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PRELIMINARY EVALUATION OF THE RADIOLOGICAL QUALITY OF THE WATER ON BIKINI AND ENEU ISLANDS

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Contents

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Abstract

In June of 1975 a survey was conducted to determine the residual radioactivity in the terrestrial environment on the two main islands (Eneu and Bikini) of Bikini Atoll. The objective was to evaluate the potential radiation doses that could be received by the Bikinians scheduled to return to their atoll. This report describes the radiological quality of the groundwater during June 1975 (from data obtained from water samples collected at old and new well sites on both islets) and the cistern water on Bikini island. Based on the analyses of these samples, the cistern water from Bikini Island is both chemically and radiologically acceptable as drinking water in accordance with standard limits established by the U. S. Public Health Service. On both islands the quality of the ground water varies from one site to another. At some wells both chemical and radiological quality are acceptable; at others one or both is unacceptable according to U. S. Public Health Standards.

Introduction

A project was undertaken to evaluate the potential radiation doses that could be received by the Bikinians scheduled to return to their atoll. Data were provided by a survey conducted during June 1975 to determine the residual radioactivity in the terrestrial environment on Bikini and Eneu Islands of Bikini Atoll. The survey included the measurement of environmental gamma-ray exposure rates and the collection of samples of soil, ground water, cistern water, and vegetation for use in assessing the internal doses via pertinent food chains.

This report describes the radiological quality of the ground water during June 1975, based on data obtained from water samples collected at old and new well sites on the islands. Results are also included on the radionuclide levels in three rainwater cisterns on Bikini Island.

The chemical quality and radiological quality of the water are compared to standards established by the U. S. Public Health Service and to the recommended maximum permissible water concentrations from FRC part 20 standards for protection against radiation.[1]

Field Operations, Observations and Procedures

Between June 16 and June 24, 1975, five new wells for ground-surface water were established on the island of Bikini and two were established on Eneu Island. The locations of the new Bikini wells (HFH 1 through HFH 5) and the previously established open well (HFH 7) are shown in Fig. 1 along with the locations of the three rainwater cisterns sampled. Figure 1 also shows the locations of the new wells FWR 1 and FWR 2)on Eneu and the previously established wells (FWR 3 and FWR 4) along with pertinent landmarks for reference. The new wells were located to give the best possible definition of the quality of the surface ground water over an island area as large as possible. We had planned to establish additional wells in the southern parts of Bikini and Eneu but were unable to do so because of time restrictions.

The wells were started by excavating a pit with a backhoe to the depth of the ground-water surface. Hard beach rock layers were encountered at HFH 2 (2.7 m) below ground surface and at HFH 5 (at 1.4 m); rock layers were not encountered at any other locations. Then, a gas-powered hand-held auger was used to loosen the coral aggregate below the water surface to as great a depth as physically possible, and slotted 2-in.-diam PVC pipe was forced into the hole. The pipe was capped at the bottom to prevent soil from back-filling the interior of the pipe. The slots above the waterline were taped over to prevent surface debris from entering the casing from above. The hole was backfilled with the excavated soil, with the removed bottom soil being returned to the pit first.

Table 1 gives the depth to which the slotted casing extends below the surface of the water table and the depth of the water table below ground surface. Most of these water depths were measured during periods of lowest tide. There were no detectable differences in conductivity throughout the accessible length of each water column. The thickness of the freshest water layer at each location is at least equivalent to the depths of water in Table 1.

