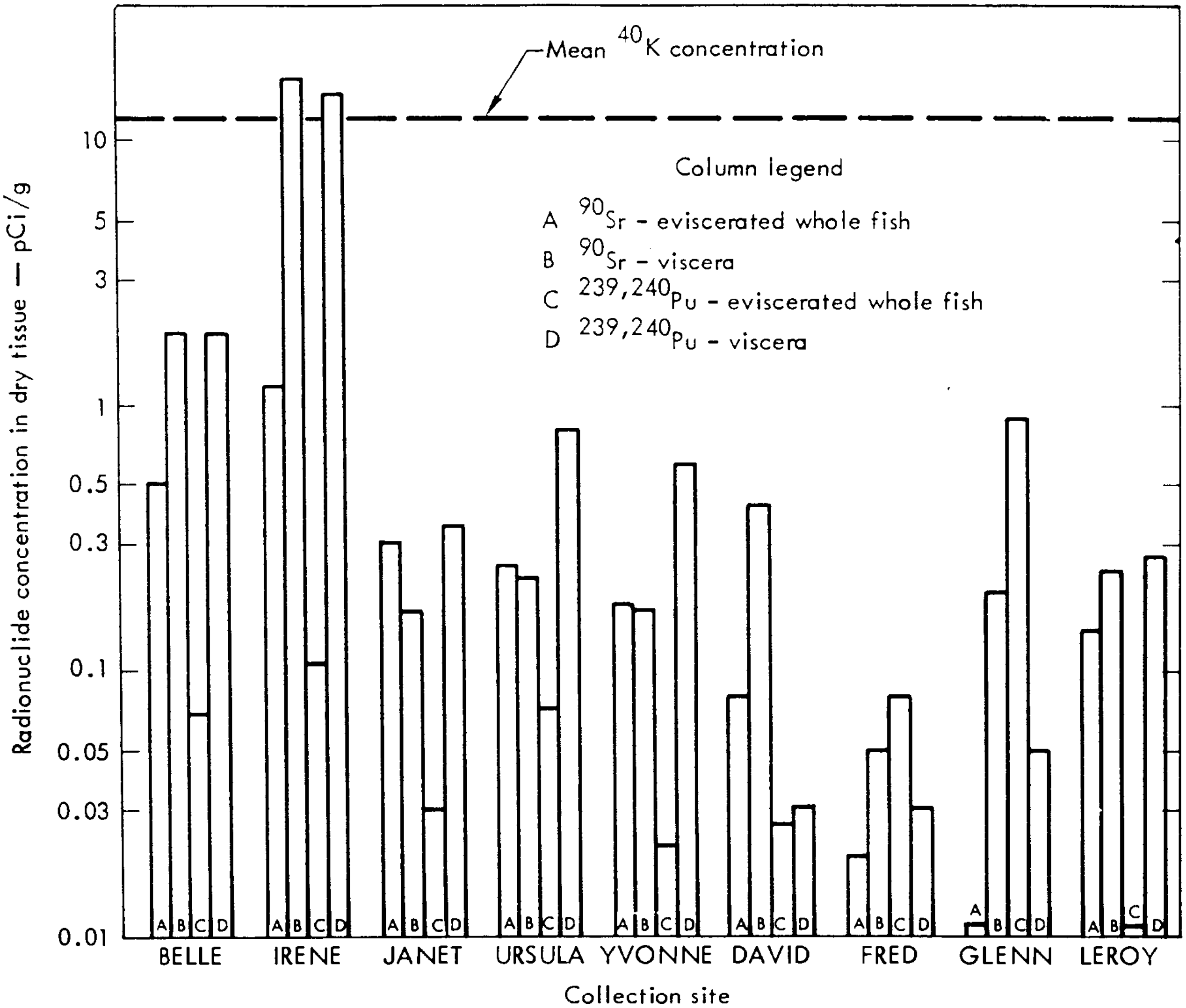

Fig. 161. Average ^{90}Sr and ^{239,240}Pu concentration in convict surgeon from Enewetak Atoll, October to December, 1972. The ^{40}K value is the mean for all convict surgeon samples.

mantle, or muscle. Figures 163-165 present the average radionuclide concentrations of these tissues for the Enewetak locations at which tridacna samples were taken.

Radionuclide distributions for sea cucumbers, spiny lobsters, and top snails were similar to those found for the tridacna, except that high concentrations were not observed in the kidney.

Radioactivity Levels in Enewetak Terrestrial Biota

The terrestrial biota survey had as its objective the collection and analysis of all available terrestrial vegetation and animal species which could be used as a basis for estimating population doses through dietary pathways. Not all vegetable and animal components of the Enewetakese diet are currently available

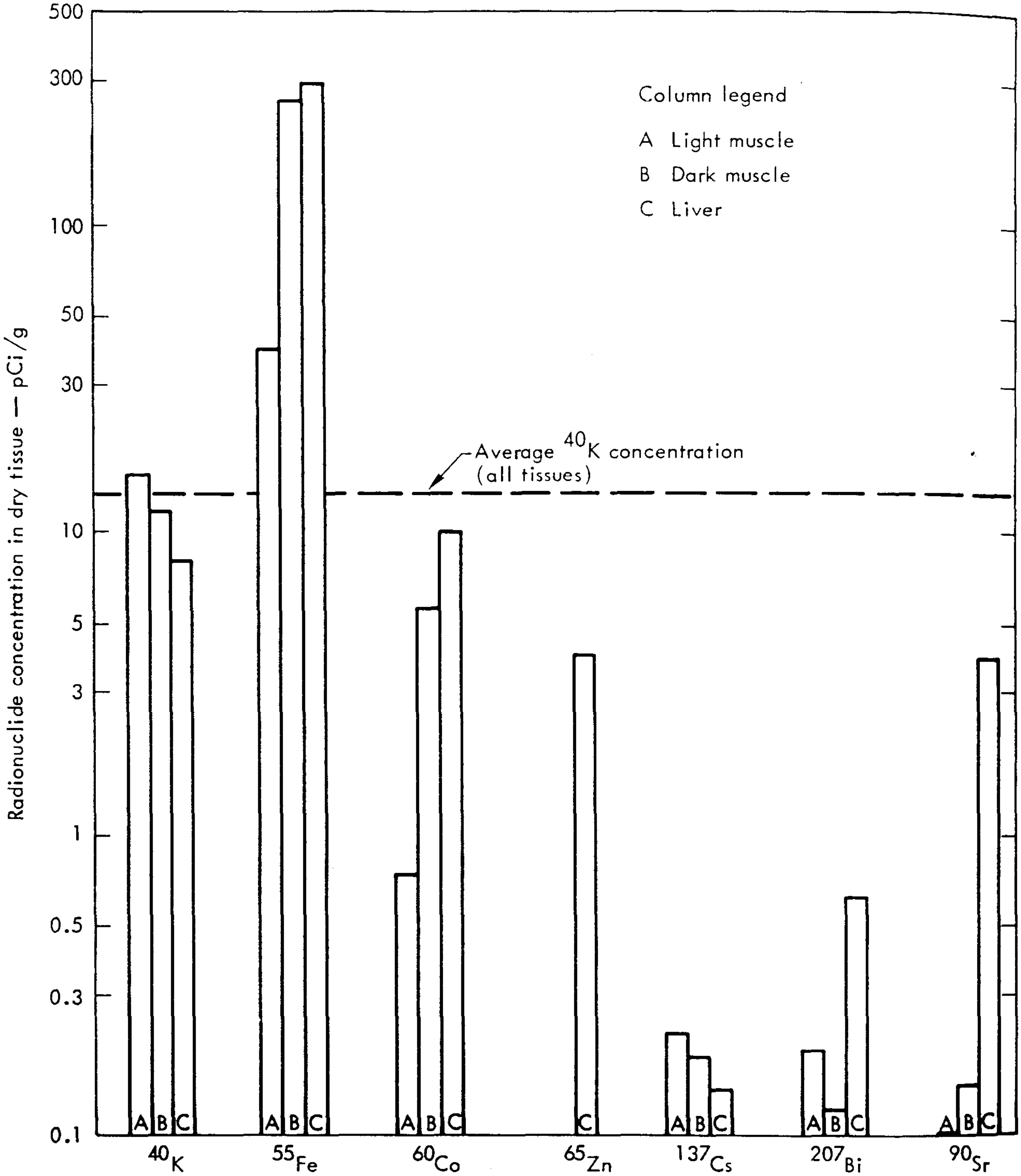

Fig. 162. Average concentration of seven radionuclides in the light muscle (A), dark muscle (B), and liver (C) of three skipjack from Enewetak Atoll, October to December, 1972.

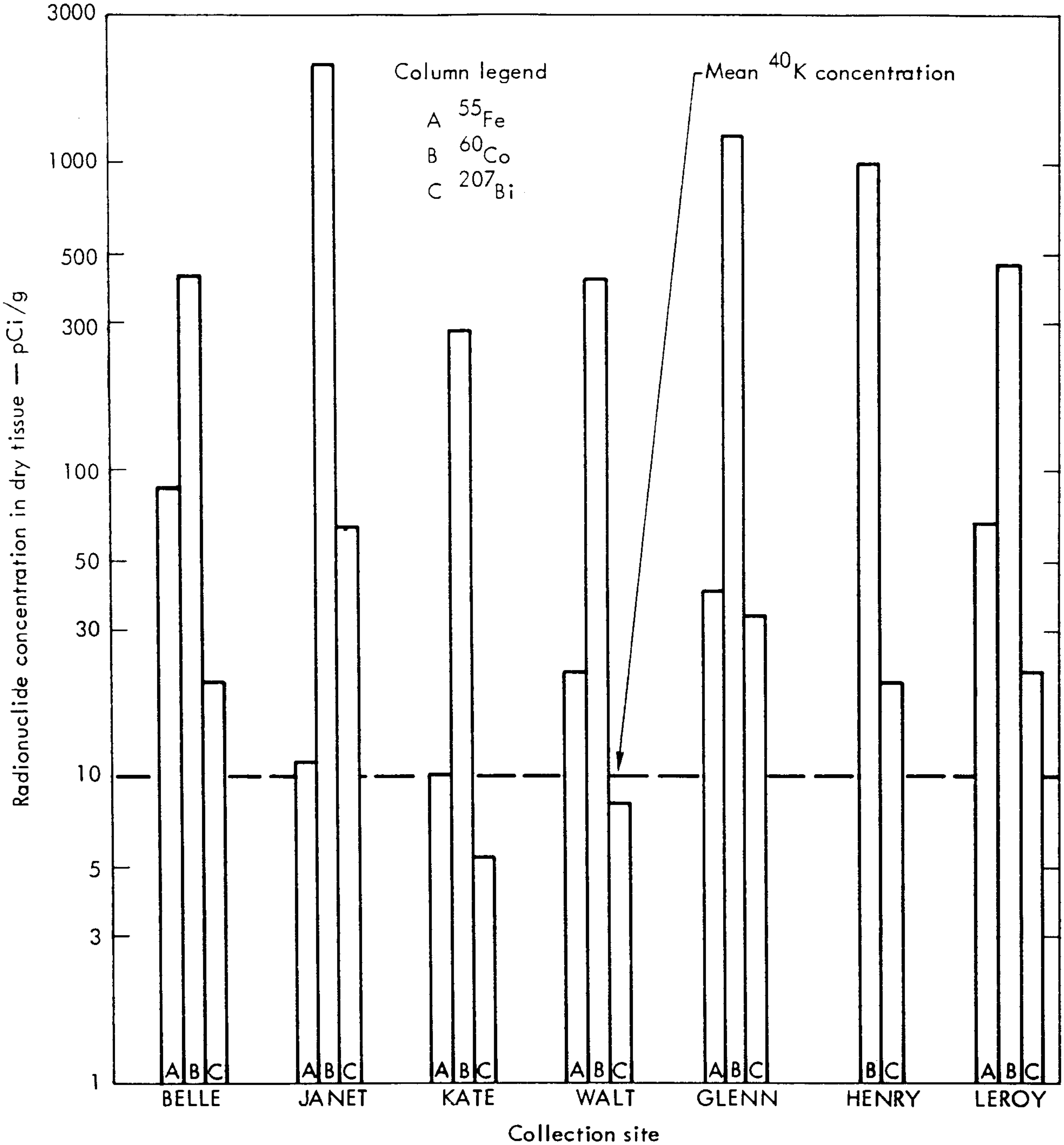

Fig. 163. Average ^{40}K, ^{55}Fe, ^{60}Co, and ^{207}Bi concentration in the kidney of Tridacna clams collected at Enewetak Atoll, October to December, 1972. The ^{40}K value is the mean of all Tridacna samples.

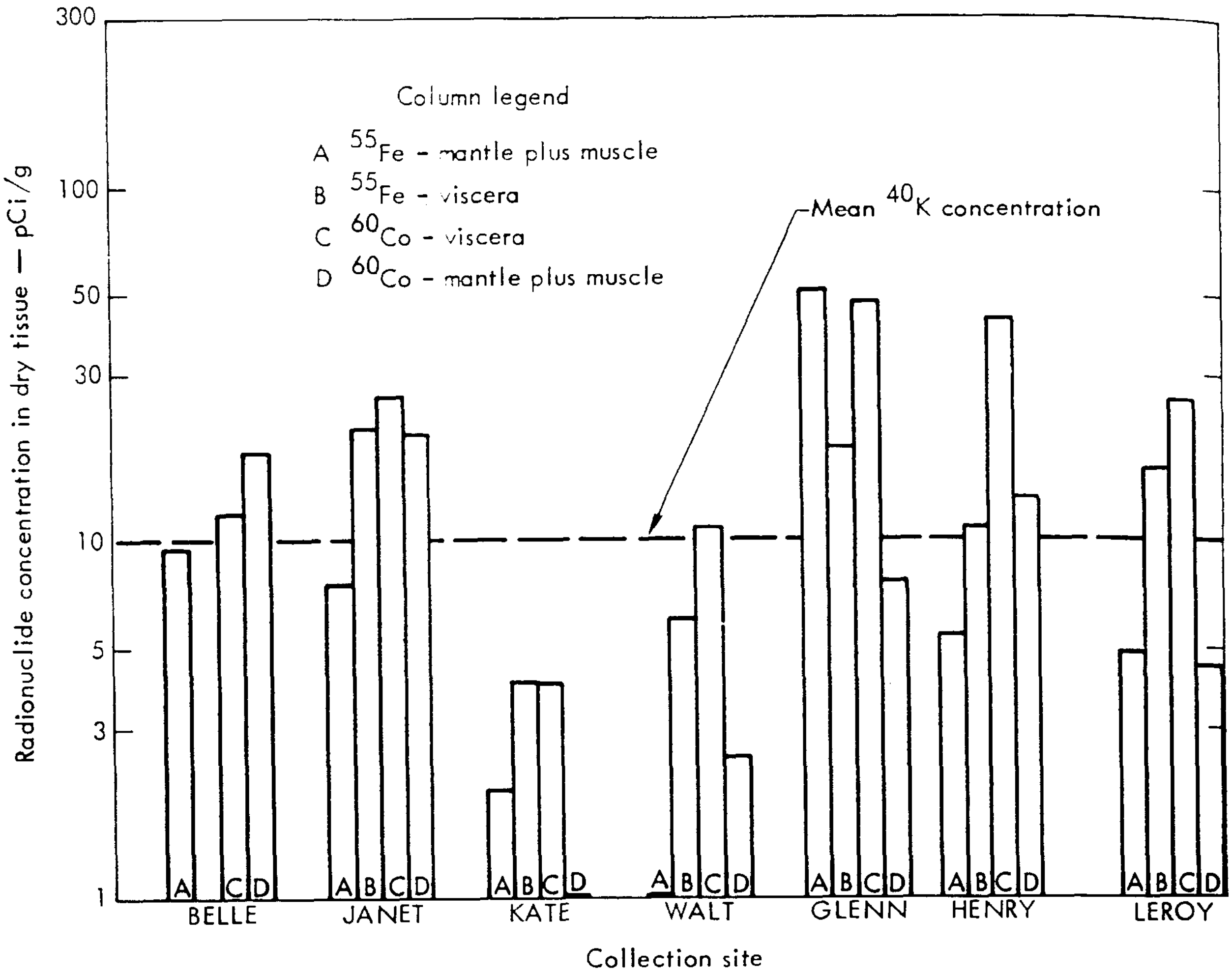

Fig. 164. Average ^{40}K, ^{55}Fe, and ^{60}Co concentration in the viscera, mantle, and muscle of Tridacna clams collected at Enewetak Atoll, October to December, 1972. The ^{40}K value is the mean of all Tridacna samples.

on the Atoll; of those that are, not all are available on every island.

A total of 1103 specimens were collected in the field as part of the terrestrial biota survey, distributed as follows:

Soils	42
Plants	208
Birds	116
Eggs	217
Rats	249
Crabs	271
Total	1103

The geographical distribution of specimen collection sites is shown in Fig. 166 and the types of edible sample collected on each island are listed in Table 221.

^{90}Sr and ^{137}Cs were observed in essentially all of the plant, rat, and crab samples and in many of the bird and egg samples. ^{55}Fe, ^{60}Co, and $^{239,240}Pu$ were observed less frequently, and isotopes such as ^{207}Bi, ^{152}Eu, and ^{151}Sm were observed occasionally.

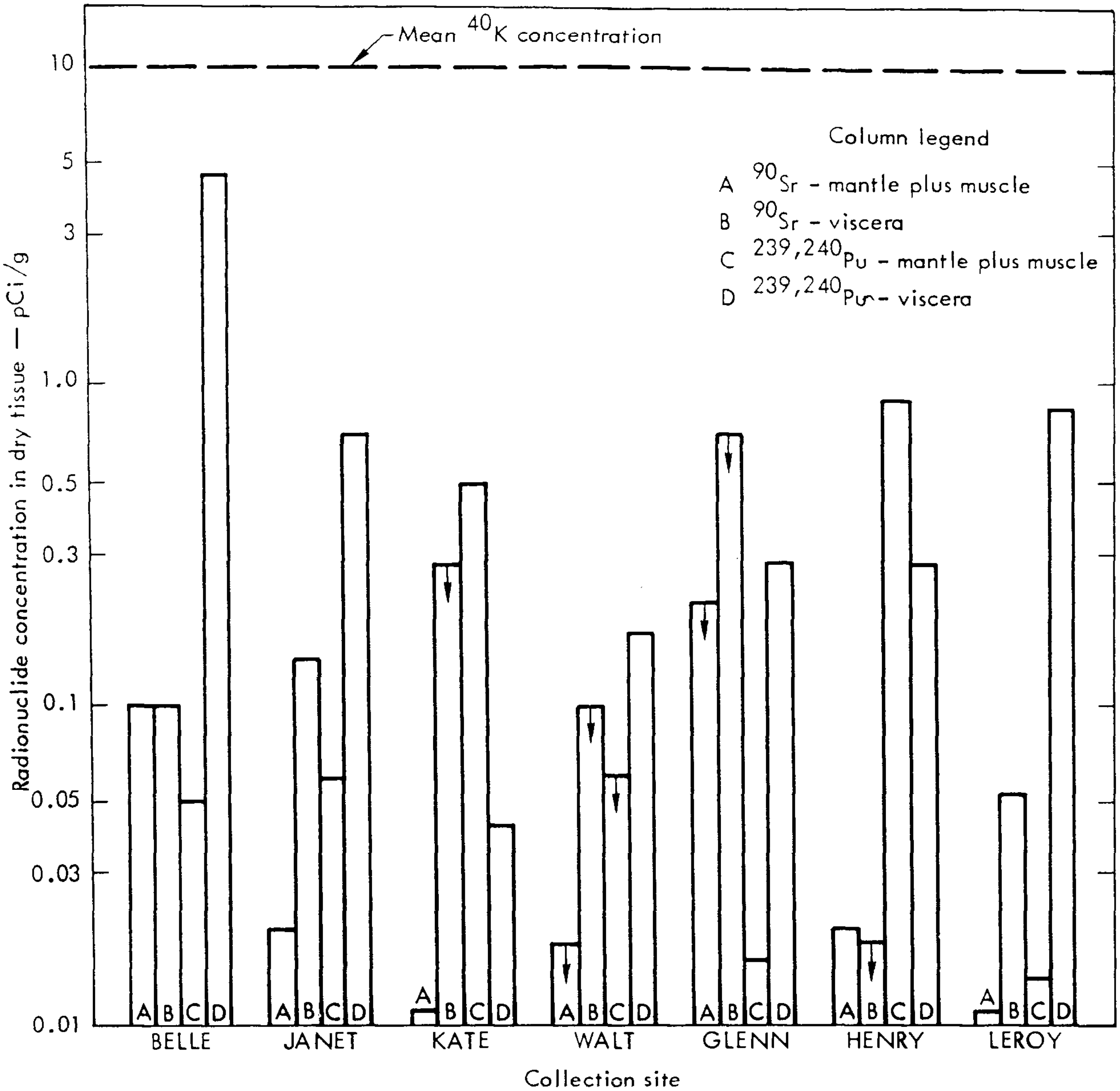

Fig. 165. Average ^{90}Sr and $^{239,240}Pu$ concentration in the viscera, mantle, and muscle of Tridacna clams collected at Enewetak Atoll, October to December, 1972. The ^{40}K value is the mean for all Tridacna samples.

Table 221. Terrestrial biota survey. Edible plants and edible animals sampled.

Island No.	Island	Coconut meat	Coconut milk	Pandanus fruit	Pandanus leaves[a]	Tacca corm	Birds	Bird eggs	Coconut crab	Rat[b]
1.	ALICE						x			
2.	BELLE			x	x					
4.	DAISY	x	x							
9.	IRENE	x	x				x	x		
10.	JANET	x	x		x		x	x		x
12.	LUCY						x			
14.	MARY	x	x				x			
15.	NANCY	x	x							
16.	OLIVE						x			
17.	PEARL						x			x
19.	SALLY				x		x	x		x
20.	TILDA				x					
21.	URSULA									x
22.	VERA	x			x					
24.	YVONNE	x					x	x		x
29.	VAN						x			
30.	ALVIN						x			
31.	BRUCE	x					x		x	
32.	CLYDE						x	x		x
33.	DAVID	x	x		x	x	x			x
34.	REX						x	x		
35.	ELMER	x			x					x
37.	FRED	x			x					
38.	GLENN	x							x	x
39.	HENRY	x						x		
40.	IRWIN	x					x	x		
41.	JAMES								x	
42.	KEITH	x		x	x		x		x	
43.	LEROY	x			x		x		x	

[a]Pandanus leaves are not eaten but serve as indicators for pandanus fruit.

[b]Rats are not eaten but serve as indicators for poultry and swine.

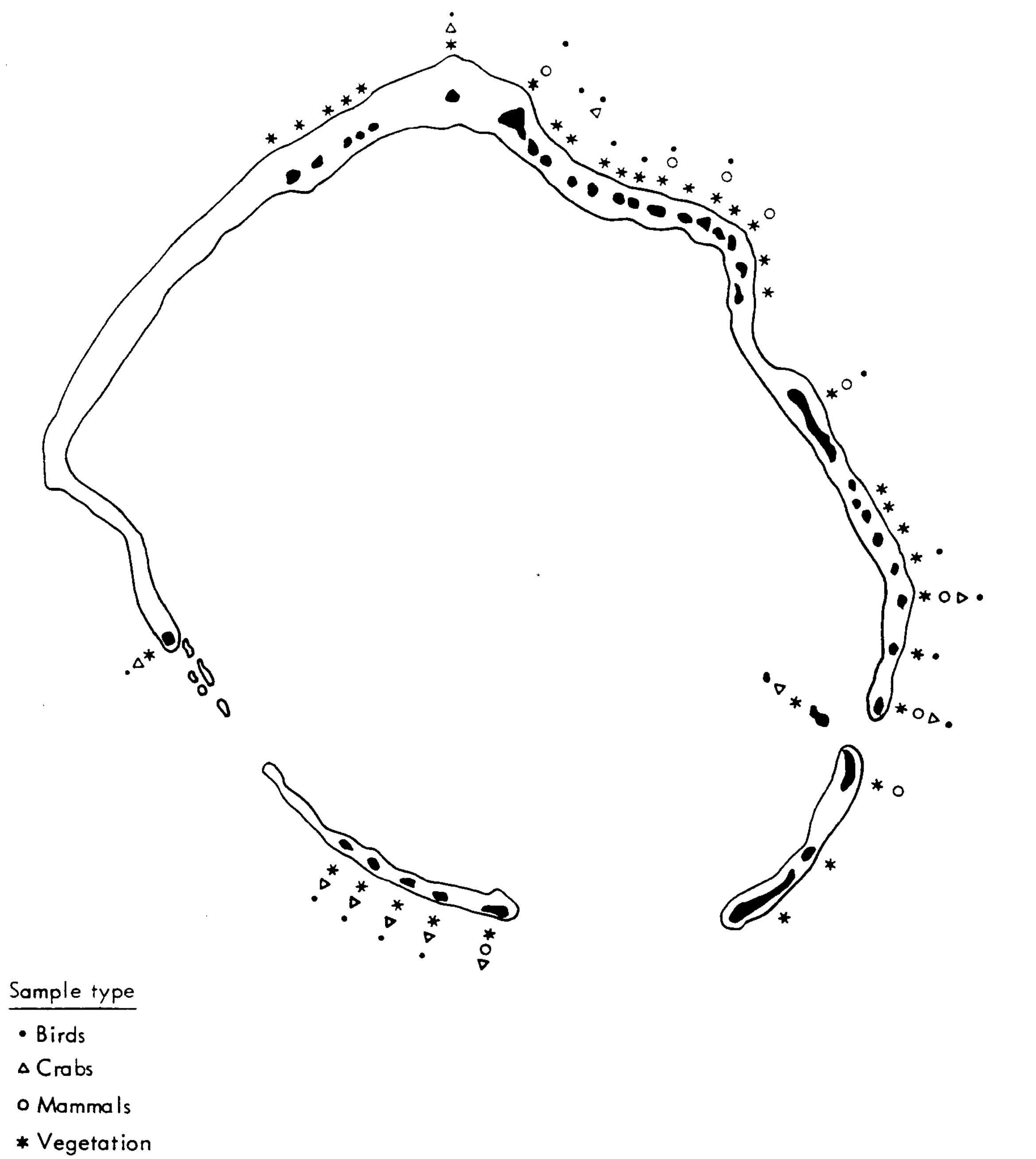

Fig. 166. Terrestrial biota program sampling locations.

