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Chemical and Radiochemical Composition of the Rongelapese Diet

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SUMMARY

The gross chemical composition of the Rongelapese diet indicates that it is low in fat, protein, and ash but fairly high in carbohydrate. The variation in gross chemical composition of the diets examined may be accounted for by the broad variability of the different diets. The habitat of the Rongelapese probably does not demand a high-energy diet, which may partially justify the lower fat intake. Levels of calcium and phosphorus seem below the minimum required for maintenance of a proper calcium-phosphorus balance. The diet seems adequate in magnesium and potassium but slightly low in sodium. The nickel, cobalt, and copper contents seem high in the Rongelap rations, manganese content is low, and iron and zinc compare favorably with minimum daily requirements.

Hight levels of cobalt-60 and zinc-65 are associated with each other and with rations containing local fish. The higher levels of strontium-90 and cesium-137 are found where local fruit was consumed. Coconut contributes little strontium-90, and pandanus the most. Rations with higher zinc-65 also contain higher levels of stable zinc, indicating that local sea foods may be the main source of zinc in the diet. Cesium-137, strontium-90, and cobalt-60 show no definite correlation with stable potassium, calcium, and cobalt, respectively. There is probably a net addition of minerals to Rongelap soils from imported foods.

INTRODUCTION

Rongelap Atoll was contaminated with radioactive fallout resulting from the Bravo test, on March 1, 1954, to the extent that the population of 82 Rongelapese had to be evacuated. Some 200 Marshallese returned to Rongelap in June, 1957, after the area had been declared again safe for human habitation. Since 1954 several surveys have determined levels of radioactive contamination at Rongelap Atoll (Dunning, 1957). In March, 1958, a study of the ecology of the atoll relative to radioactive contamination was initiated at the request of the U. S. Atomic Energy Commission, Division of Biology and Medicine.

One of the objectives of the present investigation was to determine the amount and kinds of radionuclides and minerals ingested by the Rongelapese through foods. Fat, protein, and carbohydrate were determined to provide a basis of comparison with known diets. To our knowledge there are no published data on the diet of the Rongelapese.

Rongelap Atoll lies in the northern Marshall Islands, an area of comparatively low rainfall and limited variety of agricultural products. The principal plants eaten are coconut, breadfruit, pandanus, and the arrowroot, or tacca; some squash and papaya are also grown. Bananas and taro have been introduced but are not yet in full production.

Fish, clams, langusta, birds, chickens, and pigs are eaten. Of these, the most important is fish. The coconut crab, *Birgus latro*, is considered a delicacy but is the one food item excluded from the diet because of the strontium-90 content (Dunning, 1957).

The coconut, "Ni" in Marshallese, is eaten at different stages of development. The juice

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from the immature nut is preferred for drinking, and only rarely is the germinated nut eaten. Copra, the dried coconut meat, is a staple eaten alone or mixed with other foods.

The coconut sap is collected from the cut ends of inflorescences of coconut trees set aside for this purpose in the village area. The fresh sap is partaken of by all age groups, and the fermented sap, "jekro" or "jugaroo," is consumed by adults.

Breadfruit (Ma) is eaten either baked or boiled, and also is made into a preparation referred to as "cheese." To make "cheese," the skin is removed and the pulp is placed in salt water for three days, then wrapped in breadfruit leaves and buried in the sand for at least one week before it is eaten. The Rongelapese claim that this "cheese" will keep two years or more in the sand.

Pandanus (Bop) is eaten fresh, boiled, or baked. "Jenkun," a preparation said to keep for more than five years, is prepared by baking or boiling the Pandanus keys and scraping out the pulp. The pulp is dried, usually on sheet metal, over coals until it reaches the consistency of fudge. The dried pulp is pressed into a roll and wrapped in Pandanus or coconut leaves. Slices are cut off as needed.

Tacca or arrowroot (Mokmok) tubers are washed with sea water, crushed and passed through a sieve into a pan of sea water, and allowed to settle for three or four hours. When the starch begins to coagulate, the water is decanted. Sea-water washes are repeated several times, followed by one fresh-water wash. Finally the starch is dried and stored as a powder. The powder is mixed with water for use, and either eaten immediately as prepared or boiled or baked.