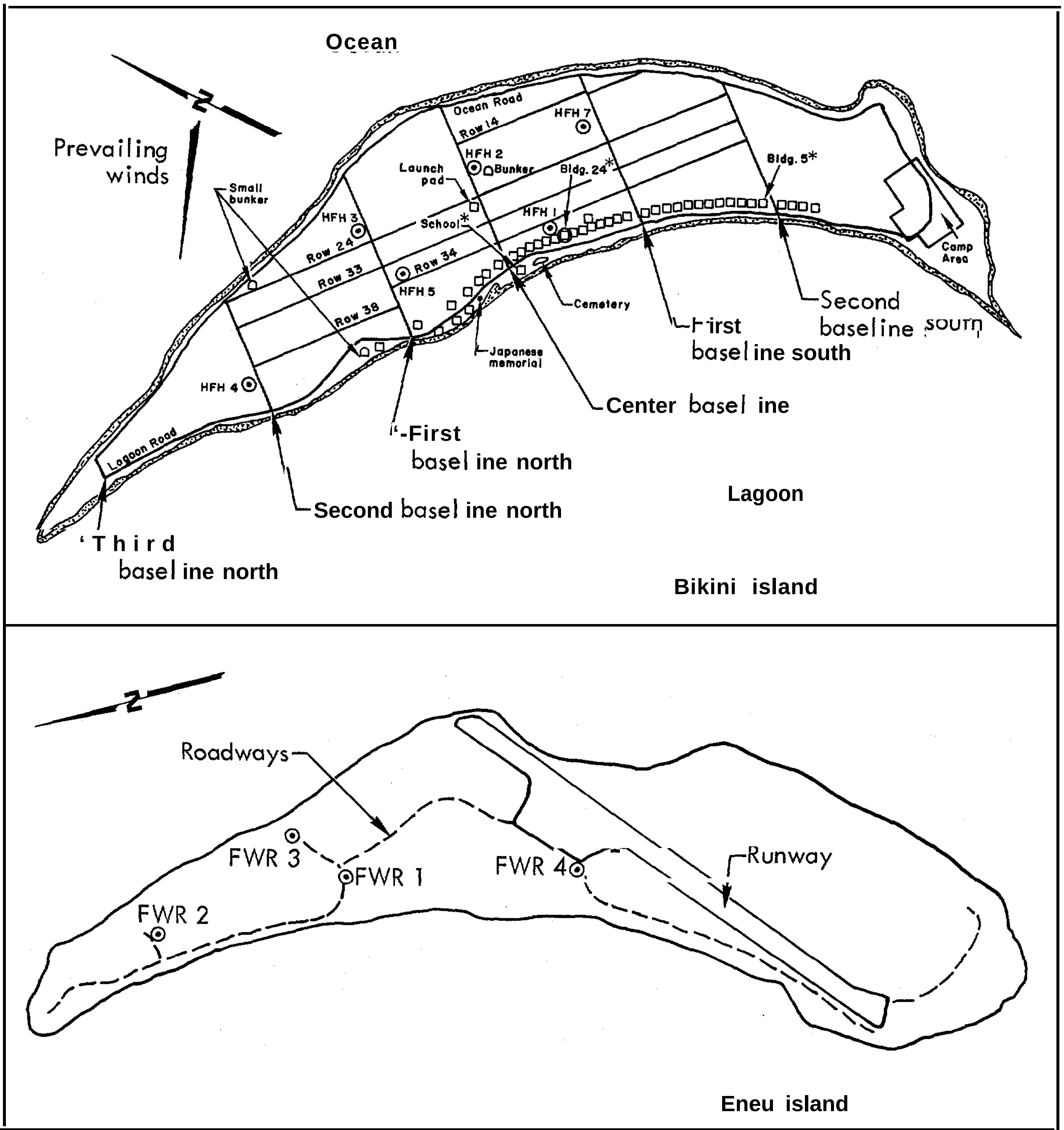

Fig. 1. Locations of wells on Bikini (upper) and Eneu (lower) Islands. An asterisk indicates that the building had an associated rainwater cistern that was sampled.

Table 1. Depths of wells at Bikini and Eneu Islands.

Island	Well	Depth of well casing below water table (m)	Depth of water table below ground surface (m)
Bikini	HFH 1	1.21	2.48
	HFH 2	0.73	2.72
	HFH 3	0.87	2.33
	HFH 4	0.82	2.80
	HFH 5	0.73	2.67
	HFH 7[a]	0.6[b]	
Eneu	FWR 1	0.54	2.43
	FWR 2	0.81	1.92
	FWR 3[a]	9.0	4.0
	FWR 4[a]	--[c]	--[c]

[a]Old well [b]Open well under block casing. [c]Not measured.

The water in the wells was allowed to stabilize for one to two days before sampling. Before sampling from each well, the entire pumping system was purged with at least 100 liters of water from that well, and all collection containers were thoroughly rinsed to minimize cross-contamination of samples. Samples were withdrawn by a battery-operated pump (Fig. 2) through a section of flexible plastic tubing lowered into the pipe below the water surface. The pumping rate could be regulated by a variable-speed control over the range from a few milliliters per minute to 8 liters per minute. Conductivity was monitored during pumping by channeling the water through an in-line conductivity meter. The water then passed through two filters (1-μm and 0.4 μm) to remove suspended particulate material; these filters were subsequently analyzed for radionuclide content. The filtrate was collected for radionuclide analysis in 15-gal balck "Deldrum" containers; smaller volumes were collected for analysis of chlorinity and other constituents.

An experiment was designed to follow the chemical and radiological changes in the water that would result from continous pumping at a constant rate: Ground water at HFH 1 was pumped out continuously over a 8-hr period; a total of 3200 liters was removed from the reservoir. Conductivity was monitored throughout the entire test, and samples were collected for analysis at the start, midpoint, and end of the test. If the mean daily water consumption rate by humans is assumed to be 2 liters

