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MARCH 1957 MEDICAL SURVEY OF RONGELAP AND UTIRIK PEOPLE THREE YEARS AFTER EXPOSURE TO RADIOACTIVE FALLOUT

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Background

This report presents the results of a medical survey carried out in March 1957 on the Marshallese people who were accidentally exposed to radioactive fallout in March 1954. The accident occurred following the detonation of a large thermonuclear device during experiments at Bikini in the Pacific Proving Grounds. An unpredicted shift in winds caused deposition of significant amounts of fallout on four nearby inhabited Marshall Islands and on 23 Japanese fishermen aboard their fishing vessel, the Lucky Dragon. Sixty-four inhabitants of the island of Rongelap, 105 nautical miles away from the detonation, received the largest fallout exposure among the inhabited islands: an estimated dose of 175 r whole-body gamma radiation, beta lesions of the skin, and epilation from contamination of the skin and slight internal absorption of radioactive material. The Japanese fishermen probably received a similar exposure, although estimation of their dose is much less certain. Also 18 Rongelap people away on a nearby island (Ailingnae), where less fallout occurred, received only about half this exposure. Twenty-eight American servicemen on an island (Rongerik) further away received about the same amount of radiation as did the 18 people on Ailingnae. Lastly, 157 Marshallese on Utirik Island, some 200 miles distant, received only about 14 r whole-body radiation. The fallout was not visible on this island and no skin effects were seen.

The initial findings have been reported on the Marshallese and Americans[1] and the Japanese fishermen.[2] Subsequent examinations of the Rongelap people have been reported at the following times after exposure: six months,[3] one year,[4] and two years.[5] The present report concerns the examination of the Rongelap and Utirik people three years after exposure to fallout radiation. In addition examinations were carried out on an unexposed comparison population.

SUMMARY OF PAST FINDINGS

The following is a brief summary of the past findings which can be found in detail in the references.[1,3-5]

During the first 24 to 48 hr after after exposure, about two-thirds of the Rongelap people experienced anorexia and nausea and a few vomited and had diarrhea. At this time many also experienced itching and burning of the skin and a few complained of lachrymation and burning of the eyes. Following this, the people remained asymptomatic until about two weeks after the accident, when cutaneous lesions and loss of hair developed, due largely to beta irradiation of the skin. The effects of the radiation can best be summarized under three headings according to the mode of irradiation: penetrating irradiation, skin irradiation, and internal irradiation.

Penetrating Irradiation

The people on the island of Rongelap received an estimated whole-body dose of 175 r gamma radiation. Depression of peripheral blood elements occurred as follows (see Figures 7-15):

Lymphocytes fell promptly and by the third day were 55% of control values (unirradiated Marshallese) in adults, and about 25% in children. There was only slight recovery by six months. Through the two-year examinations the mean values of these cells were still below the control levels. At two years the lymphocytes were about 75 to 80% of the mean level of the comparison population.

Neutrophils fluctuated considerably during the first few weeks but fell gradually to a low of about 50% of control values by the sixth week after exposure; recovery was slow. At six months counts were still below control levels, but by one year post-exposure they had returned to the level of the comparison population.

Platelets fell to about 30% of the control values by the fourth week. By six months they had reached 70% of the controls; at one year the mean platelet count was still below that of the control population but slightly higher than at the six-month survey. At two years the platelets, though still slightly below the control level, showed some further increase over the one-year level.

The depression of blood elements in the Ailingnae group who received an estimated dose of 69 r was similar to that in the other group except that it was less marked. Even though the dose of irradiation received by the Utirik people was quite low (about 14 r), a slight depression of platelets was observed during the first month post-exposure.

Changes in the hematocrit were not remarkable in any of these groups.

Clinical observations revealed no disease processes or symptoms which could be attributed to radiation effects aside from skin lesions, loss of hair, and early symptoms. The diseases encountered were no more severe or frequent in the irradiated than in the nonirradiated population even during the period of greatest depression of the peripheral blood elements. Up until the two-year examination no deaths had occurred among the irradiated people. It was difficult to evaluate the effects on fertility; however, a number of apparently normal babies were born and further pregnancies occurred. No opacities of the lens or other eye changes were found that could be attributed to irradiation. The height and weight of the irradiated children were slightly less than those of the unirradiated children of the same age, but because of the small numbers of children involved, no definite statement could be made.

Beta Irradiation of the Skin

No accurate estimate of the radiation dose to the skin could be made. Lesions of the skin and epilation appeared about two weeks after exposure, largely on parts of the body not covered by clothing. Most of the lesions were superficial; they exhibited pigmentation and dry, scaly desquamation and were associated with little pain. Rapid healing and repigmentation followed. Some lesions were deeper, exhibited wet desquamation, and were more painful; a few became secondarily infected. Repigmentation gradually took place in most instances, and some of the healing lesions, particularly on the back of the neck, developed hyperpigmentation of a grayish, dusky color and a thickening of the skin with "orange-peel" appearance. At one year, however, this type of pigmentation was greatly reduced. Deeper lesions on the dorsum of the feet continued to show lack of repigmentation, with scarring in some cases. At two years post-exposure 15 cases continued to show residual skin effects largely in the form of pigment aberrations, and some atrophy and scarring. Histopathological studies of the skin showed changes consistent with radiation damage. A common finding in acute lesions was spotty transepidermal damage accompanied by atrophy and flattening of the rete pegs with areas of relatively normal skin between. The dermis was much less affected than the epidermis. Biopsies taken on later surveys showed considerable improvement but with some persisting changes.* In no case was there evidence of any premalignant or malignant change.