The papaya is eaten fresh, sometimes mixed with rice or grated coconut.

The fish consumed are primarily reef fish such as the goatfish, *Mulloidicthys* sp., mullet, *Neomyxus* sp., surgeon-fish, *Acanthurus* sp., and the siganids. The fish are eaten baked, boiled, or raw. The three fish we have observed the Rongelapese to eat raw are goatfish, mullet, and siganids. Fish are also preserved by baking and then drying in the sun. Sometimes salt is added before the fish are dried.

The langusta, spiny lobster, is eaten boiled. The clams are either boiled as a chowder or baked in the shell in a covered pit. The clam meat is sometimes also dried in the sun after baking and kept for several days.

Birds are eaten either baked or boiled, and are also dried following precooking. Bird eggs, usually hard boiled, form only an incidental part of the diet; they are used principally when the Rongelapese are visiting islands other than their main island or nearby Ailinginae Atoll.

Pig and chicken are eaten primarily on special occasions.

The source of fresh water in the area is cisterns. Ground water, though potable in certain areas during the rainy season, is not ordinarily drunk.

Of the imported foods, rice, wheat flour, and canned corned beef appear to be the most important. Many other products are imported from time to time, such as sardines, C-ration, ship's biscuit, and candy. In 1958 large quantities of C-rations were consumed. Many individuals prefer the imported foods.

MATERIALS AND METHODS

The samples were collected during a single 24-hr period in September, 1959, at Rongelap Island, taking care that the composition and the amount corresponded to the composition and amount actually eaten by the individual. (Bwio Soap, former village secretary, and Neil Morriss, Trust Territory Resident Agriculturist at Rongelap Atoll at that time, or one of the authors collected each sample.) Wet weights of the samples were taken in the field. The samples were then dried at 90°C and shipped to the University of Washington, Seattle.

Caution must be used in collecting to be reasonably sure that such daily rations are a true representation. Misunderstanding and a misguided desire to please can easily lead some Rongelapese to provide merely a collection of miscellaneous food items rather than actual daily rations of prepared food. It was felt that a few samples composed of items and portions actually seen to be consumed were preferable to many samples of uncertain origin. Consequently, some samples proffered by individuals were discarded.

Even so, there are obvious discrepancies. Sample number 3 (Table 1), for example, appears to be ridiculously low in the total amount consumed. Doubtless there must have been some "snacking," but the eating habits of the Rongelapese are irregu-

Table 1. Description of food rations collected at Rongelap Island in September, 1959 (each sample is a 24-hr ration).

Sample no.		Description	Wet wt. (g)	Total dry wt. (g)
1	a)	Pandanus paste, boiled rice and baked fish (mixed)	253	374.68
	b)	Partly baked bread dough with bully beef	252	
	c)	Bully beef sandwiches	195	
2	a)	Coconut meat (green)	30	175.85
	b)	Pandanus "pie"	16	
	c)	Baked fish	23	
	d)	Sardines, canned	20	
	e)	Boiled rice w/coconut milk	249	
3	a)	Breadfruit, baked	41	87.12
	b)	Coconut and bread dough, baked	24	
	c)	Bread	31	
	d)	Bully beef	17	
	e)	Ship's biscuit	13	
	f)	Rice w/coconut milk, boiled	49	
4	a)	Coconut, ripe	72	321.69
	b)	½ papaya	57	
	c)	Rice and fish mixed	306	
	d)	Bread, local (coconut milk, not saved)	81	
5	a)	Rice and fish mixed	243	203.16
	b)	Bread, local	80	
	c)	Rice	197	
6	a)	Breadfruit, baked	203	484.10
	b)	Coconut w/baked dough	203	
	c)	Fish, baked	126	
	d)	Bread, local	75	
	e)	Coconut, entire	50	
	f)	Rice, boiled	291	
	g)	Sardines, canned	154	
7	a)	Pandanus keys, raw	115	314.90
	b)	Goatfish, baked	26	
	c)	Sardines, canned	101	
	d)	Rice, boiled	721	
8	a)	Fish, baked	155	440.50
	b)	Bread, local	145	
	c)	Bully beef	66	
	d)	Sardines, canned	94	
	e)	Rice, boiled	622	
9	a)	Rice and fish mixed	421	262.30
	b)	Rice and fish mixed	64	

lar and it was impractical to follow each individual throughout the day. Therefore, all of the samples collected (Table 1) should probably be considered as erring toward the low side for total consumption. However, there does appear to be a reasonable agreement with quantities listed by Murai (1954) from a study at Majuro Atoll. Catala (1957) pointed out the difficulties of obtaining quantitative data in these areas.