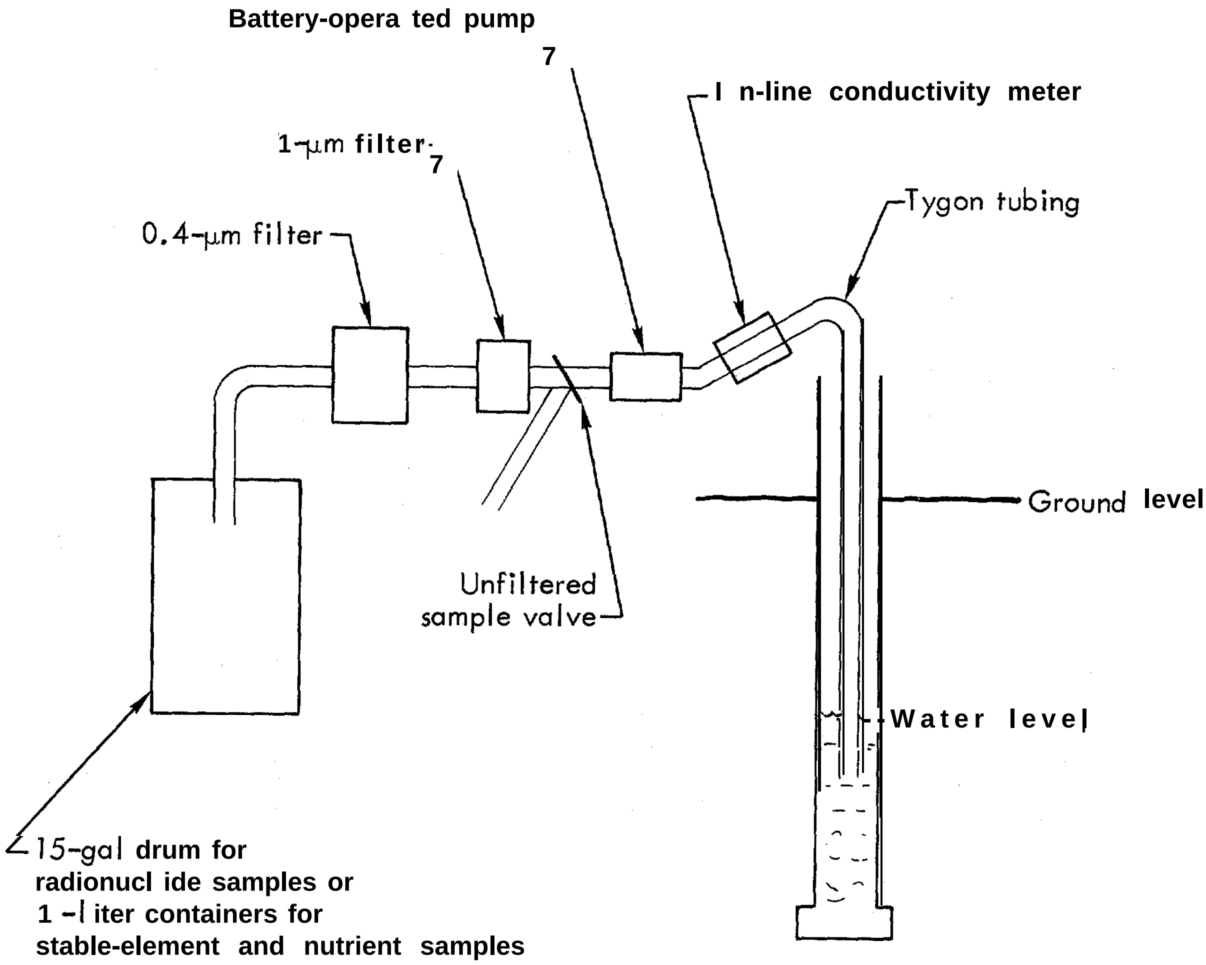

Fig. 2. Diagram of the pump arrangement for collection of ground-water samples.

per day, the total volume removed was equivalent to what could have been used by 100 people in 16 days. The usable ground water is therefore a valuable resource to the people of the atoll.

A similar test was conducted at FWR 1 on Eneu, but only 2400 liters was removed during a half-day pumping period. Samples were taken at the beginning and end of this test. The conductivity of the water during the pumping operations at these two wells is shown in Fig. 3, which also relates conductivity to the time of sampling.

A 15-gal filtered water sample was also obtained from the old Bikini well (HFH 7). From our discussions with the Bikini people as well as from our own observations, large quantities of the ground water from this well are being withdrawn almost daily for crop irrigation. This water has also been used for drinking

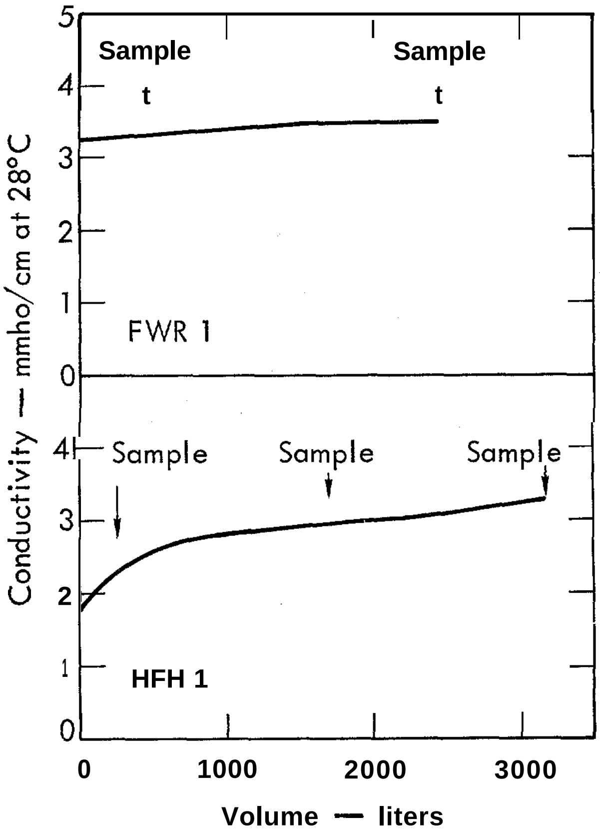

Fig. 3. In-line conductivity vs volume pumped for wells HFH 1 and FWR 1.

Below it the salinity rapidly increases in almost linear fashion to the bottom. A total of 64 liters was pumped from the surface layer; no change in water conductivity occurred. This well casing must be slotted in some manner to permit rapid horizontal recharge. The bottom water, of course, was brackish and smelled very strongly of hydrogen sulfide; it contained a considerable amount of black suspended material of unknown composition.