For a given sample type, the radionuclide content generally corresponded with levels of soil contamination found on the Atoll. Data for ^{90}Sr and ^{137}Cs in coconut meat versus island sampling location, for example, are plotted in Fig. 167 and it is apparent that concentrations are significantly higher on the northern islands (islands 1-24) than on those on the southern part of the Atoll.

Since the main vegetation components in the human diet (coconut, pandanus,

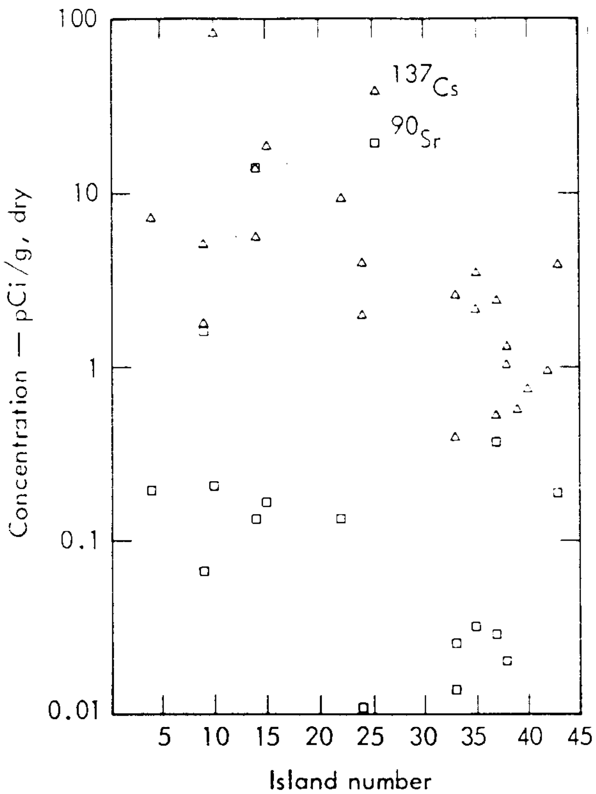

Fig. 167. Concentrations of ^{90}Sr and ^{137}Cs in coconut meat.

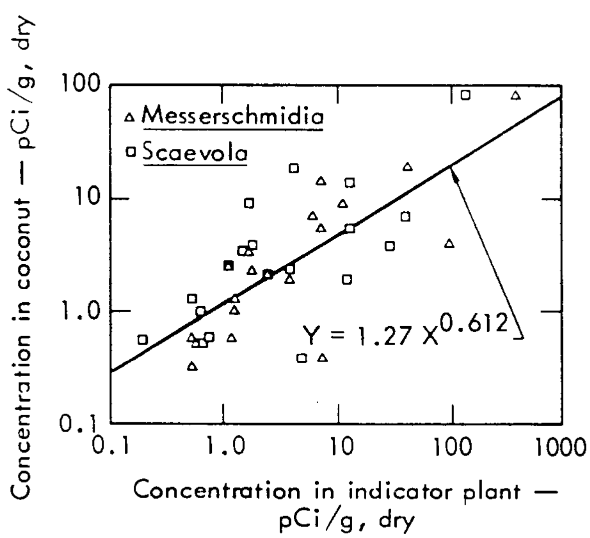

Fig. 168. Statistical correlation between ^{137}Cs in coconut meat and ^{137}Cs in Messerchmidia and Scaevola.

and breadfruit) are not growing now on all of the northern islands, the ubiquitous Messerschmidia and Scaevola were sampled and analyzed extensively with the intent that they be used as "indicator species" for estimating doses from the edible plants should they become available. The correspondence between ^{137}Cs activity in coconut meat and Messerschmidia and/or Scaevola from the same location is shown in Fig. 168.

To increase accuracy, dose estimates to the human population through the terrestrial vegetation pathway should be based on the geographical distribution of radionuclides. In order to do this, however, a correlation between nuclide content of vegetation and nuclide content of soil must be established. As an example of the correlations that have been developed, data for ^{137}Cs in Messerschmidia and Scaevola vs ^{137}Cs in soil are shown in Fig. 169.

Similarly, data obtained from rats – the only mammals now found on the Atoll – were found to correlate with the vegetation radionuclide levels. For example, correlations for ^{137}Cs in rat muscle vs Messerschmidia/Scaevola are shown in Fig. 170, and for ^{90}Sr in rat bone vs Messerschmidia/Scaevola are shown in Fig. 171.

Three classes of data obtained from the terrestrial biota survey, therefore, have been used to estimate potential human doses through the terrestrial food pathway:

- Data obtained from the edible organisms where they were available.
- Data obtained from the correlation between edible plants – indicator

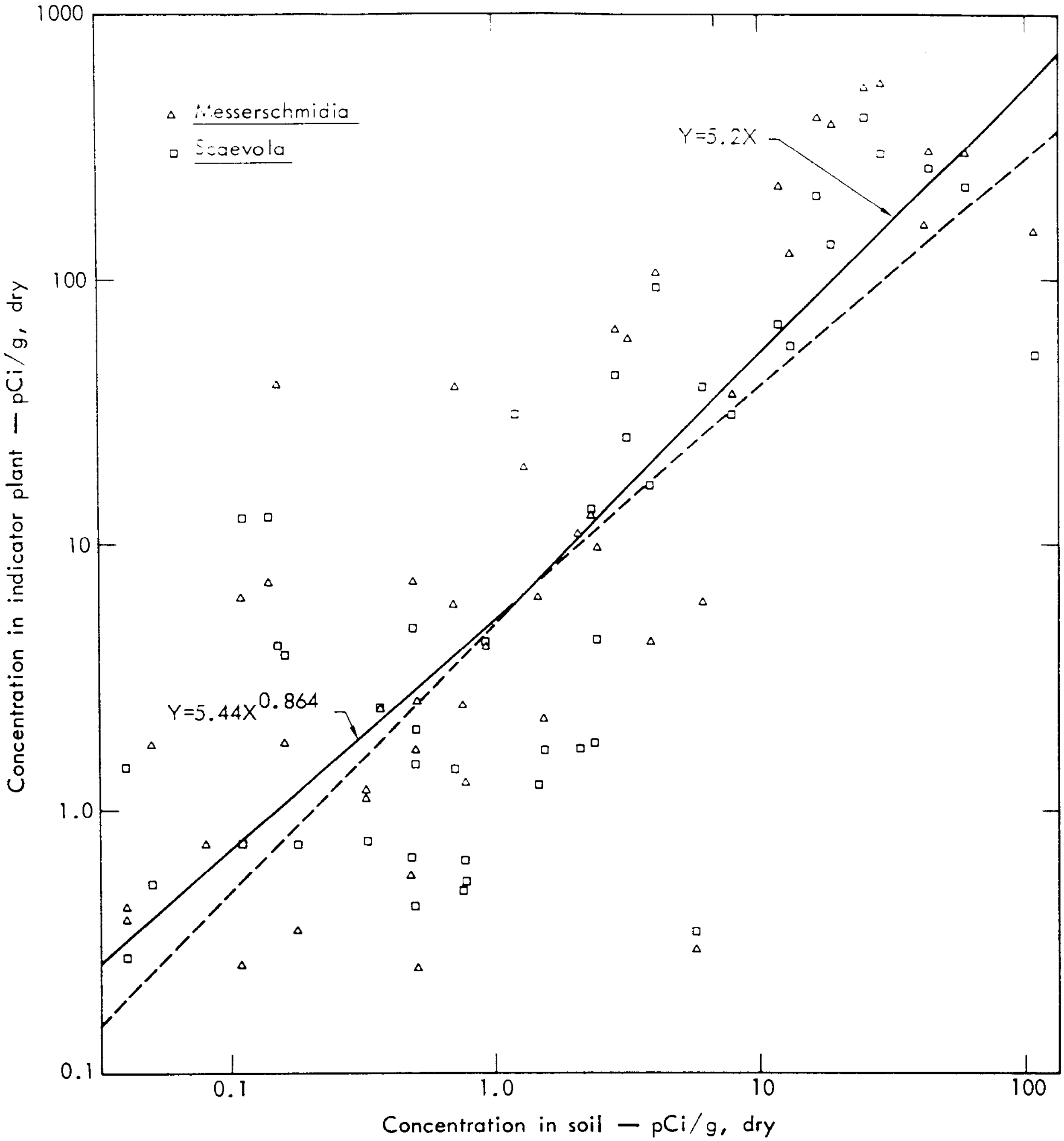

Fig. 169. Statistical correlation between ^{137}Cs in Messerschmidia and Scaevola and ^{137}Cs in soil.

plants – soil and applied to the plant component of the diet.

- Data obtained from the correlation between rats – indicator plants – soil and applied to the meat component of the diet.

Radioactivity Levels in Enewetak Air

A total of 32 samples of airborne Enewetak particulate debris have been analyzed to determine inhalation exposures likely to be encountered by residents of

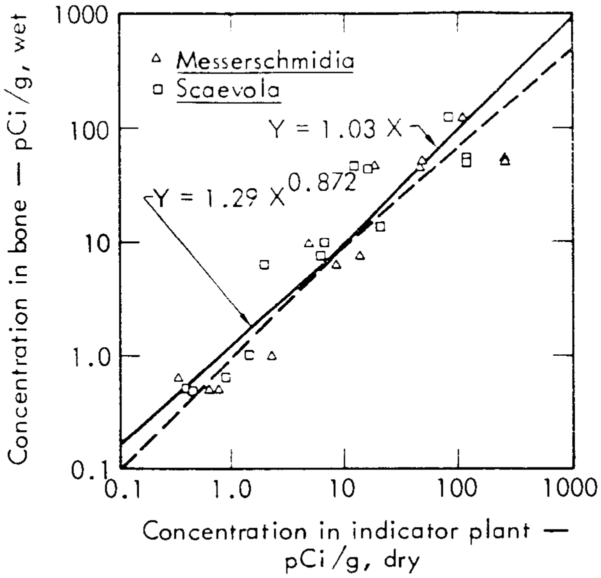

Fig. 170. Statistical correlation between ^{90}Sr in rat bone and ^{90}Sr in Messerschmidia and Scaevola.

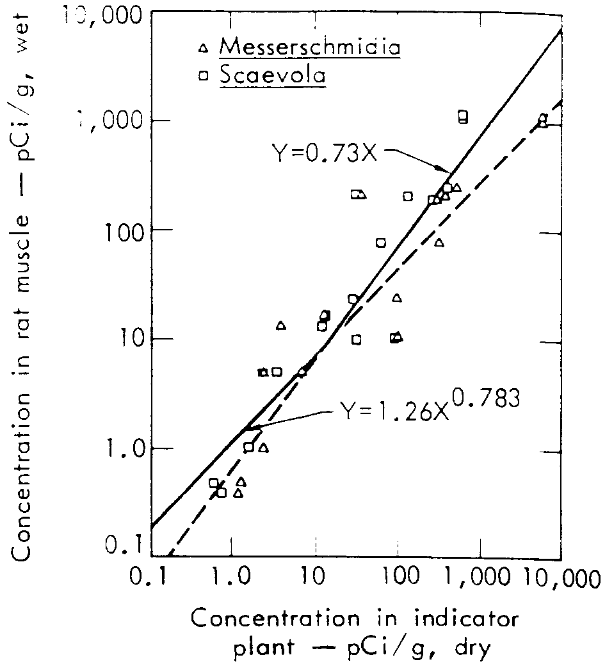

Fig. 171. Statistical correlation between ^{137}Cs in rat muscle and ^{137}Cs in Messerschmidia and Scaevola.

the Atoll. Samples were taken using the following three types of equipment:

- Ultra High-Volume Air Sampler (UHVS) – Used to sample large volumes of air in short time intervals. Typical samples were taken at a rate of 2000 m^3/hr for a continuous 24-hr period.
- Low-Volume Air Sampler (VCS) – Used to sample for extended periods. Typical samples were taken at a rate between 8 and 20 m^3/hr for a continuous 7-day period.
- Anderson Cascade Impactors (ACI)– Used to obtain data on the particle-size distribution of airborne radioactivity. These samplers operated at a throughput rate of 34 m^3/hr, sampled for 7- to 10-day periods, and separated each sample into the following particle-size ranges: 0.1-1.1, 1.1-2.0, 2.0-3.3, 3.3-7.0, and >7 μm.

Air samples were taken on FRED, DAVID, SALLY, JANET, and YVONNE, which are islands that include the full range of airborne activity levels likely to be found on the Atoll.

A number of radionuclides were detected in the surface air, including ^{7}Be (53 day), ^{40}K (1.26×10^9 yr), ^{54}Mn (303 day), ^{95}Zr (65 day), ^{103}Ru (39.6 day), ^{106}Ru (1.0 yr), ^{125}Sb (2.7 yr), ^{137}Cs (30 yr), ^{144}Ce (285 day), ^{239}Pu (2.4×10^4 yr), ^{238}Pu (86 yr), and ^{241}Am (458 yr). ^{7}Be and ^{40}K are naturally occurring activities. ^{54}Mn, ^{95}Zr, ^{103}Ru, ^{106}Ru, ^{125}Sb, and ^{144}Ce are intermediate-life activation and fission products found in current worldwide fallout, but present in Enewetak soils in only very reduced quantities due to radioactive decay in the long interval since testing ended. Longer-life ^{137}Cs,

Table 222. Comparison of radionuclides in surface air (fCi/m^3) on Enewetak, Livermore, California, and Balboa, Panama.

Nuclide	YVONNE	Remainder of Enewetak Atoll	Livermore, Calif., 1972	Balboa, Panama, 9°N 79°W, 1972-1973
^{7}Be	< 49-193	< 6-116	90-250	43-143[c]
54Mn	< 0.6-2.1	< 0.14-4.0	-	-
^{95}Zr	< 0.4-0.4[a]	0.03-0.3	0.005-0.4	< 0.9-8.5
^{103}Ru	< 5.5-5.5[a]	NDET[b]	0.29-3.4	-
^{125}Sb	< 0.27-0.27[a]	NDET	0.04-0.23	-
^{106}Ru	< 0.9-2.6	< 0.2-1.6	0.14-2.9	-
^{137}Cs	< 0.49-0.82	< 0.04-2.5	0.63-3.2	0.09-1.7
^{144}Ce	< 2.5-3.7	< 0.22-1.9	0.24-3.1	0.7-11.2
$^{239,240}Pu$	< 0.03-2.6	< 0.001-0.025	0.01-0.05	< 0.001-0.030
^{238}Pu	< 0.04-0.13	< 0.0028-0.008	0.001-0.005	< 0.001-0.003
^{241}Am	< 0.3-0.30[a]	NDET	NDET	NDET

[a]Detected only one sample.
[b]Not detected.
[c]Oct.-Dec. 1972 range.

^{238}Pu, ^{239}Pu, and ^{241}Am in air could be from either local resuspension or from worldwide fallout. A comparison of activity levels at Enewetak with those observed at Livermore, California, and Balboa, Panama is shown in Table 222. It appears that, with the exception of the single sample on which 5.5 fCi/m^3 of ^{103}Ru was observed, the only airborne radionuclides present at levels consistently higher than those at the other two locations were the Pu-Am species on YVONNE, a result not too surprising, considering the known soil contamination levels on that island.

Of the 32 air samples, four were taken in October 1972 before typhoon Olga struck, and the remainder were taken between November 28 and December 19, 1972. Wind speeds were almost always greater than 10 knots and often greater than 20 knots at all sampling locations. In addition, frequent light rain showers served to keep the ground surface damp. Table 223 presents climatological data which have been published for Enewetak and Kwajalein. It is apparent that December represents a fairly average month as far as total rainfall and rainfall frequency are concerned, while average windspeeds are higher than those observed most of the year.

Radioactive Scrap and Buried Debris

Holmes and Narver, Inc., as part of the engineering survey they conducted

Table 223. Climatological data for Kwajalein and Enewetak.[a]

	Percentage of total time at each wind-speed interval												
Wind speed, knots[b]	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Av
0-3	1	1	1	0	1	1	6	10	16	9	3	1	4.2
4-10	15	12	22	20	27	27	49	60	59	63	42	20	34.7
11-21	68	80	70	75	69	70	44	29	24	28	53	70	56.7
22-33	15	7	7	5	3	2	1	1	1	0	2	9	4.4
>33	1	0	0	0	0	0	0	0	0	0	0	0	0
Prevailing wind direction and frequency[b]	NE 86%	NE 87%	NE 81%	NE 77%	NE 67%	NE 64%	E/NE 36% each	E 31%	NE 27%	NE 33%	NE 55%	NE 74%	-- --

Precipitation[c]													Yr	Yr. of record
Av. amount, in.	1.02	1.84	1.86	1.28	4.57	3.37	6.45	6.81	6.24	9.09	6.30	2.63	51.46	30
Greatest amount, in.	1.95	10.21	7.33	3.86	8.38	7.03	15.35	14.41	13.17	18.07	17.38	9.18	69.86	13
Least amount, in.	0.12	0.40	0.37	0.49	0.37	1.33	1.36	4.22	1.53	2.60	1.94	0.86	24.42	13
Mean number of days, 0.01 in. or more.	11	10	13	13	16	16	21	21	20	21	21	16	198	10

[a]U. S. Hydrographic Office, Sailing Directions for the Pacific Islands, H. O. Pub. No. 82, Vol. 1, Second Edition (1964), updated to Dec. 5, 1970.

[b]Wind data for Kwajalein.

[c]Precipitation data for Enewetak.

for DNA,* estimated that there were approximately 7200 yd^3 of contaminated metal and concrete present on Enewetak Atoll in December 1972. AEC radiation monitors accompanied the H&N crews in order to identify the radioactive material. Table 224 shows the distribution of this debris on islands where this type of survey was conducted. The amounts of material listed should be taken only as an approximate lower limit, particularly on islands such as PEARL, where very heavy underbrush prevented the survey party from covering all parts of the island. In addition, it is conceivable that radioactive scrap material may be found on the other northern islands (KATE, LUCY, MARY, NANCY, OLIVE, URSULA, VERA, and WILMA), even though none of them contains ground-zero sites, and neither the aerial radiological survey nor the ground survey parties detected this type of debris.

On the southern islands, there were four locations where radioactive scrap material was found:

- On the north end of ELMER (in the "C" level area of Fig. B.37.1.b in Appendix II) there are several pieces of scrap iron with activity levels above local background.
- In the central part of ELMER (the large "E" level area of Fig. B.39.1.b) a partially shielded ^{60}Co source was found in a small storage building.

*Engineering Study for a Cleanup Plan, Enewetak Atoll-Marshall Islands, Holmes and Narver, Repts. HN-1348.1 and HN-1348.2 (1973).

Table 224. Contaminated metal and concrete scrap on Enewetak Atoll.

Island	Approximate scrap quantities	Remarks
ALICE	10 yd^3	Background is up to 170 $\mu R/hr$. An M-boat wreck on beach reads 8 mR/hr.
BELLE	Small ($<$ 10 yd^3)	Background up to 250 $\mu R/hr$.
CLARA	Small ($<$ 10 yd^3)	Background up to 100 $\mu R/hr$.
DAISY	Small ($<$ 10 yd^3)	Background up to 140 $\mu R/hr$.
EDNA	None	Sandbar
IRENE	Moderate[a]	Up to 1.2 mr/hr.
JANET	568 yd^3	Activated scrap metal in all sizes can be found in piles or individual pieces scattered over the island at levels up to 8 mr/hr.
PEARL	317 yd^3	Confined to SGZ area. Levels up to 5 mr/hr.
RUBY	196 yd^3	
SALLY	2106 yd^3	Scrap-metal activity levels up to 0.12 mr/hr. Alpha levels on concrete surfaces up to 10^3 dpm/50 cm^2.
TILDA	1 yd^3	
YVONNE	4064 yd^3	Activity levels up to 60 mr/hr.
Total	7262 yd^3	

[a]Reference does not identify volume.

- In the south-central part of ELMER (the small "E" level area of Fig. B.39.1.b) there appears to be scrap metal or other radioactive debris on, or just below, the ground surface in heavy underbrush.
- On the north-central shore of GLENN (the "C" area of Fig. B.48.1.b) there is a derelict barge which is contaminated with detectable amounts of ^{207}Bi.

Because of the extremely low ambient radiation levels on the southern islands and the sensitivity of the aerial survey equipment, we can be reasonably confident that we have found all material above ground with activity levels greater than a few microroentgens per hour. On FRED, for example, the highest radiation level found (the "D" area in Fig. B.46.1.b) proved to be coming from barrels of fly ash stored in a warehouse intended to be

Table 225. Living patterns describing the geographical locations for activities involved in daily living.

	Pattern I	Pattern II
Residence	FRED, ELMER, or DAVID	FRED, ELMER, or DAVID
Agriculture	ALVIN through KEITH	KATE through WILMA + LEROY
Fishing	Entire Atoll	Entire Atoll
	Pattern III	**Pattern IV**
Residence	JANET	BELLE
Agriculture	JANET	BELLE
Fishing	Entire Atoll	Entire Atoll
	Pattern V	**Pattern VI**
Residence	JANET	JANET
Agriculture	KATE through WILMA + LEROY	ALICE through IRENE
Fishing	Entire Atoll	Entire Atoll

used for PACE drilling operations. Similarly, the nearby "C" level area proved to be a ^{60}Co source stored in a lead container in a locked building properly labeled, but of which we were unaware before the survey started.

POPULATION DOSE ASSESSMENT

The total radiation dose to the Enewetak people returning to Enewetak Atoll is determined by the sum of the contributions of each of the exposure pathways; i.e.,

$$\text{Dose} = D_{\text{inhalation}} + D_{\text{external gamma}} + D_{\text{marine food chain}} + D_{\text{terrestrial food chain}}$$

The contribution of each pathway to the total dose for an individual depends on living patterns and diet. Six living patterns, shown in Tables 225 and 226, have been selected for the dose assessment on the basis of statements made by the Enewetak people as to how and where they would like to live after they return. Similarly, the diets shown in Table 227 have been selected on the basis of the best current information on the dietary habits of the Enewetak people, the current distribution of edible species on the Atoll, and growth periods before harvest for edible species which will have to be established after return. In addition, these assessments assume that the Enewetak people will continue their current practice of using catchment rainwater for drinking and that underground

Table 226a. Estimated time distribution (in percent) for men, women, children, and infants, with emphasis on residence island. Pattern A.

	Village area	Beaches	Interior	Lagoon	Other islands
Men	50	5	15	10	20
Women	60	10	10	0	20
Children	55	10	15	5	15
Infants	85	5	0	0	10

lens water, where available, will not be a significant part of the diet.

$D_{inhalation}$

$^{239,240}Pu$ has been found to be the only significant contributor to inhalation doses on Enewetak Atoll. Airborne radioactive species observed during the survey, however, were identified as originating almost entirely from world-wide fallout or cosmic-ray activity. In order to make a conservative estimate of inhalation dosages, it has been assumed that the returning population will be exposed to air with an average dust loading of 100 $\mu g/m^3$, with the same $^{239,240}Pu$ content as the local soil, all 0.4 μm in diameter and low in solubility.

Using these assumptions and $^{239,240}Pu$ concentrations obtained from the soil samples, inhalation doses to bone, liver, and lung for each of the six living patterns have been estimated and are shown in Tables 228-230.

The "unmodified" cases represent calculations based on the $^{239,240}Pu$ content of the top 2 cm of soil, while the "modified" cases represent calculations based on the average $^{239,240}Pu$ content of the top 15 cm of soil. The latter condition would obtain if the soils were plowed or mixed during the replanting operations.

$D_{external\ gamma}$

Using gamma levels obtained from the aerial survey, estimates of the external gamma dose associated with each of the living patterns have been calculated (Table 231). In this table the "unmodified"

Table 226b. Estimated time distribution (in percent) for men, women, children, and infants with emphasis on additional time spent on nonresidence islands. Pattern B.

	Village area	Beaches	Interior	Lagoon	Other islands
Men	40	5	20	10	25
Women	50	5	15	5	25
Children	50	5	15	10	20
Infants	70	5	5	0	20

Table 227. Postulated diet for the returning adult Enewetak population for time of return and for 10 yr after initial return.