The components of each sample were dried to constant weight in the laboratory at Seattle (Table 1). The entire diet for each individual was then homogenized in water with a high-speed blender, dried at 98°C, and pulverized to a fine powder. Subsamples of the powder were taken for fat, protein, carbohydrate, and radiochemical analyses. Portions weighing 40–250 g were wet-ashed with HNO_3 and H_2O_2, and the ash dried in 250-ml beakers for gamma-ray spectroscopy.

The gamma-counting equipment consisted of a 3-in. thallium-activated sodium iodide crystal used in conjunction with a 256-channel analyzer with a digital print-out. The total counts per minute under the photopeak were calculated by summing counts per minute of all channels included in the peak and subtracting the background counts. The counting efficiency for the gamma energies measured was determined by calibrating the instrument with standards with an error of ± 10%.

Following analysis by gamma spectroscopy, the ashed samples were dissolved in a known volume of 1*N* HNO_3. Strontium-90 was determined on an aliquot by the method of Kawabata and Held (1958), in which a combination of nitric acid precipitation and ion-exchange procedures is used.

Calcium was determined by permanganate titration of oxalic acid and confirmed by flame spectrophotometry, with the internal standard technique of Chow and Thompson (1955). Potassium was determined by flame spectrophotometry at 766-mμ wavelength, and independently confirmed with estimation of potassium by titration of the cobaltinitrite with potassium permanganate (Hibbard and Stout, 1933). Sodium was determined at 589-mμ wavelength. The standardization procedure and general function of the system have been described by Chakravarti and Joyner (1960).

In determining magnesium, an aliquot of the ashed sample was dissolved in 0.1*N* HCl and the solution passed through a Dowex-50 X8 100-200 resin column of precalculated capacity. Interfering anions were removed by elution with two-column volumes of distilled water. The resin was then stripped of cations with three-column volumes of 2*N* HCl, and the eluate was neutralized to methyl orange with concentrated NH_4OH. Calcium was removed by precipitation with ammonium oxalate followed by boiling and filtration. The filtrate was

Table 2. Composition of rations from Rongelap Island (dry-weight basis).

Constituent		Sample no. 1	2	3	4	5	6	7	8	9
Proximative analyses (%)										
Moisture		46.5	48.0	50.2	37.7	60.9	59.7	67.3	59.3	45.9
Fat		3.73	1.64	1.35	1.34	4.35	8.47	2.80	3.60	2.82
Protein		15.1	10.7	11.6	9.65	7.65	23.7	14.5	25.9	8.65
Carbohydrate		30.5	37.8	32.7	49.2	21.3	3.57	10.9	6.98	38.9
Ash		4.17	1.87	4.13	2.19	5.83	4.62	4.54	4.28	3.71
Chemical composition										
Calcium	mg/g	0.761	0.593	0.920	0.571	0.381	2.13	1.29	0.624	0.455
Magnesium	mg/g	0.804	0.797	1.13	0.938	0.777	1.10	0.657	0.760	0.814
Sodium	mg/g	3.42	2.44	6.20	1.97	2.59	4.57	7.32	3.22	2.77
Potassium	mg/g	2.28	1.39	3.12	3.34	1.12	4.60	2.55	2.95	1.52
Phosphorus	mg/g	0.134	0.061	0.024	0.119	0.056	0.358	0.203	0.823	0.102
Nitrogen	mg/g	24.2	17.1	18.5	15.5	12.3	37.8	23.9	41.3	13.8
Nickel ppm	(mg/kg)	0.0	24.	4.6	1.7	33.	5.4	25.	3.2	1.7
Manganese	(mg/kg)	.71	1.0	.22	2.7	2.5	2.9	3.3	2.2	1.7
Cobalt	(mg/kg)	2.1	.80	.30	.63	.00	.27	.33	.12	.29
Copper	(mg/kg)	14.	27.	8.9	20.	5.6	22.	7.5	6.8	2.8
Iron	(mg/kg)	66.	69.	44.	34.	33.	47.	33.	71.	29.
Zinc	(mg/kg)	24.	14.	16.	13.	16.	48.	37.	41.	29.