All of the 15-gal water samples were returned to LLL for processing. (The samples for chemical analysis were sent to Dr. R. Buddemeier at the University of Hawaii.) One separation technique is used to isolate ^{90}Sr, ^{137}Cs, plutonium, and other radionuclides from all samples regardless of water salinity. Standardized

during periods of drought. Large-volume samples were also pumped from the two old wells on Eneu (FWR 3 and 4) and from three rain-water cisterns sampled on Bikini Island (see Fig. 1).

Well FWR 3 had been drilled and cased to a depth of 13 m below ground level. No record can be found to indicate why, when, or for what purpose this well was established. A salinity profile of the water column was made (Fig. 4). The upper fresher layer is approximately 2 m thick.

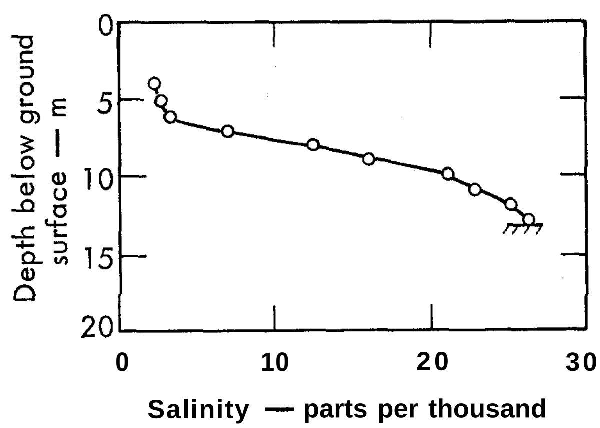

Fig. 4. Salinity profiles of ground-water column at FWR 3.

mixed carrier solutions (containing stable carriers of Cs, Sr, Co, Bi, Sb, rare earths and either ^{242}Pu or ^{236}Pu and ^{243}Am) are added to the acidified samples. The radionuclides are separated from the water and suspended samples using a published procedure[2] with some modifications. A complete description of these modifications and our newer separation technique will be published.[3] Precipitation from the water samples with ferric hydroxide or manganese dioxide scavenges any plutonium radionuclides, ^{241}Am, ^{60}Co, ^{207}Bi, ^{125}Sb, or rare earth radionuclides. This precipitate is then counted on low-level gamma spectrometers for qualitative and quantitative assay of the latter gamma-emitting radionuclides in the sample.

In the 55-liter samples, ^{60}Co, ^{207}Bi, ^{155}Eu, ^{125}Sb, or ^{241}Am were not detected at levels above our lowest detection limits: 0.12, 0.10, 0.15, 0.12, and 0.10 pCi/1, respectively, for those radionuclides.

The filter samples were dry-ashed and counted on gamma spectrometers; only ^{137}Cs was detected. The other gamma-emitting radiocuclides in the particulate phase were below the limits listed above.

The ashed filters were then processed to separate and analyze plutonium and ^{90}Sr.

No attempt was made to separate or determine ^{55}Fe or any beta-emitting radionuclides such as ^{147}Pm or ^{151}Sm, which are known to be present in environmental samples from Bikini[4] and Enewetak[5] Atoll.

Water Quality Standards

The sections that follow give general descriptions of our chemical and radiological results. Before our results could be compared, it was necessary to define a standard for the freshness of the water. We use, but only as a guide and reference for the reader, the recommended limits of U. S. Public Health Service. The following two paragraphs are quoted from Public Health Service Publication 956.[6]

(a) The following chemical substance should not be present in a water supply in excess of the listed concentrations when other more suitable supplies are or can be made available:

Chloride	250 mg/1
Nitrate	45 mg/1
Sulfate	250 mg/1
Total dissolved solids	500 mg/1

(b) The Advisory Committee, in considering limits which should be established for drinking water, recommended limits for only two of the above Ra^{226}, I^{131}, Sr^{90}, Sr^{89} nuclides, Radium-226 (3μμc/l) and Strontium-90 (10μμc/l). Water supplies shall be approved without further consideration of other sources of radioactivity intake of Radium-226 and Strontium-90 when the water contains these substances in amounts not exceeding 3 and 10μμc/l, respectively."

Dose Assessment

The data obtained in this survey will be used to compute and interpret the integrated radiological dose to an adult male from the ingestion of any quantity of the ground or cistern water. Table 2 lists information obtained from updated dose codes[7]: the dose value in millirem, which when multiplied by the daily consumption in picocuries, yields the integrated dose. For example, assume that the drinking water contains 200 pCi/liter of ^{137}Cs, 50 pCi/liter of ^{90}Sr, and 0.1 pCi/liter of $^{239,240}Pu$, and that the water intake of the adult male is 2 liters per day. Under these conditions, the 30-year integrated dose is 0.18 rem to the whole body from ^{137}Cs, 0.31 rem to the skeleton from ^{90}Sr, and 0.25 mrem to the skeleton and 0.26 mrem to the liver from $^{239,240}Pu$. In the construction of this dose table, it was assumed that the radionuclide levels in the source

Table 2. Integrated dose in millirem per picocurie ingested per day.

Years of intake	^{137}Cs (Whole body)	^{90}Sr (Skeleton)	^{239}Pu (Skeleton)	^{239}Pu (Liver)
1	0.014	0.058	0.0021	0.0017
5	0.095	0.44	0.052	0.041
10	0.19	1.05	0.20	0.16
30	0.46	3.10	1.26	1.28
50	0.64	4.39	4.67	3.22
70	0.75	5.18	8.77	5.72

water remain unchanged with time except for loss due to radioactive decay. If the water concentrations either increase or decrease with time, the resulting real integrated doses will be changed proportionally. It must be kept in mind, therefore, that the dynamics of radionuclide circulation in the ground water reservoirs must be understood before any realistic long-term dose prediction can be made.

