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Lawrence Livermore National Laboratory

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RADIONUCLIDE CONCENTRATIONS IN FISH AND INVERTEBRATES FROM BIKINI ATOLL

ABSTRACT

This report is prepared to have in a single document a summary of all of the available data on the concentrations of radionuclides in samples of fish and invertebrates that were collected from Bikini Atoll between 1977 and 1984 for our analysis. Some results were presented in other published reports, and more detailed discussions of previously unpublished results are planned for future publications. Therefore, only a brief discussion of some results is provided here. As in other global studies, ^{137}Cs was found in the highest concentrations in edible flesh of all species of fish and in the lowest concentrations in the bone or liver. The mean concentration of ^{137}Cs in muscle of reef fish from the southern part of the atoll is comparable to the global-fallout concentration measured in market samples of fish collected from Chicago, IL, U.S.A., in 1982. Strontium-90 is associated generally with non-edible parts of fish, such as bone or viscera. Twenty-five to fifty percent of the total body burden of ^{60}Co is accumulated in the muscle tissue; the remainder is distributed among the liver, skin, and viscera. The mean concentration of ^{60}Co in fish has been decreasing at a rate faster than radiological decay alone. Most striking is the range of ^{207}Bi concentrations among different species of fish collected at the same time and place. Highest concentrations of ^{207}Bi were consistently detected in the muscle (and other tissues) of goatfish and some of the pelagic lagoon fish. In other reef fish, such as mullet, surgeonfish, and parrotfish, ^{207}Bi was usually below detection limits by gamma spectrometry. Over 70% of the whole-body activity of ^{207}Bi in goatfish is associated with the muscle tissue, whereas less than 5% is found in the muscle of mullet and surgeonfish. Neither $^{239+240}$Pu nor ^{241}Am is accumulated significantly in the muscle tissue of any species of fish. Apparently, ^{238}Pu is in a more readily available form for accumulation by fishes than $^{239+240}$Pu. Based on a daily ingestion rate of 200 g of fish flesh, dose rates to individuals through the fish-food ingestion pathway are well below current Federal guidelines.

INTRODUCTION

Bikini Atoll is located in the northern Marshall Islands at about 11°36' N, 165°22' E. The atoll now consists of 23 small coral islands surrounding a lagoon 35-km long, 21-km wide, and 630 km^2 in area. The average depth of the lagoon is 45 m. The total land area of the atoll is 6.2 km^2. The Marshallese island names and the code letters and numbers we have assigned for reference to the islands of the atoll are shown in Table 1.

Bikini Atoll is one of two sites in the northern Marshall Islands used by the United States as testing grounds for nuclear devices from 1946 to 1958. The U.S. code names for the nuclear tests[1] are shown in Table 2, and the approximate locations[2,3] of these tests are indicated in Fig. 1. The locations in Fig. 1 designated by the letter "K" are old disposal sites for island debris removed in the 1969 cleanup of Bikini and Eneu Islands.[4] Most of the tests were detonated on barges anchored in the lagoon or on the reef. Two tests were air drops, two were under water, and three were surface

Table 1. Present islands of Bikini Atoll.

Assigned island locator letter and number[a]	Marshallese name	Assigned island locator letter and number[a]	Marshallese name
B-1	<u>Nam</u>	B-13	<u>Aerokoj-Aerokojlol</u>
B-2	<u>Iroij</u>	B-14	Bikdrin
B-3	Odrik	B-15	Lele
B-4	Lomilik	B-16	Eneman
B-5	Aomen	<u>B-17</u>	<u>Enidrik</u>
<u>B-6</u>	<u>Bikini</u>	B-18	Lukoj
B-7	Bokantauk	B-19	Jelete
B-8	Iomeler	B-20	Adrikan
B-9	Enealo	B-21	Oroken
<u>B-10</u>	<u>Rojkere</u>	<u>B-22</u>	<u>Bokoetoktak</u>
B-11	Eonjebi	<u>B-23</u>	<u>Borkdrlul</u>
<u>B-12</u>	<u>Eneu</u>		

[a] Names and codes underlined designate islands with fishing sites.

Table 2. Announced nuclear detonations at Bikini Atoll.

Test	Date	Type	Map ref. (Fig. 1)
Able	6/30/46	Air drop	A
Baker	7/24/46	Under water	A
Brovo	2/28/54	Surface	B
Romeo	3/26/54	Barge	B
Koon	4/6/54	Surface	C
Union	4/25/54	Barge	D
Yankee	5/4/54	Barge	D
Cherokee	5/20/56	Air drop	E
Zuni	5/27/56	Surface	C
Flathead	6/11/56	Barge	F
Dakota	6/25/56	Barge	F
Navajo	7/10/56	Barge	D
Tewa	7/20/56	Barge	G
Fir	5/11/58	Barge	B
Nutmeg	5/21/58	Barge	H
Sycamore	5/31/58	Barge	B
Maple	6/10/58	Barge	I
Aspen	6/14/58	Barge	B
Redwood	6/27/58	Barge	I
Hickory	6/29/58	Barge	H
Cedar	7/2/58	Barge	B
Poplar	7/12/58	Barge	J
Juniper	7/22/58	Barge	H

explosions. Different quantities of the radioactive fission and activation products, generated during the explosions, were deposited on the lagoon and on the islands of the atoll.

The U.S. moratorium on testing began on October 31, 1958, and marked the end of all nuclear testing at the atoll. However, even today quantities of long-lived fission products, such as ^{137}Cs, ^{90}Sr, ^{155}Eu, and ^{113m}Cd; activation products, such as ^{55}Fe, ^{60}Co, and ^{207}Bi; and transuranium

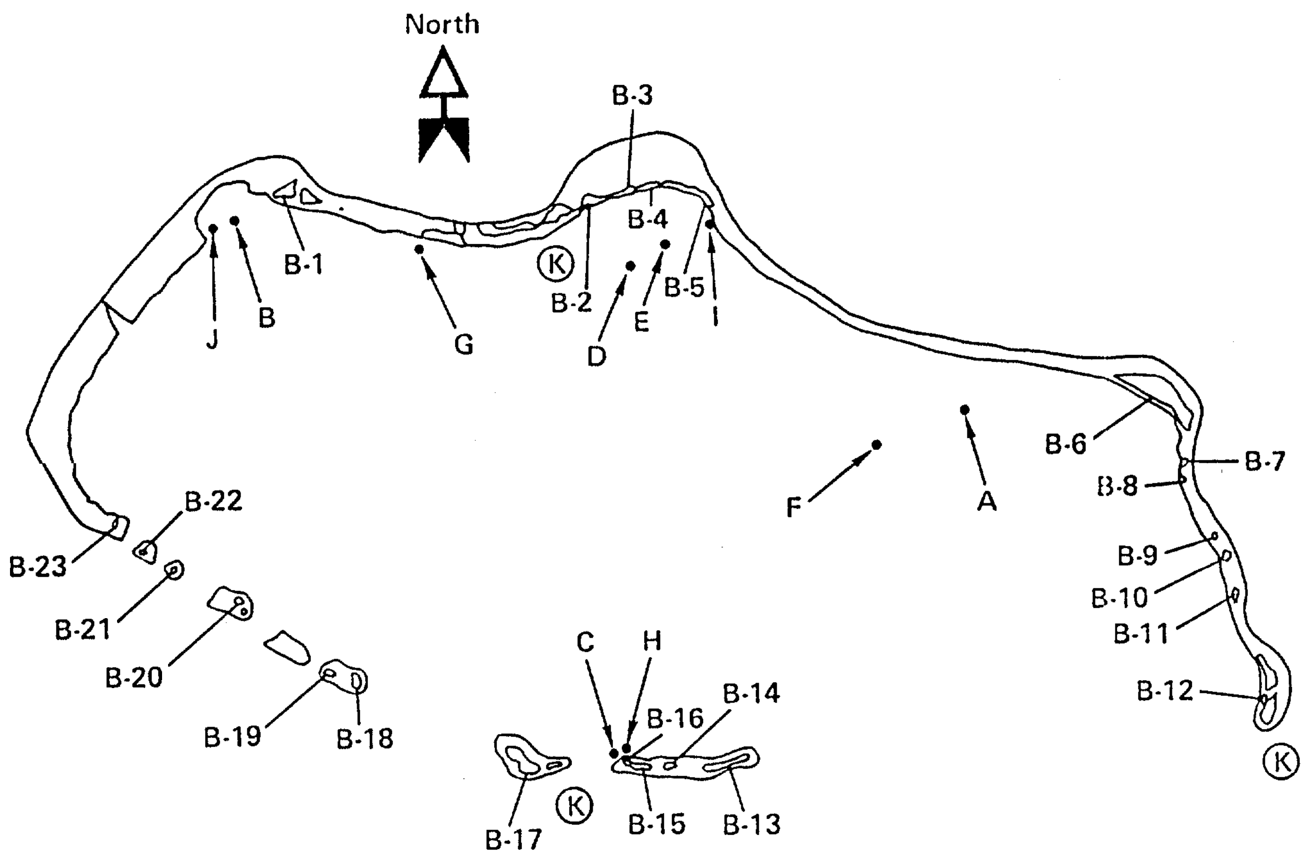

Figure 1. Bikini Atoll showing assigned island locator letters and numbers, locations of nuclear tests, and soil-disposal sites.

radionuclides, such as ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, and ^{241}Am persist in the atoll's environment. They are accumulated to different levels by indigenous terrestrial and aquatic plants and animals that may be used as food by people.

In the marine environment, the contaminated lagoon sediments are the major source of man-made radionuclides for fish and other marine organisms. In 1977, we initiated detailed studies at Bikini Atoll to define the physical, chemical, and biological transport mechanisms and the fate of transuranic and other long-lived radionuclides in this environment. A variety of species of fish was collected for radionuclide analysis. One objective of our studies was to provide an updated assessment of radiological dose to individuals via the marine food pathway, fish being one of the major marine-food products in the Marshall Islands. Data from this assessment were published in 1982.[5] Our second objective was to evaluate the biological accumulation and behavior of the transuranium isotopes at the atoll. This task continued through 1985.

In conjunction with on-going studies at Enewetak Atoll, the collections and analyses of fish samples were conducted with several additional research objectives in mind. Among these objectives were studies to assess the differences in the concentrations of specific radionuclides in fish from different trophic levels, the magnitude of radionuclide concentration factors for different species of fish, the changes in body burdens of radionuclides in fish with time, the tissue distributions of different radionuclides in different species of fish, the differences in radionuclide concentrations in fish from different regions of the atoll, and the usefulness of the current data for modeling concentrations of radionuclides accumulated by species of fish in similar or different marine environments.

The marine program at Bikini Atoll, supported by the Office of Health and Environmental Research of the Department of Energy, was phased out in 1985. Some of the results generated from this program were discussed in published reports.[6-10] However, a great deal of data on radionuclide concentrations in fish have not been included in the documents referred to above. This report is prepared to have, in one document, all available data on the concentrations of radionuclides in samples of fish and invertebrates that we collected from Bikini Atoll between 1977 and 1984. This document and previously published reports[6-17] contain nearly all of the historical data on concentrations of radionuclides in fish from Bikini Atoll since the initiation of nuclear testing.

The radionuclides for which data are reported include all those detected by gamma spectrometry. In addition, the concentrations of ^{90}Sr, ^{113m}Cd, ^{238}Pu, $^{239+240}Pu$, ^{241}Am, ^{210}Po, ^{210}Pb, and ^{210}Bi are reported for those samples where radiochemical analysis was performed.

COLLECTION METHODS

Throw nets were used exclusively to catch reef fish in shallow water from the islands noted in Table 1. (We used the letter and number island identification system in Fig. 1 rather than the Marshallese name only for convenience.) Large pelagic fish were collected on sport fishing gear while trolling in the lagoon. All fish were returned to the research ship, segregated by species, sealed in plastic bags, and frozen. The samples were shipped by air to Lawrence Livermore National Laboratory (LLNL), Livermore, CA, for processing. Over 1550 fish representing different reef and pelagic species were caught for analysis at Bikini Atoll between 1977 and 1984.

SPECIES COLLECTED, FEEDING HABITS, AND TROPHIC-LEVEL RELATIONSHIPS

The principal species collected are those that are commonly eaten by the Marshallese people. These fish are relatively abundant, have different feeding habits, and, in some cases, represent species for which previous radiological data were available for comparison. The feeding habits and trophic level assignments described below are from descriptions by Hiatt and Strasburg.[18]

Mullet, Crenimugil crenilabis and Neomyxus chaptalii, are herbivorous, detrital feeders that ingest considerable quantities of bottom sediment along with their food. Convict surgeonfish, Acanthurus triostegus, are herbivorous browsers that feed on small algal fronds and filamentous algae that grow on reef rock or on the base of dead coral. Mullet and surgeonfish belong to the second trophic level. Goatfish, Mulloidichthys samoensis, consume fossorial and other benthic fauna, including small clams, crustaceans, other invertebrates, and small fish. This species belongs to the third trophic level. Parrotfish, Scarus sordidus, are common reef-dwelling, grazing omnivores that feed on live coral heads and occasional algae. Parrotfish are placed in the fourth trophic level because their food source (live coral polyps that feed on zooplankton) is assigned to the third trophic level.

Larger benthic, midwater, and surface carnivores were also occasionally collected near islands from the lagoon. Jacks, Caranx melampygus (Ulua) and Elegatis bipinnulatus (rainbow runner), are fast-swimming carnivores that feed on small fish and squid. Elegatis bipinnulatus may occasionally eat swimming crustacea. Snappers, Aprion virescens (grey snapper) and Lutjanus bohar (red snapper), are hovering, midwater-to-surface carnivores. Another snapper, Letherinus kallopterus (pigfish), is a bottom dweller that feeds primarily on benthic crustacea. Jacks and snappers are in the fourth trophic level. Tuna, Euthunnus affinis (bonito) and Gymnosarda nuda (Dog Tooth Tuna), and mackerel, Grammatorcynus billineatus, are large, rapid-swimming carnivores that feed on small fish and any other prey of proper size. They represent species of the fifth trophic level. In the remainder of this report, common names rather than scientific names will be used for convenience.