Table 3. Composition of rations for a 24-hr period from Rongelap Island.*

Constituent		Sample no. 1	2	3	4	5	6	7	8	9
Wet wts.	(g)	700.0	338.0	175.0	516.0	520.0	1201.0	963.0	1082.0	485.0
Moisture	(g)	325.	162.	87.9	194.	317.	717.	648.	641.	223.
Fat	(g)	14.0	2.88	1.17	43.2	8.84	41.0	8.82	15.8	7.38
Protein	(g)	56.6	18.8	10.1	31.0	15.5	114.	45.5	114.	22.7
Ash	(g)	15.6	3.29	3.59	7.06	11.8	22.4	14.3	18.8	9.74
Carbohydrate	(g)	288.	151.	72.3	240.	167.	306.	246.	292.	222.
Calcium	(g)	0.285	0.104	0.080	0.184	0.077	1.03	0.407	0.275	0.119
Magnesium	(g)	0.301	0.141	0.088	0.302	0.158	0.531	0.207	0.335	0.214
Sodium	(g)	1.28	0.429	0.540	0.634	0.526	2.21	2.30	1.42	0.727
Potassium	(g)	0.854	0.244	0.272	1.07	0.228	2.23	0.803	1.30	0.399
Phosphorus	(g)	0.036	0.012	0.002	0.038	0.011	0.173	0.064	0.080	0.027
Nitrogen	(g)	9.06	3.00	1.61	4.99	2.49	18.3	7.52	18.2	3.62
Nickel	(mg)	0.0	.91	.40	.51	6.7	2.6	7.7	1.4	.45
Manganese	(mg)	.27	.18	.02	.86	.50	1.4	1.0	.99	.45
Cobalt	(mg)	.78	.14	.03	.20	0.0	.13	.10	.05	.07
Copper	(mg)	5.3	4.7	.77	6.3	1.1	11.	2.4	3.0	.73
Iron	(mg)	25.	12.	3.9	11.	6.7	23.	10.	31.	7.5
Zinc	(mg)	8.9	2.4	1.4	4.3	3.2	23.	12.	18.	7.7

* Calculated from Table 2, wet-to-dry ratio, and weight of total sample.

Table 4. Radioisotopes (disintegrations per minute per gram) in rations from Rongelap Island (dry-weight basis).

Sample no.	Co^{60}	Zn^{65}	Mn^{54}	Cs^{137}	Sr^{90}
1	0.35 ± .12[a]	0.40 ± 0.29	−0.04 ± 0.09	61.4 ± 0.60	0.84 ± 0.07
2	0.52 ± .25	−1.03 ± 0.53[b]	0.11 ± 0.20	14.1 ± 0.50	1.63 ± 0.16
3	0.12 ± .32	−2.40 ± 1.0	−0.49 ± 0.39	21.1 ± 0.87	1.[illegible] ± 0.25
4	0.23 ± .13	−0.76 ± 0.28	−0.07 ± 0.10	17.6 ± 0.38	0.43 ± 0.06
5	0.43 ± .22	−0.07 ± 0.45	−0.11 ± 0.16	3.6 ± 0.28	0.21 ± 0.09
6	0.90 ± .13	1.70 ± 0.30	−0.23 ± 0.09	16.1 ± 0.29	0.66 ± 0.06
7	0.56 ± .14	[illegible].87 ± [illegible].35	−0.19 ± 0.10	20.0 ± 0.38	0.86 ± 0.08
8	1.20 ± .15	2.30 ± 0.41	−0.21 ± 0.11	3.0 ± 0.17	0.22 ± 0.05
9	0.33 ± .16	0.05 ± 0.35	−0.003 ± 0.13	2.6 ± 0.21	0.32 ± 0.08