Bikini Island Cistern Water

Unfiltered water samples were collected on 21 June 1975 from the rainwater cisterns connected to Bldgs. 5 and 24 and the school on Bikini Island. The available chemical and radiological data from these samples are given in Table 3.

The data summarized in the table indicate that the water appears to be chemically adequate for drinking purposes, as was anticipated, as well as suitable for any household or agricultural use. Chloride and sulfate concentrations are well below the limits established for drinking water by the U. S. Public Health Service. The total coliform content of the water was not determined.

The measured radionuclides were also low in concentration in these samples. The measured ^{90}Sr concentrations are roughly two to

Table 3. Analytical data from cistern water sampled on 21 June 1975 on Bikini Island (Bikini Atoll).

	Chemicals (ppm)							Radionuclides $(pCi/l)^a$		
Bldg.	Cl^-	SO_4	Sr	K	Ca	Na	Mg	^{137}Cs	^{90}Sr	$^{239,240}Pu$
5	35.6	6.4	0.1	8.4	8.5	26.7	2.2	2.5(1)	1.1(11)	7.9×10^{-3} (5)
	23.1	3.8	0.1	9.1	10.5	19.8	1.3	1.8(2)	1.9(2)	13.7×10^{-3} (4)
	21.5	0	0.2	6.0	18	16	0.7	1.7(2)	1.42(7)	29.0×10^{-3} (2)

[a]The values in parentheses are the 1-σ counting errors expressed as percentages of the listed values.

three times the 1974 average concentration of 0.5 pCi/liter in New York City tap water[8] but are equivalent in value to the average New York City tap water concentrations measured during the peak fallout years of 1963-1966. The present levels are also similar to the 1971-1973 water concentrations in Lake Ontario.[9] These present levels of ^{90}Sr in the Bikini wells are less than 20% of the drinking-water limit of 10 pCi/liter established by the U. S. Public Health Service for domestic supplies and are 0.4% of the FRC limit of 300 pCi/liter. The ^{137}Cs levels are higher than the 1974 tap water concentrations for New York City but are only 0.01% of the maximum permissable concentration of 20 nCi/liter based on FRC guidelines. The average concentration of $^{239,240}Pu$ in the cistern water is less than 0.0003% of the FRC concentration guideline. Interestingly, the average $^{239,240}Pu$ concentration of 17 fCi/liter in the cistern water is greater than the average surface groundwater concentrations at Eneu (9 fCi/liter) but much lower than the average concentration (44 fCi/liter) in Bikini surface groundwater.

Examination of the radionuclide concentrations in the cistern water and comparisons with other data reveal that the largest percentage of the radioactivity in the water must originate, surprisingly, from sources other than worldwide fallout. Consider first that the $^{137}Cs/^{90}Sr$ ratio varies between 0.93 and 2.27 in the three samples. One would expect that fallout depositions of these two radionuclides would be much more uniform over the small areas encompassing the three buildings attached to the cisterns. Shown in Table 4 are the ^{90}Sr concentrations in rainfall at several Pacific islands between 1968 and 1974. When the B-year mean values are plotted as a function of latitude, the interpolated mean quantity of fallout ^{90}Sr expected in rainwater at the latitude of Bikini Atoll is only 0.1 pCi/liter. The cisterns have, on the average, 15 times this concentration. Since the cisterns were constructed after 1969, we can only conclude that fallout ^{90}Sr, and by analogy ^{137}Cs and $^{239,240}Pu$, contribute only a small percentage to the levels of those radionuclides found in the cistern samples. This assessment suggests that either the radionuclides are being leached from the concrete of the cisterns (which was locally derived and locally mixed) at some small but finite rate, or that resuspended, airborne labeled soil particulates accumulated on the roof drainage surface between rains are subsequently washed into the cisterns.

Table 4. ^{90}Sr in yearly rainfall (pCi/liter).[a]

Island	1968	1969	1970	1971	1972	1973	1974	6-year mean
Wake	0.35	0.47	0.44	0.35	0.28	0.07	0.25	0.32
Johnston	.36	.51	.26	.54	.14	.05	.68	.36
Guam	.20	.11	.13	.13	.10	.02	.10	.11
Yap	.12	.07	.11	.07	.05	.008	.07	.071
Truk	.08	.08	.10	.08	.03	.003	.06	.061
Koror	.095	.04	.07	.07	.05	.003	.06	.055
Majuro	.11	.09	.14	.09	.03	.006	.06	,075
Ponape	0.08	0.07	0.09	0.10	0.03	0.008	0.05	0.061

[a]Data from Ref. 8.

Eneu and Bikini Ground Water

The available chemical and radiological data for ground water samples from Eneu and Bikini islands, respectively, are shown in Tables 5 and 6. All ground water was filtered through a 0.4-μm filter. Thus, the table entry, for example, for ^{137}Cs (Part.), refers to the quantity of ^{137}Cs associated with the particulate material held on a 0.4-μm filter normalized to a liter volume; the ^{137}Cs (Sol.) refers to the quantity that passed through the filter with the water.