Pigmentation of the semilunar area of the fingernails and toenails was observed in about 90% of the people about three weeks after exposure. By six months pigmentation had largely grown out with the nail and had disappeared in most cases.

Internal Irradiation

Radiochemical analysis of numerous urine samples of the exposed personnel showed some degree of internal absorption of radioactive materials, probably brought about through eating and drinking contaminated food and water. Calculations of the body burden of these materials, however, showed that the concentration was too low to result in any serious effect. Analysis of urine samples six months after exposure showed only barely detectable radioactivity present in some cases. At two years radiochemical examination of pooled urine samples showed $Sr^{90} = 0.6$ and Ce^{144}-$Pr^{144} = 7.0$ disintegrations per minute per 24-hr sample. (The samples were not analyzed

*In some sections acanthosis, absence of pigment in the basal layer, and atrophy and benign dyskeratosis were noted in the stratum spinosum of the epidermis. Changes noted occasionally in the dermis consisted of areas of homogenization and increased density of collagen, alteration in the distribution of mucopolysaccharide, presence of mucin in areas of degeneration, and capillary dilatation.

Figure. 1. Medical team.

for Cs^{137}.) These values are far below the accepted maximum permissible body burdens.

Present Survey

INTRODUCTORY MATERIAL

The examination of the Rongelap people was carried out at the Marshall Islands Memorial Hospital at Majuro, Marshall Islands. (The people have been quartered at Majuro Atoll since the initial examinations were completed at Kwajalein.) In addition to the irradiated group, a comparison group of unirradiated Rongelap people was also examined.

The medical team consisted of nine American physicians and scientists, one Marshallese practitioner, and six technicians (Figure 1). Continuity of these studies has been aided by the fact that several members (physicians and technicians) have been with the team since the initial studies. This is also important in regard to insuring standardization of techniques from year to year (particularly in regard to the hematological studies).

Following a three-week period of examinations at Majuro, the medical team proceeded via Navy LST to Utirik Island (some 350 miles distant)

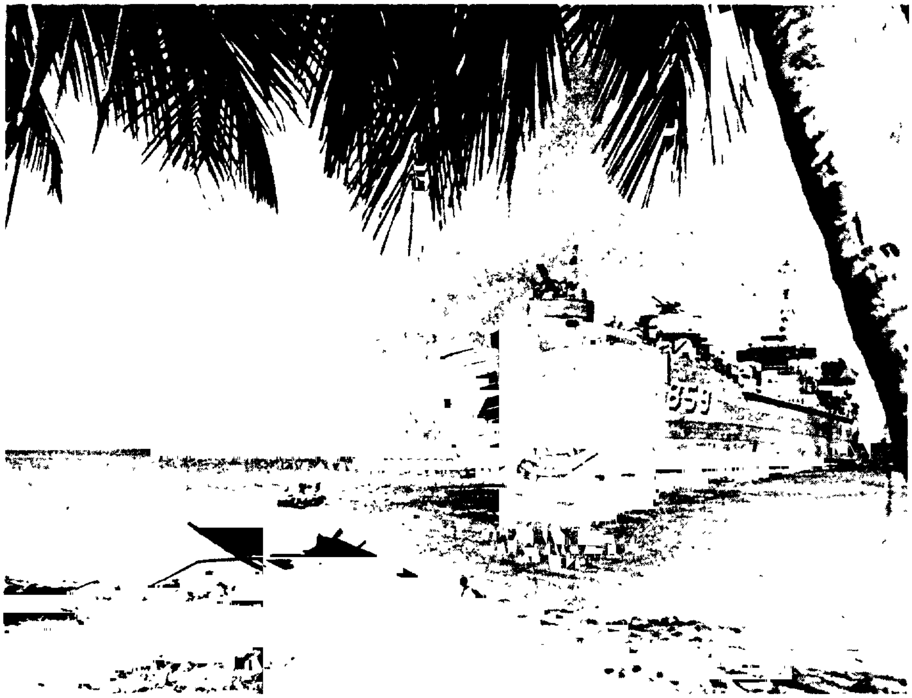

Figure 2. Ship.

Figure 3. Examination tent.

where 144 people were examined. The ship served as a base of operations and laboratory (Figure 2). The physical examinations at Utirik were carried out in tents ashore (Figure 3).