SAMPLE PROCESSING AND ANALYSIS

Sample processing and analysis began with counting and partially thawing the fish from each location. The total weight, length, and sex of each fish was recorded. Each fish was dissected into muscle tissue, bone (cranial, thoracic, vertebrae, ribs, pelvic and pectoral girdle), skin and scales (fins discarded), stomach (gizzard) contents, liver, and remaining viscera that generally included large and small intestines with contents, stomach wall, spleen, kidney, and mesenteries. The concentrations determined in the viscera samples are regrettably less descriptive than those for other tissues because of the matrix of organs and tissues represented. In some instances, however, a finer division of the visceral components was made. Each separate tissue and organ of the species from the same catch was pooled. It was necessary to pool tissues from a particular catch for analysis because of the low concentrations of transuranic radionuclides anticipated in edible muscle tissue. This resulted in the mixing of fish from several populations (weight classes) and of different sexes. Because mixing masked any differences in concentration related to weight (size), sorting of different size classes for processing was accomplished, in some instances, to assess the relationship of radionuclide concentration with weight. We were unable to relate any differences in concentrations of specific radionuclides with sex. Gills were separated from the fish but not analyzed. Our experience at Bikini and Enewetak Atolls showed that gills were frequently contaminated with sediment. Gills are not eaten and questionable information would be gained from their analysis because of the possible contamination.

After the wet weight was determined, each pooled fish tissue sample was dried in ovens at 90°C to constant dry weight and ashed in muffle furnaces at 450°C. The only samples not prepared in this way were the samples to be analyzed for ^{210}Po. In those cases, wet tissues and organs were used.

The scientific objectives for the analysis of fish in the Marshall Island program changed over the years. For example, initially fish were collected to assess the concentration of radionuclides in tissues of different species of

Table 3. Mean dry/wet weight ratios of fish tissues and organs.

Fish common name	Tissue or organ - mean dry/wet wt ratio					
	Muscle	Bone	Gizzard contents	Viscera	Skin	Liver
Mullet						
Crenimugil	0.23±0.01	0.60±0.07	0.62±0.05	0.35±0.07	0.53±0.05	0.24±0.05
Neomyxus	0.23±0.01	0.58±0.03	0.58±0.03	0.41±0.06	0.51±0.03	0.28±0.03
Surgeonfish	0.22±0.01	0.59±0.03	0.15±0.04	0.19±0.04	0.38±0.03	0.23±0.03
Goatfish	0.23±0.02	0.52±0.05	0.22±0.08	0.29±0.05	0.50±0.05	0.25±0.03
Parrotfish	0.22±0.04	0.56±0.02	0.44±0.09	0.41±0.04	0.43±0.03	0.40±0.12
Ulua	0.24±0.01	0.65±0.02	0.19±0.03	0.26±0.03	0.41±0.03	0.27±0.03
Jack	0.24±0.01	0.62±0.05	0.25±0.03	0.25±0.02	0.38±0.05	0.25±0.04
Rainbow runner	0.26±0.01	0.62±0.03	0.22±0.02	0.32±0.05	0.48±0.02	0.33±0.07
Snapper	0.23±0.01	0.61±0.05	0.11±0.04	0.23±0.01	0.44±0.07	0.27±0.03
Mackerel	0.24±0.01	0.54±0.03	0.26±0.02	0.25±0.02	0.35±0.02	0.26±0.03
Bonito	0.29±0.01	0.64±0.02	0.24±0.02	0.22±0.01	0.56±0.01	0.32±0.02

fish. As the program progressed, dose assessment became an important issue, so our attention focused on the analysis of edible muscle tissue from fish collected at different locations. Later our interests shifted to evaluate the concentrations in muscle among different species collected simultaneously from the same lagoon location. As a result, not every tissue and organ separated from the fish collected over the years were processed for radionuclide analysis.

The mean dry/wet weight ratios for the tissues and organs most frequently analyzed are shown in Table 3. The dry/wet weight ratios of the stomach contents are of particular interest, because the differences noted attest to the different feeding habits of different species. The percentage that the organ or tissue was of the whole body fresh weight was also determined for several species. These values are given in Table 4.

The ashed samples were transferred to aluminum or plastic containers, sealed, and analyzed by gamma spectrometry at LLNL using a variety of Ge(Li)-diode detector systems. Counting times were usually 1000 min or longer for each sample. A general purpose computer program, called GAMANAL,[19] was used

Table 4. Mean percent of whole body weight of tissues and organs of fish.

Tissue or organ	Mean % Crenimugil	Neomyxus	Surgeonfish	Goatfish	Snapper
Muscle	58.9	55.3	66.3	66.3	76.7
Bone	6.9	5.5	8.0	8.0	9.1
Skin	7.1				
Scales	7.0				
Skin and scales	14.1	14.1	11.6	11.6	9.3
Eyes	1.2	0.7	1.2	2.6	1.8
Ovary	1.0	2.4	1.5		
Testes	1.8	1.2	1.1		0.23
Gill	1.8	1.4	1.6		0.7
Liver, viscera, and gizzard	13.6		7.9		
Viscera and gizzard	12.7	17.9	7.2	6.5	1.8
Viscera and liver	11.8				
Viscera	10.9	16.1	6.5		
Gizzard	1.8	1.8			
Liver	0.9	1.7	0.7	0.4	0.5
Gizzard contents	0.7	0.7	0.7	0.08	0.03

for the data reduction of all gamma-ray spectra. In GAMANAL, the observed photopeak in the measured spectra is compared with a library of gamma-ray fission and activation products and naturally occurring radionuclides to identify the radionuclides in the sample. The program then applies correction factors for sample size, density, counting time, counting geometry, and decay to convert the measured counting rate to pCi /g of sample on the date of collection. The program also generates an upper-limit amount of specific spectral radionuclides based on those spectral regions where signals would be seen if the radionuclide were present in detectable quantities. Our minimal detectable concentrations (based on a counting time of 1000 min) for each of the longer-lived, man-made, gamma-emitting radionuclides routinely or occasionally detected in samples from the Marshall Islands are shown in Table 5.

Table 5. Detection limits (1σ) of selected gamma-emitting radionuclides in the Bikini Atoll environment as a function of sample size.

Sample size (g)	pCi/sample - 1000 minutes counting time							
	^{40}K	^{60}Co	^{110m}Ag	^{125}Sb	^{137}Cs	^{155}Eu	^{207}Bi	^{241}Am
3 ± 2	10	1.0	1.0	1.2	0.5	0.9	0.8	1.5
10 ± 5	15	1.6	1.8	1.7	0.8	1.4	1.5	2.5
70 ± 30	20	2.4	3.2	2.9	1.2	2.4	2.2	4.0
160 ± 60	30	3.6	4.5	4.6	1.8	4.0	3.2	7.5

After gamma analysis, a number of samples were selected for radiochemical analysis for ^{90}Sr, ^{137}Cs, ^{113m}Cd, $^{238,239,240}Pu$, ^{241}Am, ^{210}Po, ^{210}Pb, and ^{210}Bi. Activities of these radionuclides were measured using either alpha-spectrometer systems or low-background beta detectors. Measurements of these radionuclides were conducted because some were judged to be of potential significance for dose assessments and others were analyzed to meet specific programmatic objectives. The ^{137}Cs was often radiochemically separated from muscle tissue and analyzed to confirm the measurements made by gamma spectrometry, which, in turn, provided a useful laboratory calibration for quality control.

Quality of data has always been an important aspect of our analytical measurements. As a standard practice, 5 to 10% of our time is devoted to quality-assurance work in all projects involving analytical measurements. This quality-assurance work includes

- Analysis of background samples and blanks.
- Instrument calibration.
- Duplicate sampling and analysis.
- National and international interlaboratory standardization.
- Replicate measurements.
- Analysis and calibration traceable to National Bureau of Standards samples.
- Appropriate statistical analysis of the results.

RESULTS AND DISCUSSION

Collection information, such as island sampled, common and scientific names of fish, number of fish pooled per sample, sex, average whole body weights, and average lengths, is presented in the odd-numbered tables in the Appendix. There is an odd-numbered table for fish for each collection period and a final odd-numbered table for invertebrates. Each of these tables is followed by an even-numbered table showing the radionuclide concentrations in the separated tissues and organs from the species collected. The radionuclides detected most frequently in the muscle tissue and other organs by gamma spectrometry included (in addition to naturally occurring ^{40}K) ^{137}Cs, ^{60}Co, and ^{207}Bi. Occasionally the radionuclides ^{155}Eu, ^{241}Am, ^{125}Sb, ^{108m}Ag, ^{102m}Rh, and ^{113m}Cd were also detected (by gamma spectrometry) in the viscera, liver, or stomach (gizzard) content samples of fish collected from the more contaminated regions of the atoll. The concentrations of the transuranics and other radionuclides in tissues and organs analyzed by wet chemical methods are also listed. The locations of the islands sampled (island locator letter and number) are shown in Fig. 1. All concentrations are listed relative to dry weight, but the dry/wet weight ratios provided may be applied to convert concentrations to a wet-weight basis.

Representative whole fish concentrations of several radionuclides were reconstructed from the tissue and organ concentration data, and the percentages of the respective tissues to whole body weight are given in Table 4 for species representing three trophic levels (surgeonfish, mullet, trophic level II; goatfish, trophic level III; snapper, trophic level IV) collected from different islands of the atoll in 1978. These values were used to compute the percent of the whole body activity associated with the respective tissues. The results from these calculations are shown in Table 6 and are discussed in the following sections.

CESIUM-137 IN FISH

The results in Table 6 show that most ^{137}Cs accumulated by fish from the atoll is found associated with the edible flesh; the lowest percentages are associated with bone or liver. Concentrations of ^{137}Cs in the flesh of all four species are approximately equivalent to the concentration in the reconstructed whole body. There is no straightforward relationship between

Table 6. Reconstructed total body radioactivity associated with tissues and organs analyzed[a] and measured muscle-tissue concentration.

Radionuclide	Common name of fish	Island locator	Percent of total body activity in tissue or organ: Muscle	Bone	Skin	Liver	Viscera	Gizzard contents	Reconstructed whole fish concentration pCi/kg wet wt[b]	Measured muscle tissue concentration pCi/kg wet
^{137}Cs	Surgeonfish	B-10	75	0.7	15	0.5	2	0.7	42	47
	Mullet	B-1	53	0.3	13	2	26	1	206	198
	Goatfish	B-27	68	<0.9	7	<0.4	17	<0.2	47	48
	Snapper	B-23	92	<0.3	4	<0.2	0.7	10.01	123	147
^{90}Sr	Surgeonfish	B-10	2	46	10	0.2	34	1	23	0.62
	Mullet	B-5	0.06	2	3	0.07	82	8	518	0.52
	Goatfish	B-17	2	40	29	0.05	22	<0.[illegible]	109	3.2
	Snapper	B-1	0.9	63	34	<0.1	<0.1	<0.[illegible]2	19	0.23
^{60}Co	Surgeonfish	B-10	36	6	19	12	17	4	47	26
	Mullet	B-23	28	3	17	22	25	0.[illegible]	810	410
	Goatfish	B-17	38	2	12	5	35	0.[illegible]	462	263
	Snapper	B-23	48	0.1	14	25	11	0.[illegible]	331	206
^{207}Bi	Surgeonfish	B-10	<18	<13	<9	33	19	<3	2	<0 ≤
	Mullet	B-23	5	1	4	5	76	5	54	4
	Goatfish	B-17	67	4	10	1	10	<0.[illegible]	225	226
	Snapper	B-23	81	<0.1	3	2	2	<0[illegible]	279	330
$^{239+240}Pu$	Surgeonfish	B-10	0.2	5	3	2	80	4	29	0.1
	Mullet	B-23	0.2	0.5	0.5	5.3	82	7	380	1.1
	Goatfish	B-17	0.1	0.7	0.9	0.8	90	0.1	44	0.07
	Snapper	B-1	4	26	50	11	6	0.3	2	0.1
^{241}Am	Surgeonfish	B-10	0.1	2	2	1	85	5	12	.03
	Mullet	B-23	0.9	0.2	0.5	4	69	21	69	1.0
	Goatfish	B-17	0.1	1	1	1	89	0.2	14	0.03
	Snapper	B-1	2	24	51	17	5	0.3	1	0.04

[a] Muscle, skin, bone, liver, viscera, and gizzard contents account for 93 to 98% of total fish weight. Data are from 1978 collections. Concentrations in gills, eyes, and reproductive organs were not determined.

[b]
$$\frac{\left(\Sigma \frac{\text{pCi}}{\text{kg wet tissue}} \times \text{\% tissue of whole body wt}\right)}{\Sigma \text{ \% tissue of whole body wt}} = \frac{\text{pCi}}{\text{kg wet wt}} \text{ whole fish}$$

Table 7. Mean concentrations of ^{137}Cs in the flesh of reef and pelagic fish from different islands and during different collection periods.

Island locator	Number of samples	^{137}Cs (pCi/kg wet wt) Mean	Range
B-1	11	265 ± 111[a]	130-460
B-5	9	181 ± 138[a]	40-370
B-6	12	66 ± 70[a]	12-240
B-10	3	26 ± 18[a]	14-50
B-12	6	24 ± 20[a]	7-62
B-13	2	16 ± 7[a]	11-21
B-17	6	42 ± 28[a]	12-90
B-23	2	33 ± 16[a]	20-45
Pelagic species	13	164 ± 113[b]	60-380
All reef fish (all lagoon locations)			
1977-1978	28	119	
1980-1981	11	146	
1982-1984	12	97	
1977-1984	51	113	

[a] Mean concentration for all mullet, surgeonfish, goatfish, and parrotfish collected between 1977 and 1984.
[b] Mean concentration from all pelagic species collected between 1977 and 1984.

the trophic position of the fish and their muscle burden of ^{137}Cs. The largest fraction of the ^{137}Cs is found in the muscle tissue of the fourth-trophic-level fish, snapper, and the lowest fraction in the second-trophic-level fish, mullet. However, surgeonfish, also a second-trophic-level species, have a larger fraction of the total ^{137}Cs in muscle tissue than is found in the third-trophic-level fish, goatfish.

The data on the concentrations of ^{137}Cs in the muscle tissue of fish are presented here in several ways to help in the interpretation of results. Table 7 contains a summary of the mean and range of ^{137}Cs concentrations (no corrections were made for radioactive decay) in the muscle tissue of reef fish from different islands and of pelagic species from the lagoon during the 8-year period. Concentrations of ^{137}Cs in the muscle tissue of all species of fish during this period ranged from 7 to 460 pCi /kg wet weight. The maximum concentration of ^{137}Cs in flesh, 460 pCi/kg wet weight, was measured in surgeonfish collected from island B-1 in 1983, and the mean concentration in the flesh of all reef fish during the 8-year period was 113 pCi /kg wet weight. The computed annual whole-body dose-equivalent rate to individuals from ^{137}Cs in the fish ingestion food pathway would have been less than 1 mrem (assuming a consumption rate of 200 g of fish flesh per day and a concentration of 113 pCi /kg wet weight).