It is not the purpose of this study to assess the chemical quality of the ground water for human consumption but to make our chemical data available to the agency or group responsible for such assessments. We can state, however, that by U. S. Public Health Standards,[6] the ground water at FWR 2 and FWR 3 on Eneu and at HFH 3 on Bikini would be considered brackish; that at FWR 4 on Eneu and at HFH 2 and HFH 4 on Bikini appears to be definitely potable; and at FWR 1 on Eneu and HFH 1, HFH 5 and HFH 7, the water is chemically acceptable for household and agricultural purposes, and for drinking if the taste can be tolerated. Recall

Table 5. Ground-water data from Eneu Island.

Well	Date drilled	Date sampled	Hour sampled	Concentration (ppm) Cl	SO_4	Sr	K	Ca	Na	Mg
FWR 1	6/23	6/24	0835	553	121	1.6	11.8	66.5	337	64.5
			1250	565	128	1.5	11.3	63.5	339	67.8
FWR 2	6/23	6/24	1430	1820	299	2.2	36	122	995	132
FWR 3S[b]	?	6/22	1330	1420	374	1.4	31	56	825	123
3B[b]				13610	1870	415	263	216	7760	854
FWR 4	?	6/22	1510	30.9	4	0.7	0.2	41.8	14.3	17.1

Well	Hour sampled	Concentration[a] ^{137}Cs (pCi/l) Sol.	^{137}Cs (pCi/l) Part.	^{90}Sr (pCi/l) Sol.	^{90}Sr (pCi/l) Part.	^{239}Pu (fCi/l) Sol.	^{239}Pu (fCi/l) Part.
FWR 1	0835	35.3(1)	1.17(2)	71 (1)	0.81	3.5(6)	9.5 (10)
	1250	30 (1)	0.73(3)	45.6(1)	0.56	3.3(8)	1.6 (22)
FWR 2		69.1(1)	0.95(3)	66 (2)		23.5(4)	8.4 (17)
FWR 3S[b]		32 (2)	0.59(2)	1.3(13)	0.03	0.72(22)	1.42(16)
3B[b]		20 (3)	0.49(5)	1.0(9)		0.32(30)	1.1 (15)
FWR 4		1.1(5)	0.57(2)	3.4(5)	0.11	0.85(18)	0.67(27)

[a] Sol.: soluble fraction; Part. = particulate fraction. The values in parentheses are the 1-σ counting errors expressed as percentages of the listed values.

[b] S, surface; B, bottom.

Table 6. Ground-water data from Bikini Island.

Well	Date drilled	Date sampled	Hour sampled	Concentration (ppm) Cl	SO_4	Sr	K	Ca	Na	Mg
HFH 1	6/17/75	6/21/75	0840	381	109	2.0	23.1	55.5	255	62.5
			1145	489	124	2.0	23.1	63.5	318	74.0
			1545	555	134	2.7	27.0	65.0	357	81.8
HFH 2	6/17/75	6/19/75	1100	6.1	20	1.2	2.5	61.8	42.5	25.8
HFH 3	6/18/75	6/20/75	0850	1390	303	2.3	37.9	84.0	805	124
HFH 4	6/19/75	6/20/75	1100	53.3	60	1.3	9.5	64.8	57.5	79.5
HFH 5	6/18/75	6/19/75	1600	344	124	1.2	18.2	36.7	221	52.3
HFH 7	?	6/20/75	1330	315	77	1.7	12.1	46.0	193	50.8

Well	Hour sampled	Concentration[a] ^{137}Cs (pCi/l) Sol.	^{137}Cs Part.	^{90}Sr (pCi/l) Sol.	^{90}Sr Part.	$^{239,240}Pu$ (fCi/l) Sol.	$^{239,240}Pu$ Part.	Ratio $^{238/239,240}Pu$ Sol.
HFH 1	(0840 hr)	480	9.9	87(1)	1.31	40.0	3.3(13)	0.0026(9)
	(1145 hr)	629	10.9	46(1)	0.57	5.9	1.3(32)	<0.004
	(1545 hr)	695	15.6	38(1)	0.48	4.7	1.9(21)	<0.004
HFH 2		294	12.0	77	1.37	7.5	71.3(4)	[illegible] (35)
HFH 3		335	8.3	227		38.2	8.4(10)	<0.008
HFH 4		226	6.5	260		89	33.6(4)	<0.001
HFH 5		530	8.5	180		25.6	13.4(12)	0.004(60)
HFH 7		250	5.8	1.0		9.8	2.0(22)	0.022(30)

[a] Sol.: soluble fraction; Part. = particulate fraction. The values in parentheses are the 1-σ counting errors expressed as percentages of the listed values.

that the water from HFH 7, considered somewhat brackish by some western standards, has been used for drinking in the past.