Several unfavorable factors associated with the examinations should be mentioned:

1) *The language barrier* made the examinations difficult since very little English is spoken by the Marshallese. However, sufficient interpreters have been available to assist the medical team.

2) *The lack of vital statistics* from the Marshallese imposes a serious difficulty in interpretation and evaluation of the medical data. Such statistics would be extremely helpful in evaluating the long-term effects of radiation. In recent years records of births, deaths, etc., have been kept by the health aids or magistrates and supposedly forwarded to the district administrator; however, such records have been poorly kept or lost and thus vital statistics are practically nonexistent.

3) Another factor was the *uncertainty of exact ages* of some of the Marshallese, particularly in the older groups, largely due to lack of written birth records. Except for the first, birthdays are little observed.

4) The medical status is also complicated by *unhygienic living conditions* evidenced by the presence of parasitic infestation, chronic skin diseases, and extremely poor oral hygiene. Possibly dietary deficiencies also exist (this will be further evaluated on later surveys).

5) During the course of these studies over the past three years, *difficulties have been encountered in obtaining what could be considered as entirely adequate populations to act as comparison groups* for the irradiated people. Two separate comparison groups had been used in the past, each comparable to the exposed group in size and closely matched for age and sex. These groups are represented in hematological graphs of this report as A and B (B_1 and B_2). The A population was chosen at Majuro at the time of the initial examinations, but at six months post-exposure it was found necessary to select another group, the B_1 group, since many members of the A group were missing (had migrated to other islands, etc.). At the two-year examination, the B group (B_2) was used again even though about one-third of the group was missing. The people in the A and B groups were mostly Marshallese from the eastern chain of the Marshall Islands and are considered to be anthropologically slightly different from people of the western island chain to which the Rongelapese under study belong.[8]

At the time of the present survey, it was found that during the preceding year the Rongelap population had doubled at Majuro Atoll by the influx of other Rongelap people who had been away from the island at the time of the accident but had since returned. This situation was most fortunate, since this group of people was of the same stock (blood relatives) and was living with the population under study under the same environmental conditions. These people provided a uniquely appropriate group to serve as a comparison population. Moreover, they matched reasonably well for age and sex and would be available for future examinations since they planned to return to Rongelap Island to live. This group is represented as C in the graphs. For the growth and development studies, as many of the old B-group children as could be found were examined in addition to the Rongelap children in order to expand the number for comparison and furnish further longitudinal data for yearly studies.

EXAMINATIONS

Histories were taken by a Marshallese practitioner with particular emphasis on the interval history during the past year.

Complete *physical examinations* were carried out including examination of the skin with color photography and biopsies of selected lesions; ophthalmological studies including slit-lamp observations, visual acuity, and accommodation; growth and development studies in children (less than 20 years of age) including anthropometric measurements and x-ray examinations of the left wrist and hand for bone development studies; audiometer examinations on all over 30 years of age; ECG records on all over 40 years of age; and x-ray examinations as deemed necessary.

Hematological examinations included three complete blood analyses including WBC, differential, platelet counts (phase microscopy), and hematocrit (microhematocrit method) done at about weekly intervals. (Only one complete blood study was carried out on the Utirik people except for repeat examinations on those with abnormal counts.) In addition, sickling tests (sodium bisulfide technique) were run, and smears were obtained for reticulocyte counts, alkaline phosphatase studies, and basophil counts (4000 cells). Blood was obtained for hemoglobin classification.

Sera were obtained for protein determinations by proteinometer and copper sulfate techniques; A-G ratios and electrophoretic studies in 37 people; and cholesterol and creatinine determinations.

Eight irradiated and nine unirradiated people were used in a study of immunological response to tetanus toxoid. The primary stimulus of tetanus toxoid had been given 2½ months previously. Sera were obtained just prior to the second injection of toxoid and then six days later. Subsequently, tetanus toxin-antitoxin titrations of the sera were obtained for the two groups in mice by the methods previously described.[6]

Routine urine analyses were carried out on everyone.

Radiochemical analysis. Pooled urines were obtained, plus a few sufficiently large samples from individuals, for radiochemical analyses from both exposed and unexposed groups. Analyses for Cs^{137} and Sr^{90} were carried out at the Walter Reed Army Institute of Research.

Whole-body gamma-ray spectroscopy. Four exposed Rongelap people, two Utirik people, and a comparison Marshallese male accompanied the team to the United States. Whole-body gamma spectroscopy for determining body burdens of gamma emitters was carried out on them at the human radiation detector at Argonne National Laboratory. The counts were made by placing the individuals in a room with 8-in.-thick steel walls and by the use of an 8-in. crystal and 256-channel analyzer.[7]

RESULTS*

Interval History

During the past year the general health of the people has been satisfactory according to Marshallese standards with no obvious change from last year. No contagious diseases appeared since the previous report except for a minor epidemic of upper respiratory infections and an undiagnosed epidemic of acute gastroenteritis principally affecting the children. The latter epidemic was self-limited to two to three days. There were no hospitalizations for major illnesses or injuries.