Between 1977 and 1984, generally higher concentrations of ^{137}Cs were measured in muscle of reef fish from the northwest quadrant of the atoll (B-1 to B-5), and the lowest levels were found associated with reef species from the eastern reef of the atoll. In 1982, marine fish fillets purchased from stores in the Chicago area of the United States, contained 23 ± 2 pCi/kg of ^{137}Cs derived from global fallout.[20] Table 7 shows that the mean concentrations of ^{137}Cs in fish from islands B-10 to B-23 are now comparable to the fallout levels in the store-purchased fish.

In Table 8 are shown several examples of the different concentration for ^{137}Cs (pCi/kg wet weight) measured in the muscle tissue of different reef species collected from the same island during different years. The mean concentrations determined for all lagoon species during yearly intervals are shown in Table 7. There does not appear to be any precise trend indicating that the concentrations of ^{137}Cs in the muscle of these fish have been changing over the years at some consistent rate. There also appears to be no clear trends of consistent differences in concentrations among the different reef species simultaneously sampled from the same location (see Appendix). In 1978, for example, at island B-1, the highest concentration among the different reef species was measured in mullet (Crenimugil). At Island B-1 in 1983 and at B-6 in 1980, the concentration in surgeonfish exceeded the measured concentration in mullet and goatfish. In 1984, the measured concentration of ^{137}Cs in the muscle tissue of goatfish was larger than the concentration measured in any of the pelagic species collected off the island; however, at B-6 and B-23 in 1978 and at B-6 in 1980, the concentration in goatfish was lower than the levels detected in pelagic species from the respective islands.

Table 8. Concentrations of ^{137}Cs in the muscle tissue of fish collected from locations at Bikini Atoll at different times.

Period sampled	^{137}Cs (pCi/kg wet wt)					
	Mullet (Crenimugil)		Surgeonfish (Acanthurus)		Goatfish (Mulloidichtys)	Mullet (Neomyxus)
	B-1	B-6	B-1	B-5	B-6	B-17
1/77	263					40
11/78	397		133	226	21	12
9/80		51			12	
2/81	227	60		320		
8/83	287		430	43		
9/84		53			16	13

Unless there is some unforeseen impact on the lagoon, such as the disposal of uncontained, contaminated soil to the lagoon floor, there should be no significant change in the mean concentration of ^{137}Cs in the flesh of fish collected from Bikini in the near future (other than a continuous reduction from radioactive decay). Any concentrations of ^{137}Cs in the muscle tissue of fish caught at the atoll in future years should fall below the upper limit noted in the last 8-year period. Hence, future dose rates to individuals from ^{137}Cs in the fish-food pathway may be predicted with a reasonable degree of certainty from a knowledge of the islands to be fished, the consumption rate of reef and pelagic fish, and parts of the fish normally eaten.

STRONTIUM-90 IN FISH

Concentrations of ^{90}Sr were measured in the tissues from a small subset of the fish, primarily from the collections made in 1978. Inspection of Table 6 shows that most of the ^{90}Sr accumulated by fish is, unlike ^{137}Cs, associated with non-edible parts such as bone and viscera. In surgeonfish, goatfish, and snapper, most of the body burden of ^{90}Sr is found in the bone tissue. In mullet, however, the viscera contains the major fraction of ^{90}Sr. The high concentration of ^{90}Sr in the viscera is probably due to ^{90}Sr associated with the bottom sediments, which are ingested with food and are present in the intestinal tract. Intestinal tract contents were not separated from the viscera sample.

Concentration of ^{90}Sr in the muscle tissue from all fish ranged from 0.2 to 5.7 pCi/kg wet weight. The mean concentration in muscle tissue is 1.7 pCi/kg wet weight. At this concentration and a consumpt on rate of 200 g of muscle tissue/d, the resulting mean dose-equivalent rate from ^{90}Sr in the marine fish-food ingestion pathway is less than 0.1 mrem/y. Concentrations of ^{90}Sr associated with muscle tissue are less than 3% of the concentration in the reconstructed whole fish (Table 6). Estimated dose-equivalent rates of ^{90}Sr from muscle only or from whole fish ingestion will differ by orders of magnitude. Therefore, it is misleading to use whole fish (or eviscerated whole fish) concentration data for ^{90}Sr to estimate radiological dose to individuals from ^{90}Sr in the marine fish-food pathway.

COBALT-60 IN FISH

Between 1958 (the end of nuclear testing at the atoll) and 1984, ^{60}Co levels in the atoll environment decreased by a factor of 5 from radioactive decay alone ($t_{1/2}$ = 5.26 y). However, measurable concentrations of ^{60}Co are still found in fish and other aquatic organisms. In fish, 25 to 50% of the total body burden of ^{60}Co is present in the muscle tissue, with most of the remainder distributed among the liver, skin, and viscera (see Table 6). The levels of ^{60}Co in the muscle tissue of reef fish from different regions in the atoll differ somewhat in the same way as that of ^{137}Cs except that fish from the southwest portion of the atoll contain concentrations comparable to those in fish caught in the northwest quadrant of the atoll. Concentrations of ^{60}Co in the muscle tissue of bottom-feeding mullet and goatfish were consistently higher than levels in other reef species, such as surgeonfish and parrotfish, and in pelagic species caught from the same island of the atoll. This pattern is repeated when concentrations in other tissues and organs of the different species are compared.

In Table 9 are shown mean concentrations in the muscle of reef and pelagic fish collected from the lagoon during different periods between 1977 and 1984. The mean concentration of ^{60}Co in the muscle tissue of fish has been decreasing at a rate faster than that from radiological decay alone. When appropriate data were found, a comparison was made between the concentrations in specific tissues and organs measured in the 1977-to-1984

Table 9. Mean concentrations of ^{60}Co in the muscle tissue of reef and pelagic fish collected at different times.

	Collection year intervals	Number of samples	^{60}Co (pCi/kg wet wt)	
			Mean concentration	Range in concentrations
All reef species	1977-1978	27	235±209	19-897
	1980-1981	12	146±110	31-430
	1982-1984	12	60±51	7-180
All pelagic species	1977-1978	4	166±124	
	1981-1984	6	81±56	43-199

collections to those detected in the same tissues of the species collected from the same locations during 1964 and 1969.[11,13] A least-squares fit of the appropriate present and historical data shows that the mean level of ^{60}Co has been declining in the tissues of fish from Bikini with an effective decay constant of $0.22 \pm 0.05\ y^{-1}$ (effective half-life of 3.2 y). The effective decay constant is the sum of the physical decay constant ($0.1317\ y^{-1}$) and an environmental loss rate term that reflects the removal rate of ^{60}Co. This removal rate is usually expressed as the ecological half-life (or decay constant) and has a value for ^{60}Co of 7.8 y. The disappearance of ^{60}Co from Bikini lagoon and its availability to fishes is controlled both by radiological decay and by processes of remobilization, transport, and dilution. If ^{60}Co continues to decline in the environment at the present rate, the mean concentration of ^{60}Co in the edible muscle tissue of fish from the lagoon should be less than 20 pCi/kg wet weight by the year 1990.

BISMUTH-207 IN FISH

The presence of ^{207}Bi ($t_{1/2}$ = 33.4 y) was first reported in marine samples obtained from the Pacific Proving Grounds in 1961.[21] It was formed possibly from a series of nuclear reactions such as $^{207}Pb(p,n)$ or $^{206}Pb(p,\gamma)$, assuming stable lead was present during testing as shielding material near the nuclear devices.[22] Other than a recent report describing ^{207}Bi as a component in global fallout debris,[23] it has not been detected elsewhere as a component of any waste discharged to aquatic environments from nuclear facilities.

Most striking was the range of concentrations found in tissues and organs among different species of fish collected at the same time and place (see Appendix). For three species of reef fish, mullet, surgeonfish, and parrotfish, ^{207}Bi in most parts of the fish was usually below detection limits by gamma spectrometry. However, the radionuclide was consistently detected in the muscle and other organs of goatfish and the pelagic lagoon fish. Over 70% of the whole-body activity of ^{207}Bi in goatfish and pelagic fish is associated with the muscle tissue, whereas less than 5% (when detected) is found in the muscle of mullet and surgeonfish. Between 1977 and 1984, the concentrations in goatfish muscle ranged from a high of 1360 pCi/kg wet weight to a low of 17 pCi/kg wet weight, with the lowest levels found in fish collected from the eastern reef of the lagoon. There was no clear trend in the data to indicate that the concentration of ^{207}Bi in the muscle of goatfish was changing with time at some constant rate. At B-1 and B-5, for example, the levels in muscle tissue were significantly less during the period of 1981-1983, compared to the concentrations measured in 1978. On the other hand, at B-6 and B-12, the concentrations measured in the muscle tissue of goatfish collected in 1984 were no different than the concentrations detected in 1978.

TRANSURANIUM RADIONUCLIDES IN FISH

Several reports on the concentrations of the transuranium elements in Bikini fish have been published by this laboratory.[9,10,24] Only previously unpublished results and a few highlights from published data will be discussed in this report.

The data in Table 6 show that both $^{239+240}Pu$ and ^{241}Am are not significantly accumulated in the muscle tissue of any species of fish. Less than 1% of the total body burden of both $^{239+240}Pu$ and ^{241}Am is associated with the muscle tissue of all reef species. Somewhat higher fractions, but lower concentrations, were found associated with muscle tissue of pelagic species. The distributions of $^{239+240}Pu$ and ^{241}Am among the other tissues of the reef and pelagic species are also different. For example, the bone and skin of reef fish contain much less of the total body burden than that of snapper. These differences appear to be independent of location and the level of contamination and much more dependent on species.

Arithmetic mean concentrations of $^{239+240}Pu$, ^{238}Pu, and ^{241}Am in edible muscle tissue from all fish collected at Bikini during different periods between 1977 and 1984 are shown in Table 10. The results also show that there has been essentially no change in the mean concentration of $^{238+240}Pu$ during the years of collection. Mean concentrations of the transuranic radionuclides in the flesh of fish from Bikini Atoll are a fraction of a pCi/kg wet weight. Barring any major impact on the lagoon environment that might affect the availability of the transuranic radionuclides to marine organisms, mean concentrations in the flesh of fish collected over the next 10 to 20 years should not differ greatly from present-day values. The 30-y committed-dose equivalent to the bone marrow of individuals from the transuranic radionuclides in the fish-flesh-ingestion pathway (using 200 g/d as the ingestion rate and the mean value for flesh concentration) ranges from 3 to 6 mrem. This range results from increasing the adult gut-transfer coefficient for plutonium[9] from 1×10^{-4} to 5×10^{-4}.

In fish with relatively high body burdens of $^{239+240}Pu$, the ^{238}Pu to $^{239+240}Pu$ activity ratio in the muscle and other internal organs was usually higher than the activity ratio found in the material ingested by the fish. In many cases, the error associated with the measurements of ^{238}Pu was large, and it could be argued that the differences among the samples were not real.

Table 10. Summary of transuranic concentrations in the flesh of all fish from Bikini Atoll.

		pCi/kg wet wt [a]		
	Period	$^{239+240}Pu$	^{238}Pu	^{241}Am
Arithmetic mean	1977-1978	0.39±0.34		
	1977-1981	0.37±0.32		
	1977-1984	0.29±0.30	0.020±0.021	0.18±0.28
Range in values	1977-1984	<0.007-1.1	<0.002-0.08	<0.01-1.1

[a] If the radionuclide concentration was below limits of detection, the value of the concentration was not included in the average.

However, the patterns repeat themselves regardless of the error associated with counting, indicating that the trends found for the different ratios among the tissues and gut-content samples of the fish are real. This pattern pointed to the possibility of discrimination between isotopes of plutonium, which is difficult to accept from a purely chemical viewpoint. The following steps were taken to analyze if discrimation between the isotopes of plutonium was taking place. Gizzard and intestinal contents were removed from samples of mullet collected from the more-contaminated regions of Bikini and equilibrated with seawater for 5 hours. (Five hours is the normal time for the ingested material to pass through the gut of mullet.) From this experiment, the $^{238}Pu:^{239+240}Pu$ activity ratio was determined in the solid phase and in solution. Five sets of results are shown in Table 11. In every case, more ^{238}Pu relative to $^{239+240}Pu$ is measured in solution, which indicates that ^{238}Pu in the material ingested by fish must be in a more readily soluble form than $^{239+240}Pu$.

The concentrations of $^{239+240}Pu$ and ^{241}Am in fish from the lagoon differ markedly from organ to organ and species to species. Less than 20% of the samples showed the same relative amounts of ^{241}Am and $^{239+240}Pu$ in the body parts analyzed. Concentrations of plutonium in most fish parts from any location collected during different years have comparable concentrations, showing that the fish maintain restricted feeding territories. The concentration ratio of ^{241}Am to $^{239+240}Pu$ in muscle, bone, skin, or liver was always either equivalent to or less than the ratio in the gut contents or

Table 11. Activity ratios of $^{238}Pu:^{239+240}Pu$ in liquid and solid phases of gut contents after equilibration with seawater.

Solid phase	Liquid phase	Solid:liquid phase
0.0081	0.13	0.062
0.048	0.11	0.43
0.003	0.14	0.021
0.010	0.22	0.045
0.0034	0.27	0.13

viscera. If the internal body burdens of transuranic nuclides are accumulated by the fish through the gut, then it could be concluded that in most cases there is a discrimination against ^{241}Am relative to $^{239+240}$Pu in different tissues.

The radionuclides ^{242}Cm, ^{243}Cm, and ^{244}Cm have been detected in some fish tissues from Bikini. Concentrations of ^{243}Cm and ^{244}Cm are a few percent of the $^{239+240}$Pu concentrations and ^{242}Cm is less than 1% of the $^{239+240}$Pu levels in the entire fish. The detection of ^{242}Cm ($t_{1/2}$ = 163 d), approximately 25 years after the end of testing, indicates the presence of a parent radionuclide, ^{242m}Am, in the environment.

OTHER RADIONUCLIDES IN FISH

Concentrations of ^{113m}Cd and naturally occurring ^{210}Pu, ^{210}Po, and ^{210}Bi determined in fish samples are listed in the Appendix. Discussions of the concentrations and significance of these radionuclides at Bikini Atoll have been presented in the literature[6-8] and will not be repeated here.