The USPHS recommends that drinking water containing Cl, SO_4, and dissolved solids exceeding, respectively, 250, 250, and 500 mg/liter not be used if other less mineralized supplies are available. However, it should also be emphasized that, according to USPHS data, more than 100 public supplies in the U. S. provide water with more than 2000 mg/liter of dissolved solids. Newcomers and casual visitors would certainly find these waters almost intolerable, and, although some of the residents use other supplies for drinking, many are able to tolerate if not to enjoy these highly mineralized waters with no ill effects. Hence, if the taste can be tolerated, the water from the chemically acceptable wells could be used for drinking by the Bikinians. However, a recent study[10] has shown that the concentrations of some water components such as SO4 Na, Ca, and Cl in some U. S. water supplies are close to or within chronic toxicity limits that could lead to weight loss, diarrhea in infants, urinary disease, strong physiological effects, and arthritic conditions in humans. Many of the same chemical constituents measured in the brackish and chemically acceptable wells on Bikini and Eneu are close to the limits defined in Ref.[10]

ENEU ISLAND: RADIONUCLIDES

The radionuclide concentrations vary among the ground-water samples collected from the Eneu locations. The ^{137}Cs, ^{90}Sr, and $^{239,240}Pu$ concentrations show no obvious correlations with water freshness, and the $^{137}Cs/^{90}Sr$ ratios in the water show us apparent geographical patterns. At FWR 1, for example, the ^{90}Sr is higher in concentration than ^{137}Cs but is significantly lower than ^{137}Cs in both the surface and bottom water from FWR 3. At FWR 2 the concentrations of the two radionuclides were comparable. Although the levels of both ^{137}Cs and ^{90}Sr are low at FWR 4, the ^{90}Sr concentration exceeded the ^{137}Cs level. In contrast, comparison of the radionuclides in Bikini ground water shows that the ^{90}Sr was either comparable to the ^{137}Cs or much lower. The two islands differ either with respect to the mechanisms regulating the cycling of these two radionuclides or with respect to the relative inventories of ^{137}Cs and ^{90}Sr in the sources supplying the water reserviors.

On the average, 2.4% of the total ^{137}Cs was found associated with the particulate material 'in the Bikini ground-water samples. Except for FWR 4, the fraction is similiar to the average fraction at Eneu. At FWR 4, 34% of the ^{137}Cs in the water is associated with particulate material. This unusually high percentage indicates that this water contains unique particulates having a high affinity for ^{137}Cs.

The water at FWR 4 is of high quality, however, and has low levels of radionuclides. The levels of ^{90}Sr and ^{137}Cs are comparable to those in the Bikini cisterns and in U. S. fresh-water supplies. The ^{90}Sr level is 34% of the USPHS limit of 10 pCi/liter. One point of caution is advised, however, before recommendations are made regarding the radiological quality of this water, with respect to ^{90}Sr. We have not yet analyzed all particulate fractions for ^{90}Sr, and since the Bikini people probably will use unfiltered water will for domestic purposes, the total concentration of ^{90}Sr in the water will be slightly higher. However, we do not anticipate that the increase will be more than 20% of the concentration in the soluble fraction. This is a conservative estimate based on our present data and our ground-water data at Enewetak.[11] FWR 1 has the next freshest ground water, but the ^{90}Sr concentrations in the two samples taken at the beginning and end of the continuous pumping experiment exceed the USPHS limit of 10 pCi/liter. The USPHS recommends that

> "when the concentration of 10 pCi/l are exceeded, a water supply shall be approved by the certifying authority if surveillance of total intake of radioactivity from all sources indicates that such intakes are within the limits recommended by the Federal Radiation Council for control action".

Therefore before this water is recommended as usable, a complete dose assessment of all pathways must first be completed. Also, because the concentrations in the water may either increase or decrease with time, it must be remembered that regardless of the total assessment, if the water levels are critical to the total dose, the dynamics of the radionuclides in the ground water must be understood before any realistic long-term dose prediction can be made. The concentrations in the ground water will depend on the soil burdens, the rates of leaching and groud-water recharge, the ground-water residence time, and other physical, biological and chemical factors.

The freshness of the water at FWR 4 apparently relates to the geography of the area. The runway probably acts as a large catchment system for rain-fall, draining large quantities of fresh water that recharge the ground-water reservoirs around the perimeter. It is quite possible that exploration of the area between FWR 4 and FWR 1 and the area south of FWR 4 along the runway perimeter both to the east and west will uncover quantities of usable ground water. In a northerly direction from FWR 1, the water tends to be more brackish (see FWR 2 data in Table 5). The only hope of uncovering drinkable ground water in the northern area would be to chance upon a perched lens.

BIKINI ISLAND: RADIONUCLIDES

The average concentrations of ^{137}Cs, ^{90}Sr, and $^{239,240}Pu$ in the ground water from the newly established wells on Bikini were much higher than those at Eneu. Interestingly, although the ^{137}Cs and $^{239,240}Pu$ concentrations in the ground water at the old established Bikini well site (HFH 7) were higher than the respective levels at the old Eneu well (FWR 4), the concentration of ^{90}Sr in the soluble fraction from HFH 7 is lower than the level at FWR 4 on Eneu by a factor of 3. Except for HFH 7, the ^{90}Sr groundwater concentrations at the other Bikini locations exceeded the USPHS recommended limit of 10 pCi/liter.

As at Eneu, the radionuclide concentrations in Bikini surface ground-water samples are variable. Both the ^{90}Sr and $^{239,240}Pu$ are in higher concentration in the ground water from locations north of the center baseline (HFH 3, HFH 4, HFH 5) than in the waters south of this road. The ^{137}Cs concentrations show no apparent geographical correlation and none of the radionuclide concentrations appear related to water freshness. Of the newly established wells, HFH 4 is found to have the lowest ^{137}Cs concentration and the highest ^{90}Sr concentration in its water. The last two samples pumped from HFH 1 were found to have the lowest ^{90}Sr concentrations and the highest ^{137}Cs concentrations among the newly established wells. These data might suggest that the concentration of ^{137}Cs is inversely related to the concentration of ^{90}Sr, but no such relationship appeared in our ground-water data from Enewetak.