Food item	Diet, g/day: At time of return,	Diet, g/day: 10 yr after return
Fish	600	600
Domestic meat	60	100
Pandanus fruit	0	200
Breadfruit	0	150
Wild birds	100	20
Bird eggs	20	10
Arrowroot	0	40
Coconut	100	100
Coconut milk	100	300
Coconut crabs	25	25
Clams	25	25
Garden vegetables	0	0
Imports	200-1000	200-1000
	1030 plus imports	1570 plus imports

Table 228. Cumulative rems to organs from $^{239,240}Pu$ via inhalation pathway, **bone.**

LIVING PATTERN	PCI/G IN SOIL	5 YRS	EXPOSED 10 YRS	30 YRS	50 YRS	70 YRS
I. MODIFIED	0.05	0.0000	0.0000	0.0003	0.0009	0.0018
UNMODIFIED	0.12	0.0000	0.0001	0.0007	0.0022	0.0043
II. MODIFIED	2.00	0.0001	0.0008	0.0122	0.0360	0.0720
UNMODIFIED	4.70	0.0003	0.0020	0.0287	0.0846	0.1692
III. MODIFIED	7.30	0.0004	0.0031	0.0445	0.1314	0.2628
UNMODIFIED	17.00	0.0010	0.0071	0.1037	0.3060	0.6120
IV. MODIFIED	15.00	0.0009	0.0063	0.0915	0.2700	0.5400
UNMODIFIED	77.00	0.0046	0.0323	0.4697	1.3860	2.7720
V. MODIFIED	7.30	0.0004	0.0031	0.0445	0.1314	0.2628
UNMODIFIED	17.60	0.0011	0.0074	0.1074	0.3168	0.6336
VI. MODIFIED	9.50	0.0006	0.0040	0.0579	0.1710	0.3420
UNMODIFIED	14.70	0.0009	0.0062	0.0897	0.2646	0.5292

Table 229. Cumulative rems to organs from $^{239,240}Pu$ via inhalation pathway, liver.

LIVING PATTERN	PCI/G IN SOIL	5 YRS	EXPOSED 10 YRS	30 YRS	50 YRS	70 YRS
I. MODIFIED	0.05	0.0000	0.0000	0.0002	0.0005	0.0008
UNMODIFIED	0.12	0.0000	0.0000	0.0004	0.0011	0.0020
II. MODIFIED	2.00	0.0001	0.0005	0.0066	0.0186	0.0340
UNMODIFIED	4.70	0.0002	0.0011	0.0155	0.0437	0.0799
III. MODIFIED	7.30	0.0003	0.0018	0.0241	0.0679	0.1241
UNMODIFIED	17.00	0.0007	0.0041	0.0561	0.1581	0.2890
IV. MODIFIED	15.00	0.0006	0.0036	0.0495	0.1395	0.2550
UNMODIFIED	77.00	0.0031	0.0185	0.2541	0.7161	1.3090
V. MODIFIED	7.30	0.0003	0.0018	0.0241	0.0679	0.1241
UNMODIFIED	17.60	0.0007	0.0042	0.0581	0.1637	0.2992
VI. MODIFIED	9.50	0.0004	0.0023	0.0313	0.0883	0.1615
UNMODIFIED	14.70	0.0006	0.0035	0.0495	0.1367	0.2499

case represents the current conditions; "village graveled" shows the effect of placing a 5-cm gravel layer in the village area; and "_________ plowed" indicates the effect of thoroughly mixing the top 30 cm of soil in the specified area.

$D_{marine\ food\ chain}$

Doses via the marine and terrestrial food chains were estimated using the following differential equation to describe the intake and retention by man:

$$\frac{dC_{man}}{dt} = \frac{I f_{man} C}{M} - \lambda_{man} C_{man} \qquad (3)$$

where

C_{man} = concentration of nuclide in man, pCi/g

I = food intake, g/day,

f_{man} = fraction of nuclide ingested reaching the organ of reference,

C = concentration of nuclide in food product, pCi/g, (i.e., fish, shellfish, coconut, land crab, etc.),

M = mass of the organ of reference, (g),

and

λ_{man} = effective elimination rate of nuclide from man, (day^{-1}).

$(\lambda_{man} = \lambda_{biological} + \lambda_{radioactive})$

The concentration C in the food products is calculated assuming that the nuclide

Table 230. Cumulative rems to organs from $^{239,240}Pu$ via inhalation pathway, lung.

LIVING PATTERN	PCI/G IN SOIL	5 YRS	EXPOSED 10 YRS	30 YRS	50 YRS	70 YRS
I. MODIFIED	0.05	0.0000	0.0001	0.0004	0.0006	0.0009
UNMODIFIED	0.12	0.0001	0.0003	0.0009	0.0016	0.0022
II. MODIFIED	2.00	0.0017	0.0044	0.0152	0.0260	0.0360
UNMODIFIED	4.70	0.0040	0.0103	0.0357	0.0611	0.0846
III. MODIFIED	7.30	0.0063	0.0161	0.0555	0.0949	0.1314
UNMODIFIED	17.00	0.0146	0.0374	0.1292	0.2210	0.3060
IV. MODIFIED	15.00	0.0129	0.0330	0.1140	0.1950	0.2700
UNMODIFIED	77.00	0.0662	0.1694	0.5852	1.0010	1.3860
V. MODIFIED	7.30	0.0063	0.0161	0.0555	0.0949	0.1314
UNMODIFIED	17.60	0.0151	0.0387	0.1338	0.2288	0.3168
VI. MODIFIED	9.50	0.0082	0.0209	0.0722	0.1235	0.1710
UNMODIFIED	14.70	0.0126	0.0323	0.1117	0.1911	0.2646

disappears only by radioactive decay, i. e., that no other processes are in operation which reduce the nuclide availability in the food chain. Therefore $C = C_o e^{-\lambda_r t}$, where C_o is the concentration observed at the time of the survey and λ_r is the radioactive decay constant. The concentration in man at any time t after initial consumption of the food is:

$$C_{man} = \frac{I f_{man} C_o}{M(\lambda_{man} - \lambda_r)} \times \left(e^{-\lambda_r t} - e^{-\lambda_{man} t}\right), \text{ pCi/g.} \quad (4)$$

The dose at any time t after initial consumption is

$$\text{Dose (rem)} = KE \int_0^t C_{man}\, dt$$

$$= KE \int_0^t \frac{I f_{man} C_o}{M(\lambda_{man} - \lambda_r)} \times \left(e^{-\lambda_r t} - e^{-\lambda_{man} t}\right) dt, \quad (5)$$

where K is a conversion constant from pCi/g to rem and equals 5.1×10^{-5} $\frac{\text{disintegrations} \cdot \text{g} \cdot \text{rem}}{\text{pCi} \cdot \text{MeV} \cdot \text{day}}$ and E is the disintegration energy of the nuclide in MeV, including a factor for relative biological effectiveness (RBE). The final dose is then determined from the integration of the equation, i. e.,

$$\text{Dose} = \frac{K E I f_{man} C_o}{M(\lambda_{man} - \lambda_r)} \times \left[\frac{1 - e^{-\lambda_r t}}{\lambda_r} - \frac{1 - e^{-\lambda_{man} t}}{\lambda_{man}} \right], \text{ rem.} \quad (6)$$

Table 232 lists the f_{man} (FMAN), $\lambda_{radioactive}$ (LR), λ_{man} (LMAN), and disintegration energy (E) values for all of the isotopes in the dose calculations.

Fish and marine organism data from the survey have been found not to have any statistically significant differences for dose estimation purposes between samples taken in different parts of the lagoon. The radionuclide concentration, C_o, used in the marine food chain dose assessment, therefore, is the average value for all fish from the entire Atoll determined from the survey and is listed in Tables 233 and 234 for each nuclide. The average values for radionuclide concentrations listed in the tables are in pCi per gram dry weight, with data corrected to pCi per gram wet

Table 231. Estimated integral external free-air gamma doses.

Case	Living pattern	Gamma dose, rad — Time interval, yr: 5	10	30	70
I	Village: FRED/ELMER/DAVID				
	Visits to ALVIN-KEITH				
	Time distribution: Table 137				
Unmodified		0.14	0.28	0.83	1.92
II	Village: FRED/ELMER/DAVID				
	Visits to ALICE-WILMA				
	Time distribution: Table 137				
Unmodified		0.38	0.68	1.59	2.97
3. Northern islands plowed		(0.22)	(0.41)	(1.08)	(2.26)
III	Village: JANET				
	No visits to other islands				
	Time distribution: Table 137 with "other islands" time spent in interior of JANET				
Unmodified		0.94	1.71	3.95	6.66
1. Village graveled		(0.82)	(1.49)	(3.48)	(5.96)
2. JANET plowed		(0.36)	(0.68)	(1.70)	(3.24)
IV	Village: BELLE				
	Visits to ALICE-WILMA				
	Time distribution: Table 137				
Unmodified		2.72	4.78	10.06	15.50
1. Village graveled		(1.78)	(3.14)	(6.69)	(10.53)
2. Plus BELLE plowed		(0.83)	(1.47)	(3.26)	(5.47)
3. Plus Northern islands plowed		(0.68)	(1.23)	(2.77)	(4.76)

Table 231 (continued).

Case	Living pattern	5	10	30	70
V	Village: JANET				
	Visits to KATE-WILMA				
	Time distribution: Table 137				
Unmodified		0.71	1.28	2.94	5.06
1. Village graveled		(0.59)	(1.07)	(2.48)	(4.36)
2. Plus JANET plowed		(0.36)	(0.66)	(1.59)	(3.02)
3. Plus KATE-WILMA plowed		(0.29)	(0.54)	(1.36)	(2.71)

		Gamma dose, rad			
		Time interval, yr			
Case	Living pattern	5	10	30	70
VI	Village: JANET				
	Visits to ALICE-IRENE				
	Time distribution: Table 137				
Unmodified		1.15	2.03	4.39	7.13
1. Village graveled		(1.02)	(1.81)	(3.93)	(6.43)
2. Plus JANET plowed		(0.80)	(1.41)	(3.05)	(5.09)
3. Plus ALICE-IRENE plowed		(0.43)	(0.78)	(1.85)	(3.39)
VIa	Village: JANET				
	Visits to ALICE-WILMA				
	Time distribution: Table 136				
Unmodified		0.76	1.37	3.12	5.33
1. Village graveled		(0.62)	(1.12)	(2.58)	(4.51)
2. Plus JANET plowed		(0.41)	(0.75)	(1.77)	(3.27)
3. Plus Northern islands plowed		(0.30)	(0.56)	(1.40)	(2.76)
VIb	Village: JANET				
	Visits to ALVIN-KEITH				
	Time distribution: Table 136				
Unmodified		0.60	1.10	2.60	4.60
1. Village graveled		(0.48)	(0.88)	(2.14)	(3.90)
2. Plus JANET plowed		(0.25)	(0.48)	(1.26)	(2.56)
Mean population dose					
(Average of Cases I, II, III, V, and VI)					
Unmodified		0.66	1.20	2.74	4.75
1. Village graveled		(0.59)	(1.07)	(2.46)	(4.33)
2. Plus JANET plowed		(0.41)	(0.74)	(1.75)	(3.25)
3. Plus All Northern islands plowed		(0.29)	(0.54)	(1.36)	(2.70)
Sea level, U.S.A.					
(80 mrad/yr) Typical		0.40	0.80	2.40	5.60

Table 232. The disintegration energy E and the radioactive half-life LR are listed for each radionuclide. The effective biological half-time LMan and the fraction of ingested isotope reaching the organ of reference FMan are listed for three receptor organs, bone, liver, and whole body.

1			BONE MASS=	5.000E+03	LIVER MASS=	1.800E+03	WHOLEBODY MASS=	7.000E+04
NUCLIDE	E	LR	-LMAN-	-FMAN-	-LMAN-	-FMAN-	-LMAN-	-FMAN-
3 H	6.287E-03	1.549E-04	5.790E-02	9.100E-02	5.790E-02	2.600E-02	5.790E-02	1.000E+00
14 C	6.087E-02	3.314E-07	1.733E-02	2.500E-02	6.930E-02	2.600E-02	6.930E-02	1.000E+00
55FE	6.540E-03	7.032E-04	1.116E-03	1.000E-02	1.954E-03	1.300E-02	1.569E-03	1.000E-01
60CO	8.740E-01	3.609E-04	2.924E-02	2.000E-02	8.191E-03	8.310E-02	8.191E-03	3.000E-01
63NI	1.780E-02	2.064E-05	8.969E-04	1.500E-01	1.407E-03	2.000E-03	1.060E-03	3.000E-01
90SR	5.500E+00	6.781E-05	1.987E-03	3.000E-01	1.156E-01	7.800E-03	1.211E-04	3.000E-01
106RU	1.400E+00	1.899E-03	3.439E-03	3.300E-02	1.160E-02	6.300E-02	7.229E-03	3.000E-01
102RH	1.000E+00	6.544E-04	4.240E-02	1.000E-02	3.873E-02	8.000E-03	6.729E-02	2.000E-01
113CD	1.800E-01	1.356E-04	5.911E-03	9.000E-05	3.601E-03	1.900E-01	1.375E-04	5.900E-02
125SB	3.600E-01	7.032E-04	7.633E-03	3.000E-03	1.894E-02	6.000E-05	1.894E-02	3.000E-02
129 I	7.686E-02	1.187E-10	4.950E-02	7.000E-02	9.900E-02	1.200E-01	5.022E-03	1.000E+00
133BA	3.940E-01	2.637E-04	1.093E-02	3.500E-02	3.745E-04	3.000E-05	1.093E-02	5.000E-02
137CS	5.900E-01	6.329E-05	6.353E-03	9.100E-02	6.363E-03	2.600E-02	7.142E-03	1.000E+00
144CE	3.754E+00	2.432E-03	2.894E-03	3.000E-05	4.797E-03	2.500E-05	3.662E-03	1.000E-04
147PM	2.297E+00	7.032E-04	1.165E-03	3.500E-05	1.760E-03	6.000E-06	1.760E-03	1.000E-04
151SM	1.523E-02	2.110E-05	4.831E-04	3.500E-05	3.727E-03	3.500E-05	[illegible]	1.000E-04
152EU	6.600E-01	1.531E-04	3.379E-04	3.600E-05	5.610E-03	2.500E-05	3.379E-04	1.000E-04
155EU	1.600E-01	1.055E-03	1.240E-03	3.600E-05	6.511E-03	2.500E-05	1.240E-03	1.000E-04
207BI	1.000E+00	6.329E-05	5.217E-02	3.000E-04	4.026E-02	1.500E-03	1.387E-01	1.000E-02
235 U	4.600E+00	2.662E-12	8.030E-03	5.400E-05	1.899E-06	1.000E-02	8.030E-03	1.000E-04
238PU	4.600E+01	2.134E-05	4.032E-05	1.350E-05	2.323E-05	1.200E-05	3.083E-05	3.000E-05
239PU	5.300E+01	7.794E-08	1.906E-05	1.350E-05	1.977E-06	1.200E-05	9.571E-06	3.000E-05
240PU	5.300E+01	2.809E-07	1.927E-05	1.350E-05	2.180E-06	1.200E-05	9.774E-06	3.000E-05
241AM	5.700E+01	4.145E-06	2.313E-05	4.592E-05	5.161E-05	4.500E-05	2.313E-05	1.000E-04

Table 233. Average concentration, number of samples in the average, standard deviation, and high and low of the range for all fish in the entire Enewetak Atoll.

NUCLIDE	TISSUE	NO. OF SAMPLES	AVERAGE PCI/GRAM*	STANDARD DEVIATION	RANGE PCI/GRAM HIGH	LOW	AVERAGE PCI/GRAM**	LOGNORMAL MEDIAN PCI/GRAM
01003	MUSCLE	9	3.955E-01	1.517E-01	7.189E-01	1.845E-01	3.955E-01	3.712E-01
19040	MUSCLE	116	1.189E+01	5.277E+00	2.697E+01	2.982E+00	1.189E+01	1.075E+01
26055	MUSCLE	123	1.574E+01	4.108E+01	3.833E+02	1.577E-01	1.566E+01	5.063E+00
27060	MUSCLE	128	2.005E+00	5.377E+00	3.827E+01	4.063E-02	1.958E+00	5.974E-01
38090	MUSCLE	125	1.562E-01	2.460E-01	1.541E+00	1.051E-03	1.177E-01	6.308E-02
44106	MUSCLE	88	8.085E-01	4.558E-01	2.237E+00	3.017E-01	0.	7.058E-01
45102	MUSCLE	128	9.044E-02	6.601E-02	3.729E-01	1.805E-02	0.	7.165E-02
48113	MUSCLE	1	2.635E-01	0.	2.635E-01	2.635E-01	2.635E-01	2.635E-01
51125	MUSCLE	128	2.449E-01	2.581E-01	2.096E+00	7.734E-02	3.910E-02	1.970E-01
55137	MUSCLE	128	3.897E-01	7.940E-01	6.779E+00	2.636E-02	3.493E-01	1.955E-01
56133	MUSCLE	104	1.431E-01	1.205E-01	7.631E-01	2.445E-02	1.598E-02	1.004E-01
58144	MUSCLE	4	2.822E-01	1.269E-02	2.975E-01	2.699E-01	0.	2.822E-01
63152	MUSCLE	128	7.826E-02	5.899E-02	3.415E-01	2.779E-02	0.	6.329E-02
63155	MUSCLE	128	1.107E-01	7.631E-02	5.212E-01	3.097E-02	1.411E-02	9.242E-02
83207	MUSCLE	128	2.409E+00	2.233E+01	2.527E+02	1.965E-02	2.372E+00	1.350E-01
92235	MUSCLE	122	7.932E-02	4.723E-02	2.547E-01	2.271E-02	0.	6.563E-02
94000	MUSCLE	123	2.477E-01	2.083E+00	2.306E+01	4.828E-04	2.444E-01	1.257E-02
94238	MUSCLE	64	1.390E-02	2.175E-02	1.140E-01	1.002E-03	5.241E-03	7.679E-03
95241	MUSCLE	128	1.144E-01	8.462E-02	8.023E-01	2.232E-02	2.771E-02	9.298E-02

*AVERAGE (IF NON-DETECTED, CONCENTRATION SET EQUAL TO DETECTION LIMIT) PCI/GRAM
**AVERAGE (IF NON-DETECTED, CONCENTRATION SET EQUAL TO ZERO) PCI/GRAM

Table 234. Radionuclide concentrations in fish (January 1972).

Nuclide	Sample	No. of Samples	Concentration, pCi/g dry weight Average	High	Low
^{137}Cs	All fish[a]	128	0.39	6.8	0.026
^{60}Co	All fish[a]	128	2.0	38	0.041
^{90}Sr	All fish[a]	125	0.16	1.5	0.0010
^{90}Sr	Eviscerated whole fish	74	0.21	---	---
^{90}Sr	Fish muscle only	51	0.075	---	---

[a]All fish includes eviscerated whole fish and those fish where muscle was separated from bone and only the muscle was analyzed.

weight for use in the dose code by dividing by 3.5, the average wet-to-dry ratio for fish from the Atoll.

Integral doses calculated from the marine survey data are listed in Table 235 for the whole body and bone for 5, 10, 30 and 70 yr. The major contribution to the whole-body dose comes from ^{137}Cs and ^{60}Co, while the bone dose comes from ^{90}Sr, as well as from ^{137}Cs and ^{60}Co. The third line of the table gives the summation of the dose to each organ from the three isotopes. The bottom entry in the table lists the dose from all radionuclides listed in the Table 235 footnote.

D terrestrial food chain

Evaluation of the potential dose to the returning population via the terrestrial food chain has been structured on the basis of the living patterns in Table 225. The quantity of radionuclides ingested via terrestrial foods was computed from the measured and predicted concentration of activities according to the expected daily diets listed in Table 227. Except for coconut and arrowroot, the daily intake of the food items listed in this table refers to g/day of fresh food. The g/day intakes listed for coconut and arrowroot refer to the dry weight intake of coconut meat (copra) and processed arrowroot starch. Inferred initial ingestion rates assuming the diet at time of return are shown in Table 236. This diet contains only foods that are available on islands of the group at the time of return, i.e., domestic meat, birds, bird eggs, coconut crabs, and, in the case of the southern islands, coconut meat and coconut milk.

The 30- and 70-yr integral doses were calculated assuming the 10-yr post-return diet. In addition to the foods that are available at the time of return, the 10-yr post-return diet includes pandanus fruit, breadfruit, arrowroot, coconut meat, and coconut milk for all islands. The initial rates of ingestion for each island group assuming the 10-yr post-return diet are listed in Table 237. These values are presented in two parts; the rates of ingestion for the foods immediately available are presented on the left side of Table 237 under January 1, 1974, while the rates of ingestion for the foods that are to become available 8 yr after return

Table 235. Integral dose[a] for 5, 10, 30, and 70 yr from the marine food chain.

	Integral dose, rem[b]							
	5 yr		10 yr		30 yr		70 yr	
Nuclide	W. B.	Bone	W. B.	Bone	W. B.	Bone	W. B.	Bone
^{137}Cs	0.0061	0.0061	0.012	0.012	0.030	0.030	0.049	0.049
^{60}Co	0.0078	0.0078	0.012	0.012	0.017	0.017	0.017	0.017
^{90}Sr	---	0.13	---	0.31	---	0.77	--	1.3
Sum	0.014	0.14	0.024	0.33	0.047	0.82	0.066	1.4
All nuclides[c]	0.016	0.14	0.028	0.34	0.053	0.84	0.089	1.6

[a] The dose is based upon the average concentration for fish from the entire Atoll and upon a dietary fish intake of 600 g/day. These doses apply to all six living patterns.

[b] The concentration data were corrected to January 1974, the earliest possible return date to the Atoll; all integral doses are calculated for periods which begin on January 1974.

[c] Isotopes included in the "All nuclides" calculation:

^{3}H	^{60}Co	^{102}Rh	^{137}Cs	^{152}Eu	^{235}U
^{14}C	^{90}Sr	^{113}Cd	^{133}Ba	^{155}Eu	^{238}Pu
^{55}Fe	^{106}Ru	^{125}Sb	^{144}Ce	^{207}Bi	^{239}Pu
					^{241}Am

are presented on the right side of Table 237 under the 8-yr post-return date, January 1, 1982. In essence, the foods immediately available are assumed to contribute to the diet beginning January 1, 1974, and the edible plants that are yet to be established are assumed to contribute to the diet beginning January 1, 1982.

Using these data, plus the integrated dose per unit rate of ingestion to whole body and bone shown in Table 238, the integral 5- and 10-yr doses shown in Table 239 have been calculated. The 5- and 10-yr dosages particularly relate to the situation during the initial few years following return.

In computing the bone dose, the whole-body dose from ^{137}Cs and the other non-bone seekers has been added to the bone dose from ^{90}Sr and $^{239,240}Pu$. The whole-body dose has been computed as the sum of the whole-body dosages from the non-bone seekers.

Similarly, integral 30- and 70-yr doses have been calculated assuming the 10-yr post-return diet (Table 240).

Total Dose

The total 30-yr integral dose predicted for whole body and for bone for the six living patterns are listed in Table 241. This table includes the contributions from each pathway and, for

Table 236. Rate of ingestion of radionuclides from terrestrial foods assuming diet at time of return (Jan. 1, 1974).

	Ingestion rate, pCi/day					
Food item	^{3}H	^{55}Fe	^{60}Co	^{90}Sr	^{137}Cs	$^{239,240}Pu$
A. Island group ALICE-IRENE						
Pork and chicken				185	3100	
Wild birds		984	6.21	1.21	<2.4	0.143
Bird eggs		69	<0.29	0.45	<0.24	0.0074
Total		1050	6.35	187	3100	0.150
B. Island group BELLE						
Pork and chicken				302	6960	
Total				302	6960	
C. Island group JANET						
Pork and chicken				108	2320	
Wild birds		1800	7.70	0.29	2.5	0.100
Bird eggs		171	<0.39	0.97	0.6	0.074
Total		1970	7.89	109	2320	0.174
D. Island group KATE-WILMA, LEROY						
Pork and chicken				47.4	858	
Wild birds		1800	7.70	0.29	2.50	0.100
Bird eggs		113	<0.28	0.02	<0.25	0.077
Coconut crabs	0.480		1.03	1.96	7.59	0.0035
Total	0.480	1900	8.87	49.7	868	0.180
E. Island group ALVIN-KEITH						
Pork and chicken				6.18	50.9	
Wild birds		1700	6.41	0.37	2.55	0.704
Bird eggs		131	<0.35	0.02	<0.35	0.003
Coconut	29.3	<23	<2.9	3.35	68.7	<0.259
Coconut milk	14.9	<11	<1.42	0.17	3.44	<0.129
Coconut crabs	2.91		4.23	2.58	9.31	0.023
Total	47.1	1850	13.7	12.7	135	0.99

Table 237. Rate of ingestion of radionuclides from terrestrial foods assuming 10-yr post-return diet.