RADIONUCLIDES IN INVERTEBRATES

Edible species of clams and a few other invertebrates were sometimes collected by hand (free diving) in shallow areas of the lagoon. Collections for radionuclide analyses were terminated in 1980 for fear of depleting this valuable food resource at the atoll. Radiological concentration data from analysis of these few samples are included here for reference.

The clams were weighed, measured (total length), and dissected. Adductor muscles, mantle plus siphon, kidney, and remaining viscera that included gills, gonad, stomach, intestine and contents, crystalline style, heart, and nervous system were removed for analysis. Tissue samples were dried in ovens at 90°C to constant dry weight and dry ashed in muffle furnaces at 450°C for approximately 72 hours. Radionuclide concentrations in tissues of invertebrates were determined by the same procedures used to measure concentrations in fish tissues (see Sample Processing and Analysis, page 7). Collection information and radionuclide concentrations are shown in Tables A-15 and A-16 of the Appendix.

Too few samples were collected and analyzed to develop trends or meaningful relationships with the concentration data. However, it is noted that the concentrations of $^{239+240}Pu$, ^{241}Am, and ^{60}Co were consistently higher in the edible tissues of invertebrates than in the flesh of fish collected at comparable atoll locations. Highest levels of ^{60}Co were associated with the kidneys of each species of clams. Concentrations of ^{207}Bi, ^{137}Cs, and ^{90}Sr in the edible mucsle and mantle tissue were very low and, in most cases, were undetectable in the samples analyzed.

SUMMARY

Over 1550 fish representing species from all trophic levels were collected from regions of Bikini lagoon between 1977 and 1984. Concentrations of gamma-emitting radionuclides accumulated in the different tissues and organs of these fish were determined. A number of samples were selected for the radiochemical analysis of ^{90}Sr, ^{113m}Cd, $^{238,239,240}Pu$, ^{241}Am, ^{210}Po, ^{210}Pb, and ^{210}Bi. Activities of these radionuclides were measured in the tissues using appropriate alpha-spectrometer systems or low-background beta detectors. All the radionuclide concentration data are tabulated in the Appendix.

Over the 8-year period, a reasonable amount of data was developed to define adequately the range in concentrations of the different radionuclides in edible muscle tissue and other organs of fish from the lagoon at Bikini Atoll. Unless there is some unforeseen impact on the lagoon that would significantly alter the environmental concentrations of the different radionuclides, there is little reason to expect that concentrations of the different radionuclides in fish in future years will exceed the upper concentration limits determined over the last 8-year period. The present mean levels of radionuclides in edible muscle tissue of fish can be used with a reasonable degree of confidence to predict the magnitude of future radiological doses to individuals from the marine fish-food pathway at Bikini Atoll.

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APPENDIX A: CONCENTRATION DATA

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Table A-1. 1977 Fish collections - Bikini Atoll.

Island locator	Month collected	Common name	Scientific name	Number of individuals pooled/sample	Average whole body wet wt (gm)	Average standard length (mm)	Male	Female
B-1	January	Mullet	*Crenimugil crenilabis*	8	n/d[a]	325	1	7
B-2	January	Mullet	*Crenimugil crenilabis*	21	n/d	287	11	10
B-12	January	Mullet	*Crenimugil crenilabis*	11	n/d	271	1	10
B-13	January	Mullet	*Crenimugil crenilabis*	22	n/d	279	0	22
B-1	January	Mullet	*Neomyxus chaptalii*	14	n/d	221	5	5
B-10	January	Mullet	*Neomyxus chaptalii*	43	n/d	226	11	32
B-17	January	Mullet	*Neomyxus chaptalii*	58	n/d	229	9	47

[a] "n/d" means not determined.

Table A-2. 1977 Concentrations of radionuclides in fish tissue - Bikini Atoll

Sample ID	Island locator	Tissue	Dry/wet weight	^{40}K (x10^3)	$^{239+240}Pu$	^{241}Am	^{137}Cs	^{60}Co	^{207}Bi	^{238}Pu	Other
Name:		Crenimugil									
28[illegible]6		Muscle	0.253	5.1 (2)	1.5 (5)		1040 (3)	1200 (2)	<4	<0.02	
28[illegible]7		Bone	0.585	1.3 (13	19.0 (3)		38 (23)	540 (7)	<5	0.93 (8)	
28[illegible]8		Viscera[b]	0.414	4.0 (8)	6300 (2)		750 (5)	4150 (1)	140 (12)	29.5 (3)	
28[illegible]9		Stomach cont.	0.645	2 (35)	7340 (1)		740 (8)	680 (6)	190 (18)	53 (3)	
29[illegible]0		Ovary	0.232	0 (16)	58 (2)		540 (29)	7400 (5)	300 (29)	0.9 (50)	
29[illegible]1		Gill	0.189	2.2 (12	[illegible] 20 (25)		150 (19)	6350 (1)	<10	1.0 (28)	
29[illegible]2		Skin	0.532	4.7 (4)	[illegible] 34 (7)		320 (5)	1610 (1)	23 (26)	5.6 (6)	
[illegible]0		Muscle	0.245	6.4 (1)	[illegible].2 (5)		1550 (2)	1110 (1)	<2	0.10 (25)	
[illegible]1		Bone	0.629	0.9 (11)	3[illegible].0 (3)		55 (14)	280 (4)	<5	1.33 (5)	
[illegible]2		Viscera[b]	0.317	5.9 (3)	1370[illegible] (6)		1660 (14)	7500 (1)	104 (11)	590 (2)	^{102m}Rh 50 (20)
[illegible]3[c]		Stomach cont.	0.637	1.6 (24)	2530[illegible] (5)		1840 (3)	1710 (4)	252 (10)	1090 (2)	^{102m}Rh 95 (19)
[illegible]3[c]		Stomach cont.	0.637		2550[illegible] (5)					1120 (2)	
[illegible]3[c]		Stomach cont.	0.637		2870[illegible] (5)					1240 (2)	
[illegible]3[c]		Stomach cont.	0.637		2840[illegible] (6)					1250 (2)	
[illegible]4		Ovary	0.256	[illegible] (30)	4[illegible] (5)		1140 (28)	14100 (3)	<200	3 (40)	
[illegible]5		Gills	0.229	.8 (13)	[illegible]0[illegible] (25)		120 (18)	2200 (2)	<9	7.0 (6)	
[illegible]6		Testes	0.213		[illegible]3[illegible] (5)		1470 (15)	10500 (9)	<100	19 (24)	
[illegible]7		Skin	0.509	4 [illegible] (1)	11[illegible] (24)		430 (3)	1030 (1)	<3	6 (14)	
[illegible]0		Muscle	0.235	6.0 ([illegible])	0.56 (6		110 (6)	320 (6)	<2	<0.01	
[illegible]7		Bone	0.575	0.5 ([illegible]8)	6.9 (3)		<6	90 (13)	12 (26)		
[illegible]2		Viscera[b]	0.311	5.7 ([illegible])	710 (1)		53 (12)	1400 (2)	41 (11)	4.3 (6)	
[illegible]3		Stomach cont.	0.568	3.0 ([illegible]1)	070 (5)		<40	220 (18)	<30	9.4 (12)	
[illegible]4		Ovary	0.315	7.3 ([illegible]0)	10 (6)	[illegible] 7)	<40	1060 (6)	<30	<0.4	
[illegible]5		Gills	0.226	2.3 ([illegible]1)	32 (25)		<30	550 (6)	86 (18)	0.5 (23)	
[illegible]1		Skin	0.500	4.0 ([illegible])	82 (10)		35 (20)	260 (4)	<4	5.8 (8)	
2851		Muscle	0.238	6.5 (1)	0.33 (14		88 (5)	273 (5)	<2	<0.04	
2852		Skin	0.529	3.7 (3)	6 (17)		17 (28)	320 (3)	<4	0.32 (13)	
2853		Bone	0.562	0.8 (10)	7.2 (3)		<5	110 (7)	<3	0.33 (7)	
2854		Viscera[b]	0.309	7.1 (2)	440 (3)		33 (22)	2140 (3)	25 (20)	7.0 (10)	
2855		Stomach cont	0.709	1.3 (30)	130 (4)		<30	<40	<20	20.0 (4)	
2856		Ovary	0.298	9.0 (4)	12 (4)	5.[illegible]	<20	1700 (4)	<10	0.5 (35)	
2858		Gills	0.241	1.3 (18)	27 (25)		<20	980 (3)	<10	1.0 (11)	

Table A-2. (Continued)

Sample ID	Island locator	Tissue	Dry/wet weight	^{40}K ($\times 10^3$)	$^{239+240}Pu$	^{241}Am	^{137}Cs	^{60}Co	^{207}Bi	^{238}Pu	Other
				pCi/kg dry weight[a]							
Name:	Mullet	Neomyxus									
MSA 458	B-1	Muscle	0.244	12.2 (2)	3.3 (3)		950(3)	2080(3)	<12	0.03(26)	
459		Bone	0.476								
460		Gizzard cont.	0.552		9800 (2)		1100(23)	1400(20)	<150	46.1 (3)	^{155}Eu 3980(12)
461		Gizzard	0.185								
462		Liver	0.237								
463		Intestine cont.	0.450	3 5 (22)			1115(7)	1660(6)	210(16)		^{155}Eu 2880(10)
464		Viscera[d]	0.423								
465		Scales	0.576								
466		Skin	0.342								
Z≤≤8	B-1[c]	Muscle	0.315	13.0 (2)	2.5 (7)		55 (10)	67° (2)	7.2 (30		0.04 (70)
Z≤≤9		Bone		0.5 (21)	8.2 (2)		<5	11° (9)	<5	0.13 (21)	
Z≤≡0		Viscera[b]	0.338	4.9 (4)	2000 (1)		65 (16	165° (1)	77 (10	11.7 (3)	
Z≤≡1		Stomach cont.	0.568	2.0 (15)	2970 (5)		<20	30° (8)	60 (21)	14.8 (7)	
Z≤≡2		Ovary	0.334	5.5 (5)	25 (2)		<20	230° (2)	<10)	<0.07	
Z≤≡3		Testes	0.210	15 (35)	33 (12)		<300	240° (16)	<200	2.3 (70)	
Z≤≡4		Gills	0.182	2.7 (14)	61 (2)		<20	134° (4)	80 (25)	0.8 (50)	
Z≤≡5		Skin	0.513	4.4 (4)	8.1 (5)		20 (24)	55° (4)	<4	0.15 (26)	
Z≤72	B-17	Muscle	0.237	14.4 (2)	3.7 (9)	°.4 ≡3)	167 (4)	159° (1)	22 (13)	0.37 (22)	
Z≤73		Skin	0.490	4.5 (2)	15.0 (10		64 (13)	155° (1)	34 (11)	1.20 (13)	
Z≤74		Viscera[b]	0.392	3.7 (3)	3050 (3)		450 (4)	300° (1)	920 (2)	510 (2)	^{102m}Rh 180 ≤)
Z≤75		Stomach cont.		2.0 (7)	5600 (7)	101° (≈	1230 (2)	21° (7)	1050 (1)		^{102m}Rh 270 ≡)
Z≤76		Ovary	0.331	4.9 (4)	78 (5)		40 (29)	520° (1)	42 (21)	9.4 (6)	
Z≤77		Gill	0.170	3.3 (11)	190 (6)		<30	390° (2)	70 (22)	23 (7)	
Z≤78		Testes	0.228		50 (15)		<400	540° (10)	<300	7.5 (50)	
Z≤79		Bone	0.606	1.1 (14)	16 (5)		<8	41° (3)	<7	1.4 (8)	

a Numbers in parenthesis are the 1-σ counting error expressed as percent of the value listed.
b Viscera sample includes gizzard (stomach), intestine with contents, and liver.
c Replicate analysis.
d Viscera sample includes remainder of G.I. tract without contents and gonads.

Table A-3. 1978 Fish collections - Bikini Atoll.

Island locator	Month collected	Common name	Scientific name	Number of individuals pooled/sample	Average whole body wet wt (gm)	Average standard length (mm)	Male	Female
B-1	November	Mullet	<u>Crenimugil</u> <u>crenilabis</u>	12	641	298	11	1
B-5	November	Mullet	<u>Crenimugil</u> <u>crenilabis</u>	8	712	303	5	3
B-13	November	Mullet	<u>Crenimugil</u> <u>crenilabis</u>	8	492	275	3	5
B-17	November	Mullet	<u>Crenimugil</u> <u>crenilabis</u>	9	545	297	0	9
B-1	November	Mullet	<u>Neomyxus</u> <u>chaptalii</u>	18	183	208	13	5
B-5	November	Mullet	<u>Neomyxus</u> <u>chaptalii</u>	24	181	202	12	12
B-12	November	Mullet	<u>Neomyxus</u> <u>chaptalii</u>	21	209	212	13	8
B-17	November	Mullet	<u>Neomyxus</u> <u>chaptalii</u>	18	177	204	9	9
B-23	November	Mullet	<u>Neomyxus</u> <u>chaptalii</u>	35	151	193	23	12
B-1	November	Surgeonfish	<u>Acanthurus</u> <u>triostegus</u>	4	62	109	0	4
B-5	November	Surgeonfish	<u>Acanthurus</u> <u>triostegus</u>	20	65	108	12	8
B-6	November	Surgeonfish	<u>Acanthurus</u> <u>triostegus</u>	55	64	103	31	24
B-10	November	Surgeonfish	<u>Acanthurus</u> <u>triostegus</u>	46	68	108	30	16
B-12	November	Surgeonfish	<u>Acanthurus</u> <u>triostegus</u>	64	64	110	45	19
B-13	November	Surgeonfish	<u>Acanthurus</u> <u>triostegus</u>	31	88	115	8	23
B-1	November	Goatfish	<u>Mulloidichthys</u> <u>samoensis</u>	33	91	162	25	8
B-5	November	Goatfish	<u>Mulloidichthys</u> <u>samoensis</u>	22	147	187	11	11
B-6	November	Goatfish	<u>Mulloidichthys</u> <u>samoensis</u>	39	127	180	26	13
B-10	November	Goatfish	<u>Mulloidichthys</u> <u>samoensis</u>	42	111	173	32	10
B-12	November	Goatfish	<u>Mulloidichthys</u> <u>samoensis</u>	42	91	166	38	4
B-13	November	Goatfish	<u>Mulloidichthys</u> <u>samoensis</u>	31	88	115	8	23
B-17	November	Goatfish	<u>Mulloidichthys</u> <u>samoensis</u>	37	93	171	11	25
B-23	November	Goatfish	<u>Mulloidichthys</u> <u>samoensis</u>	47	86	160	36	11
B-17	November	Parrotfish	<u>Scarus</u> <u>sordidus</u>	5	840	293	0	5
Lagoon (near Bravo Crater)	November	Snapper	<u>Aprion</u> <u>virescens</u>	2	2270	520	1	1
Lagoon (W of B-6)	November	Snapper	<u>Lutjanus</u> <u>bohar</u>	1	2971	530	1	0
Lagoon (Off B-3)	November	Snapper	<u>Lutjanus</u> <u>bohar</u>	1	2214	480	0	1
Lagoon (Near Bravo Crater)	November	Jack	<u>Caranx</u> <u>sp</u>.	1	1125	490	0	1
Lagoon (W of B-6)	November	Mackerel	<u>Grammatorcynus</u> <u>billineatus</u>	1	1879	565	1	0

Table A-4. 1978 Concentrations of radionuclides in fish tissue - Bikini Atoll.