*Unless otherwise stated, the findings are those on the Rongelap people.

There had been one death among the exposed population and two infant deaths.* The death was that of a 46-year-old man who died of hypertensive heart disease. Details of this case were presented in the two-year survey report.[5] One infant death was the stillbirth of a baby of irradiated parents after a fall of the mother. The second infant death (mother only in the irradiated group) occurred after birth, apparently of a cord infection. Among the unirradiated Rongelap people there had been two miscarriages. Two women were pregnant in the irradiated group and four in the unirradiated group.

During the past year, in the exposed group several of the older people became more feeble but had no serious complaints. The village pastor was too weak to conduct services and complained of headaches, possibly associated with cataract removal the previous year. A 78-year-old man with partial hemiplegia from a former cerebral accident still needed a cane. The oldest inhabitant, a woman said to be over 100 years old, though feeble, was quite active for her age. A 12-year-old boy with rheumatic heart disease showed no further signs of decompensation but was unable to keep up with other children in their games. A 25-year-old man with leprosy showed some evidence of slight healing of the indolent ulcers present on his hands and feet. He did not appear as mentally depressed as last year, presumably because of a more tolerant attitude on the part of his fellow people. A 78-year-old man with diabetes* has his disease controlled by diet. He was most gratified that his blindness had been partially corrected by surgery and he was able to get around alone.

The people were remarkably free from psychosomatic complaints. Complaints could usually be traced to a reasonable organic cause. Many complained of abdominal pain which appeared to be secondary to attacks of acute gastroenteritis. Such attacks are not unusual, since there are no facilities for preservation of food and the climate is conducive to bacterial growth. Some of the irradiated group complained that their hair had been falling out excessively; however, this was not substantiated on physical examination and quite

*Since this survey, a death has occurred in a 78-year-old Rongelap man in the exposed group. He was a diabetic of long standing and died from what was diagnosed as coronary heart disease.

possibly was related to their previous dramatic experience with epilation.

The Marshallese appeared to have very little neurosis or psychosis. One young man in the unirradiated group had been diagnosed as having schizophrenia but only occasionally did he cause trouble.

The living conditions of the people were satisfactory. They were furnished sufficient food and their quarters were comfortable.

The second phase of the survey at Utirik Island showed that the general health of the Utirik people appeared to have been good during the previous three years. There had been five deaths in the group. The causes of the deaths could not be ascertained because of the inexperience of the health aides. As with many other reports of death in the Marshallese records, the cause "old age" was about all that could be obtained.

Physical Findings

The people both in the exposed and in the unexposed groups appeared to be generally in good physical condition and in a satisfactory state of nutrition. In Table 1 are listed the average values with standard deviations of height and weight of individuals from age 20 to 50 (including the Utirik group). A somewhat greater weight of the Utirik female is significant (Utirik versus unirradiated Rongelap, $P<0.05$). The cause for this difference is not apparent. The low standard deviation of heights for both sexes suggests considerable homogeneity in these populations. Height and weight in the children will be described below under growth and development studies.

In Table 2 are listed the major diagnoses for all these groups. In general, no diseases appear to be associated with radiation exposure in the Rongelap people. Major diseases are as prevalent in the unirradiated group as in the irradiated group. No increase in degenerative diseases and no malignancy in the irradiated Rongelap people was evident. Extensive dental caries was present in all the Marshallese, related largely to poor oral hygiene.

The incidence of congenital abnormalities (Table 2) seems unusually high. The exact nature of the abnormalities is listed in Table 3. Only in the case of congenital shortening of the fifth metacarpal was a definite familial pattern apparent. With only these four cases, however, the manner of inheritance was not clear except that it is not a simple Mendelian dominant. Of general interest was the absence of peptic ulcer. The director of the hospital at Majuro felt that peptic ulcer was almost unknown in the Marshallese. Compared to an incidence throughout life in the American populace estimated at 6%, this is an unusual finding. Perhaps the tranquil life without responsibilities and without the pressures of modern living exerts a favorable influence in this regard. Land is the only real wealth in these islands, and a complex system of matrilineal inheritance engenders feelings of security, since every Marshallese is assured rights to enough land to provide adequate food.[8] Electrocardiograms were taken on individuals for whom it appeared indicated and on all persons over the age of 40. Results showed an unsuspected stereotype among tracings other than those called abnormal – more so than one would expect to see in as random a sampling in the U.S.; and a general age appearance of the normal tracings younger than expected. From the magnitude and direction of the T vector one would expect most of these people to be 30 to 40 years of age, and none of them seemed elderly.* The young appearance of the ECG's is in contrast to the physical impression that these people age quickly.