	Ingestion rate, pCi/day											
	January 1, 1974						January 1, 1982					
Food item	^{3}H	^{55}Fe	^{60}Co	^{90}Sr	^{137}Cs	$^{239,240}Pu$	^{3}H	^{55}Fe	^{60}Co	^{90}Sr	^{137}Cs	$^{239,240}Pu$
A. Island group ALICE-IRENE												
Domestic meat				308	5170							
Pandanus fruit										941	8840	
Breadfruit										807	7570	
Wild birds		197	1.24	0.242	<0.5	0.0286						
Bird eggs		34.5	<0.14	0.226	<0.1	0.0037						
Arrowroot										47	71	
Coconut meat							23.7	664	<16.3	135	2210	18.1
Coconut milk							35.6	<37	<8.5	20	331	<1.7
Total		231	1.31	308	5170	0.0323	59.3	683	12.4	1950	19000	19
B. Island group BELLE												
Domestic meat				504	11600							
Pandanus fruit								1.34	<1.46	1540	19800	<9.5
Breadfruit								1.15	<1.25	1320	17000	<8.1
Arrowroot										77	159	
Coconut meat										221	4960	
Coconut milk										33	743	
Total				504	11600			2.50	1.35	3180	42700	8.8
C. Island group JANET												
Domestic meat				180	3870							
Pandanus fruit								7.12	<1.25	550	6610	0.082
Breadfruit								6.10	<1.07	471	5560	0.071
Wild birds		360	1.54	0.058	0.50	0.020						
Bird eggs		85.5	<0.19	0.482	0.29	0.037						
Arrowroot										28	53	
Coconut meat									<1.85	79	1650	
Coconut milk								<2.54	<2.27	12	248	<1.31
Total		445	1.64	181	3870	0.057		14.5	3.22	1140	14100	0.81

Table 237 (Continued).

Food item	Ingestion rate, pCi/day											
	January 1, 1974						January 1, 1982					
	^{3}H	^{55}Fe	^{60}Co	^{90}Sr	^{137}Cs	$^{239,240}Pu$	^{3}H	^{55}Fe	^{60}Co	^{90}Sr	^{137}Cs	$^{239,240}Pu$
D. Island group KATE-WILMA + LEROY												
Domestic meat				79	1430							
Pandanus fruit								3.94	<13.8	241	2480	0.316
Breadfruit								3.38	<11.8	207	2120	0.271
Wild birds		360	1.54	0.058	0.50	0.020						
Bird eggs		56	<0.14	0.01	<0.12	0.039						
Arrowroot										12	20	
Coconut meat							19.0	204	<1.05	34.7	619	<8.64
Coconut milk							28.5	<6.44	<2.27	5.2	93	<0.38
Coconut crabs	0.480		1.03	1.96	7.59	0.003						
Total	0.480	416	2.59	81	1440	0.062	47.5	215	14.4	500	5330	5.0
E. Island group ALVIN-KEITH												
Domestic meat				10.3	84.9							
Pandanus fruit								1.33	<0.65	9.44	85.4	0.156
Breadfruit								1.14	<0.56	8.09	73.2	0.134
Wild birds		340	1.28	0.073	0.51	0.141						
Bird eggs		65	<0.17	0.009	<0.17	0.002						
Arrowroot			Not available							0.47	0.68	
Coconut meat	29.3	<23	<2.9	3.35	68.7	<0.259						
Coconut milk	44.6	<33	<4.2	0.50	10.3	<0.386						
Coconut crabs	2.91		4.23	2.58	9.3	0.023						
Total	76.8	433	9.17	16.8	174	0.488		2.48	0.60	18.0	159	0.290

Table 238. Integrated dose per unit rate of ingestion to whole body and bone.

Nuclide	Organ	D_T, rem/pCi/day						
		Period of integration						
		2 yr	5 yr	10 yr	22 yr	30 yr	62 yr	70 yr
^{3}H	Whole body	4.51(-8)[a]	1.05(-7)	1.85(-7)	3.05(-7)	3.51(-7)	4.17(-7)	4.23(-7)
^{55}Fe	Whole body	7.50(-8)	2.35(-7)	3.73(-7)	4.29(-7)	4.32(-7)	4.32(-7)	4.32(-7)
^{60}Co	Whole body	1.27(-5)	2.96(-5)	4.65(-5)	6.09(-5)	6.33(-5)	6.46(-5)	6.46(-5)
^{90}Sr	Bone	2.87(-3)	1.08(-2)	2.39(-2)	4.99(-2)	6.33(-2)	9.70(-2)	1.02(-1)
^{137}Cs	Whole body	3.49(-5)	9.62(-5)	1.89(-4)	3.74(-4)	4.71(-4)	7.22(-4)	7.61(-4)
$^{239,240}Pu$	Bone	1.51(-6)	9.39(-6)	3.71(-5)	1.75(-4)	3.19(-4)	1.27(-3)	1.59(-3)

[a]The number within parentheses denotes the power of 10. Thus, 4.51(-8) is a contraction of 4.51×10^{-8} rem/pCi/day.

Table 239. Prediction of the dosage from ingestion of terrestrial foods assuming diet at the time of return.

	Isotope	5-yr dose, rem Whole body	5-yr dose, rem Bone	10-yr dose, rem Whole body	10-yr dose, rem Bone
A. Island group ALICE-IRENE					
	^{3}H			2.7(-6)	
	^{55}Fe	2.5(-4)[a]		4.4(-4)	
	^{60}Co	1.9(-4)		4.5(-4)	
	^{90}Sr		2.02		10.1
	^{137}Cs	0.298		1.25	
	$^{239,240}Pu$		1.4(-6)		3.4(-5)
	Subtotal	0.298	2.02	1.25	10.1
	Total 5-yr whole-body dose	0.30 rem		Total 10-yr whole-body dose	1.25 rem
	Total 5-yr bone dose	2.32 rem		Total 10-yr bone dose	11.3 rem
B. Island group BELLE					
	^{55}Fe			1.9(-7)	
	^{60}Co			1.7(-5)	
	^{90}Sr		3.26		16.3
	^{137}Cs	0.669		2.81	
	$^{239,240}Pu$				1.3(-5)
	Subtotal	0.67	3.26	2.81	16.3
	Total 5-yr whole-body dose	0.67 rem		Total 10-yr whole-body dose	2.81 rem
	Total 5-yr bone dose	3.93 rem		Total 10-yr bone dose	19.2 rem

Table 239 (Continued).

	Isotope	5-yr dose, rem		10-yr dose, rem	
		Whole body	Bone	Whole body	Bone
C. Island group JANET					
	^{55}Fe	4.6(-4)		7.4(-4)	
	^{60}Co	2.3(-4)		4.1(-4)	
	^{90}Sr		1.18		5.88
	^{137}Cs	0.223		0.831	
	$^{239,240}Pu$		1.6(-6)		7.6(-6)
	Subtotal	0.224	1.18	0.932	5.88
	Total 5-yr whole-body dose		0.22 rem	Total 10-yr whole-body dose	0.93 rem
	Total 5-yr bone dose		1.40 rem	Total 10-yr bone dose	6.82 rem
D. Island group KATE-WILMA + LEROY					
	^{3}H	5.0(-8)		2.2(-6)	
	^{55}Fe	4.5(-4)		7.3(-4)	
	^{60}Co	2.6(-4)		6.0(-4)	
	^{90}Sr		0.536		2.62
	^{137}Cs	0.0835		0.350	
	$^{239,240}Pu$		1.7(-6)		1.4(-5)
	Subtotal	0.0842	0.536	0.351	2.62
	Total 5-yr whole-body dose		0.084 rem	Total 10-yr whole-body dose	0.351 rem
	Total 5-yr bone dose		0.620 rem	Total 10-yr bone dose	2.97 rem

Table 239 (Continued)

Isotope	5-yr dose, rem Whole body	Bone	10-yr dose, rem Whole body	Bone
E. Island group ALVIN-KEITH				
^{3}H	4.9(-6)		8.7(-6)	
^{55}Fe	4.4(-4)		6.9(-4)	
^{60}Co	4.1(-4)		6.5(-4)	
^{90}Sr		0.137		0.355
^{137}Cs	0.0130		0.0311	
$^{239,240}Pu$		9.3(-6)	0.0324	3.7(-5)
Subtotal	0.0138	0.137	0.0324	0.303
Total 5-yr whole-body dose		0.014 rem	Total 10-yr whole-body dose	0.032 rem
Total 5-yr bone dose		0.151 rem	Total 10-yr bone dose	0.387 rem

[a]The number within parentheses denotes the power of 10. Thus, 2.5(-4) is a contraction of 2.5×10^{-4}.

Table 240. Prediction of the dosage from ingestion of terrestrial foods assuming 10-yr post-return diet.

Isotope	Ingestion rate, pCi/day January 1, 1974	30-yr dose, rem		70-yr dose, rem		Ingestion rate, pCi/day January 1, 1984	22-yr dose, rem		62-yr dose, rem	
		Whole body	Bone	Whole body	Bone		Whole body	Bone	Whole body	Bone
A. Island group										
ALICE-IRENE										
^{3}H						59.3	1.8(-5)		2.5(-5)	
^{55}Fe	231	1.0(-4)[a]		1.0(-4)		683	0.0003		0.0003	
^{60}Co	1.31	8.3(-5)		8.5(-5)		12.4	0.0008		0.0008	
^{90}Sr	308		19.5		31.5	1950		97.3		190
^{137}Cs	5170	2.44		3.93		19,000	7.11		13.7	
$^{239,240}Pu$	0.0323		1.0(-5)		5.1(-5)	19		0.003		0.024
Subtotal		2.44	19.5	3.93	31.5		7.11	97.3	13.7	190
Total 30-yr whole-body dose		9.55 rem				Total 70-yr whole-body dose		17.7 rem		
Total 30-yr bone dose		126 rem				Total 70-yr bone dose		239 rem		
B. Island group										
BELLE										
^{55}Fe						2.50	1.1(-6)		1.1(-6)	
^{60}Co						1.35	8.2(-5)		8.7(-5)	
^{90}Sr	504		31.9		51.4	3180		159		309
^{137}Cs	11,600	5.46		8.83		42,700	16.0		30.8	
$^{239,240}Pu$						8.8		1.5(-3)		1.1(-2)
Subtotal		5.46	31.9	8.83	51.4		16.0	159	30.8	309
Total 30-yr whole-body dose		21.4 rem				Total 70-yr whole-body dose		39.6 rem		
Total 30-yr bone dose		212 rem				Total 70-yr bone dose		400 rem		

Table 240 (Continued).

Isotope	Ingestion rate, pCi/day January 1, 1974	30-yr dose, rem Whole body	30-yr dose, rem Bone	70-yr dose, rem Whole body	70-yr dose, rem Bone	Ingestion rate, pCi/day January 1, 1984	22-yr dose, rem Whole body	22-yr dose, rem Bone	62-yr dose, rem Whole body	62-yr dose, rem Bone
C. Island group										
JANET										
^{55}Fe	445	1.9(-4)		1.9(-4)		14.5	6.2(-6)		6.2(-6)	
^{60}Co	1.64	1.0(-4)		1.1(-4)		3.22	2.0(-4)		2.1(-4)	
^{90}Sr	181		11.4		18.4	1140		56.9		111
^{137}Cs	3870	1.82		2.95		14,100	5.28		10.2	
$^{239,240}Pu$	0.057		1.8(-5)		9.1(-5)	0.806		1.4(-4)		1.0(-3)
Subtotal		1.82	11.4	2.95	18.4		5.28	56.9	10.2	111
Total 30-yr whole-body dose	7.10 rem					Total 70-yr whole-body dose		13.1 rem		
Total 30-yr bone dose	75.4 rem					Total 70-yr bone dose		142 rem		
D. Island group										
KATE-WILMA + LEROY										
^{3}H	0.480	2(-7)		2.0(-7)		47.5	1.5(-5)		2.0(-5)	
^{55}Fe	416	1.8(-4)		1.8(-4)		215	9.2(-5)		9.3(-5)	
^{60}Co	2.59	1.6(-4)		1.7(-4)		14.4	8.8(-4)		9.3(-4)	
^{90}Sr	81.0		5.13		8.26	500		24.9		48.5
^{137}Cs	1440	0.677		1.09		5330	1.99		3.85	
$^{239,240}Pu$	0.062		2.0(-5)		9.8(-5)	4.96		8.7(-4)		6.3(-3)
Subtotal		0.677	5.13	1.09	8.26		1.99	24.9	3.85	48.5
Total 30-yr whole-body dose	2.67 rem					Total 70-yr whole-body dose		4.94 rem		
Total 30-yr bone dose	32.7 rem					Total 70-yr bone dose		61.7 rem		

Table 240 (Continued).

Isotope	Ingestion rate, pCi/day January 1, 1974	30-yr dose, rem Whole body	30-yr dose, rem Bone	70-yr dose, rem Whole body	70-yr dose, rem Bone	Ingestion rate, pCi/day January 1, 1984	22-yr dose, rem Whole body	22-yr dose, rem Bone	62-yr dose, rem Whole body	62-yr dose, rem Bone
E. Island group										
ALVIN-KEITH										
^{3}H	76.8	1.3(-5)		3.3(-5)						
^{55}Fe	433	1.9(-4)		1.9(-4)		2.48	1.1(-6)		1.1(-6)	
^{60}Co	9.17	5.8(-4)		5.9(-4)		0.60	3.7(-5)		3.9(-5)	
^{90}Sr	16.8		1.07		1.72	18.0		0.898		1.75
^{137}Cs	174	0.0819		0.132		159	0.0596		0.115	
$^{239,240}Pu$	0.49		1.6(-4)		7.8(-4)	0.290		1.8(-4)		1.3(-3)
Subtotal		0.0826	1.07	0.133	1.72		0.0596	0.898	0.115	1.75
Total 30-yr whole-body dose		0.142 rem				Total 70-yr whole-body dose		0.248 rem		
Total 30-yr bone dose		2.11 rem				Total 70-yr bone dose		3.71 rem		

[a] The number within parentheses denotes the power of 10; thus, 1.0(-4) is a contraction of 1.0×10^{-4}.

Table 241. The 30-yr integral dose for the six living patterns assuming unmodified conditions.

	30-yr integral dose, rem Unmodified conditions									
	Inhalation			External	Terrestrial[b]		Marine[b]		Total	
Living pattern	Bone	Lung	Liver	Bone,[a] W.B.	W.B.	Bone	W.B.	Bone	W.B.	Bone
I	7(-4)	9(-4)	4(-4)	0.83	0.14	2.1	0.053	0.84	1.0	3.8
II	0.029	0.036	0.016	1.6	2.7	33	0.053	0.84	4.4	35
III	0.10	0.13	0.056	4.0	7.1	75	0.053	0.84	11	80
IV	0.47	0.59	0.25	10	21	210	0.053	0.84	31	220
V	0.11	0.13	0.058	2.9	2.7	33	0.053	0.84	5.7	37
VI	0.090	0.11	0.049	4.4	9.6	130	0.053	0.84	14	135

Living pattern	Village island	Agriculture	Visitation
I	Enewetak-Parry	ALVIN-KEITH	Southern Is.
II	Enewetak-Parry	KATE-WILMA + LEROY	Northern Is.
III	JANET	JANET	Northern Is.
IV	BELLE	BELLE	Northern Is.
V	JANET	KATE-WILMA + LEROY	Northern Is.
VI	JANET	ALICE-IRENE	Northern Is.

[a]Taken from the chapter on external dose estimates, Table 22.
[b]Based upon diet 10 yr after return, as described in the dietary and living patterns chapter.

the external dose assessment, is based upon the unmodified conditions for the village island. The largest contribution to the whole-body and bone doses comes from the terrestrial food chain, the external dose pathway is the next highest contributor, and the marine food chain and inhalation pathway contribute the least.* The relative contributions of each diet component to the terrestrial pathway dose is shown in Tables 242 and 243.

In general, living on JANET, visiting northern islands, and maintaining agriculture on northern islands (living patterns III, V, and VI) lead to significantly higher doses than if the village and agriculture are located on islands in the southern half of the Atoll (living pattern I). Doses for these same patterns have been calculated for 5, 10, and 70 yr and are shown in Table 244.

The most significant contribution via the terrestrial food chain is the dose to bone resulting from ^{90}Sr uptake via pandanus fruit and breadfruit. For living pattern III, for example, the total terrestrial bone dose is 75 rem, of which 74% is derived from the intake of breadfruit and pandanus. It is important to note, however, that the large contribution to the bone dose via these fruits occurs only when they are grown on northern islands. Pandanus and breadfruit grown on the less contaminated southern islands lead to much lower dose commitments.

Table 245 shows the 30-yr integral dose for the six living patterns for the modified soil condition, i.e., where the village area has 5 cm of gravel and the village island is plowed. Table 246 shows the 5-, 10-, 30-, and 70-yr dose estimates for the same conditions.

Table 247 shows the additional effect on the 30-yr integral dose of limiting growth of pandanus, breadfruit, coconut, and tacca to the southern islands, while Table 248 shows the effect of limiting all terrestrial foods to the southern islands. The effect of the combination of these preventive measures reduces the dose for living pattern III from 11 rem to 1.9 rem for whole body and from 80 to 4.7 rem for bone.

A comparison of the 30-yr integral dose for living patterns I and III relative to the average United States external background dose over 30 yr is shown in Table 249.

Plutonium isotopes, because of their long half-lives, will still be present when the other major isotopes observed at the Atoll have decayed away; therefore, Tables 250 and 251 are included to show the predicted doses from plutonium to the three major receptor organs (lung, liver, and bone) via the three relevant exposure pathways.

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*As indicated earlier, these dose calculations assume that the Enewetak people will continue their current practice of using catchment rain water for drinking and that the underground lens water supply will not be a part of their diet. An indication of doses that are to be expected from lens water may be obtained from four water samples taken on JANET in July 1971. These samples, two each from each of two 2.5-m-deep holes about 100 m from the lagoon shore, gave average concentrations of 130 pCi/liter for ^{90}Sr, and 400 pCi/liter for ^{137}Cs. ^{239}Pu concentrations were scattered (<0.03, 21, <0.03, and 17 pCi/liter) but, for our current purpose, we will assume an average value of 20 pCi/liter.

Using these concentrations, and assuming an average daily intake of 100 ml of lens water, the resulting 30-yr doses would be 0.83 rem due to ^{90}Sr, 0.019 rem due to ^{137}Cs, and 0.00082 rem due to ^{239}Pu.

The island of YVONNE presents a unique hazard on Enewetak Atoll. Pure plutonium particles are present on or close to the ground surface, randomly scattered in "hot spots" over most of the area from the tower to CACTUS crater. Examination of these "hot spots" has revealed the presence of occasional milligram-size pieces of plutonium metal, as well as smaller pieces which are physically indistinguishable in size from the surrounding coral matrix. Given these current conditions, it must be assumed that pure plutonium particles of respirable size are now also present on the surface or may be present in the future as weathering effects oxidize and break down the larger particles. Lung dose assessments for this area, therefore, must be based on inhalation of pure plutonium particles rather than those having the average plutonium content of the soil.

The potential health hazard via the inhalation pathway is sufficiently great to dictate two basic alternatives for remedial action for this island: (1) Make the entire island an exclusion area – off limits to all people, or (2) conduct a cleanup campaign which will eliminate the "hot-spot" plutonium problem and remove whatever amount of soil is necessary to reduce the soil plutonium concentration to a level comparable to other northern islands. As an indication of the volumes of soil involved, removal of a 10-cm-thick layer of topsoil in the area in which "hot spots" have been detected involves approximately 17,000 m^3 of material. Further removal of soil to reduce the maximum plutonium contamination levels to 50 pCi/g or less involves an additional 25,000 m^3 of material.

Table 242. Relative contributions of terrestrial foods to the integral dose assuming diet at time of return.

Food item	Percentage of total 5-yr ^{90}Sr dose to bone	Percentage of total 5-yr ^{137}Cs dose whole body	Percentage of total 10-yr ^{90}Sr dose to bone	Percentage of total 10-yr ^{137}Cs dose whole body
A. Island group ALICE-IRENE				
Domestic meat	98.9	100	43.9	46.9
Pandanus fruit			26.8	24.7
Breadfruit			23.1	21.1
Wild birds	0.65	<0.08	0.29	0.04
Bird eggs	0.24	<0.008	0.11	0.004
Arrowroot			1.3	0.20
Coconut meat			3.9	6.2
Coconut milk			0.57	0.93
B. Island group BELLE				
Domestic meat	100	100	44.2	47.1
Pandanus fruit			27.0	24.6
Breadfruit			23.2	21.1
Arrowroot			1.4	0.20
Coconut meat			3.9	6.2
Coconut milk			0.58	0.92

Table 242 (continued)

Food item	Percentage of total 5-yr		Percentage of total 10-yr	
	^{90}Sr dose to bone	^{137}Cs dose whole body	^{90}Sr dose to bone	^{137}Cs dose whole body
C. Island group JANET				
Domestic meat	99. 1	100	43. 9	47. 0
Pandanus fruit			26. 9	24. 8
Breadfruit			22. 9	20. 8
Wild birds	0. 27	0. 11	0. 12	0. 05
Bird eggs	0. 89	0. 03	0. 39	0. 01
Arrowroot			1. 4	0. 20
Coconut meat			3. 9	6. 2
Coconut milk			0. 59	0. 93
D. Island group KATE-WILMA + LEROY				
Domestic meat	95. 4	98. 8	43. 1	46. 3
Pandanus fruit			26. 4	24. 7
Breadfruit			22. 7	21. 1
Wild birds	0. 58	0. 29	0. 26	0. 14
Bird eggs	0. 04	<0. 03	0. 02	0. 01
Arrowroot			1. 3	0. 20
Coconut meat			3. 8	6. 2
Coconut milk			0. 57	0. 93
Coconut crabs	3. 9	0. 87	2. 4	0. 41
E. Island group ALVIN-KEITH				
Domestic meat	48.7	37. 7	41. 7	30. 9
Pandanus fruit			7. 6	9. 6
Breadfruit			6. 5	8. 2
Wild birds	2. 9	1. 9	2. 5	1. 5
Bird eggs	0. 2	<0. 26	0. 13	0. 21
Arrowroot			0. 38	0. 08
Coconut meat	26. 4	50. 9	22. 6	41. 8
Coconut milk	1. 4	2. 5	1. 1	2. 1
Coconut crabs	20. 3	6. 9	17. 4	5. 6

Table 243. Relative contributions of terrestrial foods to the integral dose assuming 10-yr post-return diet.

Food item	Percentage of total 30-yr dose: ^{90}Sr dose to bone, Commencement date 1/1/74	Percentage of total 30-yr dose: ^{90}Sr dose to bone, Commencement date 1/1/82	Percentage of total 30-yr dose: ^{137}Cs dose to whole body, Commencement date 1/1/74	Percentage of total 30-yr dose: ^{137}Cs dose to whole body, Commencement date 1/1/82	Percentage of total 70-yr dose: ^{90}Sr dose to bone, Commencement date 1/1/74	Percentage of total 70-yr dose: ^{90}Sr dose to bone, Commencement date 1/1/82	Percentage of total 70-yr dose: ^{137}Cs dose to whole body, Commencement date 1/1/74	Percentage of total 70-yr dose: ^{137}Cs dose to whole body, Commencement date 1/1/82
A. Island group ALICE-IRENE								
Domestic meat	16.7		25.5		14.2		22.3	
Pandanus fruit		40.2		34.7		41.4		36.2
Breadfruit		34.5		29.6		35.5		31.0
Wild birds	0.01		<0.002		0.01		<0.002	
Bird eggs	0.01		<0.0005		0.01		<0.004	
Arrowroot		2.0		0.28		2.1		0.29
Coconut meat		5.8		8.7		5.9		9.1
Coconut milk		0.85		1.3		0.88		1.4
Subtotal	17	83	26	74	14	86	22	78
B. Island group BELLE								
Domestic meat	16.7		25.4		14.3		22.3	
Pandanus fruit		40.2		34.5		41.5		36.1
Breadfruit		34.5		29.6		35.6		31.0
Arrowroot		2.0		0.27		2.1		0.29
Coconut meat		5.8		8.7		6.0		9.0
Coconut milk		0.86		1.3		0.89		1.4
Subtotal	17	83	25	75	14	86	22	78

Table 243 (Continued).

	Percentage of total 30-yr dose				Percentage of total 70-yr dose			
	^{90}Sr dose to bone		^{137}Cs dose to whole body		^{90}Sr dose to bone		^{137}Cs dose to whole body	
	Commencement date		Commencement date		Commencement date		Commencement date	
Food item	1/1/74	1/1/82	1/1/74	1/1/82	1/1/74	1/1/82	1/1/74	1/1/82
C. Island group JANET								
Domestic meat	16.7		25.7		14.2		22.6	
Pandanus fruit		39.6		34.8		41.2		36.6
Breadfruit		34.4		29.3		35.3		30.7
Wild birds	0.005		0.003		0.005		0.003	
Bird eggs	0.05		0.002		0.04		0.002	
Arrowroot		2.0		0.28		2.1		0.29
Coconut meat		5.8		8.7		5.9		9.1
Coconut milk		0.88		1.3		0.90		1.4
Subtotal	17	83	26	74	14	86	23	77
D. Island group KATE-WILMA + LEROY								
Domestic meat	16.6		25.2		14.2		22.0	
Pandanus fruit		39.8		34.8		41.2		36.2
Breadfruit		34.2		29.7		35.4		30.9
Wild birds	0.01		0.009		0.01		0.008	
Bird eggs	0.002		0.003		0.002		0.002	
Arrowroot		2.0		0.28		2.0		0.29
Coconut meat		5.7		8.7		5.9		9.0
Coconut milk		0.86		1.3		0.89		1.4
Coconut crabs	0.41		0.13		0.35		0.12	
Subtotal	17	83	25	75	15	85	22	78

Table 243 (Continued).