Sample ID	Island locator	Tissue[b]	Dry/wet weight	pCi/kg dry weight[a]							
				^{40}K ($\times 10^3$)	$^{239+240}Pu$	^{241}Am	^{137}Cs	^{60}Co	^{207}Bi	^{238}Pu	Other
Name:	Mullet	Crenimugil									
9133	B-1	Muscle	0.245	4.2 (2)	2.6 (5		1620 (1)	3660 (1)	16 (21)	0.045 (25)	
9134		Bone	0.648	0.6 (18)	93 (3)	20.9 (4)	37 (22)	1360 (2)	<6	1.20 (4)	
9135		Stomach cont.	0.654	1.4 (22)	8000 (20)	5400 (29)	910 (4)	730 (5)	190 (11)	44 (4)	
9136		Viscera	0.413	3.8 (3)		1220 (2)	1000 (2)	4510 (1)	130 (11)		
9137		Skin	0.569	4.0 (5)	33 (2)	10.3 (3)	390 (4)	3450 (1)	<6	0.36 (12)	
9138		Liver	0.253	16.2 (6)			1450 (8)	79200 (1)	460 (15)		^{108m}Ag 340 (14)
7245	B-5	Muscle	0.257	13·9 (1)	1.09 7		1450 (1)	947 (1)	<3	0.031 (30)	
7246		Bone	0.611	1·2 (14)	42 (6)		80 (12)	440 (5)	<7	1.0 (13)	
7247		Stomach cont.	0.598	1·7 (23)	10000 (3)	5150 (3)	3400 (2)	760 (5)	40 (33)	210 (1)	
7248		Viscera	0.431	3·8 (6)	4000 (20)	930 (4)	2310 (1)	1920 (2)	40 (15)	148 (1)	
7249		Skin	0.575	4·4 (4)	15.0 (6)	4.2 (7)	400 (4)	890 (3)	<5	0.41 (30)	
7250		Liver	0.291	0.6 (8)	1810 (2)	740 (4)	720 (12)	33400 (1)	<60	39.5 (3)	
7212	B-13	Muscle	0.232		0.36 (7)					0.032 (35)	
7213		Bone	0.593		8.90 (4)					0.22 (21)	
7214		Stomach cont.	0.639		1260 (3)	610 (3)	<20	155 (26)	60 (32)	23.9 (6)	
7215		Viscera	0.404	4.5 (4)	740 (3)	98 (2)	50 (16)	630 (3)	35 (13)	13.6 (2)	
7216		Skin	0.552	4.9 (4)	4.2 (6)		19 (30)	250 (6)	<5	0.08 (40)	
7217		Liver	0.241	17.8 (8)	840 (2)	333 (2)	<90	20000 (1)	<70	20 (16)	
7293	B-17	Muscle	0.222	16.3 (1)	1.25 6)	0.3 (80)	400 (2)	640 (2)	<3	0.08 (22)	
7294		Bone	0.616	1.4 (11)	23 (5)	5.5 (4)	<9	120 (28)	<6	2.1 (11)	^{244}Cm 0.07 (33)
7295		Stomach cont.	0.305		210 (4)		<200	<500	<300	9.4 (20)	
7296		Viscera	0.212	14.3 (2)	147 (3)		360 (6)	5060 (1)	50 (21)	11.2 (13)	
7297		Skin	0.539	4.9 (4)	11.0 (6		100 (10)	590 (3)	<6	1.1 (15)	
7298		Liver	0.228	21.0 (7)			560 (22)	29300 (2)	360 (20)		^{108m}Ag 210 (21)
Name:	Mullet	Neonmyxus									
9127	B-1	Muscle	0.244	11.9 (2)	2.2 (6)	0.50 (12)	810 (2)	1760 (1)	<5	<0.03	^{90}Sr 2.0 (35)
9128		Bone	0.584		27 (4)	9.7 (7)	<20	450 (5)	<13	0.47 (26)	^{90}Sr 211 (4)
9129		Stomach cont.	0.567		7130 (3)	5700 (4)	610 (16)	800 (14)	180 (28)	56.3 (8)	^{90}Sr 4470 (3)
9130		Viscera	0.457	3.2 (4)	3350 (3)	2130 (4)	660 (2)	2220 (2)	150 (6)	22.6 (4)	^{90}Sr 2320 (3)
9131		Skin	0.551	5.3 (4)	11.3 (7)	3.6 (13)	350 (5)	1440 (2)	<7	<0.04	^{90}Sr 164 (2)
9132		Liver	0.266	11.4 (6)	11.4 (7)		690 (13)	43800 (1)	180 (25)		

Table A-4. (Continued)

Sample ID	Island locator	Tissue[b]	Dry/wet weight	^{40}K ($\times 10^3$)	$^{239+240}Pu$	^{241}Am	^{137}Cs	^{60}Co	^{207}Bi	^{238}Pu	Other
				pCi/kg dry weight[a]							
Name:	Mullet	Neonmyxus (continued)									
7224	B-5	Muscle	0.243	10.3 (2)	1.1 (12)	0.34 (12)	247 (3)	1000 (1)	<4	0.07 (80)	^{90}Sr 2 2 (25)
7225		Bone	0.572	21.5 (4)	10.8 (5)					0.47 (24)	^{90}Sr 304 (3)
7226		Stomach cont.	0.492		5800 (2)	14700 (6)	1270 (7)	1160 (8)	<60	143 (4)	^{90}Sr 2500 (3)
7227		Viscera	0.441	3.2 (4)	6200 (5)	8800 (5)	410 (3)	1690 (1)	30 (21)	150 (6)	^{90}Sr 5400 (2)
7228		Skin	0.558	12.8 (4)	8.8 (7)	4.5 (7)	150 (12)	2100 (2)	<7	<0.1	^{90}Sr 180 (2)
7229		Liver	0.278	11.3 (5)	1030 (5)	230 (4)	170 (25)	26600 (1)	<40	26.7 (17)	^{90}Sr 80 (31)
7194	B-12	Muscle	0.247	11.9 (1)			36 (11)	403 (2)	<3		
7195		Bone	0.548	0.6 (23)			<9	50 (22)	<5		
7196		Stomach cont.	0.493	4.4 (16)			<40	430 (11)	<30		
7197		Viscera	0.466	3.0 (3)			20 (22)	380 (2)	24 (11)		
7198		Skin	0.540	4.5 (3)			<8	320 (3)	<5		
7199		Liver	0.293								
7299	B-17	Muscle	0.241	8.9 (9)			<50	5160 (2)	<40		
7300		Bone	0.566	0.8 (19			<9	210 (6)	<7		
7301		Stomach cont.	0.551	3 (36)			380 (19)	1100 (11)	190 (25)		
7302		Viscera	0.465	4.3 (4)			116 (10)	1420 (1)	99 (9)		^{102m}Rh 24 (34)
7303		Skin	0.526	5.1 (4)			50 (22)	600 (3)	<6		
7304		Liver	0.246	12.3 (9)			<70	10600 (2)	190 (26)		
7305	B-23	Muscle	0.232	10.9 (2)	4 7 (3	4.7 (3)	95 (7)	1770 (1)	19 (20)	0.14 (13)	
7306		Bone	0.569	0.4 (21)	61 (4)	6.7 (4)	<6	700 (2)	18 (22)	2.3 (8)	
7307		Stomach cont.	0.709	1.3 (22)	5000 (20)	2950 (3)	190 (11)	740 (4)	490 (4)	155 (4)	
7308		Viscera	0.426	3.3 (4)	4100 (2)	630 (3)	160 (11)	2680 (1)	540 (2)	140 (2)	
7309		Skin	0.559	4.6 (4)	22 (5)	4.6 (5)	<8	1780 (2)	25 (20)	0.7 (18)	
7310		Liver	0.291	1.4 (6)	4110 (2)	530 (7)	<50	35400 (1)	570 (7)	129 (2)	^{108m}Ag 80 (26)
Name:	Surgeonfish - Acanthurus										
9159	B-1	Muscle	0.222	14.3 (3)	5 (20)	2.4 (28)	600 (1)	1050 (2)	<10	<0.5	^{90}Sr 26 (53)
9160		Bone	0.642		48 (7)	11 (11)	<50	<70	<40	1.1 (67)	^{90}Sr 950 (3)
9161		Stomach cont.	0.220				6400 (19)	4000 (63)	<900		
9162		Viscera	0.206	17 (7)	1580 (3)	310 (6)	6750 (2)	4700 (3)	240 (21)	10 (20)	^{90}Sr 850 (4)
9163		Skin	0.393	6 (30)			4600 (5)	650 (19)	<80		
9164		Liver	0.231				1400 (37)	7200 (11)	<500		

Table A-4. (Continued)

Sample ID	Island locator	Tissue[b]	Dry/wet weight	^{40}K ($\times 10^3$)	$^{239+240}Pu$	^{241}Am	^{137}Cs	^{60}Co	^{207}Bi	^{238}Pu	Other
				pCi/kg dry weight[a]							
Name: Surgeonfish - <u>Acanthurus</u> (continued)											
7257	B-5	Muscle	0.211	18.0 (1)	0.6 (30)	0.5 (27)	1070 (1)	260 (5)	<4	0.3 (50)	^{90}Sr 6 (27)
7258		Bone	0.471		30 (7)	7.3 (8)	160 (13)	8 (24)	<10	<0.3	^{90}Sr 710 (3)
7259		Stomach cont.	0.125	21 (18)	4810 (4)	2840 (4)	<300	<900	<200	140 (14)	^{90}Sr 1590 (5)
7260		Viscera	0.143	16 4 (4)			790 (7)	4270 (2)	70 (42)		
7261		Skin	0.394	8 (8)	25 (11)	6 (16)	780 (6)	470 (9)	<20	<0.5	^{90}Sr 184 (4)
7262		Liver	0.231	14 (24)	320 (7)	150 (9)	<200	8100 (5)	<200	11 (50)	^{90}Sr <60
7352	B-6	Muscle	0.219	14.1 (2)			760 (2)	90 (7)	<3		
7353		Bone	0.601	0.4 (32)			<7	<10	<6		
7354		Stomach cont.	0.128	25 (4)			1220 (5)	1700 (6)	150 (23)		
7355		Viscera	0.141	19 (3)			1050 (2)	2320 (2)	101 (7)		
7356		Skin	0.410	8.1 (5)			690 (3)	160 (9)	<9		
7357		Liver	0.259	15.2 (5)	103 (4)	13 (60)	370 (11)	3200 (4)	400 (7)	1.7 27)	^{108m}Ag 63 (19)
7269	B-1[c]	Muscle	0.214	13.9 (2)	0.5 (20)	0.1 (56)	220 (4)	120 (14)	<3	0.12 (50)	^{90}Sr 2.9 (27)
7270		Bone	0.592		33 (4)	3.7 (9)	<7	60 (17)	<7	0.34 (43)	^{90}Sr 222 (3)
7271		Stomach cont.	0.188	16 (9)	800 (5)	404 (5)	260 (35)	1350 (7)	<60	14 (34)	^{90}Sr 230 (17)
7272		Viscera	0.173	6.0 (3)	2080 (3)	890 (3)	76 (8)	690 (2)	38 (12)	14 (7)	^{90}Sr 700 (4)
7273		Skin	0.395	6.9 (3)	20 (7)	5.1 (11)	138 (6)	193 (6)	<5	<0.2	^{90}Sr 48 (5)
7274		Liver	0.245	12 (15)	310 (7)	78 (10)	<100	3300 (5)	440 (17)	8 (50)	^{90}Sr <30
7188	B-12	Muscle	0.220	13.4 (1)			283 (2)	104 (6)	<3		
7189		Bone	0.596								
7190		Stomach cont.	0.189	0.5 (22)			<7	<11	<5		
7191		Viscera	0.177	17.3 (3)			390 (3)	960 (2)	67 (9)		
7192		Skin	0.381	7.0 (2)			177 (6)	135 (5)	<9		
7193		Liver	0.229	12 (11)			<70	2100 (5)	<60		
7218	B-13	Muscle	0.215		0.27 (8)	<1					
7219		Bone	0.593		11.5 (4)					0.25 (22	
7220		Stomach cont.	0.176	7.4 (30)	890 (2)	360 (3)	<100	1000 (15)	<100	20 (12)	
7221		Viscera	0.198	0.2 (3)	560 (4)	770 (3)	93 (13	1450 (2)	108 (9)	10.6 (5)	
7222		Skin	0.410	8.2 (3)	8.8 (7)	<3	123 (8)	180 (7)	<7	0.2 (70)	
7223		Liver	0.249	9.3 (14)	181 (3)	40 (24)	<60	2750 (4)	550 (10)	2.5 (22)	

Table A-4. (Continued)