Table 1

Mean Height and Weight in Adults (20 to 50 years old)

	Height, in.	Weight, lb
Males		
Rongelap	63.4±2.8	137±15.8
Unexposed Rongelap	64.1±1.8	140±22.9
Utirik	63.9±2.1	137±19.5
Females		
Rongelap	59.5±1.5	114±18
Unexposed Rongelap	60.0±2.2	111±24
Utirik	59.6±1.7	132±21

Growth and Development

Longitudinal studies of anthropometric data have not been completely analyzed and will not be presented at this time. Cross-sectional data for height, weight, and bone development are pre-

*Dr. Robert Grant of the National Institutes of Health generously interpreted the tracings.

Table 2

Major Diagnoses

Diagnosis	Unexposed Rongelap		Utirik		Exposed Rongelap	
	No. cases	Percent	No. cases	Percent	No. cases	Percent
Essential hypertension*	11	11	13	9	7	7
Arteriosclerotic heart disease	3	3	2	2	3	3
Cerebral arteriosclerosis	1	1	6	4	1	1
Bronchiectasis	1	1	1	1		
Emphysema			10	7	1	1
Cancer			2**	2		
Tertiary syphilis			1	1	1	1
Primary yaws			1	1		
Pulmonary tuberculosis	1	1				
G.I. parasites			1	1		
Congenital abnormalities (all types)	8	8	13	9	10	11
Asthma			4	3		
Osteoarthritis	7	7	8	5	5	5
Rheumatic heart disease					2	2
Total examined	95		144		93	

*Defined as systolic 140 mm Hg or diastolic 100 mm Hg.
**Orbital tumor, type unknown; basal cell skin carcinoma.

Table 3

Congenital Abnormalities

Diagnosis	No. in radiated group	No. in control group	No. in Utirik group
Umbilical hernia	1		6
Shortening 5th finger			1
Shortening 5th metacarpal	3	1	
Absence carpal bones			1
Polydactylism	1		
Flexion deformity finger		1	
Congenital deformity leg		1	
Anomaly feet	1		
Palatal anomaly	1		1
Tongue tied			1
Asymmetry of face	2	1	
Thyroglossal cyst		1	
Cretin (athyreatic)			1
Congenital nystagmus		1	1
Pigmentation cornea	1		
Absence testicle			1
Adrenogenital syndrome		1	
Congenital heart disease		1	

sented for the irradiated Rongelap children and the unirradiated Marshallese children. (The Utirik children are included in the unirradiated group.) Table 4 shows the mean height and weight for the exposed and unexposed children of different ages. The mean values for the weight and height, for the most part, were slightly lower in the exposed children, male and female, from about 4 through about 10 years of age. The numbers of children are too small for satisfactory statistical analysis. Recently a carefully standardized series of studies of the left wrist (which has been found to be a reliable index of skeletal age) in children of various ages has been published.[9] All x-rays of the wrists of the Marshallese children were compared to this standard,* which was obtained from studies of white American children of Northern European extraction. In Figure 4 the bone ages of the Marshallese are compared with the published standards. General retardation may be noted in skeletal maturation in the irradiated

*We are indebted to Dr. Leo Lusted of the National Institutes of Health for analyzing the x-rays for bone development.

Table 4

Weight and Height of Children (Mean Values)

	Males				Females			
	Weight		Height		Weight		Height	
Age	Exposed	Controls*	Exposed	Controls	Exposed	Controls	Exposed	Controls
4	33.7 (5)**	31.5 (6)	37.5 (5)	38.1 (6)	26 (1)	37.3 (3)	34.5 (1)	40 (3)
5		33.3 (3)		39.3 (3)	33 (2)	37 (1)	39.5 (2)	41.5 (1)
6		44.2 (6)		45.2 (6)	37.5 (2)	45.5 (6)	40.2 (2)	45.4 (6)
7	42.3 (3)	47.8 (4)	43.3 (3)	46.4 (4)	42.5 (2)	47.8 (5)	44.0 (2)	48.8 (5)
8	42.0 (1)	55.0 (2)	45.25 (1)	50.5 (2)		51.3 (7)		48.1 (7)
9		57.3 (3)	50.0 (1)	53.2 (3)	50.0 (3)	68.0 (3)	48.8 (3)	51.9 (3)
10	64.0 (1)	64.6 (5)	51.5 (1)	52.1 (5)		87.7 (3)		54.7 (3)
11	68.0 (1)	69.0 (2)	53.0 (1)	54.0 (2)	56.0 (2)	85 (1)	51.7 (2)	55.0 (1)
12	79.0 (1)	81.5 (6)	57.25 (1)	57.3 (6)	115.0 (1)	116.0 (1)	58.0 (1)	57.0 (1)
13		83.0 (1)		58.5 (1)				
14		100.0 (1)		60.5 (1)				
15	140 (1)	121 (1)	65.0 (1)	62.0 (1)	108 (1)	106 (6)	58.0 (1)	58.0 (6)
16	114 (1)	132 (1)	62.0 (1)	65.0 (1)		106 (1)		59.5 (1)
17		102 (2)		59.7 (2)	113 (2)	98 (1)	60.0 (2)	60.0 (1)
18		127 (1)		64.7 (1)	109 (1)	131 (2)	60.2 (1)	61.8 (2)
19		124 (4)		63.5 (4)	131 (2)	113 (6)	59.6 (2)	60.0 (6)