	Percentage of total 30-yr dose				Percentage of total 70-yr dose			
	^{90}Sr dose to bone		^{137}Cs dose to whole body		^{90}Sr dose to bone		^{137}Cs dose to whole body	
	Commencement date		Commencement date		Commencement date		Commencement date	
Food item	1/1/74	1/1/82	1/1/74	1/1/82	1/1/74	1/1/82	1/1/74	1/1/82
E. Island group ALVIN-KEITH								
Domestic meat	33.3		28.3		30.3		26.2	
Pandanus fruit		24.1		22.5		26.5		25.0
Breadfruit		20.6		19.4		22.7		21.4
Wild birds	0.24		0.17		0.22		0.16	
Bird eggs	0.03		0.06		0.03		0.05	
Arrowroot		1.2		0.18		1.3		0.20
Coconut meat	10.8		22.9		9.9		21.2	
Coconut milk	1.6		3.4		1.5		3.2	
Coconut crabs	8.3		3.1		7.6		2.9	
Subtotal	54	46	58	42	50	50	54	46

Table 244. The 5-, 10-, 30-, and 70-yr doses for the six living patterns assuming unmodified conditions.

	Total integral dose, rem Unmodified conditions							
Living pattern	5 yr		10 yr		30 yr		70 yr	
	W. B.	Bone	W. B.	Bone	W. B.	Bone	W. B.	Bone
I	0.17	0.58	0.35	1.4	1.0	3.8	2.3	8.5
II	0.48	1.3	1.1	4.3	4.4	35	8.0	68
III	1.2	2.6	2.7	9.2	11	80	20	150
IV	3.4	6.9	7.6	25	31	220	56	420
V	0.81	1.6	1.7	4.9	5.7	37	10	71
VI	1.5	3.8	3.3	14	14	135	25	250

Table 245. The 30-yr integral dose for the six living patterns assuming modified conditions.

	30-yr integral dose, rem Modified conditions[a]									
Living pattern	Inhalation			External	Terrestrial		Marine		Total	
	Bone	Lung	Liver	Bone, W.B.	W.B.	Bone	W.B.	Bone	W.B.	Bone
I	3(-4)	4(-4)	2(-4)	0.83	0.14	2.1	0.053	0.84	1.0	3.8
II	0.012	0.015	6.6(-3)	1.1	2.7	33	0.053	0.84	3.9	35
III	0.045	0.056	0.024	1.7	7.1	75	0.053	0.84	8.9	78
IV	0.092	0.11	0.050	3.3	21	210	0.053	0.84	24	215
V	0.045	0.056	0.024	1.6	2.7	33	0.053	0.84	4.4	35
VI	0.058	0.072	0.031	3.1	9.6	130	0.053	0.84	13	135

[a]Modified by graveling the village area and by plowing the village island.

Table 246. The 5-, 10-, 30-, and 70-yr doses for the six living patterns assuming modified conditions.

Living pattern	Total integral dose, rem Modified conditions[a]							
	5 yr		10 yr		30 yr		70 yr	
	W. B.	Bone	W. B.	Bone	W. B.	Bone	W. B.	Bone
I	0.17	0.58	0.35	1.4	1.0	3.8	2.3	8.5
II	0.48	1.3	1.1	4.3	3.9	35	8.0	68
III	0.60	2.1	1.7	8.2	8.9	78	16	150
IV	1.5	5.0	4.3	22	24	215	46	410
V	0.46	1.3	1.0	4.3	4.4	35	8.0	68
VI	1.1	3.4	2.7	13	13	135	23	250

[a]Modified by gravelling the village area and plowing the village island.

Table 247. The 30-yr integral dose for the six living patterns assuming modified conditions and agriculture on the southern islands.

Living pattern	30-yr integral dose, rem Modified conditions[a] and pandanus, breadfruit, coconut, and tacca grown on southern islands									
	Inhalation			External	Terrestrial[c]		Marine		Total	
	Bone	Lung	Liver	Bone, W. B.	W. B.	Bone	W. B.	Bone	W. B.	Bone
I	3(-4)	4(-4)	2(-4)	0.83	0.14	2.1	0.053	0.84	1.0	3.8
II	0.012	0.015	0.0066	1.1	0.77	7.1	0.053	0.84	1.9	9.1
III	0.045	0.056	0.024	1.7	1.9	15	0.053	0.84	3.7	18
IV	0.092	0.11	0.050	3.3	5.7	39	0.053	0.84	9.1	43
V	0.045	0.056	0.024	1.6	0.77	7.1	0.053	0.84	2.4	9.6
VI	0.058	0.072	0.031	3.1	2.5	23	0.053	0.84	5.7	27

[a]Modified by graveling the village area and by plowing the village island.

Table 248. The 30-yr integral dose for the six living patterns assuming modified conditions and agriculture on the southern islands.

	30-yr integral dose, rem Modified conditions[a] and agriculture on southern islands									
	Inhalation			External	Terrestrial		Marine		Total	
Living pattern	Bone	Lung	Liver	Bone, W.B.	W.B.	Bone	W.B.	Bone	W.B.	Bone
I	3(-4)	4(-4)	2(-4)	0.83	0.14	2.1	0.053	0.84	1.0	3.8
II	0.012	0.015	0.0066	1.1	0.14	2.1	0.053	0.84	1.3	4.1
III	0.045	0.056	0.024	1.7	0.14	2.1	0.053	0.84	1.9	4.7
IV	0.092	0.11	0.050	3.3	0.14	2.1	0.053	0.84	3.5	6.3
V	0.045	0.056	0.024	1.6	0.14	2.1	0.053	0.84	1.8	4.6
VI	0.058	0.072	0.031	3.1	0.14	2.1	0.053	0.84	3.3	6.1

[a]Modified by graveling the village area and by plowing the village island.

Table 249. The 30-yr integral dose from all pathways compared to U. S. external background dose.

	30-yr integral dose,[a] rem			
	Unmodified case		Modified case	
Location	Whole body	Bone	Whole body	Bone
Enewetak Atoll Living pattern I	1.0	3.8	1.0	3.8
Enewetak Atoll Living pattern III	11	80	8.9	78
Enewetak Atoll Living pattern III, agriculture confined to southern islands	4.2	7.0	1.9	4.7
U. S. background only[b]	3.0	3.0	3.0	3.0

[a]Sum of all pathways for the Enewetak living patterns (i.e., external, inhalation, marine, and terrestrial).
[b]Based upon background of 100 mrem/yr at sea level.

Table 250. The plutonium 30-yr integral dose to bone, liver, and lung via the three exposure pathways. This table

Table 250. The plutonium 30-yr integral dose to bone, liver, and lung via the three exposure pathways. This table assumes unmodified conditions on the village island.

Living pattern	Marine			Terrestrial			Inhalation			Total		
	Plutonium 30-yr integral dose, rem Unmodified conditions											
	Bone	Liver	Lung	Bone	Liver	Lung	Bone	Liver	Lung	Bone	Liver	Lung
I	0.018	0.047	-	5.0(-5)	1.8(-4)	-	7(-4)	4(-4)	9(-4)	0.018	0.048	9(-4)
II	0.018	0.047	-	1.5(-3)	5.0(-3)	-	0.029	0.016	0.036	0.049	0.068	0.036
III	0.018	0.047	-	6.9(-3)	5.3(-3)	-	0.10	0.056	0.13	0.12	0.11	0.13
IV	0.018	0.047	-	3.0(-3)	0.010	-	0.47	0.25	0.59	0.49	0.31	0.59
V	0.018	0.047	-	5.0(-5)	1.8(-4)	-	0.11	0.058	0.13	0.13	0.11	0.13
VI	0.018	0.047	-	3.0(-3)	0.010	-	0.090	0.049	0.11	0.11	0.11	0.11

Table 251. The plutonium 30-yr integral dose to bone, liver, and lung via the three exposure pathways. This table assumes modified conditions.

Living pattern	Marine			Terrestrial			Inhalation			Total		
	Plutonium 30-yr integral dose, rem Modified conditions											
	Bone	Liver	Lung	Bone	Liver	Lung	Bone	Liver	Lung	Bone	Liver	Lung
I	0.018	0.047	-	5.0(-5)	1.8(-4)	-	3(-4)	2(-4)	4(-4)	0.018	0.047	4(-4)
II	0.018	0.047	-	1.5(-3)	5.0(-3)	-	0.012	0.0066	0.015	0.032	0.057	0.015
III	0.018	0.047	-	6.9(-3)	5.3(-3)	-	0.045	0.024	0.056	0.070	0.076	0.056
IV	0.018	0.047	-	3.0(-3)	0.010	-	0.092	0.050	0.11	0.11	0.11	0.11
V	0.018	0.047	-	5.0(-5)	1.8(-4)	-	0.045	0.024	0.056	0.063	0.071	0.056
VI	0.018	0.047	-	3.0(-3)	0.010	-	0.058	0.031	0.072	0.079	0.088	0.072

Appendix I

Planning and Operations Directive (NVO-121) — 1972 Enewetak Atoll Precleanup Radiological Survey

I. BACKGROUND

A. History and Purpose

The Enewetak Atoll was extensively used during the 1950's for atmospheric nuclear testing, necessitating displacement of individuals living there. Since the United States Government is prepared to release legally the entire atoll to the trust territory government at the end of 1973, subject to retention of some minor residual rights, rehabilitation of the atoll has been proposed. In anticipation of possible rehabilitation, a preliminary survey of the Enewetak Atoll was conducted by NV during May 1972 to facilitate comprehensive survey planning. This survey established partial information on the extent of radioactive material on the Atoll, but the information was not sufficiently comprehensive to permit careful assessment of the radiological implications of test debris remaining on the atoll or of cleanup costs for material that must be removed before the native population can return. A comprehensive survey is required in order that these assessments may be made. The AEC has accepted responsibility for conducting this survey and has assigned it for Headquarters coordination to DMA and has directed NV to implement the program.

The purpose of this Planning and Operations Directive is to provide guidance and to define responsibilites for the conduct of this survey.

B. Political Considerations and Interagency Arrangements

Within the AEC the Assistant General Manager for Military Application is responsible for coordination with the Department of the Interior (including Trust Territories Administration), the Department of Defense, the Environmental Protection Agency, and all other Washington level agencies and officials. There has been established an interagency Washington level coordinating group charged with definition of overall Enewetak Atoll objectives, with one member each from the Department of Interior, Department of Defense, and AEC.

C. Objectives of the Survey

Specific objectives of the Enewetak Atoll pre-cleanup radiological survey are as follows:

1. To locate and identify contaminated and activated test debris.
2. To locate and evaluate any significant radiological hazards which may complicate cleanup activities.
3. To identify sources of direct radiation and food chain-to-man paths having radiological implications.

D. Survey Plan

The Radiological Survey Plan, which describes the manner in which the technical objectives are to be achieved, is attached as Appendix A.

II. AUTHORITIES AND RESPONSIBILITIES

Authorization and guidance for the Enewetak Atoll pre-cleanup radiological survey was furnished NV per teletype from AEC Headquarters dated September 13, 1972, attached as Appendix B.

The Division of Military Application will provide overall Washington direction and will coordinate AEC policy relating to the conduct of the survey itself. Standards and requirements for the survey have been defined by the Division of Operational Safety and Biomedical and Environmental Research, and are incorporated in the Survey Plan.

Within the Nevada Operations Office, the Assistant Manager for Operations will be responsible to the Manager for successful accomplishment of the objectives of the Enewetak Atoll radiological survey, laboratory analysis effort and for preparation of the required survey and study reports. He will be supported by a Technical Director who shall have full authority and responsibility for the technical conduct and execution of the survey plan. The Assistant Manager for Operations will be assisted, to the extent required by the Assistant Manager for Engineering and Logistics, and the Director, Pacific Area Support Office, in matters of field support. Within this framework, NV's responsibilities are as follows:

1. To prepare a plan for the conduct of the field survey and for the analysis of samples obtained, utilizing necessary laboratory and contractor support.
2. To select personnel to conduct the field survey.
3. To select laboratories and personnel to accomplish the laboratory analysis work. This task includes the establishment of procedures, standards and methods for the correlation of data between laboratories.
4. To support AEC Headquarters activities required for pathway and dose assessment.
5. To arrange for necessary logistical support.
6. To maintain direct liaison with DNA for field support and to keep AEC Headquarters Divisions cognizant of field activities.
7. Pending further guidance, to address priority considerations in planning for sample analysis and for the biological pathway and dose assessment portions of this task.
8. To develop the appropriate survey reports and submit them to AEC Headquarters.

III. ORGANIZATION

The organization for the Enewetak Atoll radiological survey program is incorporated in Appendix A.

IV. SURVEY EXECUTION

The survey will be conducted over a period of about eight weeks starting on or about October 13, 1972.

The field party performing this survey is expected to include representatives of:

1. Division of Operational Safety, (DOS), HQ
2. Office of the Assistant Manager for Operations (AMO), NV
3. National Environmental Research Center (EPA/NERC), Las Vegas, Nev.
4. Laboratory of Radiation Ecology (LRE), University of Washington
5. Lawrence Livermore Laboratory (LLL)
6. Holmes and Narver, Inc. (H&N)
7. Eberline Instrument Corporation (EIC)

The Laboratory effort will continue for some months following the survey and is described in detail in Appendix A.

Initial deployment of equipment and personnel will be via military special air mission from Travis Air Force Base to Enewetak. Personnel rotation and sample shipments will be handled by normal military and commercial aircraft. A schedule of field survey personnel is attached as Appendix C.

V. PROGRAM FUNDING

Funds in the amount of $314,000 have been made available for this survey. Of this, $100,000 was provided by DOS and $214,000 by DMA.

Costs will be reported by contractors in category 03-30-01-02 (on-contingent technical support). The Finance Division will record costs as necessary to account for the various funding sources.

Contractors will be provided funding in financial plans in the above category.

LLL internal effort associated with this survey will be costed within LLL program funding.

APPENDIX A

Enewetak Radiological Survey Plan

29 September 1972

W. E. Nervik, Technical Director

I. INTRODUCTION

Purpose: AEC Headquarters has accepted responsibility for conducting a comprehensive radiological survey of the Enewetak Atoll. DMA has been given responsibility within Headquarters for the survey and they, in turn, have delegated the responsibility to NVOO. In the wording of the 13 September 1972 implementing directive from DMA to NVOO:

"It is the overall AEC purpose to gain a sufficient understanding of the total radiological environment of Eniwetok Atoll to permit judgments as to whether all or any part of the atoll can safely be reinhabited and, if so, what steps toward cleanup should be taken beforehand and what post-rehabilitation constraints must be imposed. It is necessary to thoroughly examine and evaluate radiological conditions on all islands of the atoll and in the local marine environment prior to commencement of cleanup activities in order to obtain sufficient radiological intelligence to develop an appropriate cleanup program.

Specifically, it is necessary:

1- To locate and identify contaminated and activated test debris,
2- To locate and evaluate any significant radiological hazards which may complicate cleanup activities, and
3- To identify sources of direct radiation and food chain-to-man paths having radiological implications.

You are directed to plan, organize, and conduct a radiological field survey to develop sufficient data on the total radiological environment of Eniwetok Atoll to permit the assessments on which the judgments described above can be made. This survey should be accomplished as soon as possible upon completion of the necessary planning and coordination. It should consider the total environment pertinent to rehabilitation including both external radiation dosage and biological food-chain considerations. It is anticipated that technical standards and requirements will be provided by responsible divisions within AEC Headquarters."

Organization: The organization of the field survey, the analytical work, and the interpretive effort associated with the Enewetak Program has largely been determined by the following considerations:

1. At the Headquarters level the Division of Biology and Environmental Research (DBER) will have responsibility for assessing the radiological implications of sources of direct radiation and food-chain-to-man paths. DBER will provide guidance as to the data needed from the field to conduct the assessment.

2. The Division of Operational Safety (DOS) will share responsibility for planning the survey and will provide the coordination of these plans and their extension during the survey with the Assistant General Manager for Environmental Safety (AGMES). DOS will also provide information on the survey to EPA staff at the Washington level upon request. DOS will review and evaluate all data and assessments relevant to the feasibility of various cleanup methods and methods for disposal of hazardous materials, and will make recommendations on requirements, guidelines, and environmental and health protection standards to be employed during cleanup operations.

3. The Enewetak Atoll is currently under the jurisdiction of the Air Force (SAMTEC), and contractor field operations people are on the atoll supporting the PACE experiments. DOD (DNA) has agreed that these people will support the survey program also. The PACE experiments are now standing

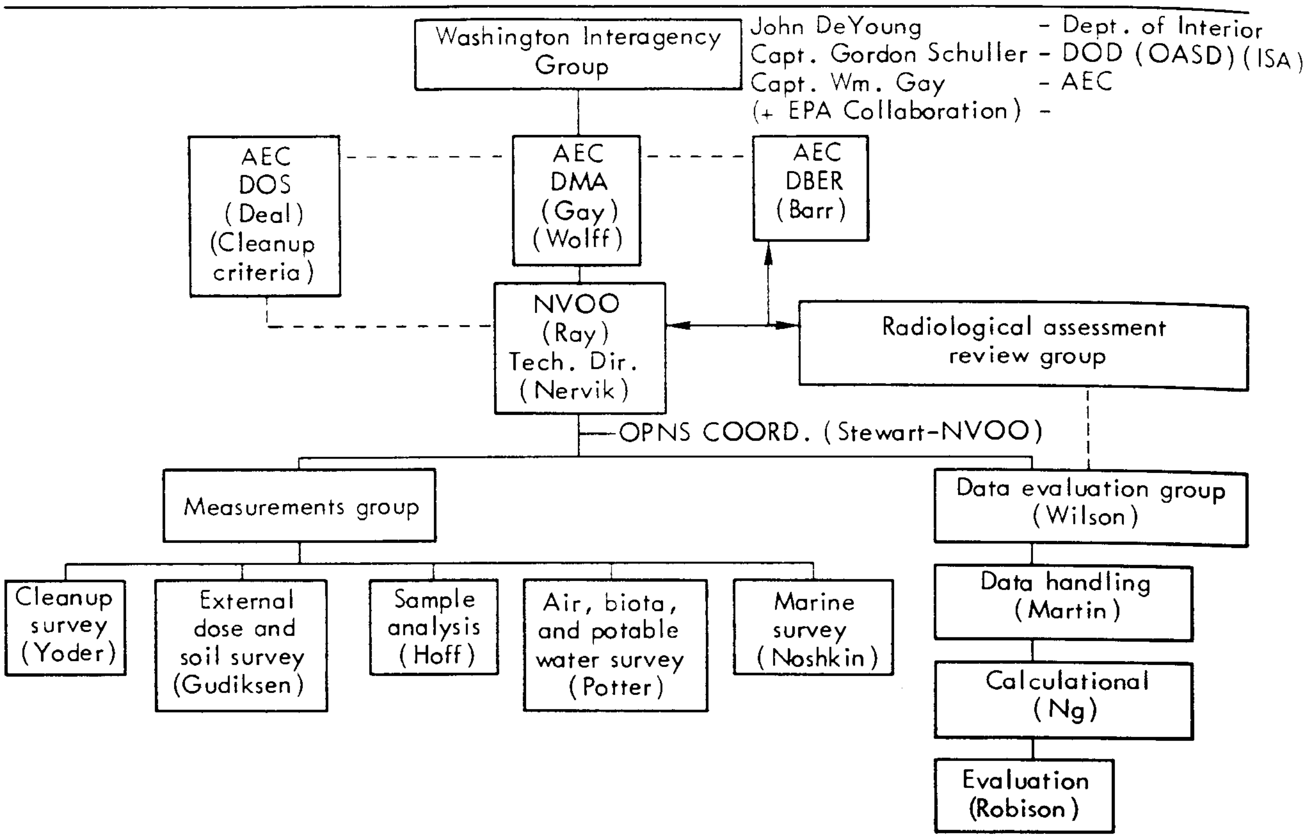


Fig. A.1. Organization of the Enewetak Survey Program.

down, and the PACE people are off the Atoll pending approval of the appropriate environmental statements. In order that we do not put an undue strain on the support capabilities, the radiological survey should be completed before the PACE people return. Their return is now scheduled for January 1, 1973.

4. The Radiological Survey is a fairly large effort superimposed on technical organizations which already have made commitments for their people for FY 73. The number of qualified organizations able and willing to respond is therefore limited.

5. Since no compromise on the quality or comprehensiveness of the survey will be acceptable, participants are being chosen on the basis of their being able to do the necessary high-quality work in the time frame in which it is needed.

With these considerations in mind, an organizational chart of the Enewetak Survey Program is shown in Fig. A.1. NVOO is the primary organization for implementing the survey, interacting with DMA, DBER, and DOS at the headquarters level. The survey itself, and the interpretive effort associated with it, have been divided into eight categories: the Radiological Assessment Review Group appointed by DBER; Field Operations Coordination at NVOO; measurements involving the Cleanup Survey; External Dose and Soil Survey; Air, Biota, and Potable Water Survey; Marine Survey; and

Sample Analysis; and Data Evaluations. Authors of detailed plans for each of the last six categories are indicated on the chart. It is now expected that the program will involve personnel from the following organizations: NVOO, NERC (EPA), LLL, LASL, MCL, Univ. of Wash., HASL, Eberline Inst. Co., TTPI, Univ. of Hawaii, DOS, and DBER, plus organizations not yet identified involved in the Radiological Assessment Review Group.

For orientation purposes a map of Enewetak Atoll is shown in Fig. A.2. Previous surveys in May and July of this year indicate that radiological contamination levels vary from light (1-10 μR/hr at 3 ft) for islands on the

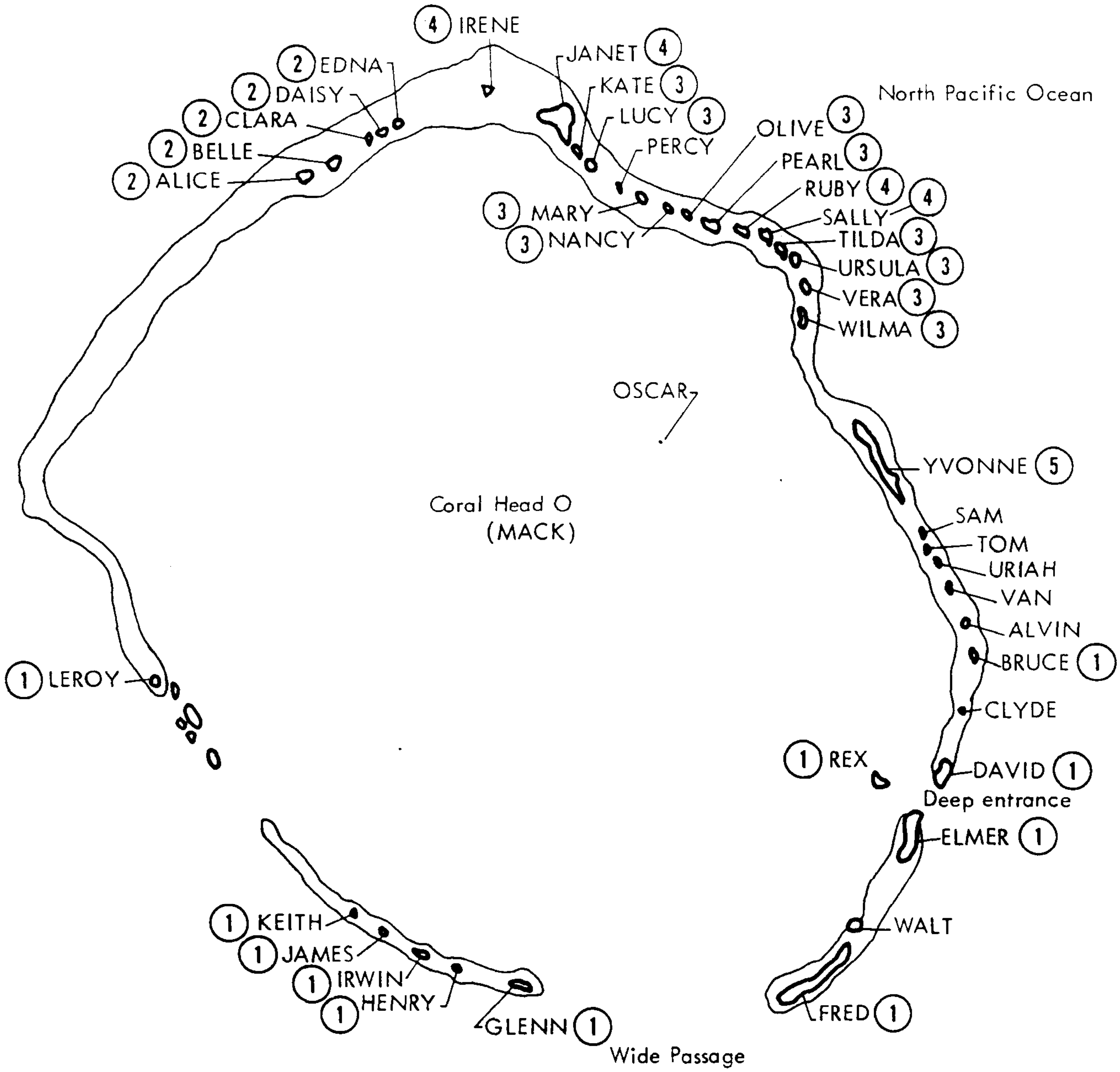


Fig. A.2. Radiological contamination levels on Enewetak Atoll. Least contaminated, 1; lightly contaminated , 2 (already surveyed): believed lightly contaminated, 3 (not surveyed); moderate contamination, 4; and heavy contamination, 5.

southern half of the Atoll to heavy (>1000 μR/hr at 3 ft) on Runit, with islands on the northern half of the Atoll in intermediate categories. As can be seen from Fig. A.2, no survey data are available for at least 10 of the islands. Data on radiological levels in the marine environment and in air are particularly scarce. Our intent is to obtain samples and data from the least contaminated islands first, then move to the more highly contaminated islands, and end on Runit. The marine work will run concurrently with the terrestrial survey. This is not, however, meant to imply that the least contaminated land areas have the least contaminated adjacent marine environment. Currents and other processes in the lagoon have probably redistributed the initial inventories of radionuclides to the extent that any attempt to predict relative contamination levels in the marine area near each island is presently impossible.