Sample ID	Island locator	Tissue[b]	Dry/wet weight	^{40}K ($\times 10^3$)	$^{239+240}Pu$	^{241}Am	^{137}Cs	^{60}Co	^{207}Bi	^{238}Pu	Other
				pCi/kg dry weight[a]							
Name:	Goatfish - <u>Mulloidichthys</u>										
9121	B-1	Muscle	0.220	18.2 (2)	0.84 (24)	0.34 (2)	673 (3)	2600 (1)	6180 (2)	<0.1	^{90}Sr 15.6 (5)
9122		Bone	0.517		13.7 (7)	9.9 9)	128 (16)	930 (3)	780 (4)	0.4 (83	^{90}Sr 2030 (3)
9123	B-1	Stomach cont.	0.195				<700	18500 (1)	5500 (11)		
9124		Viscera	0.251	4.9 (11)	293 (3)	197 (4)	430 (13)	22300 (4)	820 (2)	7.5 (13)	^{90}Sr 47 (13)
9125		Skin	0.551	5.7 (4)	8.5 (9)	4 (9)	200 (13)	3030 (2)	1740 (2)	<0.06	^{90}Sr 1350 (2)
9126		Liver	0.240	21.8 (3)	730 (5)	450 (18)	450 (18)	07000 (1)	2800 (2)	27 (20)	^{90}Sr 90 (46)
7251	B-5	Muscle	0.225				230 (4)	1650 (2)	400 (8)		
7252		Bone	0.544				<20	490 (4)	60 (28)		
7253		Stomach cont.	0.278								
7254		Viscera	0.244	14.8 (6)			400 (33)	51700 (1)	960 (9)		
7255		Skin	0.531	7.1 (3)			60 (26)	2680 (1)	153 (6)		
7256		Liver	0.269	20.6 (7)			<200	71300 (1)	750 (13)		
7370	B-6	Muscle	0.219	18.9 (1)			95 (6)	300 (3)	81 (4)		
7371		Bone	0.505	0.7 (26)			90 (12)	100 (13	<9		
7372		Stomach cont.	0.177				<400	<500	<400		
7373		Viscera	0.251	15.1 (4)			140 (23)	6890 (2)	200 (11)		
7374		Skin	0.547	6.9 (3)			27 (26)	460 (3)	40 (15)		
7375		Liver	0.257	14.3 (8)			<70	11300 (2)	210 (25)		
7263	B-10	Muscle	0.213	17.6 (1)			65 (6)	192 (3)	103 (3)		
7264		Bone	0.514	0.7 (19)			<7	<10	18 (27)		
7265		Stomach cont.	0.208				<400	<600	<300		
7266		Viscera	0.214	16.8 (4)			<30	2770 (2)	150 (14)		
7267		Skin	0.513				<7	<10	30 (41)		
7268		Liver	0.241	17.7 (9)			<70	6940 (2)	200 (28)		
7200	B-12	Muscle	0.222	16.6 (1)	<0.03	0.05 (43)	86 (6)	430 (2)	195 (2)	<0.06	^{90}Sr 1.9 (18)
7201		Bone	0.521	0.8 (20)	3.3 (12)	1.5 (11)	<10	70 (28	30 (24)	<0.06	^{90}Sr 240 (3)
7202		Stomach cont.	0.203		150 (30)	55 (41)	<500	<800	<400	<1	^{90}Sr 700 (57)
7203		Viscera	0.291	12.1 (5)	264 (4)	143 (5)	100 (34)	3880 (2)	410 (6)	4 (25	^{90}Sr 79 (8)
7204		Skin	0.512	7.2 (3)	1.5 (10)	1.5 (1°)	30 (27)	520 (3)	68 (9)	<0.1	^{90}Sr 107 (3)
7205		Liver	0.249	20 (16)			<200	8620 (5)	370 (30)		

Table A-4. (Continued)

Sample ID	Island locator	Tissue[b]	Dry/wet weight	pCi/kg dry weight[a] ^{40}K (x10^3)	$^{239+240}Pu$	^{241}Am	^{137}Cs	^{60}Co	^{207}Bi	^{238}Pu	Other
Name: Goatfish - Mulloidichthys (continued)											
7206	B-13	Muscle	0.219								
7207		Bone	0.505		3.2 (7					0.09 (75)	
7208		Stomach cont.	0.187	25 (37)	9 (40)	25 (30)	<500	3500 (29)	<400		
7209		Viscera	0.210	18.7 (4)	28 (4)	12 (70)	<40	6930 (2)	1010 (4)	1.1 (20)	
7210		Skin	0.537	6.9 (2)	1.90 (3)		20 (37)	540 (3)	220 (6)	0.07 (15)	
7211		Liver	0.230	22 (9)	171 (3)	56 (8)	<100	14200 (4)	1080 (9)	8.2 (16)	
7281	B-17	Muscle	0.229	15.1 (2)	0.32 (23)	0.13 (31)	211 (4)	1150 (2)	990 (2)	0.17 (46)	^{90}Sr 14 (7)
7282		Bone	0.548	0.5 (32)	7.3 (8)	4.4 (7)	<9	230 (19)	230 (5)	0.7 (30)	^{90}Sr 1000 (2)
7283		Stomach cont.	0.364		178 (16)	80 (16)	<400	5000 (24)	<400	<10	^{90}Sr <300
7284		Viscera	0.361	8.4 (4)	1690 (4)	530 (4)	346 (10)	6900 (1)	980 (3)	226 (4)	^{90}Sr 1000 (3)
7285		Skin	0.448	5.1 (11)	7.6 (8)	2.7 (8)	60 (31)	1080 (3)	440 (5)	0.8 (30)	^{90}Sr 610 (3)
7286		Liver	0.220	7.6 (17)	400 (6)	137 (8)	<200	27400 (1)	2930 (6)	30 (21)	^{90}Sr 60 (90
7311	B-23	Muscle	0.214	18.3 (1)			225 (6)	1800 (1)	2800 (1)		
7312		Bone	0.485	0.5 (27)			<10	710 (3)	480 (3)		
7313		Stomach cont.	0.214				<700	12200 (8)	<700		
7314		Viscera	0.217	16.4 (4)			110 (42)	31300 (1)	5690 (2)		
7315		Skin	0.545	6.9 (3)			50 (23)	2640 (2)	1070 (2)		
7316		Liver	0.282								
Name: Parrotfish - Scarus											
7287	B-17	Muscle	0.209	7.6 1)			670 (2)	9[illegible] ([illegible])	<4		
7288		Bone	0.589	1.42 (9)			<8	<10	<5		
7289		Stomach cont	0.541				<200	400 (26)	<90		
7290		Viscera	0.524	3.4 (5)			186 (6)	290 (8)	18 (27		
7291		Skin	0.467	5.6 (5)			163 (7)	340 (5)	<9		
7292		Liver	0.491	3.8 (7)			120 (16)	500 (4)	<10		
Name: Snapper - Aprion											
7328	Bravo Crater	Muscle	0.233		0.47 (10	0.15 (15)				0.04 (75)	^{90}Sr 1.0 (20)
7329		Bone	0.653	1.3 (8)	8.9 (6)	4.9 (5)	46 (17)	23 (65)	730 (2)	<0.04	^{90}Sr 205 (3)
7330		Stomach cont	0.153	4 (42)	30 (18)	90 (11)	<300	8830 (6)	300 (22	<10	^{90}Sr <100
7331		Viscera	0.346	3.2 (4)	19.3 (5)	9.1 (7)	160 (8)	5460 (1)	520 (2)	0.4 (45)	^{90}Sr <3

Table A-4. (Continued)

Sample ID	Island locator	Tissue[b]	Dry/wet weight	pCi/kg dry weight[a] ^{40}K (x10^3)	$^{239+240}$Pu	^{241}Am	^{137}Cs	^{60}Co	^{207}Bi	^{238}Pu	Other
Name: Snapper - Aprion (continued)											
7332		Skin	0.547	6.8 (5)	19.7 (5)	12.4 (6)	390 (5)	590 (4)	1640 (2)	<0.1	^{90}Sr 127 (3)
7333		Liver	0.277	13.4 (9)	162 (4)	148 (6)	700 (22)	127000 (1)	9370 (2)	2.6 (41)	^{90}Sr <20
7340	W of	Muscle	0.217	18.5 (1)	0.3 (25)	<0.3	230 (4)	380 (4)	50 (10)		
7341	B-6	Bone	0.671	1.0 (19)	11.9 (5)		<10	100 (11)	<9	0.14 (55)	
7342		Stomach cont.	0.0747		<20	<20	<600	4000 (24)	<600		
7343		Viscera	0.257	7.8 (4)	92 (4)	60 (16)	60 (27)	4270 (1)	80 (16)	1.8 (25)	^{113m}Cd 90000 (29)
7344		Skin	0.568		60 (8)		50 (42)	<10	<9	2 (50)	
7345		Liver	0.247	16 (10)	140 (12)	480 (20)	<100	32200 (1)	680 (17)	6 (90)	^{113m}Cd 1.2×10^6 (17)
7346	Off	Muscle	0.204	20.7 (2)			720 (3)	1010 (2)	1620 (2)		
7347	B-23	Bone	0.647		1.7 (22)		<6	<6	<7		
7348		Stomach cont.	0.0945				<450	5600 (11)	<400		
7349		Viscera	0.237	6.4 (5)	182 (3)	78 (5)	200 (10)	8670 (1)	950 (2)	5.7 (12)	^{90}Sr 120 (7)
7350	Off	Skin	0.559	3.0 (12)	2.2 (15)	2.4 (25)	100 (16)	870 (3)	180 (6)	1.0 (30)	^{90}Sr 180 (4)
7351	B-23	Liver	0.238	10 (24)			<200	68300 (1)	4800 (5)		
Name: Jack - Caranx											
7322	Near	Muscle	0.242	18.[illegible] (2)			1060 (2	134[illegible] (2	500 (2)		
7323	Bravo	Bone	0.638		1.8 (2	1 [illegible] (38)	<10	<2[illegible]	30 (36)	1.[illegible] (23)	^{90}Sr 98 (3)
7324	Crater	Stomach cont.	0.123	45 ([illegible])			<700	1130[illegible] (8)	<500		
7325		Viscera	0.209	16.2 ([illegible]6)	54 ([illegible])	[illegible]4 (14)	780 (1[illegible]	1180[illegible] (2)	570 (11)	[illegible]7 (50)	^{90}Sr <8
7326		Skin	0.517		0.6 (65)	1 3 (33)				<[illegible].2	^{90}Sr 22 (7)
7327		Liver	0.228	14 (26)			<200	9460 (4)	850 (20)		
Name: Mackerel - Grammatorcynus											
7334	4 miles	Muscle	[illegible].236	19.9 (1[illegible]			334 [illegible]	227 (5)	17 (25)		
7335	W of	Bone	[illegible].572	1.2 (2[illegible]	0.6 (50)	[illegible] 8 (31)	<10	40 (30)	<10	<0.2	^{90}Sr 36 (10)
7336	B-6	Stomach cont.	[illegible].168				<600	<500	<500		
7337		Viscera	[illegible].243	15.5 (6)			170 (24	2580 (3)	3900 (3)		^{108m}Ag 160 (16)
7338		Skin	[illegible].364	11.6 (4)	3 8 (21)	4 (29)	230 (13	530 (6)	<17	<0.5	^{90}Sr <9
7339		Liver	[illegible].285	18			<200	6000 (7)	1500 (12)		

a Number in parenthesis is the 1-σ counting error expressed as percent of the value listed.
b Viscera sample for all of the 1978 collection includes the stomach but does not include: the stomach contents, intestines or reproductive organs.

Table A-5. 1980 Fish collections - Bikini Atoll.

Island locator	Month collected	Common name	Scientific name	Number of individuals pooled/sample	Average whole body wet wt (gm)	Average standard length (mm)	Male	Female
B-6	September	Mullet	Crenimugil crenilabis	14	634	286	4	7
B-6	September	Mullet	Crenimugil crenilabis	7	923	331	4	3
B-6	September	Goatfish	Mulloidichthys samoensis	39	157	198	15	11
B-6	September	Snapper	Letherinus kallopterus	1	2767	500		1

Table A-6. 1980 Concentrations of radionuclides in fish tissue - Bikini Atoll.

Sample ID	Island locator	Tissue	Dry/wet weight	pCi/kg dry weight[a] ^{40}K ($\times 10^3$)	$^{239+240}Pu$	^{241}Am	^{137}Cs	^{60}Co	^{207}Bi	^{238}Pu	Other
Name: Mullet *Crenimugil*											
MSA 372	B-6	Muscle	0.261	13.1 (2)	0.43 (14)		200 (3)	670 (1)	<3		
373		Bone	0.503								
374		Gizzard Cont	0.592	4.1 (30)							
375		Gizzard	0.231								
376		Liver	0.281								
377		Intest. Cont	0.487	3 5 2			530 (7)	760 (2)	<20		
379		Scales	0.611								
380		Skin	0.413								
MSA 848	B-6	Muscle	0.256	4.6 2			414 (4)	873 (3)	<5		
849		Bone	0.393								
850		Gizzard Cont	0.632		4000 (4)		314 (27)	380 (16)	<60	22 (4)	^{155}Eu 600 (18)
851		Gizzard	0.212	11.2 (11)			240 (23)	2080 (6)	<60		
852		Liver	0.265	13.5 (19)	720 (2)		290 (40)	10840 (3)	<100	11 (7)	
853		Viscera	0.368	5.9 (6)	2000 (5)		352 (8)	1840 (2)	37 (30)	10 (5)	^{155}Eu 430 (15)
854		Intest. Cont	0.558	2.5 (20)			418 (13)	699 (5)	<25		^{155}Eu 570 (14)
855		Scales	0.670	2.5 (9)			50 (34)	557 (3)	<12		
856		Skin	0.412	5.4 (15)			140 (27)	2425 (15)	<33		
Name: Goatfish - *Mulloidichthys*											
MSA 841	B-6	Muscle	0.234	17.0(2)			52 (14)	134 (8)	80 (7)		
842		Bone	0.325	0.8 (40)			<25	91 (25)			
843		Intest. Cont.	0.586	5.1 (35)	213 (2		<140	340 (37)	<115	1.1 (13)	
844		Viscera	0.278	7.1 (2)	66 (2		<19	850 (4)	94 (14)	0.5 (15)	
845		Liver	0.254	15 (17)	138 (3		<180	3118 (8)		1.5 (30)	
846		Scales	0.606	3.7 (7)			<15	99 (15)			
847		Skin	0.343	10.2 (10)			<50	352 (16)			

Table A-6. (Continued)

Sample ID	Island locator	Tissue	Dry/wet weight	pCi/kg dry weight[a]							
				^{40}K ($\times 10^3$)	$^{239+240}Pu$	^{241}Am	^{137}Cs	^{60}Co	^{207}Bi	^{238}Pu	Other
Name: Snapper - <u>Letherinus</u>											
MSA 164	B-6	Muscle	0.234								
165		Bone	0.540	1.1 (20)			<20	<20	<20		
166		St. contents									
167		Viscera	0.262	7.1 (9)			89 (37)	2080 (3)	160 (18)		
168		Skin	0.518	7.6 (22)			<80	132 (40)	<60		
169		Liver	0.338								
182		Muscle	0.234	19.7 (2)	<0.02		300 (8)	160 (12)	130 (9)		
183		Muscle		19.4 (3)	<0.05	0.14 (50)	270 (10)	150 (26)	150 (10)		

[a] Numbers in parenthesis are the 1-σ counting error expressed as percent of listed value.