*Control children include unexposed Rongelap, Rita Village (Group *B*), and Utirik group.
**Numbers in parentheses represent numbers of children in groups.

children, particularly in the 4 to 9-year-old group. Figure 5 shows a graph of the deviation from the American standard for this age group in the irradiated and the Marshallese comparison groups of children. Statistical analysis by use of the t test shows that these are significantly different ($P<0.05$). These children were irradiated at ages 1 to 6 years, which appears to be a sensitive period for such effects. Figure 6 shows the bone age of children from the same groups but 4 years younger, and it is apparent that there is no difference between the groups. This is reasonable, since most of the children were born after the radiation exposure, and in a negative sense emphasizes the differences between exposed and unexposed children in the older age groups.

Ophthalmological Examinations

Table 5 shows a list of the more prevalent (and pertinent) disorders of the eyes found in the exposed Rongelap (including Ailingnae) and Utirik people and in the unexposed groups. Similar types of abnormalities were found in all groups. The incidence of certain abnormalities was slightly higher in the exposed Rongelap people; however, compared with last year there has been no increase. The possible significance of the increased conjunctival and corneal abnormalities will be discussed. Slit-lamp observations revealed no polychromatic plaques or lenticular opacities characteristic of radiation damage. Particular effort was made to obtain accurate accommodation and visual acuity tests, and results revealed no differences between the exposed and unexposed populations. However, because of difficulties in carrying out the tests through interpreters, the accuracy of the results in many instances is somewhat uncertain.

Examination of the Skin

Impetiginous lesions were quite prevalent among the children in both the exposed and unexposed groups, as has been observed in the past. Fungus infections of the skin were prevalent among the adults. Only one case of yaws was seen, in an Utirik child. As mentioned earlier, there was one case of leprosy in a young man which was present prior to irradiation. The indolent ulcers of his feet

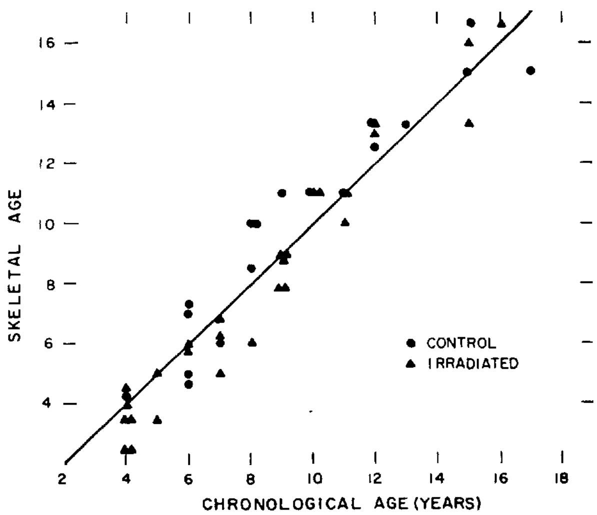

Figure 4. Skeletal maturation.

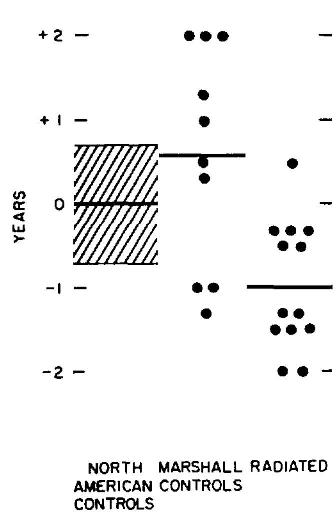

Figure 5. Deviation from normal bone age values, 4 to 9 years old.

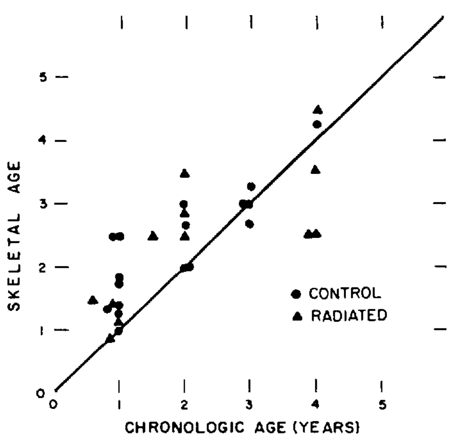

Figure 6. Skeletal maturation.

Table 5

Percent Incidence of Eye Disorders

Eye disorder	Exposed Rongelap	Utirik	Unexposed Rongelap
Pinguecula	9.4	4.5	4.8
Pterygium	20.9	9.9	7.7
Corneal pigmentation	3.1	0	0
Cataracts	15.7	11.7	5.8
Vitreous floaters	7.1	0.1	2.9
Retinopathy, arteriosclerotic	2.1	0	1.0
Arcus senilis	12.5	7.8	0

and hands showed slight improvement over last year.