[a] 0.95 counting error.
[b] Negative values are given to indicate that there are errors in addition to the counting error which cannot be specifically accounted for.

made basic with 1N NH_4OH; 5% $(NH_4)_2HPO_4$ was added until a precipitate formed, and an excess of NH_4OH was then added during constant stirring. The precipitate, magnesium ammonium phosphate, was allowed to settle overnight, removed by filtering, dissolved in 3 drops of concentrated H_2SO_4, and made to volume with water. Magnesium was determined by titrating an aliquot of this solution against a standard EDTA solution using the indicator Eriochrome Black T.

Total phosphorus was determined by the colorimetric method of Fleischer *et al.* (1958).

The transition elements nickel, manganese, cobalt, copper, iron, and zinc were determined colorimetrically by methods described by Sandell (1959). The elements were initially separated by selective elution of their chloride complexes from an anion-exchange resin. Kraus and Moore (1953) have shown that the chloride complexes of the transitional elements nickel through zinc are adsorbed onto a strongly basic anion-exchange resin (Dowex 1) and are selectively eluted at different molarities of HCl. Following the same principle, Joyner and Chakravarti (1960) suggested techniques that were applied to these samples.

Protein nitrogen was determined by the Kjeldahl method.

Fat was determined by a modification of the Johnson method (Winton and Winton, 1945). Methylene chloride was the extracting solvent.

Ash content was determined as the nitrate form by drying an aliquot of the ashed sample to constant weight.

Moisture content was calculated from the wet-weight to dry-weight ratio.

Total carbohydrate and like substances were estimated by subtracting moisture, fat, protein, and ash from the total solids and calculating the carbohydrate content by difference.

RESULTS AND DISCUSSION

Table 1 lists the components of the 24-hr food rations collected at Rongelap Island. Tables 2 and 3 show proximate composition and trace-element content of the rations, and Tables 4 and 5 present levels of radioisotopes. Results are given on a percentage or unit weight basis (Tables 2 and 4) and as amount for total diet (Tables 3 and 5). The former basis permits comparison of the relative composition of individual rations and facilitates evaluation of the contributions made by specific items in each diet; the latter basis shows the actual amounts consumed in a 24-hr period.

In evaluating the chemical constituents consumed by an individual in a 24-hr period, the gross weight of the total diet is of much importance. By comparing the proximate chemical composition on a percentage basis with the published chemical composition of some of the items constituting the samples, it is possible to account for the variation in moisture, fat, protein, carbohydrate and ash content of the different diets.

Since information on the nutritional aspects of the Rongelapese diet is limited, comparison of the data with data for other areas is probably not meaningful. The gross percentage composition indicates that the diets are generally low in fat, protein, and ash but fairly high in carbohydrate content.

When the data in Table 3 are compared with the recommended daily dietary allowances published by the Food and Nutrition Board of the National Research Council, the

24-hr rations of the Rongelapese appear to be generally below the level recommended for protein. Since fat allowances are based more on food habits than on physiological requirements, no definite conclusion can be drawn about the apparent low fat content of these diets. The habitat of the Rongelapese probably does not demand a high-energy diet, which may partially justify the lower fat intake.

The calcium content of the 24-hr ration seems to be much lower than the suggested normal requirement (Nutritional [illegible], 1958). On the same basis, the magnesium levels seem to be adequate but the phosphorus levels are far below what is necessary to maintain a proper calcium-phosphorus balance in a good diet. The sodium levels appear to be slightly below the normal suggested intake levels, although no information is available as to the minimum daily requirement of sodium. The potassium level is lower than the sodium content, which is generally the case in most diets.

Kent and McCance (1941) have suggested that an ordinary adult diet will supply [illegible]–0.5 mg of nickel daily. On the basis of these values, the nickel content of the 24-hr Rongelapese rations appears to be higher than usual in some cases. Nickel salts frequently gain access to food from corrosion of nickel vessels, and small quantities of nickel may also be found in various manufactured foods. It also may be that some of the native food components are high in nickel content.