In this survey, we will design and carry out our field studies in the Atoll with sensitivity to preservation of the natural environment. This means that we will make an effort to utilize the literature, outside experts, and our own experience in order to sample living populations and soils so as not to generate imbalances. Special care will be taken to avoid the addition of persistent toxic material, wastes, and refuse, and to leave the environment of the Atoll in at least as good a condition as when we entered it.

II. RADIOLOGICAL STATUS AND DOSE EVALUATION

The Data Evaluation Group is an integral part of the program plan for Enewetak, and this Group has been involved since the inception of the study in the development of a measurement and evaluation plan which optimizes the return of information aimed at the objectives. The design of the program has been formulated after considering the following requirements:

1. Program focus. That the program plan be developed in response to a well-defined charter and objectives, as stated and discussed in the first section of this report.
2. Use of existing data. That past studies and data be brought to bear on the measurement and evaluation program design, including survey data from Enewetak and Bikini and the more general literature on radioactivity in food chains in the Atoll. Such data have provided guidance for developing measurement plans which will give comprehensive information for assessing radiological aspects of future habitability and the feasibility of cleanup prior to rehabilitation.
3. Integrated program structure. That information and materials flow through a system of sample collection, identification, analysis, and interpretation which provides for the best utilization of time and resources, minimizes errors and losses, and allows for rapid feedback and long-term access to samples, raw data, and logic

sequences which lead to results and interpretations.

4. Technical resources for evaluation. That the evaluation of data for radiological assessment be approached in a way which utilizes the very latest understanding of radioactive transport in the environment and of mechanisms and parameters affecting the dose to man. This principle is to be implemented by drawing on resources and capabilities in a number of institutions, including LLL, LASL, HASL, and the University of Washington. In addition, information on projected living patterns of future inhabitants which might influence a radiological assessment will be evaluated with the assistance of experienced individuals. Contact is being made with Dr. John Tobin, an anthropologist very familiar with the living habits of the native population in this matter, and we will also draw on scientific investigators of long experience in the Atoll, such as Drs. Held and Seymour of the University of Washington. Additional key participants and consultants are listed in Table A. 1.

5. Communication of results. Finally, that the evaulation, as it proceeds in time, will be in close communication with the Division of Bio-Medical and Environmental Research (DBER) through a review committee headed by Dr. Nathaniel Barr (see Fig. A.1). The advantages to such a communication are twofold:

   a. For maintaining point-in-time cognizance of our activities, methods, and results, which will enable DBER to review the final product more intelligently and more effectively under time constraints, and

   b. For providing guidance during the progress of the survey and to serve as a point of contact for information available across the whole research program in the AEC on environmental radioactivity, including AEC experience in DBER and DOS regarding radiological assessment and rehabilitation on Bikini.

Table A.1. Major participants in the data Evaluations Group.

Group leader:	D. Wilson (LLL)
Data handling and computations:	W. Martin, W. Phillips (LLL)
Calculations:	Y. Ng (LLL), B. Bennett (HASL), B. Rich (LLL)
Evaluations and applications:	W. Robison (LLL), B. Rich (LLL), C. Richmond (LASL), D. Wilson (LLL)
Consultants:	J. Tobin (TTPI), E. Held (AEC), A. Seymour (U. of Wash.), P. Gustafson (ANL), M. McLaughlin (HASL), P. Conard, M. D. (BNL)

The "Radiological Report on Bikini Atoll," April 1968, by Dr. P. F. Gustafson, then of DBM/AEC and now of ANL, provides an excellent backdrop against which to view the current Enewetak evaluation program. Comparison and contrast of the two situations (Bikini and Enewetak) regarding radiological aspects provide a number of facts useful in developing a program plan. Most relevant to the Enewetak program is to emphasize the similarity in the environments and the expected lifestyles of the future inhabitants. One could elaborate on second-order differences as they exist or as they are to be expected, but it is most important to point out two major considerations:

1. Regarding the major pathways, evaluation can be based primarily upon the expected similarity which will exist in lifetstyle and habits between the returning Bikinians and Enewetakese. The predominant protein source will be from marine fish, but, where possible, coconuts, pandanus, and arrowroot will be cultivated for food. A diet can be constructed on the basis of the Rongalese diet, as was done by Gustafson for Bikinians, and adjusted as indicated by information gained on the specifics of Enewetak Atoll.
2. Serious contrast can be made, however, between Enewetak Atoll and Bikini Atoll as regards the base radiological contamination, which is both larger for Enewetak and compounded by the larger amounts of ^{239}Pu and other transuranics. Thus, while we cannot yet speak of the relative importance of long-lived fission products, activation products, or alpha radioactive elements, it will be necessary to provide comprehensive assessment of the latter class of radionuclides in order to put these in perspective to the others. This will include assessment of both the inhalation and ingestion pathways.

In brief, the assessment is organized around a pathway-dose two-dimensional matrix. Radionuclide composition of dose transfer media such as foods, air, and water will be coupled with existing models of intake and metabolism to calculate potential dosages, taking into consideration the projected patterns of living of the future inhabitants.

The major pathways under consideration are:

1. External radiation
2. Internal radiation
   a. Terrestrial foods
   b. Marine foods
   c. Water
3. Inhalation, submersion

An understanding of the data base to be generated for these assessments can be obtained in the following sections of this program plan. It is our goal to provide all the data needed to order the relative importance of radionuclides and pathways on the overall picture of radiological assessment for habitability at this time, and to provide data and interpretations which will guide cleanup assessment. These data, however, will not, in all cases, be sufficient to predict potential dosages over the long term. This point is made to emphasize that limitations in the data base may exist which will not allow detailed pathway modeling and projection of infinite future dosages in all cases.

Previous studies at Enewetak provide a basis for developing a list of radionuclide species to be encountered in the measurements program (see

Table A.2. Radionuclides to be expected in the Enewetak environment.

Isotope	$T_{1/2}^{phys}$, days	$T_{1/2}^{Eff.}$[a], days	Emission	Critical organ[b]	Energy, MeV $\Sigma EF (RBE)_n$
^{3}H	4.5×10^3	12	β^-	W.B.	0.0063
^{14}C	2×10^6	12	β^-	Sol. fat	0.054
		10		Submersion W.B.	0.054
^{55}Fe	1.1×10^3	600	ϵ(x ray)	Sol. spleen	0.0065
		3.2×10^3		Insol. lung	0.0065
				Insol. GI	0.0065
^{60}Co	1.9×10^3	9.5	β, γ	Sol. W.B.	1.5
				Sol. GI	0.44
				Insol. lung	0.72
				Insol. GI	0.44
^{63}Ni	2.9×10^4	800	β	Sol. bone	0.11
				Insol. lung	0.021
				Insol. GI	0.021
^{90}Sr	10^4	6.4×10^3	β	Sol. bone	1.1
				Insol. lung	1.1
				Insol. GI	1.1
^{102}Rh	1.06×10^3	10.4	ϵ(x ray)	W.B.	1.2
^{102}Rh	206	10.4	β^-, β^+	W.B.	0.39
^{125}Sb	876	38	β, γ	Sol. W.B.	0.34
		100		Sol. bone	0.69
				Sol. GI	
		100		Sol. lung	0.23
		100		Insol. lung	0.26
				Insol. GI	
^{137}Cs	1.1×10^4	70	γ, β	Sol. W.B.	0.59
		138		Insol. lung	0.41
				Insol. GI	0.34
^{147}Pm	920	570	β	Sol. bone	0.35
				Sol., insol. GI	0.069
				Insol. lung	0.069
^{151}Sm	3.7×10^4	1.4×10^3	β	Sol. bone	0.13
				Sol., insol. GI	0.041
				Insol. lung	0.042
^{152}Eu	4.7×10^3	559	β, γ	Sol. GI	0.65
		1.1×10^3		Sol. kidney	0.71
				Insol. lung	0.71
^{154}Eu	5.8×10^3		$\beta^-, \epsilon, \gamma$	Sol. GI	0.20
		1.2×10^3		Sol. kidney	0.25

Table A.2. (Continued).

Isotope	$T_{1/2}^{phys}$, days	$T_{1/2}^{Eff.}$[a], days	Emission	Critical organ[b]	Energy, MeV $\Sigma EF\ (RBE)_n$
		1.2×10^3		Sol. bone	0.045
				Insol. lung	0.86
^{155}Eu	621	314	β,γ	Sol. GI	0.075
		438		Sol. kidney	0.083
		439		Sol. bone	0.28
				Insol. lung	0.095
^{207}Bi	2.9×10^3	5	γ	Sol. GI	0.24
		6		Sol. kidney	0.33
				Insol. lung	0.45
^{235}U	2.6×10^{11}	100	α,β,γ	Sol. GI	46
				Sol. kidney	46
				Sol. bone	230
				Insol. lung	46
^{238}U	1.7×10^{12}	100	α,γ	Sol. GI	0.43
		15		Sol. kidney	43
				Insol. lung	43
^{238}Pu	3.3×10^4	2.3×10^4	α,γ	Sol. bone	280
				Insol. lung	57
^{239}Pu	8.9×10^6	7.2×10^4	α,γ	Sol. bone	270
				Insol. lung	53
^{240}Pu	2.4×10^6	7.1×10^4	α,γ	Sol. bone	270
				Insol. lung	53
^{241}Am	1.7×10^5	2.3×10^4	α,γ	Sol. kidney	57
		5.1×10^4		Sol. bone	280
				Insol. lung	57

[a]Half-life in man following uptake in tissue.

[b]Abbreviations: GI (Gastrointestinal tract): W. B. (Whole body).

III

Table A.2). This list may not be complete, and the study may turn up other induced activities. Nevertheless, it is most probable that a small number of radionuclide species will lead to the majority of significant dosages as was found for Bikini. In addition to the transuranics, we expect ^{90}Sr, ^{137}Cs, ^{60}Co, and perhaps ^{55}Fe to be major contributors to dosage, depending on the pathway considered and the circumstances.

Most of this work of assessment will be straightforward and will consist of applying food-chain and dosimetric data well in hand in the literature and available in such sources as ICRP No. 2. However, we recognize the importance of the results of the measurement program in generating new information on the transport and fate of the heavy elements and also recognize our reliance on other current research and evaluation activities in the areas of heavy-element biological distribution and dosimetry in man.

We plan to work closely with DBER and groups such as the NVOO Applied Ecology Group and the AIBS Advisory Committee on Plutonium, particularly to interpret the significance of plutonium in the context of habitability and cleanup.

III. EXTERNAL DOSE AND SOIL SURVEY

This soil survey plan is based largely on the draft plan dated 31 August 1972 developed through consultation among the following individuals: Drs. Seymour, Held, Nelson, Welanda, and Schell (Univ. of Wash.), Drs. Eberhart and Gilbert (BNW), Mr. McCraw (DOS), and Mr. Lynch (NVOO).

The survey has been divided into four phases. Phase I is designed to identify any unsuspected radiological problems on the least contaminated islands. Phase II includes islands which have been subjected to fallout to various degrees (minor to somewhat severe) and construction activities which could have modified the distribution of radionuclides. Phase III deals with islands which have been sites for, or very near to, surface ground zeros and/or extensive test activities. Contamination exists in the form of activated metal debris, radioactive-waste disposal areas, distributed fallout, and localized plutonium contamination. The survey will also include an estimate of the extent of radioactive scrap metal situated on these islands. Finally, Phase IV addresses Runit (YVONNE), the most heavily contaminated island.

The selection process for survey priorities is based upon insult determination of each island from examination of historical records and current radiological data provided by preliminary surveys of Eniwetok Atoll in July 1971, May 1972, and of Runit in July 1972.

Field Meter Survey

The survey includes a very detailed examination of the geographical variability of the gamma exposure rate in air on each island due to the gamma rays of greater than 100 keV emitted by radionuclides deposited in the soil. These nuclides are primarily fission and neutron activation products. The Baird-Atomic scintillation instrument, which utilizes a 1 × 1-in. NaI crystal, will be used to make these measurements. Similarly, the flux of gamma rays of energies less than 100 keV due to ^{239}Pu and ^{241}Am will be measured by the FIDLER. This instrument consists of a 1/8-in.-thick × 5-in.-diam NaI crystal connected to a rate meter. The geographical variation of these measurements will enable the survey teams to locate the areas contaminated with radioactivity where soil samples may be collected for laboratory analysis to determine the concentrations of specific radionuclides present.

Aerial Radiological Measurements

This method has been used by EG&G, Inc. for several years for rapidly and economically surveying large land areas for radioactive deposition and for the location of lost radioactive sources. The data provided by such a survey will be extremely valuable in guiding the field survey teams in the conduct of their surveys. It will greatly reduce the possibility of the survey teams missing contaminated areas and at the same time increase their efficiency by eliminating their need to extensively survey uncontaminated areas.

The EG&G airborne radiation detection system that we propose to utilize consists of two pods mounted on a helicopter or light aircraft. Each pod contains 20 5 $\times$ 2-in. NaI crystals. The signals from these detectors are summed and submitted to a data-acquisition system. The output is monitored by eight single-channel analyzers and a multichannel analyzer for gamma spectral analysis. Also included in the system is an inertial navigation system whose output is recorded simultaneously with the radiation data on magnetic tape.

If the system were mounted on a helicopter traveling at 100 ft/sec, the spatial resolution for ^{241}Am on the surface is approximately 100 ft when using the single-channel mode of operation. High-energy gamma emitters may be located with a spatial resolution of about 50 ft, based upon the accuracy of the inertial navigation system. The minimum limits of detection for ^{60}Co and ^{137}Cs is about 1 μR/hr and approximately 1 μCi/m^2 for ^{241}Am. The system may also be flown satisfactorily on small fixed-wing aircraft, but the spatial resolution is directly related to airspeed.

The total weight of the system is 1400 lb and requires three people to operate. It would take approximately 1-3 weeks to complete the survey, depending upon meteorological conditions.

Aerial photographs of the islands may also be taken with a separate EG&G system which incorporates four Hasselblad cameras equipped with 80-mm lenses. High-resolution photographs obtained with this system are a necessity in order to accurately identify locations where soil samples and survey meter readings were obtained, as well as to assist in assessing the amount of cleanup that will be required.

Soil-Sampling Program

The soil-sampling program of the survey will be conducted in a manner that will insure statistically meaningful results. Several types of soil samples will be collected for analysis: (1) A sample consisting of two 15-cm-deep cores of 30-cm^2 area each; (2) a surface soil sample collected by a "cookie cutter" of 30-cm^2 area to a depth of 5.0 cm; and (3) a profile collection based upon sidewall sampling in a trench in which complete samples of fixed horizontal area are taken to selected depths. The increments of depth are chosen according to predicted, suspected, or known radioisotope concentration vs depth relationships and also according to any soil horizons present at the sample location. Nominal depth increments in centimeters will be: 0-2, 2-5, 5-10, 10-15, 15-25, and 25-35 and at 15-cm intervals below 35 cm. If a soil horizon is encountered, the interface lines will be chosen as the increments from the horizon rather than the fixed nominal increments from the surface.

Locations for the collection of soil samples will be chosen on the basis of (1) random selection and (2) ground or aerial survey meter readings. These are described below:

A. Samples collected on the basis of random selection

1. Each island will be divided by a narrow grid, (i.e., approximately 2500 points or 50 × 50-ft grid, whichever is smaller). All areas defined by such a grid will be numbered.

2. If stratification is desired and in order, the strata will be chosen and indicated on the grid network.

3. Individual sample areas will then be chosen within each stratification or grid by selection of the appropriate coordinate number, utilizing random-number tables. The number of samples per island or group has been previously determined through consideration of desired goals and statistical significance.

4. The exact location of the sample collection is to be the center of the area chosen by the random-number technique described in No. 3 above. It is realized that the determination of such a point with any great precision or accuracy in the field is technically impractical in most cases. It is most important, however, that the sample collector make every reasonable effort to locate the position as closely as possible. In particular, the sample should come from within a 10 × 10-ft area defined as the center area of the grid point. Ideally, the sample will come from the exact center of this limited area as just stated. In the field the location will be identified as indicated on the map but will be located probably by pacing or other field direction. The spot so determined by such pacing will be the actual spot at the end of the designated number of paces, and no other. If there is some obstacle to sampling at this specified location (e.g., a concrete pad), then that fact should be recorded in the field and no sample taken.

5. Each sample will be bagged and marked with an appropriate identification code.

B. Samples collected on the basis of survey meter readings.

1. Additional samples will be collected from locations where abnormally high readings were

obtained from either the Baird-Atomic scintillator or the FIDLER.

2. Each sample will be bagged and marked with an appropriate identification code.

Field Analysis

A radiation counting laboratory will be established on Enewetak Island. This laboratory will contain a 3 × 3-in. NaI detector and an intrinsic Ge detector, plus associated electronics. These detectors will allow scanning of the samples for gamma-emitting fission and neutron-activation products, as well as for ^{241}Am. The data obtained by this scanning process should provide information which may influence the collection of additional samples from contaminated areas. This information will also be valuable in determining future analyses to be performed on the samples after their arrival on the continent.

Preliminary Soil-Sampling Schedule

As mentioned earlier, the survey will address the least contaminated islands first and proceed to the more heavily contaminated islands.

The following is a more detailed listing of the islands within each of the four phases. Also included is a preliminary estimate of the number and types of soil samples to be collected from each island. The number of 0-5 cm and 0-15 cm samples is arrived at on the basis of one of each for approximately 10^5 ft^2 of surface area and the number of 0-35 cm (profile) samples on the basis of one per 8 × 10^5 ft^2 of area or a minimum of two per island. The other (profile) samples are for special situations, such as decontamination pads or areas in which field activities have disturbed the original soil.

Phase I

Island	Approx area, (10^5 ft^2)	Number of samples: 0-5 cm	0-15 cm	0-35 cm (profile)	Other (profile)
GLENN	25	25	25	3	
HENRY	13	13	13	2	
IRWIN	7.5	8	8	2	
JAMES	4.8	5	5	2	
KEITH	11	11	11	2	
LEROY	7	7	7	2	
REX	2	3	3	2	
BRUCE	9	9	9	2	
DAVID	48	48	48		6 (4 ft)
ELMER	80	96	96	4	10 (4 ft)
FRED	140	58	58		7 (4 ft)
Total		283	283	21	23

Phase II

Island	Approx area, (10^5 ft^2)	0-5 cm	0-15 cm	0-35 cm (profile)	Other (profile)
		Number of samples			
ALICE	10	20	20	2	
BELLE	20	30	30	3	
CLARA	2	8	8	2	
DAISY	1	8	8	1	
EDNA	0.3	5	5	1	
KATE	8	20	20		2 (2 ft)
LUCY	10.5	20	20		3 (2 ft)
MARY	6	20	20	2	
NANCY	9	20	20	3	
OLIVE	14	21	21	3	
PEARL	27	41	41	3	
TILDA	15	30	30	3	
URSULA	12	24	24	3	
VERA	10	20	20	2	
WILMA	7	20	20	—	2 (2 ft)
Total		307	307	28	7

Phase III

Island	Approx area, (10^5 ft^2)	0-5 cm	0-15 cm	0-35 cm (profile)	Other (profile)
		Number of samples			
IRENE	20	30	30	6	4 (6 ft)
JANET	120	150	150		15 (6 ft)
SALLY	37	40[a]	40[a]	10[a]	6 (6 ft)
Total		220	220	16	

[a]Will be influenced by the extent of PACE activities on this island.

Phase IV

The only island included in this phase is YVONNE, which to our knowledge is the most contaminated island in the Atoll. Field surveys will be conducted with the FIDLER and the Baird-Atomic scintillator in order to supplement data obtained during previous surveys. The objective here will be to obtain survey data on at least as small a grid pattern as is obtained for the other islands. Similarly, a number of soil samples will be collected in selected locations for purposes of evaluating the extent of cleanup required to rehabilitate the island. The extent of which additional data can be obtained by the survey group which speak to either the radiological hazard on Runit or to the engineering aspects of the cleanup operation is not clear at this time. The kind and amount of such additional data will be determined in the field by the survey team.

Thermoluminescent Dosimetry Program

Since the energy response of the Baird-Atomic NaI scintillator is non-linear, the measurements made by this instrument may not be a true measure of the external dose rate produced by the gamma-emitting radionuclides deposited in the soil. To overcome this deficiency we plan to incorporate a thermoluminescent dosimetry (TLD) program which will provide a correlation between the NaI scintillator measurements and the actual does rate measured by the TLDs.

This program will utilize a combination of LiF and CaF_2:Dy TLD packets. Approximately 40 packets will be placed at selected locations in such a manner that a broad range of dose rates from 2 μR/hr to 200 μR/hr will be measured for the correlation study. In order to eliminate exposure during transit time, the dosimeters will be annealed at Enewetak Island just prior to their placement in the field. After having been exposed for one month or more in the field, the TLD packets will be recovered and read out at Enewetak Island.

IV. AIR, BIOTA, AND POTABLE WATER SURVEY

The objectives of the terrestrial air, biota, and potable water sampling program are:

(a) To collect representative samples of edible plants and animals for radionuclide analysis and subsequent estimation of food-chain transfer of radionuclides to future inhabitants.

(b) To measure airborne radioactivity for assessment of the inhalation pathway of exposure, particularly for ^{239}Pu. The air-sampling program will address this exposure route at the numerous "clean islands" and also in the more contaminated areas such as the environment on Runit (YVONNE).

(c) To correlate the food-chain sampling program with the field gamma measurements and soil-sampling program in order to maximize the information available to quantify rates and mechanisms of transfer of radionuclides from soil to man through food chains. The field survey team will obtain plant samples wherever possible from the soil-sampling sites; the terrestrial food-chain team will obtain some soil samples, where necessary, in the areas where they sample edible plants such as pandanus and arrowroot.

1. Air Sampling

Airborne particulates will be sampled by means of three types of samplers:

a. Ultra-high volume (UHV) samplers—Two calibrated UHV samplers will be operated at a rate of 1000 cfm. One such sampler will be operated continuously on Enewetak Island (FRED). The other sampler will be transported from island to island for measurements. Measurements will be made also at selected offshore sites on the LCU. Both samplers will be supported by gross meteorological measurement of wind speed and direction to aid in the interpretation of sources of detected radioactivity.

b. Low-volume (LV) samplers—A large number of calibrated 5-cfm LV samplers will be fielded and operated on a semicontinuous basis. Banks of these samplers will operate continuously on board the Palumbo and the LCU used in marine sampling and transportation. Others will be fielded strategically to investigate radionuclide levels in air downwind from contaminated areas.

c. Anderson cascade impactors—Two 20-cfm, five-stage cascade impactors will be used to obtain long-term samples of air for investigation of the size distribution of airborne radioactive particles.

This combination of air samplers will be utilized to address the question of potential exposure to future inhabitants through inhalation of airborne radioactive particles. The initial plan will provide sufficient data to ascertain whether or not ^{239}Pu exists in the air at levels in excess of worldwide fallout background and to define the locations and circumstances of any such elevated levels. These samples will be analyzed on a priority basis so that results can be reviewed by the Data Evaluations Group early in the study. These evaluations will be used to decide on any adjustments in the air-sampling program design and scope which can be proposed to the Technical Director for implementation.

2. Biota Sampling

The terrestrial food-chain team will focus their effort on obtaining samples of arrowroot, pandanus, coconut, crabs, birds, and such other plant and animal organisms as may constitute the diet of future inhabitants. The edible vegetation samples will be collected as available and in conjunction with appropriate soil samples. Edible animal species will be collected as available by trapping or shooting.

Inedible plant species to be used as indicators for soil-root-plant pathways will be collected with the soil survey group. At least two or three species that occur on all islands will be used for this purpose in order to obtain comparative data. Samples of these will be collected on the lagoon side, ocean side, and in the central parts of each island at points where soil samples are collected. These will be returned to the Enewetak laboratory for identification and processing.

Rats, which are not considered to be a part of the human food chain, are the only mammals existing on the islands and may be considered as an indicator species. These will be trapped and specific organs will be analyzed for radioactivity. Collection sites for all specimens will be identified on the radiological survey maps for later correlation.

3. Potable Water

The only potable water on the Atoll is derived either from rain water or the distillation plant on Enewetak. Samples of these will be collected for radiochemical analysis, along with sludge samples from the distillation plant. In addition, a marginal lens exists on Engebi which we plan to sample.

4. Onsite Laboratory at Enewetak

An onsite laboratory will be established on Enewetak for processing samples obtained by the biota field teams. This will include: forced draft ovens for drying plant material for shipment, dissecting equipment for separating organs from animal species, and counting-equipment screening of specimens before they are returned to LLL. The principal equipment to be used will consist of a pair of 4 × 4-in. NaI detectors and two single-channel analyzers. A few selected samples will also be screened with a Ge(Li) system in order to determine their radionuclide content.

The Data Evaluations Group will be in charge of coordinating collection of data and samples, sample coding preparation, counting and other activities in this onsite laboratory.