Table A-7. 1981 Fish collections - Bikini Atoll.

Island locator	Month collected	Common name	Scientific name	Number of individuals pooled/sample	Average whole body wet wt (gm)	Average standard length (mm)	Male	Female
B-1	February	Mullet	*Crenimugil crenilabis*	14	714	320	6	7
B-5	February	Mullet	*Crenimugil crenilabis*	7	911	336	1	6
B-6	February	Mullet	*Crenimugil crenilabis*	8	1314	391	0	8
B-6	February	Mullet	*Neomyxus chaptalii*	38	176	217	25	11
B-13	February	Mullet	*Neomyxus chaptalii*	23		231		
B-5	February	Surgeonfish	*Acanthurus triostegus*	33	76	114	16	12
B-5	February	Goatfish	*Mulloidichthys samoensis*	44	126	189	22	18
B-5	February	Parrotfish	*Scarus sordidus*	3	695	267	1	2
Lagoon	February	Mackerel	*Grammatorcynus billineatus*	1	1113	490	0	1

Table A-8. 198 Concentrations of radionuclides in fish tissue - Bikini

Sample ID	Island locator	Tissue	Dry/wet weight	pCi/kg dry: ^{40}K ($\times 10^3$)	$^{239+240}Pu$	^{241}Am	^{137}Cs	^{60}Co	^{207}Bi	^{238}Pu
Name: Mullet - Crenimugil										
MSA 356	B-1	Muscle	0.253	3 7 (2)	2 8 ≤		900 (3)	877 (2)	<4	0.045 (40)
357		Bone	0.573							
358		Gizzard cont.	0.305		62∞ (20)		<3000	5300 (48)	<2100	37 (25)
359		Gizzard	0.217							
360		Liver	0.246							
361		Viscera cont.	0.191							
362		Viscera	0.242							
363		Scales	0.598							
364		Skin	0.365							
MSA 186	B-5	Muscle	0.284	2.3 (2)			1200 (2)	610 (2)	<5	
187		Bone	0.681	0.8 (37)			<3	150 (13	<20	
188		Viscera	0.364	5.4 (4)			1450 (2)	2490 (2)	120 (9)	
189		Scales	0.650	3.7 (6)			300 (6)	290 (5)	<9	
190		Skin	0.333	6.0 (13)			990 (6)	1800 (4)	<30	
191		Liver	0.249	9 (34)			1200 (23)	25900 (2)	<200	
MSA 253	B-6	Muscle	0.255	4.2 (2)	0 86 0	0.14 (10)	234 (4)	510 (2)	<4	0.02 (75)
254		Bone	0.561	0.8 (34)			<20	230 (9)	<20	
255		Stomach cont.	0.617	1.5 (24)	4430 (3)		230 (16)	230 (13	70 (26)	25.7 (2)
256		Viscera	0.379	2.5 (5)			131 (6)	570 (2)	30 (13)	
257		Skin	0.337	8.2 (6)			120 (21)	1110 (4)	<20	
258		Scales	0.662	1.5 (4)			20 (20)	199 (3)	<4	
259		Liver	0.257	2.4 (13)			700 (15)	15700 (3)	200 (33)	
260		Gizzard	0.220	9.0 (11)			220 (20)	1460 (3)	<30	
Name: Mullet - Neomyxus										
MSA 401	B-6	Muscle	0.2ᴲ8	1.ᴲ (6)	0 97 (4)		127 (10)	370 (8)	<≤	
402		Bone	0.5ᴲ5	0.ᴲ (30)			<15	80 (21		
409		Liver	0.2.8		850 (2)					4 (6)
406		Viscera	0.3≤7		940 (3)					7.3 (4
MSA 530	B-13	Muscle	0.265	5 (2)			43 (14)	171 8	<5	
403		Gizzard cont.	0.563		≈200 (1)					1ᴲ (4)
405		Gizzard	0.494		.800 (1)					1= (4)

Table A-8. (Continued)

Sample ID	Island locator	Tissue	Dry/wet weight	^{40}K ($\times 10^3$)	$^{239+240}Pu$	^{241}Am	^{137}Cs	^{60}Co	^{207}Bi	^{238}Pu
				pCi/kg dry weight[a]						
Name: Surgeonfish - Acanthurus										
MSA 224	B-5	Muscle	0.222	14.1 (4	0.97 (8)	0.68 (18)	1440 [illegible]	460 (7)	<20	0.02 (90)
225		Bone	0.570				<30	150 (16)	<20	
226		Stomach cont.	0.188	12 (35	4050(2)	2640 (2)	<400	5780 (13)	<200	154 (3)
227		Viscera	0.159	17.2 (			1560 (1[illegible])	7780 (2)	130 (36)	
228		Skin	0.464	7.3 (			500 (1[illegible])	470 (4)	<30	
229		Liver	0.306				<500	11900 (5)	1200 (24)	
Name: Goatfish - Mulloidichthys										
MSA 233	B-5	Muscle	0.232	16.5 (2	1.22 (5)	0.55 (6)	360 (5)	1860 (2)	240 (4)	0.07 32)
234		Bone	0.491				<20	870 (5)	45 (3)	
235		St. content	0.484	4 (37)	12000 (6)		750 (20)	9200 (3)	500 (18)	648 (2
236		Viscera	0.269	13 (9)			600 (19)	21800 (1)	540 (12)	
237		Scale	0.599	3.2 (1[illegible]			<20	970 (3)	40 (28)	
238		Skin	0.312	9.6 (8			240 (22)	870 (2)	120 (25)	
239		Liver	0.264	12 (22)			<200	[illegible]900 (2)	<200	
Name: Parrotfish - Scarus										
MSA 240	B-5	Muscle	[illegible].216	9.3 (3)	1.38 (7	[illegible] 37 [illegible]	1080 (4)	190 (14)	<20	0.04 (45)
241		Bone	[illegible].465	1.8 (29)			<30	140 (21)	<30	
242		Stomach cont	[illegible].429	3.4 (24)	13200 (3)		960 (6)	1570 (4)	120 (23)	471 (1)
243		Viscera	[illegible].491	9.7 (27)			1620 (10)	3200 (6)	<100	
244		Skin	[illegible].252	5.(16)			800 (15)	560 (20)	<90	
245		Scales	[illegible].532	3.0 (15)			260 (13)	270 (18)	<20	
246		Liver	[illegible].515				<200	1140 (22)	<100	
Name: Mackerel - Grammatorcynus										
MSA 247	Lagoon	Muscle	0.236	20 4 (2)	0.09 (35)		420 5	270 (7)	30 (32)	
248		Bone	0.465				<90	<90	<70	
250		Viscera	0.253				<400	4500 (9)	<300	
251		Skin	0.353	1[illegible] (23)			<200	620 (19)	<100	

[a] Numbers in parenthesis are the 1-σ counting error expressed as percent of listed value.

Tabl≤ A-9. 1982 Fish collections - Bik ni Atoll.

Island locator	Month collected	Common name	Scientific name	Number of individuals pooled/sample	Average whole body wet wt (gm)	Average standard length (mm)	Male	Female
B-6	March	Mullet	*Neomyxus chaptalii*	31	199	223	'2	14
B-5	June	Mullet	*Neomyxus chaptalii*	33	243	232	.7	14
B-22	June	Ulua	*Caranx melanpygus*	1		1070	1	
B-22	September	Ulua	*Caranx melanpygus*	2	2020	454		

Table A-10. 1982 Concentrations of radionuclides in fish tissue - Bikini Atoll.

Sample ID	Island locator	Tissue	Dry/wet weight	pCi/kg dry weight[a]							
				^{40}K ($\times 10^3$)	$^{239+240}Pu$	^{241}Am	^{137}Cs	^{60}Co	^{207}Bi	^{238}Pu	^{210}Po
Name: Mullet - Neomyxus											
MSG 363	B-6	Muscle	0.222	3 6 2	1.40 (2)		94 (8)	231 (6)	<4		1370 (3)
364		Bone	0.514		8.7 (3)			99 (17)		0 13 (30)	3800 (3)
365		Gizzard cont.	0.535		1620 (2)		600 (20)			11 (11)	1500 (4)
366		Gizzard	0.222	9.2 (13			<90	340 (19)			
367		Viscera cont.	0.362	3.0 (8)	1440 (2)	600 (13)	720 (14)	240 (9)	40(25)	10.8 (8)	5900 (3)
368		Viscera	0.278		740 (2)			240 (9)		4.9 (7)	750 (2)
369		Scale	0.633								
370		Skin	0.359								
371		Liver	0.234		480 (3)					7.7 (7)	44000 (3)
MSG 372	B-5	Muscle	0.226	3 2 (2)			300 (3)	590 (2)	<4		
373		Bone	0.513				<20	122 (16)			
374		Gizzard cont.	0.338			14 (5)	810 (24)	1120 (14)			
375		Gizzard	0.224	3 4 (37)		8.2 (10)	510 (15)	1490 (5)			
376		Viscera cont.	0.248								
377		Viscera	0.241								
378		Scales	0.619								
379		Skin	0.334	5.4 (15			120 (20)	870(6)			
380		Liver	0.248								
Name: Ulua - Caranx											
MSA 967	B-22	Muscle	0.227	20.4 (3)			1670 (4)	215 (4)	490 (10)		
968		Skin	0.452	4.3 (12)			330 (12)	330 (10)	230 (11)		
969		Stomach in	0.215	6.8 (7)			420 (7)	1560 (2)	526 (4)		
970		Liver	0.265	8.9 (16)			240 (40)	6520 (1)	4120 (3)		
971		Spleen	0.260	12.(43)			<300	4000 (9)	8150 (4)		
972		Pyloric caeca	0.213	8.7 (11)			400 (15)	1700 (4)	870 (5)		
973		Gonad	0.190	7 (40)			473 (28)	2710 (8)	1610 (10)		
974		Viscera cont	0.168					2220 (17)	<400		
975		Viscera wall	0.236	4. (30)			300 (25)	1740 (12)	1240 (6)		
MSG 421	B-22	Muscle	0.22	13.m (2)			1640 (2)	246 (5)	166 (5)		
423		Viscera	0.24								
426		Skin	0.29	7. (12			970 (8)	326 (15	435 (10)		

[a] Numbers in parenthesis are the 1-σ counting error expressed as percent of listed value.

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REPORT BY

THE AEC! TASK GROUP ON RECOMMENDATIONS FOR

CLEANUP AND REHABILITATION OF ENEWETAK ATOLL

June 19, 1974

APPENDIX V

Annual Bone and Whole-Body Doses

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1. Introduction

The purpose of this appendix is to evaluate the potential annual bone doses for adults and children for the six living patterns considered in the Enewetak Radiological Survey Report (NVO-140). The bone doses presented in NVO-140 were calculated for mineral bone for adults as integrated doses for 5-, 10-, 30-, and 70-yr periods. Bone and whole-body doses to children were not considered separately because in most cases the doses predicted for adults are usually a good estimate of the dose to children. For example, the external gamma contributes similarly to both adults and children. Strontium-90 and ^{137}Cs contribute over 95% of the food-chain dose and there is evidence to show that doses to children from ingestion of ^{137}Cs are usually less than those to adults. Strontium-90 differs from ^{137}Cs. Doses to children can exceed adult doses; however, the additional dose increment to children over the first 1 to 5 yr is not large and increases the integral 30- and 70-yr doses by only a few percent. With the uncertainties involved in other parts of the dose assessment, for example the actual diet at time of return, the differentiation between child and adult integrated doses was not included in the tables.

Because of the magnitude of some of the 30-yr integral bone doses, it was decided that annual bone doses should be evaluated to indicate the living patterns and agricultural situations which are within FRC guides for annual bone doses. The more detailed assessment of bone doses is directed at estimating the dose to the critical cell population at risk in bone - the bone marrow - rather than to the entire bone mass, as was calculated in the original report (IWO-140). In adopting this approach, we are following the recommendations of the ICRP (ICRP-11) and the approach of Spiers used by UNSCEAR (22).

The following text considers the information available for estimating the doses to the fetus, the newborn, and children relative to adults, and also the dietary changes which are assumed for children.

2. Dose to Fetus and Newborn Relative to Adults

The Sr/Ca ratio in the fetus and in mothers' milk is determined by the Sr/Ca ratio in the maternal blood. Sr/Ca discrimination across the placental barrier and across the mammary gland is nearly the same.[1,2] In fact, the observed ratio OR $\frac{\text{fetus or mothers' milk}}{\text{maternal blood}}$ (OR = $\frac{(\text{pCi } ^{90}\text{Sr/g Ca}) \text{ milk or fetus}}{(\text{pCi } ^{90}\text{Sr/g Ca}) \text{ maternal blood}}$) is ~ 0.5.[1-3] Therefore, the Sr/Ca ratio of the fetus or newborn is very similar to that of the mothers' milk.

There is considerable evidence to show that the OR milk/diet for human breast milk is in the range of 0.1 to 0.16.[3,5] The same observed ratio exists for the fetus and newborn relative to the adult diet.[1,2] This ratio has been observed directly and can also be calculated from data which indicate that the average OR body/diet for adults is 0.25;[1,6] when this is combined with a further discrimination of approximately a factor of 2 across the placental or mammary membrane, the range of values of 0.1 to 0.16 for milk or fetus is obtained.

As a result, the Sr/Ca ratio in the fetus and newborn is approximately 1/8 to 1/10 that of the adult, and the resulting dose to the fetus is less than that to adults.