During the pumping experiment at HFH 1, the ^{137}Cs ground-water concentrations increased over the day, but both the ^{90}Sr and $^{239,240}Pu$ concentrations were lower in the final samples than in the first sample. These data demonstrates that a single radionuclide should not be used as universal indicator to describe the temporal variations of other radionuclides in the ground-water reservoirs. Coincident with the radionuclide changes during pumping at HFH 1, the chemical quality of the water slowly changed over the day as well. Therefore, it is recommended that to assure the best-quality water for any use, withdrawal rates should not exceed 8 liters/min.

The mean ^{137}Cs concentration in the surface ground waters at Bikini was 430 ± 179 pCi/liter. An additional 2.4% is associated with the particulate phase. The present total ^{137}Cs concentration is, on the average, 2.5% of the recommended FRC concentration guideline for drinking water. In a recent report, Conard[12] shows ^{137}Cs and ^{90}Sr concentrations in well water samples from several Bikini locations for the years 1971, 1972, and 1973. Since no locations or identifications were given with Conard's data, we have averaged both the ^{137}Cs and ^{90}Sr concentrations for each year and have plotted the values, together with our 1975 mean concentrations, as a function of time in Fig. 5. Although the standard deviations during any single year are large, the data strongly indicate that the mean ^{137}Cs ground-water concentrations have declined over the last four years, while the ^{90}Sr concentrations appear to have increased over this same interval. These data demonstrates again the great need for detailed assessment of the mechanisms controlling the cycling of individual radionuclides in the ground-water reservoirs if the long-term radiological doses to populations using this water are to be properly assessed.

Although there are significant errors associated with the measurement of ^{238}Pu in the water samples, the concentrations of ^{238}Pu are low.

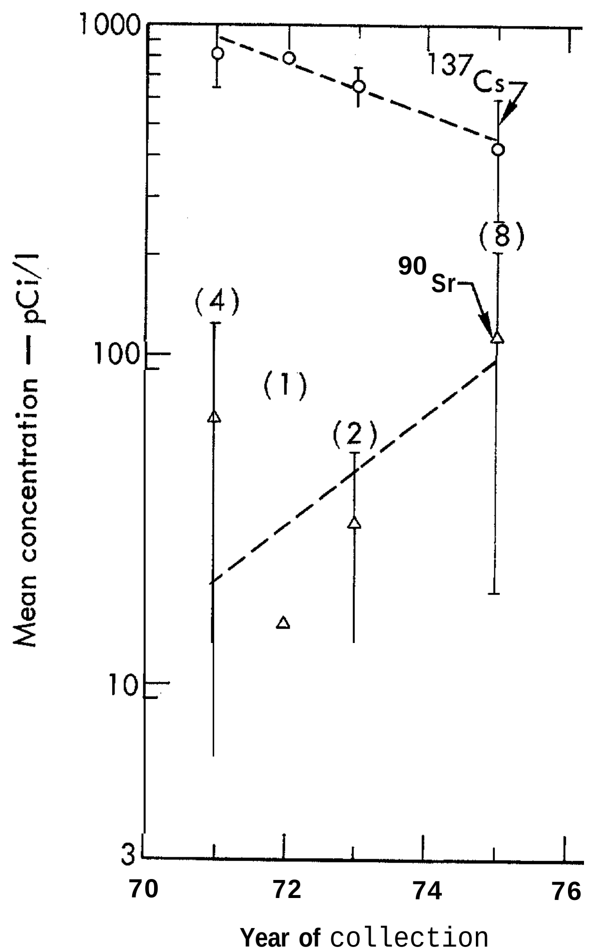

Fig. 5. Changes in ground-water concentrations of ^{137}Cs and ^{90}Sr with time at Bikini Island. Numbers in parenthesis are number of sample analyzed.

The ^{238}Pu concentrations in the soluble fractions are on the average 1.3% of the $^{239,240}Pu$ levels In general, the lowest $^{238}Pu/^{239,240}Pu$ ratios (averaging 0.004) are found in the ground water at wells HFH 3, HFH 4, and HFH 5, north of the center baseline road.

From our ground-water studies at Enewetak, a relationship was developed between the mean $^{239,240}Pu$ concentrations in the surface ground waters of any island and its median soil inventory. The relationship is

$^{239,240}Pu$ (fCi/l) in filtered surface ground water = $(8 \pm 4.9 \times 10^{-3}) \times {}^{239,240}Pu$ (mCi/km^2) in the respective island soil column to a depth of 125 cm.

If this relationship is applicable to any Pacific atoll where similar mechanisms are moving plutonium to the ground water reservoirs, it can be used to predict soil inventories from ground-water data. The mean concentration of $^{239,240}Pu$ in the soluble fraction in the Bikini ground water is 27.6 fCi/liter. Using this value and the above relationship, we estimate that the median soil inventory on Bikini Island is $3.5 \pm 1.3 \times 10^3$ mCi/km^2. The mean concentration in the ground waters at Eneu is 6.4 fCi/liter which, with the above relationship, indicates that the median soil burden on Eneu will be $0.8 \pm 0.5 \times 10^3$ mCi/km^2. We eagerly await completion of the soil analyses to adequately test the applicability of this model in its present form.

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