V. ENEWETAK AQUATIC PROGRAM

The mission of the aquatic survey will be to define the contributing radioactivities in the lagoon and reef areas of the Atoll to assess exposure pathways to individuals utilizing the aquatic environment. Sources and levels of activity in the lagoon and reef will be defined using indicator organisms, in situ detectors, sediment, and water analyses. Samples of edible marine vertebrates and invertebrates will be collected and analyzed for specific radionuclides. Many species will be collected from the reef and lagoon areas that were surveyed in 1964. Changes in activities levels noted over the 8-yr period will be assessed. Several methods of assessing the residence time of specific radionuclides in the lagoon environment will be employed.

The types and quantities of samples required will be discussed in the next sections. The entire program, covering both survey and food-chain sampling, will be integrated in order to best use our available sampling facilities.

Program Implementation

The development of the aquatic program in the Enewetak lagoon was originally designed to take advantage of facilities offered by the research vessel, R. V. Palumbo from the Puerto Rico Nuclear Center. The Palumbo left Puerto Rico on August 20 enroute to San Diego, Hawaii, Kwajalein, Bikini, and Enewetak. The mission of the vessel is in support of a DBER-funded program involving individuals from the University of Washington, Lawrence Livermore Laboratory, and Puerto Rico Nuclear Center investigating the biogeochemical behavior of the transuranium elements in a labelled marine environment. Due to mechanical failures and other operational problems, the Palumbo has been in the San Diego Naval Shipyard since September 9 undergoing extensive repairs. The vessel left San Diego on September 28. If no further delays are encountered enroute, the Palumbo's present schedule would delay its arrival time in Enewetak by 16 days. The ship will therefore be available in the Enewetak area no earlier than November 18. Although it will be very useful to utilize the Palumbo in the Enewetak lagoon survey we are unable to plan on its availability. In order to conduct a meaningful program early in the survey, additional vessels are being readied for the lagoon work. They include:

(1) LLL Boston Whaler - 17-ft length

Equipped with bottom depth indicator; 65-hp Mercury outboard and 7.5-hp auxilliary motor; davit for over the side work with approximately 500 ft of 3/32-in. steel cable on a hand-operated winch. The vessel will be available for coring, water sampling, dredging, plankton tows, and in situ detection measurements. The ship will be used principally to support near shore and reef work.

(2) An "A" frame is presently under construction to mount on the LCU now enroute to Enewetak. A portable gasoline engine-powered winch containing 1000 ft of 3/32-in. stainless steel hydrographic cable will also be mounted on the vessel. The LCU will have the capability to conduct all phases of marine sampling and would be used principally to sample the offshore region of the lagoon.

(3) Other ships of opportunity would be used to ferry personnel and gear to reef areas and, when practical, to assist in plankton tows.

If and when the Palumbo arrives in Enewetak, its facilities will be employed to supplement the ongoing program. If, however, the two facilities (Boston Whaler and the LCU) are the only ships available, a complete program addressing all the survey goals could be conducted in 10-12 wk without the Palumbo. This estimate is based on having perfect weather the entire period for 8-10 hr/day, 6-7 days/wk.

A network of buoys will be placed in the lagoon as fixed reference points during the survey. All personnel operating the whaler and sampling from the LCU will be trained and knowledgeable in all sampling techniques. All samples gathered will be properly coded and sample locations plotted on charts. Locations will be determined by using sighting compasses and estimates based on running time and speed from fixed reference points. The whaler will contain all necessary safety equipment and tow a spare six-man raft. The raft will be a means of transport to shallow reef areas.

The aquatic program, independent of the Palumbo, will require five personnel. Two people will operate the whaler and three will sample from the LCU.

The sampling program will proceed from less contaminated areas of the lagoon to the more highly contaminated areas in order to lessen the probability of sample contamination.

Aquatic Survey Goals and Methods

Purpose: To define the activity levels in the lagoon and reef environment in order to assess levels of external exposure and the degree of aerial contamination.

	Objective	Method
A.	To assess surface exposure over the reef. Only reef covered with less than 3 ft of water will be assayed.	Personnel operating from rafts or on foot utilizing β-γ survey meters.
B.	Immersion dose in offshore beaches.	Analysis of water and sediment samples and in situ detection methods using the Boston Whaler.
C.	Definition of activity levels in the lagoon and major outflow areas over the reefs.	
	1. Assessment of sediment concentration levels. (a) Shore to 10-fathom terrace in lagoon. (b) Terrace to deep basin of lagoon. (c) Deep basin. (d) Craters.	Using the Whaler and LCU, sediment cores, grab samples, suspended material, and bottom water will be collected and analyzed. An in situ detector will be used to define relative activity levels of the bottom. A detailed bottom survey using an in situ NaI detector will be conducted off Runit, followed by extensive sediment sampling. The device used to obtain a bottom sample in any area will depend entirely on the composition of the sediment. The sediment in the lagoon varies from fine sand to coral and algae. The percent of each type of bottom material depends on location, although, in general, a higher percentage of fine material is found closer to shore where a corer may be used. In the deeper area of the lagoon higher percentages of formanifera and nolimeda debris dominate. In these areas dredging and grab sampling will be more successful.
	2. Water concentration.	Surface-to-bottom profiles will be obtained by pumping 55-liter water samples. Samples will be obtained from 18 stations in the lagoon and 18 stations over the reef. Both the Whaler and LCU will be utilized. Fifty 5-gal bottom water samples and suspended sediment will be obtained in the Runit area.

3. Additional supplementary data required to assess relative concentration levels in the lagoon.	A variety of indicator organisms will be obtained by dredging the sediment and coral knolls in the lagoon from the LCU and Whaler. Daily plankton collections and invertebrates will complement this effort. Species of algae will be obtained from reef areas for analysis.

Miscellaneous activities

The desalination plant will be studied, with emphasis on the fate of the sludge discharged from the plant.

Samples to meet survey requirements

Water

48 55-liter water samples from the open lagoon and reef.

50 5-gal bottom samples from the Runit area and craters.

Sediment

100 core samples, 2- and 3-in. diam 200 grab samples 100 dredge samples 50 suspended sediment samples 50 Runit cores	Detailed vertical profiles of radionuclide concentrations in 20 selected cores will be determined. All other samples will be rapidly scanned for relative activity levels and selected samples quantitatively analyzed. Activity levels in vertical sections Runit cores will be determined in about 50 samples.

Biota

(1) 200 plankton samples	If similar areas are sampled, many individual tows will be combined for analysis, especially if the plankton yield is low. All samples will be rapidly scanned in the field and a selected number quantitatively analyze on the continent.
(2) Invertebrates, including: Sponges Urchins Sea cucumber Clams Coral Starfish Langusta	Specimens will be collected from all accessable reef areas. 400-500 individual samples are anticipated and all will be surveyed for relative activity levels. A selected number, probably no more than 200, will be quantitatively analyzed. Included in the latter estimate are all species used in the diet. Some selected shells and coral will be carefully analyzed and correlated with growth rates and concentrations, as indicators of changes in the environment as a function of time.

(3) Gut contents of bottom-feeding fish collected in different areas will be analyzed to assess concentration levels in lagoon areas.

Comparison of the activity levels in each of the above sample types will be used to contour activity levels in the lagoon and reef. Data from many sample types, especially edible organisms, will be used for dose assessment. Field recommendations will be forwarded to the laboratory for guidance in sample preparation and analysis.

Food-chain dose assessment requirements

Purpose: To provide samples in order to determine the activity levels in all edible marine species. The data are required to assess dose from aquatic food sources.

There will be close coordination with the radiological assessment team who will generate the information regarding Marshallese diet and define the percentage of each marine trophic level in the diet. This information is necessary to determine the sample size of a species needed, type of species, and post-treatment method of the sample. Assessment of the levels of activity in carnivores, bottom-feeding carnivores, omnivores, herbivores, and all invertebrates will be made. Dietary habits of the Marshallese people will be considered in the treatment of samples. Some species may be consumed whole. The analysis on these defined specimens will be made on the entire fish. For those species where only the flesh or other organs are consumed, the sampl will be dissected and the tissue analyz The variability in activity levels in similar species from different areas will be determined. Sampling sites w include those areas visited by the 1964 survey team. Fishing methods will include trawls, gill nets, long lines, traps, rod and reel, and spearing. Although the fishing will be operationally defined, 200 to 300 samples are anticipated for quantitative analys of all detectable radionuclides.

VI. RADIOCHEMICAL ANALYSES

Required analytical measurements on samples recovered in the survey o Enewetak Atoll are summarized in this document. The information is presented in tabular form, beginning with a description of various sample types (Table A.3) and estimated quantities to be recovered. In Table A.4 we summarize how sample will be handled, including treatment at Enewetak, form in which the material will be shipped, and necessary initial treatment required before samples are ready for routine analys

In Table A.5 we summarize the kinds of analyses expected to be necessary, including a list of nuclide which have been detected in Enewetak samples taken in earlier years. Mos of the samples will be GeLi gamma counted as a routine matter. The question as to how many samples will require dissolution and wet chemical analyses can be answered accurately only as the planning and sample recove progress. We need an assessment

Table A.3. Sample type, quantity.

	Predicted total
I. Soil survey program	
A. Soil profiles, 200 × 6 = 1200	
3-in. diam, 0-1, 1-2, 2-3, 3-6, 6-9, 9-12	
115 cc/in., 170 g/in.	
B. Six-in. deep cores 800	
3-in. diam, 0-6-in. two adjacent (2 kg)	
C. Two-in. deep cores 800	
3-in. diam, 0-2-in. 300 g each	
II. Aquatic sampling program	
A. Plankton	200
B. Sediment	100 + selected samples
C. Seawater	100
48 (55-liter), 50 (18-liter)	
D. Coral - Selected samples for use as indicator organisms	
E. Invertebrates	
Sea cucumbers Tridacna Spider snail Spiney lobster	200
F. Vertebrates	
Edible reef fish and indicator species Larger lagoon fish (sharks, albacore, tuna, grouper, etc.)	200-300
III. Biota samples	
A. Vegetation - nonedible	300
- edible	50-100
B. Terrestrial animals (including dissected parts)	150
C. Potable water	15
IV. Air samples	
A. High-volume samplers	100
B. Low-volume samplers	80
C. Anderson cascade impactors	80

of the importance of ^{90}Sr analyses; we expect to infer Pu content from ^{241}Am measurements in some samples where more precise Pu analytical measurement by wet chemistry is not required. We anticipate that the more difficult ^{55}Fe and ^{63}Ni analysis will be performed only on selected samples, principally from the aquatic food chain.

In Table A.6 we list the laboratories and their capabilities which will be used to perform analytical measurements.

Table A.4. Initial sample processing.

	Treatment at Enewetak	Shipping form	Initial treatment
I. Soils	Package	As recovered	Dry, grind (ball mill), weigh, package, NaI co
II. Aquatic samples			
A. Plankton	Freeze	Frozen	Dry ash.
B. Sediment			
1. Grab samples	Freeze	Frozen	Dry, grind, weigh, analyze.
2. Cores	Freeze	Frozen	Section (volume, wet wt thaw, dry, grind, weigh analyze.
C. Sea water	Acidify	As water	Analysis
D. Coral	Freeze	Frozen	See soils.
E. Invertebrates	Freeze	Frozen	Weigh, thaw, (dissect ?) dry, (dry ash), weight, analyze.
F. Vertebrates	Freeze (filet?)	Frozen	Same as item E.
III. Biota samples			
A. Vegetation	Dry	Dry	Dry, grind, homogenize analyze.
B. Terrestrial Animals	Freeze	Frozen	Weigh, thaw, (dissect?) dry, (dry ash), weigh, analyze.
C. Potable water	Acidify	As water	Analyze
IV. Air samples	Package	As recovered	Analyze

VII. CLEANUP ASSESSMENT PLAN

During the field survey of the Islands in the Enewetak Atoll, an attempt will be made to evaluate possible cleanup mechanisms and provide data for future engineering estimates of the decontamination operation. This decontamination assessment is anticipated to take the following form:

1. An estimate of the quantity activated materials and debris fr previous tests will be made. Spe attention will be made to record, preliminary sense, location, amc and radiation levels of the debris should be removed before reoccu

2. An attempt will be made tc evaluate the feasibility of collecti single particles or "hot spots" by

Table A. 5. Kinds of analyses required.

I. Gamma counting

A. In general, no dissolution nor chemical separation will be required prior to gamma spectrometry. There could be occasional exceptions to this rule, e.g., sea water will require processing.

B. It is expected that essentially all samples will be gamma counted. In many cases, this may be the only analysis required.

C. Nuclides which are expected to be observed and which can be quantitatively measured by gamma spectrometry:

^{40}K, ^{60}Co, ^{106}Ru, ^{137}Cs, $^{152,154,155}Eu$, ^{241}Am, ^{125}Sb, ^{207}Bi, ^{108m}Ag, ^{65}Zn, ^{102}Rh, U and Th chain daughters.

II. Dissolution of sample

A. Plutonium analyses

1. Alpha counting $^{238,239+240}Pu$

2. Mass spectroscopy $^{239,240,241,242}Pu$ where warranted

B. ^{90}Sr-beta counting of ^{90}Y daughter

C. Other nuclides: ^{55}Fe, ^{63}Ni, ^{147}Pm, ^{151}Sm, ^{14}C

Soft-radiation emitters will require specific chemical separation.

III. Tritium

Table A. 6. Laboratory analytical capability.

Laboratory	Kind of analytical work	Sample rates
LLL	Initial sample preparation, soils	400 samples/month for initial sample preparation of soils
	Initial sample preparation, biota (including dissolution of all marine samples)	
	Complete analytical treatment, sea water	
	Gamma analysis, all types of samples	
MCL	Gamma analysis	
	Soil dissolution, chemical analyses for Pu, ^{90}Sr	
	Complete analytical treatment, air filters	
UW	^{55}Fe analysis	Not established
	^{90}Sr analysis	
Contract analyses	Gamma analysis	
	Soil dissolution, chemical analyses for Pu, ^{90}Sr	200-500 samples/month
NERC(EPA)	Chemical analysis for Pu	Not established

simple excavation techniques or sieving. Various sized screens will be taken to evaluate the feasibility of separating contaminated debris rather than removal of all contaminated soil and/or coral. The character of the contamination in various areas will be evaluated in terms of the feasibility of removing localized hot spots in preference to whole-scale excavation. An attempt will also be made to locate localized hot areas which will require total excavation.

3. A literature search is presently underway and will be continued to evaluate the applicability of modifying existing techniques, other than whole-scale bulldozing, in decontaminating large contaminated areas.

4. Through evaluation of field survey data, the extent of contaminated areas will be mapped, and contamination profiles folded into the data in order to estimate the total area requiring cleanup.

VIII. SCHEDULES

A schematic diagram of the schedule for the Enewetak Radiological Survey Program is shown in Fig. A.3.

We now expect that the field survey group will depart for Enewetak on or about October 12, 1972 and that the work on Enewetak will take approximately eight weeks. Samples taken in the field are to be returned to Livermore on weekly scheduled flights. Processing and analysis will begin as soon as the first samples arrive at LLL.

The first data that are expected to be available are those taken in the field (sample types and locations, survey instrument readings, etc.). These should be in reportable form by January 1, at which time a review

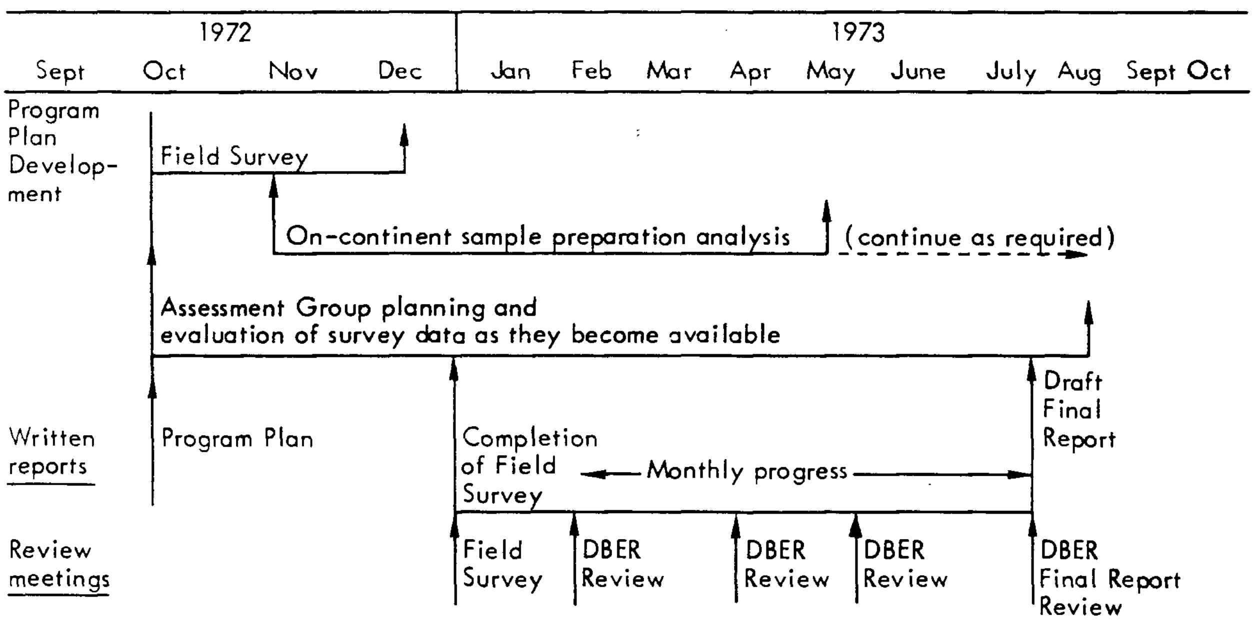


Fig. A.3. Schedule for the Enewetak Radiological Survey Program.

meeting may be scheduled to discuss the status of the program.

Considering all available laboratory capabilities, sample preparation and analysis will certainly take a number of months to complete. Samples will be processed on a priority basis according to the needs of the Radiological Assessment Group, so that the DBER assessment and review can proceed on a continuous schedule rather than wait for all data to become final. The DBER review schedule shown in Fig. A.3 is a very tentative one. Every attempt will be made to speed up the process, without compromising on quality or completeness, of course, but no one should be under the impression that gathering this much experimental data and interpreting it will be accomplished overnight.

APPENDIX B

R 132155Z SEPT 72
FM USAEC FRANK A CAMM WASHDC
TO: USAEC M E GATES LAS VEGAS NEV
INFO: LT GEN C H DUNN DNA WASHDC

UNCLAS SUBJECT: RADIOLOGICAL SURVEY OF ENIWETOK

PARA. AS A RESULT OF COMMITMENTS MADE BY AMBASSADOR WILLIAMS AND INITIAL AGREEMENTS REACHED DURING AN INTERAGENCY MEETING HELD ON SEPTEMBER 7, 1972, IT IS THE OVERALL AEC PURPOSE TO GAIN A SUFFICIENT UNDERSTANDING OF THE TOTAL RADIOLOGICAL ENVIRONMENT OF ENIWETOK ATOLL TO PERMIT JUDGMENTS AS TO WHETHER ALL OR ANY PART OF THE ATOLL CAN SAFELY BE REINHABITED AND, IF SO, WHAT STEPS TOWARD CLEANUP SHOULD BE TAKEN BEFOREHAND AND WHAT POST-REHABILITATION CONSTRAINTS MUST BE IMPOSED. IT IS NECESSARY TO THOROUGHLY EXAMINE AND EVALUATE RADIOLOGICAL CONDITIONS ON ALL ISLANDS OF THE ATOLL AND IN THE LOCAL MARINE ENVIRONMENT PRIOR TO COMMENCEMENT OF CLEANUP ACTIVITIES IN ORDER TO OBTAIN SUFFICIENT RADIOLOGICAL INTELLIGENCE TO DEVELOP AN APPROPRIATE CLEANUP PROGRAM. SPECIFICALLY, IT IS NECESSARY:

1. TO LOCATE AND IDENTIFY CONTAMINATED AND ACTIVATED TEST DEBRIS,
2. TO LOCATE AND EVALUATE ANY SIGNIFICANT RADIOLOGICAL HAZARADS WHICH MAY COMPLICATE CLEANUP ACTIVITIES, AND
3. TO IDENTIFY SOURCES OF DIRECT RADIATION AND FOOD CHAIN-TO-MAN PATHS HAVING RADIOLOGICAL IMPLICATIONS.

PARA. YOU ARE DIRECTED TO PLAN, ORGANIZE, AND CONDUCT A RADIOLOGICAL FIELD SURVEY TO DEVELOP SUFFICIENT DATA ON THE TOTAL RADIOLOGICAL ENVIRONMENT OF ENIWETOK ATOLL TO PERMIT THE ASSESSMENTS ON WHICH THE JUDGMENTS DESCRIBED ABOVE CAN BE MADE. THIS SURVEY SHOULD BE ACCOMPLISHED AS SOON AS POSSIBLE UPON COMPLETION OF THE NECESSARY PLANNING AND COORDINATION. IT SHOULD CONSIDER THE TOTAL ENVIRONMENT PERTINENT TO REHABILITATION INCLUDING BOTH EXTERNAL RADIATION DOSAGE AND BIOLOGICAL FOOD-CHAIN CONSIDERATIONS. IT IS ANTICIPATED THAT TECHNICAL STANDARDS AND REQUIREMENTS WILL BE PROVIDED BY RESPONSIBLE DIVISIONS WITHIN AEC HEADQUARTERS. IT IS UNDERSTOOD THAT PLANNING HAS BEEN INITIATED BY DOS AND DBER IN COOPERATION WITH FIELD ORGANIZATIONS AND SUCH PLANNING WILL SERVE AS THE BASIS FOR A COMPREHENSIVE SURVEY PLAN.

PARA. IN IMPLEMENTATING THE ABOVE OBJECTIVE YOU ARE DIRECTED TO:

1. PREPARE A PLAN FOR THE CONDUCT OF RADIOLOGICAL FIELD SURVEY AND ANALYSIS OF SAMPLES OBTAINED UTILIZING NECESSARY LABORATORY AND CONTRACTOR SUPPORT.
2. SELECT PERSONNEL NECESSARY TO CONDUCT THE FIELD SURVEY.
3. SELECT LABORATORIES AND PERSONNEL TO ACCOMPLISH THE NECESSARY LABORATORY WORK FOR ANALYSIS OF SAMPLES. THIS TASK INCLUDES ESTABLISHMENT OF PROCEDURES, STANDARDS, AND METHODS FOR CORRELATION OF DATA BETWEEN LABORATORIES. IN THIS CONTEXT YOU SHOULD PROVIDE FOR REVIEW AND REPORTING OF DATA.
4. SUPPORT PATHWAY AND DOSE ASSESSMENT ACTIONS WHICH WILL COME UNDER OVERALL TECHNICAL DIRECTION OF THE DBER, SUPPORTED BY THE DOS.
5. ARRANGE FOR NECESSARY LOGISTIC SUPPORT.
6. COORDINATE LOGISTIC SUPPORT REQUIREMENTS WITH THOSE OF THE ENGINEERING SURVEY TO BE CONDUCTED CONCURRENTLY BY DNA.
7. DIRECT LIAISON WITH DNA IS AUTHORIZED, AS REQUIRED, KEEPING COGNIZANT AEC HEADQUARTERS DIVISIONS ADVISED.
8. PENDING FURTHER GUIDANCE YOU ARE DIRECTED TO ADDRESS CONSIDERATIONS OF PRIORITY IN PLANNING FOR SAMPLE ANALYSIS AND FOR BIOLOGICAL PATHWAY AND DOSE ASSESSMENT PORTIONS OF THIS TASK. IT IS ANTICIPATED THAT A REVIEW OF THE SURVEY WILL BE CONDUCTED UPON COMPLETION OF THE FIELD EFFORT AND BY THAT TIME MORE DEFINITIVE GUIDANCE WILL BE FORTHCOMING ON PRIORITIES IN THE AREAS OF ANALYSIS AND ASSESSMENT.