The dose to a young infant being breast fed will of course also be less than that calculated for adults. The OR body/diet for young infants is 0.9;[1,4] that is, the young infant nearly equilibrates with his diet. However, the mothers' milk, as discussed previously, has a Sr/Ca ratio ~ 0.1 that of the adult diet. The OR body/diet then decreases to 0.5 for a l-year-old and by approximately 3 or 4 years of age has reached the adult value of 0.25.[2,4,6]

Similar data are available for ^{137}Cs. Cesium-137 is metabolized and turned over more rapidly in pregnant women than in nonpregnant women.[7,8] As a result, ^{137}Cs incorporation in the fetus and the resulting exposure are less than would be expected from normal retention times observed for adults. Experimental data further indicate that for the fetus and for breast-fed infants the concentration of ^{137}Cs and the resulting dose never exceeds that of the mother or of other adults.[9,10] Therefore, as indicated in reports by Rundo,[9] Iinuma et al.,[10] and Cook and Snyder,[11] the dose calculated for an adult for ^{137}Cs is a conservative estimate for the fetus and the newborn.

3. Dose to Children Relative to Adults

^{137}Cs — A considerable body of evidence is available which indicates that the half-time for ^{137}Cs in the body is a function of age, with a more rapid turnover for younger ages.[11-14] The biological half-time appears to be the order of 10-15 days for 1- to 2-year-old children and increases to ~ 100 days by age 20. It then remains reasonably constant throughout adult life. The body mass is less for the younger age groups, and these two factors tend to offset each other in dose calculations. Doses to children are generally less than for adults as a result of the combination of these two offsetting factors. When the relative dietary intake is included, children receive a lesser dose than adults. Therefore, dose estimates for adults are usually a conservative estimate for children.

^{90}Sr — Reports by Loutit,[15] Bennett,[16] and Rivera[17] indicate that the pCi ^{90}Sr/g Ca in human bone is greater for ages l-5 than for ages greater than 6 yr, including-adults. However, the turnover rate is much more rapid and the retention time much shorter for ^{90}Sr in ages l-5. The combination of these two factors determines the bone burden, the annual dose, and the dose commitment resulting from a specified ingestion of ^{90}Sr. For children, these two factors tend to offset each other; the resulting dose to children, therefore, is not straightforward and is dependent upon the relative interaction of these two factors.' Any comparison with adults must therefore take into account the age dependence of these factors, as well as the difference in dietary intake. The model reported by Bennett[16] is therefore used for estimating the doses to children.

4. Dose Models and Diet

^{90}Sr — Models developed by ICRP for estimating the bone dose from ingested ^{90}Sr are considered to be age invariant.[18-20] A recent model from Bennett[16] does model the child separately from the adult, and this model is applied for estimatingthe bone doses to children.

The bone-marrow dose-rates to children are calculated by combining Bennett's model for children with the approach developed by Spiers[21] and used in the UNSCEAR report[22] for estimating bone-marrow dose from the mineral or matrix bone dose. The values used for converting D_o doses, to bone-marrow and endosteal cell doses, are 0.314 and 0.434 respectively. Bennett's model also extrapolates to the adult case and is combined with the Spiers approach for predicting the bone-marrow doses to adults.

The bone mass is assumed to correlate directly with body mass, and these data as a function of age are taken from Spiers.[21] These body masses are based upon average data from the U.S. population and a factor of 0.85 was incorporated to account for the smaller size of the Enewetakese. The calcium concentration in bone (gCa/g bone) as a function of age is taken from Bennett.[16]

In calculating the mineral bone dose (D_o dose) in NVO-140, the approach of ICRP[18] was followed, using a QF = 1 and n = 5. The doses calculated from this model are compared to the 3-rem/yr guide (ICRP 9)[23] for bone for general public. However, in assessing the annual dose to both children and adults, the bone marrow is taken as the critical organ, and the recommendations in ICRP 11[24] are used.

In this model the quality factor is still one (QF = 1), and the "n" factor is no longer applicable. The bone marrow is considered in the category of sensitive blood-forming organs, and the corresponding dose guide for such organs is 0.5 rem/yr rather than the 3 rem/yr for mineral bone.

^{137}Cs — In the dose model for ^{137}Cs, it is assumed that the loss of ^{137}Cs from the body can be described as an exponential loss with a turnover time that varies as a function of age.[10-14] The annual dose is calculated, always taking into account the residual body burden from the previous year. Body mass as a function of age is taken from Spiers.[21] Initial dietary intakes are calculated and doses are predicted, based upon the initial intake and the exponential loss of ^{137}Cs in the diet at a rate equal to the physical half-time of ^{137}Cs.

Diet — The diet for adults is that listed in the original report NVO-140. For children from ages 1 through 10, the intake of coconut milk and coconut meat is doubled to 600 and 200 g/day, respectively. These two products are the most likely to be consumed in greater quantity by children than by adults. The rest of the diet for children is assumed to be one-half of the adult diet.

At age 10, it is assumed that the child is on the full adult diet. From information available, this is a conservative assumption in that children are not usually considered to reach the average adult intake until age 14 or 15. However, because of the diet changes which occur at 10 yr (i.e., pandanus, breadfruit, coconut, etc., which become available) it is convenient to use this point for adjusting the child to the adult diet, and if anything, this adjustment produces a slightly conservative dose estimate for the children due to the high ^{90}Sr content in the adult diet.

5. Results

The results of the calculations based upon the models described above and upon the diets listed in IWO-140 and altered for children as previously discussed, are listed in Tables 1-8. The data are presented as maximum annual bone-marrow and whole-body doses. The living patterns are listed after Tables 1 and 6 for convenience of reference; they are the same as those listed in NVO-140.

The annual doses for external exposure and for food chain exposure from ^{137}Cs and ^{90}Sr are calculated for 70 yr, beginning at either age 1 or age 20. The three different components contributing to the dose produce a maximum dose at different times. The external component, for instance, is maximum at 1 yr and decreases thereafter with the physical half-life of ^{137}Cs and ^{60}Co; the effective decay depends on the particular percentage of each isotope in the soil. Strontium-90 delivers its maximum dose several years after intake of the nuclide begins. The year of maximum dosage depends upon whether an adult or child is considered and upon whether or not a diet change is involved at some point in time. The dosage from ^{137}Cs incorporated in man via food chains tends to peak early and decreases exponentially thereafter. The annual dose is then selected for the years at which the sum of these three components was maximum.

The maximum annual bone-marrow doses are listed in Table 1 for the case where no restrictions are placed upon the location of agriculture and source of the diet and no modifications are made for external gamma on the village island. Table 2 lists the results for the case where no restrictions are placed upon the diet but where the village island has been modified by plowing and graveling. Living Pattern 1, where the home island and agriculture are on southern islands, is the only living pattern for these two situations where the total bone-marrow doses do not exceed 50% of the FRC guide; in this instance, it is less by a factor of 5. All other living patterns lead to an annual dose which for at least 1 yr, and in most cases several years, exceeds the FRC guide.

The results also indicate that there is not a great deal of difference between the predicted child and adult maximum annual doses. This is due in part to the assumed diets of adults and children and the large ^{90}Sr and ^{137}Cs intake via the food chains for such products as pandanus, breadfruit, coconut, and meat. For coconut milk and coconut meat, the children are assumed to have an intake twice that of the adults, but until age 10 the rest of the dietary intake is assumed to be one-half that of the adults.

Table 3 lists the results for the six living patterns when pandanus and breadfruit are grown on southern islands only. As a result of this action, three living patterns fall within 50% of the FRC guide — Patterns 1, 2, and 5. When pandanus, breadfruit, coconut, and tacca are all confined to southern islands, then Living Pattern 3 also falls within the guide (Table 4). If the total diet is confined to the southern islands, then all living patterns are within FRC guide, and the only variation among living patterns is the result of the difference in external exposure for each of the situations (Table 5). For all the cases where there is a restriction on the agriculture and diet, it is assumed the village island will be plowed and graveled.

Similar results for whole-body exposure for the four different agricultural situations are presented in Tables 6-10. With no restrictions on the diet, Living Patterns 1, 2, and 5 are under FRC guides. Therefore, the bone-marrow is the more limiting feature. When the other agricultural conditions are used, the living patterns which fall below the FRC guide are the same as those for the bone-marrow dose.

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Table 1. Maximum annual bonemarrow dose (rem).
No restrictions on diet
Village island unmodified for external gamma

Living Pattern	Start January 1974 Child [a]	Start January 1974 Adult [a]	Start January 1984 Child [b]	Start January 1984 Adult
1	0.047	0.045	0.047	0.043
2	0.314	0.294	0.282	0.290
3	0.790	0.760	0.759	0.754
4	2.27	2.15	2.17	2.13
5	0.361	0.348	0.333	0.344
6	1.10	1.04	1.03	1.02

Living Pattern	Village island	Agriculture	Visitation
1	Enewetak-Parry	ALVIN-KEITH	Southern Is.
2	Enewetak-Parry	KATE-WILMA + LEROY	Northern Is.
3	JANET	JANET	Northern Is.
4	BELLE	BELLE	Northern Is.
5	JANET	KATE-WILMA + LEROY	Northern Is.
6	JANET	ALICE-IRENE	Northern Is.

[a] Diet change at 10 yr., i.e., 1984.

[b] Diet change at 10 yr., i.e., 1994.

Table 2. Maximum annual bonemarrow dose (rem).

No restrictions on diet

Village island graveled and plowed

	Start January 1974		Start January 1984	
Living Pattern	Child [a]	Adult [a]	Child [b]	Adult
1	0.047	0.045	0.047	0.043
2	0.314	0.294	0.282	0.290
3	0.718	0.677	0.680	0.672
4	2.08	1.92	1.93	1.90
5	0.317	0.300	0.285	0.296
6	1.06	0.989	0.988	0.977

Table 3. Maximum annual bonemarrow dose (rem).

Pandanus and breadfruit from southern islands

Village island graveled and plowed

	Start January 1974		Start January 1984	
Living Pattern	Child [a]	Adult [a]	Child [b]	Adult
1	0.047	0.045	0.047	0.043
2	0.148	0.149	0.200	0.142
3	0.293	0.294	0.418	0.284
4	0.786	0.774	1.16	0.749
5	0.151	0.178	0.201	0.148
6	0.428	0.437	0.574	0.419

[a] Diet change at 10 yr., i.e., 1984.

[b] Diet change at 10 yr., i.e., 1994.

Table 4. Maximum annual bonemarrow dose (rem).

Pandanus, breadfruit, coconut, tacca from southern islands

Village island graveled and plowed

	Start January 1974		Start January 1984	
Living Pattern	Child [a]	Adult [a]	Child[b]	Adult
1	0.047	0.045	0.047	0.043
2	0.122	0.130	0.092	0.101
3	0.168	0.204	0.138	0.166
4	0.415	0.516	0.325	0.392
5	0.121	0.135	0.094	0.106
6	0.253	0.354	0.202	0.254

Table 5. Maximum annual bonemarrow dose (rem).

Total diet from southern islands

Village island graveled and plowed

	Start January 1974		Start January 1984	
Living Pattern	Child [a]	Adult [a]	Child [b]	Adult
1	0.047	0.045	0.047	0.043
2	0.097	0.091	0.071	0.069
3	0.094	0.094	0.077	0.079
4	0.199	0.193	0.133	0.129
5	0.096	0.096	0.074	0.074
6	0.189	0.213	0.123	0.134

[a] Diet change at 10 yr., i.e., 1984.

[b] Diet change at 10 yr., i.e., 1994.

Table 6. Maximum annual whole-body dose (rem).

No restrictions on diet

Village island unmodified for external gamma

Living Pattern	Start January 1974 Child[a]	Adult[a]	Start January 1984 Child[b]	Adult
1	0..039	0.039	0.038	0.039
2	0.234	0.236	0.200	0.233
3	0.619	0.630	0.531	0.628
4	1. 81	1. 80	1.54	1. 79
5	0.285	0. 291	0.252	0. 291
6	0.798	0. 812	0.674	0.802

Living Pattern	Village island	Agriculture	Visitation
1	Enewetak-Parry	ALVIN-KEITH	Southern Is.
2	Enewetak- Parry	KATE-WILMA t LEROY	Northern Is.
3	JANET	JANET	Northern Is.
4	BELLE	BELLE	Northern Is.
5	JANET	KATE-WILMA + LEROY	Northern Is.
6	JANET	ALICE- IRENE	Northern Is.

[a] Diet change at 10 yr., i. e., 1984.

[b] Diet change at 10 yr. , i. e., 1994.

Table 7, Maximum annual whole-body dose (rem).

No restrictions on diet

Village island graveled and plowed

Living Pattern	Start January 1974		Start January 1984	
	Child[a]	Adult[a]	Child[b]	Adult
1	0.039	0.039	0.039	0.038
2	0. 234	0. 236	0. 200	0.233
3	0. 540	0. 542	0.452	0. 540
4	1. 56	1. 55	1. 30	1. 55
5	6.237	6.241	6.204	0.240
6	0.749	0. 761	0. 631	0.757

Table 8. Maximum annual whole-body dose (rem).

Pandanus and breadfruit from southern islands

Village island graveled and plowed

Living Pattern	Start January 1974		Start January 1984	
	Child[a]	Adult[a]	Child[b]	'Adult
1	0. 039	0. 039	0. 039	0. 038
2	'0. 125	'0.128	'0.146	'0.127
3	0.245	0.252	0.304	'0. 249
4	0.662	0.663	0.846	0.656
5	0.128	0.133	0.149	0.132
6	~0,350	0. 367	0.430	0.363

[a]Diet change at 10 yr., i. e., 1984.

[b]Diet change at 10 yr., i. e., 1994.

Table 9. Maximum annual whole-body dose (rem).

Pandanus, breadfruit, coconut, and tacca from southern islands

Village island graveled and plowed

Living Pattern	Start January 1974 Child[a]	Start January 1974 Adult[a]	Start January 1984 Child[b]	Start January 1984 Adult
1	0.040	0.039	0.039	0.039
2	0.091	0.122	0.078	0.093
3	0.146	0.187	0.119	0.151
4	0.357	0.475	0.280	0.355
5	0.093	0.127	0.080	0.098
6	0.246	0. 328	0.160	0. 241

Table 10. Maximum annual whole-body dose (rem).

Total diet from southern islands

Village island graveled and plowed

Living Pattern	Start January 1974 Child[a]	Start January 1974 Adult[a]	Start January 1984 Child[b]	Start January 1984 Adult
1	0.040	0.039	0.039	0.039
2	0.090	0.083	0.065	0.066
3	0.087	0.097	0.070	0.076
4	0.192	0.191	0.126	0.126
5	0.089	0.094	0.066	0.071
6	0.182	0.211	0.116	0.131

[a]Diet change at 10 yr. , i. e. , 1984.

[b]Diet change at 10 yr., i. e., 1994.