Basu and Malakar (1940) have suggested that 4.6 mg of manganese are required per day to keep an adult male in manganese balance. On this basis, the Rongelapese food appears to be low in manganese. The average adult diet of good quality supplies 0.005–0.008 mg of cobalt daily (Harp and Scoular, 1952); in comparison the Rongelapese food appears to be fairly high in cobalt content. Tompsett's (1934) balance experiments with adult humans indicate a minimum copper requirement as low as 0.6 mg daily. The estimate of Chou and Adolph (1935) is 1–2 mg daily. The Rongelapese diet is definitely above the experimental minimum requirements given. The iron in the diet appears to compare favorably with the minimum daily requirement as suggested by the National Research Council. Eggleton (1939) has given normal daily food intake of zinc as 12 mg. The Rongelapese food appears to have large variation in zinc content, and on the average is less than 8 mg daily.

The higher levels of cobalt-60 and zinc-65 are associated with each other and with rations containing local fish. This is to be expected since these isotopes are found primarily in marine organisms ([illegible], 1957). The higher levels of strontium-90 and cesium-137 are found where local fruit was consumed. In general, higher levels of strontium-90 are coincident with higher levels of cesium-137. Coconut contributes little strontium-90, and pandanus the most.

The average value for the daily intake of strontium-90 is 83 μμc, and for calcium 0.28 g. The average daily intake in terms of "strontium units" (μμc Sr^{90}/g Ca) is then nearly 300. This value is about three

Table 5. Radioisotopes in 24-hr rations from Rongelap Island.[a]

Sample no.	μμc/24 hr				
	Co^{60}	Zn^{65}	Cs^{137}	Sr^{90}	μμc Sr^{90}/g Ca
1	59 ± 20[b]	67 ± 49	10000 ± 100	142 ± 11.8	497 ± 41.4
2	42 ± 20		1100 ± 40	129 ± 12.7	1239 ± 121.6
3			830 ± 34	49 ± 9.8	613 ± 122.5
4	33 ± 19		2000 ± 55	62 ± 8.7	339 ± 47.3
5	39 ± 20		330 ± 26	19.2 ± 8.2	248 ± 106.5
6	200 ± 48	370 ± 65	3500 ± 63	144 ± 13.1	140 ± 12.7
7	79 ± 20	120 ± 50	2800 ± 54	122 ± 11.4	300 ± 27.9
8	240 ± 30	560 ± 82	590 ± 34	46.6 ± 9.9	159 ± 36.1
9	29 ± 19		310 ± 25	37.8 ± 9.5	331 ± 82.8

[a] Calculated from Table 4, wet-to-dry ratio, and weight of total sample.
[b] 0.95 counting error.

times that of previous estimates (Dunning, 1957; Cohn *et al.* 1960). Those estimates were based on an estimated daily intake of 0.8 g of calcium, or about three times the value reported here. Thus, the significant difference between this and previous values reflects a discrepancy between observed and estimated calcium intake. It is not within the scope of this report to enter into an estimation of body burden, which has been discussed in detail by Cohn *et al.* (1960). However, it is of interest to note that the body burden as estimated from urinalysis data (Woodward *et al.*, 1959) and discussed by Cohn is consistent with a discrimination factor of four and a daily intake of about 100 $\mu\mu c$ Sr^{90}/g calcium. This would indicate either that the discrimination factor is greater than four or that these samples do not correctly represent daily calcium intake. In any case, it is obvious that continued study of Sr^{90} movement at Rongelap Atoll is necessary.

Rations containing the higher levels of zinc-65 also contain the higher levels of stable zinc, indicating that local sea foods may be the main source of zinc in the diet. Cesium-137, strontium-90, and cobalt-60 show no definite correlation with potassium, calcium, and cobalt, respectively, indicating that these elements are in large measure supplied from imported foods.

With the current means of sanitation—pit toilets and burial of garbage—on Rongelap and Eniaetok Islets there must be a net addition of minerals. The chief export, copra, is low in ash content as compared with imported foods. A quantitative evaluation of the addition would require comparison of export and import records.

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