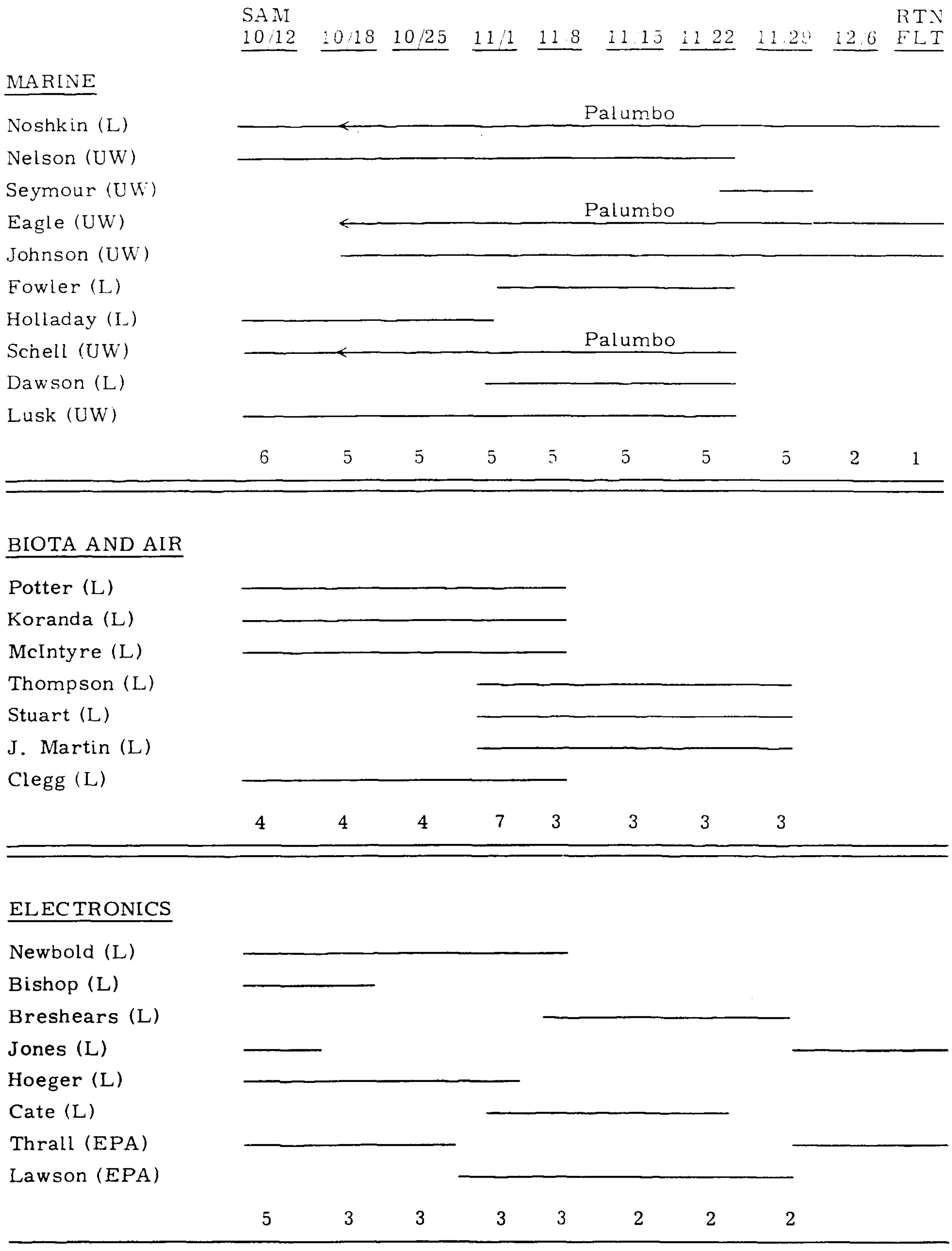
PARA. YOU ARE AUTHORIZED TO EXPEND $150 K IN THE INITIAL PLANNING AND ORGANIZATION OF THIS SURVEY. INITIALLY THE COST OF PERFORMING THIS EFFORT SHOULD BE CHARGED TO THE ON-CONTINENT PROGRAM. FOR YOUR INFORMATION, THE GENERAL MANAGER HAS APPROVED ALTERNATIVE 2 OUTLINED IN THE CONTROLLER'S MEMORANDUM DATED AUGUST 28, 1972, AND WE CURRENTLY WORKING OUT FUNDING ARRANGEMENTS FOR THE ENTIRE SURVEY. YOU WILL BE KEPT ADVISED.

MA:T:WWG:265-1.

APPENDIX C

Tenetative Schedule for Field Survey Personnel:

	SAM 10/12	10/18	10/25	11/1	11/8	11/15	11/22	11/29	12/6	RTN FLT
FIELD MANAGER										
Nervik (L)	—						—	—	—	—
Ray (NV)	—	—								
McCraw (SEC-DOS)			—	—						
Held (AEC-Reg)					—	—				
	2	1	1	1	1	1	1	1	1	1
SOIL SURVEY										
Gudiksen (L)	—	—	—	—				—	—	—
Rich (L)				—	—	—				
Myers (L)	—	—	—							
Chew (L)					—	—				
Lynch (NV)	—	—	—	—			—	—	—	—
Moore (EPA)	—	—	—			—	—	—	—	—
Costa (EPA)	—	—	—							
Martin (EPA)	—	—	—	—						
Rozell (EPA)	—	—	—	—						
Vandervoort (EPA)				—	—	—	—	—		
Peer (EPA)				—	—	—				
Lambdin (EPA)					—	—	—	—		
Horton (EPA)					—	—	—	—		
Phillips (EIC)	—	—	—	—	—	—	—	—	—	—
Parker (EIC)	—	—	—	—	—	—	—	—	—	—
Price (EIC)	—	—	—	—	—	—	—	—	—	—
Young (EIC)	—	—	—	—	—	—	—	—	—	—
Sammons (H&N)	—	—	—	—	—	—	—	—	—	—
Chambers (H&N)	—	—	—	—	—	—	—	—	—	—
	13	13	13	13	12	12	11	9	9	9



SAM 10/12
10/18
10/25
11/1
11/8
11/15
11/22
11/29
12/6
RTN FLT
MARINE
Noshkin (L)
Nelson (UW)
Seymour (UW)
Eagle (UW)
Johnson (UW)
Fowler (L)
Holladay (L)
Schell (UW)
Dawson (L)
Lusk (UW)
Palumbo
Palumbo
Palumbo
6 5 5 5 5 5 5 5 2 1
BIOTA AND AIR
Potter (L)
Koranda (L)
McIntyre (L)
Thompson (L)
Stuart (L)
J. Martin (L)
Clegg (L)
4 4 4 7 3 3 3 3
ELECTRONICS
Newbold (L)
Bishop (L)
Breshears (L)
Jones (L)
Hoeger (L)
Cate (L)
Thrall (EPA)
Lawson (EPA)
5 3 3 3 3 2 2 2

	SAM 10/12	10/18	10/25	11/1	11/8	11/15	11/22	11/29	12/6	RTN FLT
CLEANUP TECHNIQUE ASSESSMENT										
Yoder (L)										
	1					1	1	1	1	
SAMPLE PREPARATION										
Phillips (L)										
W. Martin (L)										
Qualheim (L)										
Mendoza (L)										
Wilson (L)										
Schweigher (L)										
Landrum (L)										
Hoff (L)?										
	3	3	3	3	3	3	3	3	3	3
FIELD OPERATIONS										
Steward (NV)										
Lease (NV)										
Warren (L)										
Button (L)										
	2	2	3	2	2	2	2	2	2	2
DOCUMENTARY PHOTOGRAPHY										
Wilson (L) ?										
Tyner (Pan Am)										
				2	2					
EG&G										
NaI Detector Survey										
Total + EG&G	36	31	32	37	31	29	28	23	17	29
										Average

APPENDIX D

Enewetak Precleanup Survey YVONNE Island Program Radiological Safety Plan

I. PURPOSE

The purpose of this plan is:

To provide appropriate procedures for the radiological safety of individuals, equipment and data involved in the sampling program to be conducted on YVONNE Island, Enewetak Atoll;

To minimize or prevent any unnecessary exposure, internal or external, to personnel;

To control radioactive contamination of personnel and equipment; and

To control and prevent radioactive cross-contamination of samples taken from YVONNE Island.

II. THE PROBLEM

YVONNE (Runit) Island, lying midway on the windward side of Enewetak Atoll was the site of a number of nuclear test detonations. These nuclear events occurred on the surface, in the air, and on the water near the island, contaminating the immediate vicinity to various extents (see Fig. A.4).

Through literature searches and actual surveys, the present condition of the northern half of the island is determined to be a heterogeneous conglomeration of radioactive contamination from the surface to some considerable depth, mixed and churned into the soil from various construction and earth-moving activities in support of the test operations. This contamination consists of aged fission products, activated or contaminated scrap metal, and considerable quantities of finely divided plutonium on the surface and buried underground. Evaluation of the extent of this contamination for cleanup considerations, requires a respectable soil sampling program be accomplished. The most important problem faced by the sampling effort is how to safely dig into and remove from this contaminated soil suitable samples for analysis.

A considerable area, from the "Tower Bunker" Hardtack Station 1310, north about 3000 ft contains extensive plutonium contamination, on the surface (levels of around 2×10^5 dpm/100 cm^2), as well as beneath the surface (3×10^3 pCi/g soil at 2-3 ft depth).

Other areas, the Cactus Crater lip, for example, also have plutonium contamination on the surface and at depth. There is also evidence, through reports, notes, etc., that various depressions "craters" were utilized for the burial of contaminated test debris. No specific contamination levels for these burials have been found in the reports.

It is evident that any soil-disturbing activities within the areas indicated above will probably increase the possibility of resuspension of plutonium

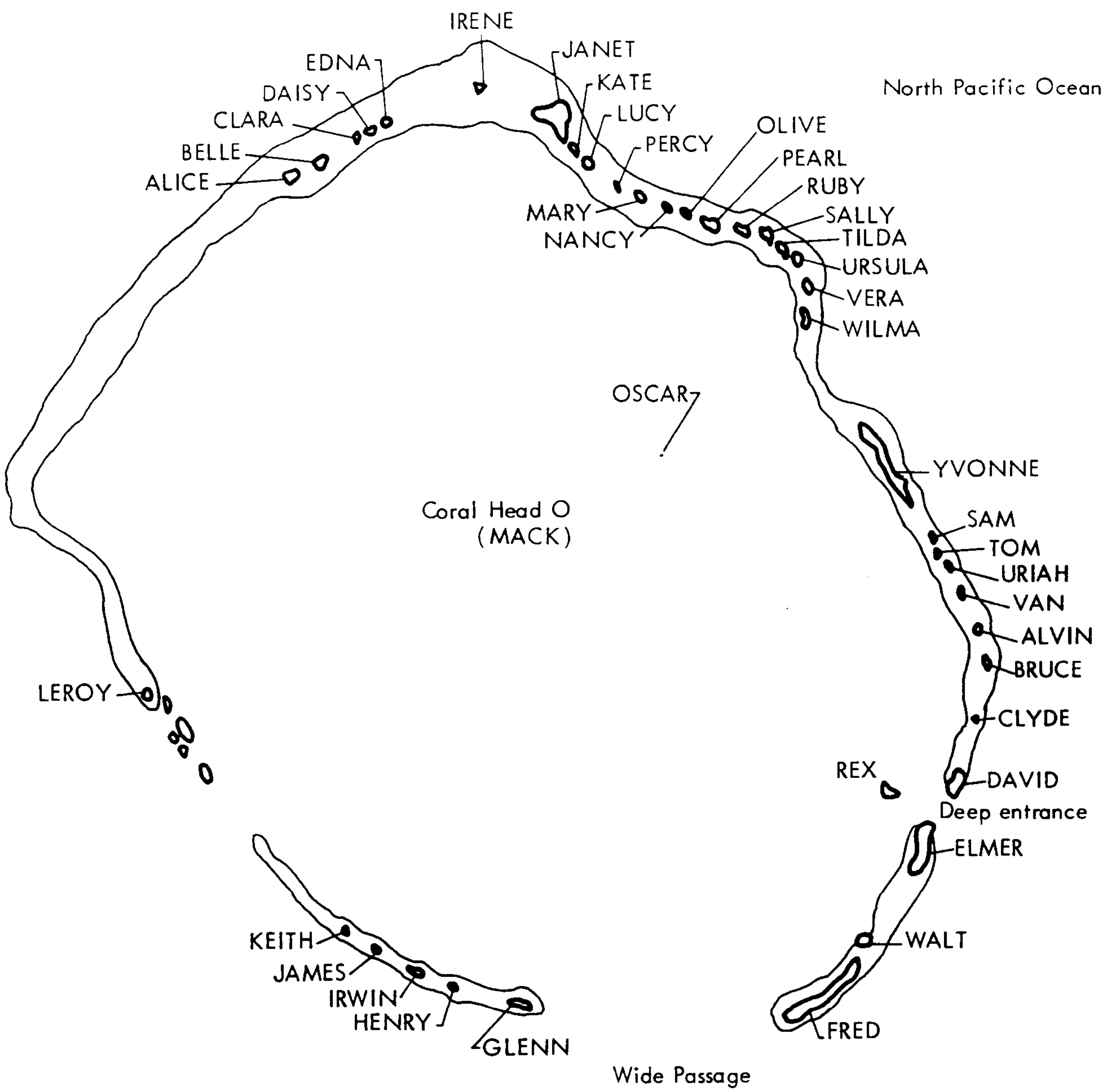


Fig. A.4. Enewetak Atoll.

particulates, and most certainly, the possibility of contamination of personnel and equipment engaged in the collection of samples. The dryness of the soil, due to the onset of the dry season, and the strong northeasterly tradewinds also increase the resuspension hazard.

III. ACCESS CONTROLS

The Island of YVONNE is accessible only by boat from Enewetak Island. Landings are made at a personnel pier, located about mid-island. A small concrete ramp exists immediately north of and adjacent to the pier for the offloading of heavy equipment by barge, LCU, or LCM. Since access to the island is confined to a relatively small area, the actual physical problem of access control is simplified.

For the purpose of this survey, a RADEX area will be established from a point just north of the personnel pier/ramp area, north to the Cactus Crater. Complete rad-safe control will be in effect within this RADEX area. A decontamination pad will be set up for equipment on the lagoon side of this RADEX area, immediately adjacent to the ramp. A personnel decontamination facility and hot line will be established next to the decon pad and will be the sole access route for personnel to the survey area (see Fig. A.5).

The hot line, decon pad, and RADEX area southern boundary will be marked with tape and signs.

No personnel will be allowed into the RADEX area without appropriate rad-safe personnel protective clothing and respiratory devices, a personnel-monitoring TLD badge, instrumentation, etc., unless deviation is approved by the health physicist in charge, as set forth in the procedures below.

IV. MONITORING

Although the principal radiological hazard on YVONNE Island can be attributed to ^{239}Pu, an alpha emitter, the presence of undetermined amounts of aged fission products and activation products provides a significant amount of beta-gamma emitters to be of additional concern.

It is intended to monitor all personnel, equipment, and areas for surface and airborne radioactive contamination emitting alpha, beta, and gamma radiation.

A. Air Monitoring

It is intended to sample for airborne contamination continuously in the immediate downwind area from the

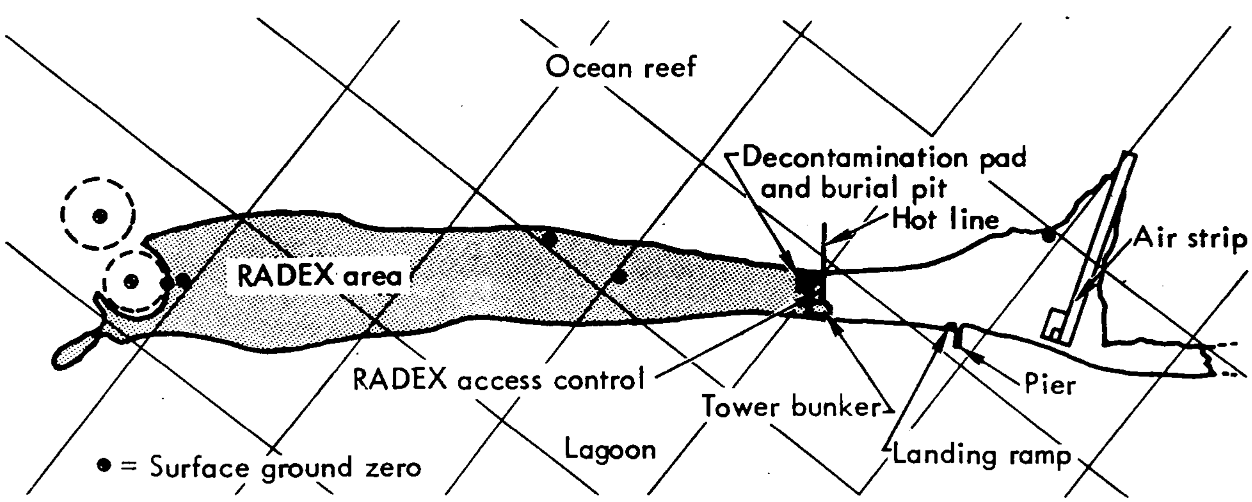


Fig. A.5. Soil sampling RADEX area, YVONNE.

soil-disturbing activities to detect and evaluate any resuspension of radioactivity. There are presently six Staplex high-volume air samplers (22 cfm with a Millipore filter, loaded) in storage on Enewetak. Two 1.5-kW Homelight gasoline-powered portable generators, appropriate transformers, and power cable are also on hand.

Three units will be placed in the downwind area. The other three will remain as backup. Samples will be changed at the end of each workday. Although it is planned to operate the samplers only during working hours, it is possible to allow them complete 24-hr operation if necessary. Additionally, two lapel-type, low-volume air samplers will be brought and will be placed one on the backhoe operator and one on a profile monitor for more realistic evaluation of breathing zone concentrations. Four small, low-volume (3 cfm) portable air samplers will also be available and used where appropriate.

Samples will be counted at Enewetak at the end of the day for gross activity and forwarded to LLL for further analysis. Daily results will be available to the sampling team leaders.

B. Portable Survey Instruments

Portable survey instrumentation, capable of detection of alpha, beta, and gamma radiations will be utilized.

1. Alpha Monitoring

Field alpha emitter detection will be done using an LLL modification of the PAC-1A alpha survey meter. This modification, termed the "LLL Blue Alphameter," is more sensitive to uniform surface contamination than the previously used PAC-1S, partly due to increased probe area and partly due to decreased probe-to-surface distance. Since the instrument is a proportional air chamber probe, rather than a scintillating surface, it is not light-sensitive when punctured.

Twelve LLL PAC-1A survey instruments with spare probes will be provided. It is also intended to have, as a backup, several PAC-1S survey instruments.

2. Gamma Monitoring

The basic instrument utilized by the survey for gamma detection is the low-range Baird-Atomic scintillator. The instrument, calibrated on ^{137}Cs is very rugged and has given excellent service in the field. It has sufficient range (0-3000 μR/hr) to be useful on most of YVONNE. Twelve Baird-Atomic Instruments are available on Enewetak.

3. Beta-Gamma Monitoring

For higher gamma exposure rates and for beta-emitter detection capability, the E500B G-M survey instrument will be utilized. Four E500B instruments are available on Enewetak.

4. Plutonium-Americium Monitoring

Monitoring for $^{239}Pu/^{241}Am$ will be done with the FIDLER probe. This instrument can also be used to locate hot spots which may or may not be plutonium or activated scrap metal. Nine FIDLER instruments are available on Enewetak.

C. Personnel Monitoring

Personnel monitoring for external exposure to beta-gamma radiation will be accomplished utilizing the LLL TLD system. All individuals leaving Enewetak Island, engaged in AEC survey activities are issued an LLL TLD packet. This packet is worn on the upper body in the same manner as a film badge. All personnel landing on YVONNE will be required to wear their TLD packet.

The TLD packets are turned in to the AEC Operations Coordinator prior to leaving Enewetak Atoll. The packets are then forwarded to LLL for reading and evaluation.

A bioassay program to evaluate and document internal contamination and exposure will be conducted. This program is indicated in Part VII.

D. Swipe Tests

Swipe tests using disks of filter paper will be used to evaluate and detect removable surface contamination on equipment and area surfaces. A routine swipe program is presently in effect on Enewetak Island to detect contamination in Buildings 11 and 15. Equipment used on YVONNE will be swipe-tested and decontaminated, if necessary, prior to its leaving YVONNE.

Swipes may be counted both in the field and at Enewetak. For both alpha and beta-gamma activity, as necessary, portable battery-powered swipe counters are available on Enewetak.

V. CONTAMINATION CONTROLS

A. Personnel Contamination Controls

Every effort will be made to prevent radioactive contamination of personnel. Initially, all personnel entering the YVONNE RADEX area or working at the hot line will be suited out in full anti-C clothing consisting of one pair of coveralls, totes, cotton gloves, and cloth hood. All seams will be taped. Those personnel collecting soil samples, displacing soil, or downwind from soil-displacing activities will wear an Acme full-face mask equipped with an Acme OAPR 282 high-efficiency canister. Upon evaluation of the hazards and the effectiveness of contamination controls, the requirement for certain anti-C apparel may be waived by the health physicist in charge of the activity.

All personnel exiting the hot-line area will do so through the hot-line station and will be monitored for alpha and beta-gamma contamination prior to, during, and after removing anti-C gear. Nose swipes will be taken after all anti-C gear is removed. Decontamination capability will be available at the hot line. Smoking and eating will not be permitted in the RADEX area.

All contaminated anti-C gear will be removed and suitably packaged at the hot line. Contaminated waste produced by the survey effort will be collected, bagged, and stored on YVONNE until cleanup activities start, when such material may be disposed of.

B. Equipment Contamination Controls

All equipment utilized in the RADEX area will be monitored with portable survey instruments and swipe-tested. It will be decontaminated if necessary.

C. Sample Contamination Controls

Levels of radioactive contamination in soil samples taken from YVONNE Island's northern portion can have considerable amounts of radioisotopes with high ^{239}Pu levels not uncommon. Therefore, caution must be exercised to prevent not only cross-contamination between individual samples but also contamination of personnel, equipment, and storage areas utilized in the recovery and processing of these samples.

1. Sample Collection

Profile samples will be collected from pits dug into the sandy soil of YVONNE Island by backhoe (3- to 4-ft profiles) and by hand (shallow 1- to 2-ft profiles and surface coring). Samples will be carefully removed from the sidewalls of the pits with special sidewall sampling tools in approximately 10-cm increments.

Each individual sample will be bagged at collection in a plastic bag and numbered. The sample will then be bagged twice more in heavy plastic bags to insure no breakage of bags and leakage of material. All samples from a single profile location will again be bagged in a single large plastic bag to keep all contents together for transfer to Enewetak.

To reduce airborne contamination during this windy, dry season, all soil collection areas will be wet down with salt water prior to any soil disturbance activities. If necessary, additional watering may be performed if the soil dries out too much.

2. Sample Monitoring

All samples passing over the hot line on YVONNE will be monitored for external alpha contamination. Samples thus found contaminated will be bagged again and marked as having surface contamination on the inner bags. Every effort will be made to prevent contamination by soil samples.

3. Segregation and Storage

Soil samples from the northern portion of YVONNE will be segregated from samples taken from other locations and kept in a specially prepared, locked facility. The floors of the special storage area will be covered with a plastic sheet to provide for easy removal of contamination in case of leakage.

4. Counting

Selected samples removed from YVONNE may be counted for americium gamma activity. Care will be taken in transfer of these samples from the storage area to the counting room and return. It will not be necessary to open any individual sample bag and thus none are to be opened. Unless from bag breakage, no contamination should result from counting activities.

5. Sample Shipping

The samples collected from the northern half of YVONNE Island may very well have specific activities high enough to be classified DOT Type A quantity, Group I shipments. All samples will be shipped to the Mainland (LLL) according to current DOT and USAF regulations. Appropriate shipping containers (DOT-approved paper tigers) will be utilized to accomplish this shipping effort. All labels, monitoring certificates, shipping documents, etc., will conform with all applicable regulations.

VI. DECONTAMINATION

A. Personnel Decontamination

A personnel decontamination facility will be provided at the hot line. A salt-water shower and wash stand will be set up. Soap and scrub brushes, etc., will be available. Personnel will be monitored crossing the hot line and will be decontaminated as necessary.

A freshwater shower and washing facilities will be available in the clean area. These facilities, an air-conditioned rest area, and hot lunch facility will be available on the LCU tied to the personnel pier during the survey activity.

B. Equipment Decontamination

An equipment decontamination pad will be set up adjacent to the concrete landing ramp. A salt-water pump and washdown capability will be provided. All equipment will be monitored as it comes out of the RADEX area through the decon pad (see Section IX). If contaminated, the equipment will be deconned at the pad. Effluent will flow back into the ground.

VII. BIOASSAY

Although every effort will be made to prevent personnel contamination, a comprehensive bioassay program will be followed to ascertain any internal contamination and document its absence or presence for the record and as an evaluation of the effectiveness of control measures.

1. Nose Swipes

Nose swipes will be taken from all personnel working in the area of airborne contamination immediately after the end of the work period when they remove their anti-C apparel. The swipes will be counted on Enewetak that evening.

2. Urine Analysis

A 24-hr collection sample of urine will be submitted by each YVONNE survey participant at the completion of the survey effort. These samples will be forwarded to the U. S. for analysis.

3. Fecal Analysis

Fecal samples will be submitted by personnel suspected of having internal plutonium contamination and others as required by the health physicist. These samples will be analyzed by counting with a FIDLER instrument in a fixed geometry on Enewetak Island.

4. Whole-Body Counting

Selected individuals known to be involved in the YVONNE sampling effort have already had baseline whole-body (lung) counts prior to their arrival on Enewetak. These individuals will be whole-body counted again upon the completion of the survey to evaluate any internal deposition acquired due to the survey effort.

VIII. SAMPLING TEAM COMPOSITION

In order to provide maximum safety and efficiency in the limited time available to the survey, and because of the difficulty of having men work in full anti-C gear, two full teams will be fielded each day, working alternate 2-hr shifts, if possible. These teams will consist of the following capabilities:

1. Backhoe operator
2. Backhoe monitor
3. Sampler, profile (two each)
4. Sampler, shallow profile and surface (two each)
5. Health physicist

Additionally, a single full-time hotline operator and an instrument technician will be required. A total of 16 personnel will be involved in sampling operations on YVONNE.

IX. CONTAMINATION CRITERIA

For the purpose of this survey, no detectable radioactive contamination, fixed or removable, will be allowed on any personnel or equipment leaving YVONNE Island. "Detectable" means detectable on a portable instrument designed to measure that type of radiation, i.e., GM, PAC, CP, etc.