Residual changes in the skin from the previous beta burns were present in 13 Rongelap people and in one Ailingnae individual, mostly on the back of the neck, the antecubital fossae, and the dorsum of the feet. These changes were not severe and consisted grossly of alterations in pigmentation in areas showing slight atrophy and scarring of the skin. In some cases pigment was increased and in others pigmentation had not completely returned. In other instances both pigmentation and lack of it were present in the same lesion, giving a blotchy and uneven color. In only a few cases (several lesions on the dorsum of the feet and one ear lesion) was there sufficient scarring to result in adhesions of the skin to subcutaneous tissues.

Biopsies were taken from four lesions and from similar areas in unirradiated individuals for comparison. Microscopically no changes were noted suggestive of neoplastic changes. Some lesions showed thickening of the corium by bands of collagen fibers, but this was no more extensive than that observed in biopsies a year ago.

Laboratory Examinations

Hematological. As in previous reports, the blood data have been classified according to age and

Table 6

Mean Blood Count by Age and Sex for the Exposed and Control Groups

	Rongelap	Ailingnae	Utirik	Unexposed Rongelap
WBC (10^3)				
3 - 5	8.6 (8)* ±1.8	12.1 (2)	10.8 (13) ±3.5	9.8 (5) ±1.6
>5	6.9 (54) ±1.7	7.0 (16) ±1.6	7.8 (108) ±3.2	6.9 (80) ±1.5
Neutro (10^3)				
3 - 5	4.1 ±1.7	5.5	5.6 ±2.7	4.0 ±1.4
>5	3.7 ±1.1	3.9 ±1.3	4.1 ±1.5	3.4 ±1.1
Lymph (10^3)				
3 - 5	3.7 ±0.6	5.6	4.4 ±1.8	4.7 ±1.5
>5	2.7 ±0.8	2.6 ±0.6	3.3 ±1.3	2.9 ±0.8
Mono (10^2)				
3 - 5	1.2 ±0.9	3.0	0.7 ±0.9	1.4 ±0.6
>5	0.7 ±0.4	0.7 ±0.5	0.8 ±0.4	0.7 ±0.6
Eosin (10^2)				
3 - 5	6.4 ±2.2	5.3	5.8 ±7.4	6.2 ±5.5
>5	4.5 ±3.0	3.7 ±2.3	2.8 ±2.7	4.0 ±2.6
Platelets (10^4)				
Males 3 - 10	32.0 (9) ±5.6	40.8 (2)	39.5 (18) ±8.8	32.6 (10) ±7.0
>10	22.1 (20) ±5.3	22.4 (5) ±3.8	28.3 (35) ±6.2	26.9 (40) ±5.5
Females > 3	28.1 (33) ±6.8	31.2 (11) ±6.9	31.2 (67) ±7.3	30.0 (34) ±7.7
Hematocrit				
Males 3 - 10	35.6 (13) ±2.4	37.5 (2)	37.0 (21) ±3.8	35.6 (17) ±2.4
>15	38.7 (16) ±3.2	40.6 (5) ±1.5	40.2 (31) ±2.4	41.0 (34) ±3.1
Females > 3	35.4 (33) ±2.6	36.5 (11) ±3.2	35.9 (68) ±2.9	35.9 (34) ±2.4

*Numbers in parentheses refer to numbers of people in age groups.

sex.* The hematological data are presented in tabular form in Table 6 and graphically in Figures 7 to 15. The mean of three separate absolute blood counts on the individuals was used in obtaining the over-all mean for comparison among various groups.

WBC. The mean total leukocyte counts were about the same in the exposed and nonexposed people (Table 6 and Figure 7). Comparison with last year's counts shows the leukocytes to have dropped slightly in contrast to the steady increase seen at six months, one year, and two years after exposure. However, the present control group also shows a correspondingly lower mean than the control groups of previous years.

The numbers of neutrophils were slightly higher than in the unexposed group in both the >5 and <5-year-old age groups (Table 6 and Figure 7). Figure 8 shows the age distribution of individual neutrophil counts compared to the mean control level. The counts are seen to be distributed about equally above and below the mean control level. Among the exposed people, 9 (14.5%) showed neutrophil counts below 2500, and 15 (17.6%) of the unexposed people showed counts at this level. Compared to last year's level, the neutrophils have

	Sex	Age, yr	Rongelap	Ailingnae	Unexposed Rongelap
*Leukocytes:	both	<5	8	2	5
	both	>5	56	16	80
Platelets.	M	<10	9	2	10
	M	>10	22	5	40
	F	all ages	33	11	34
Hematocrits:	M	<15	12	2	17
	M	>15	19	5	34
	F	all ages	33	11	34

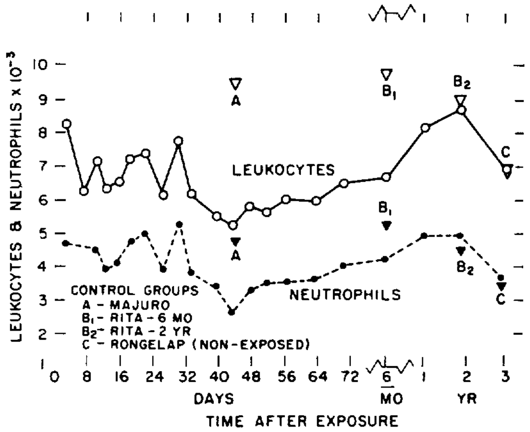

Figure 7. Leukocytes and neutrophils, Rongelap, age >5.

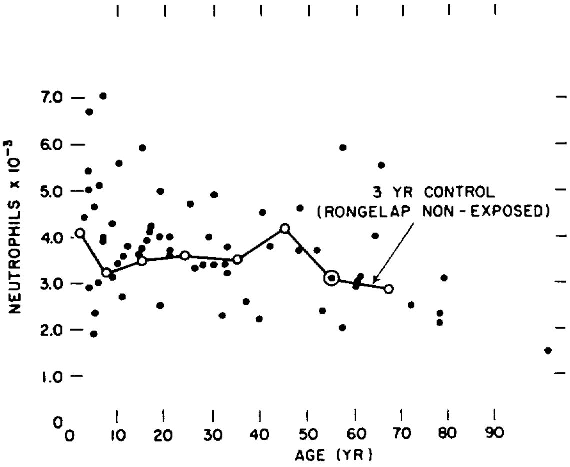

Figure 8. Neutrophils three years post-exposure, Rongelap, age >5.

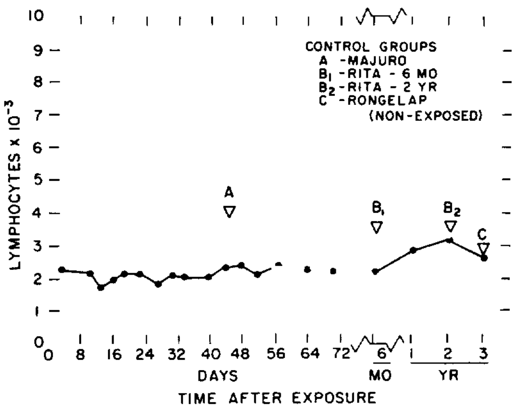

Figure 9. Lymphocytes, Rongelap, age >5.

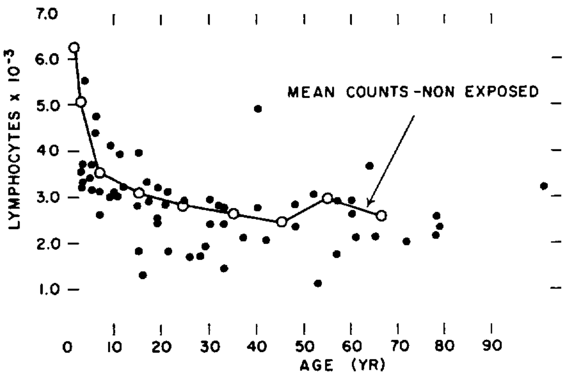

Figure 10. Lymphocytes three years post-exposure, Rongelap, age >5.

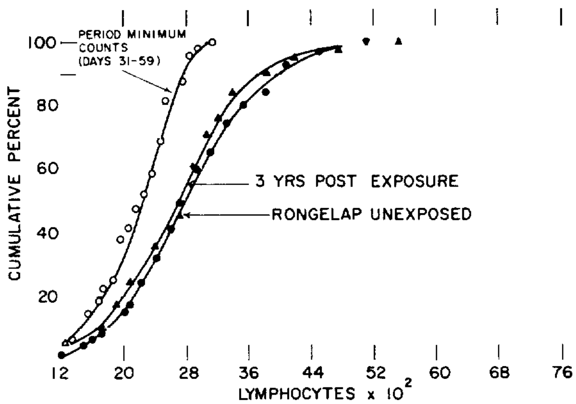

Figure 11. Lymphocytes, cumulative, Rongelap, age >5.

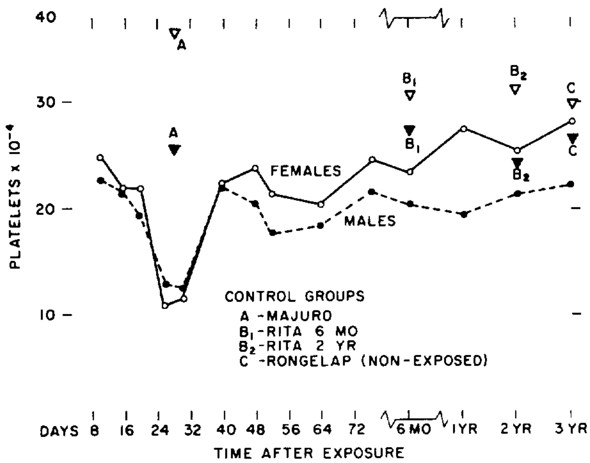

Figure 12. Platelets, Rongelap.

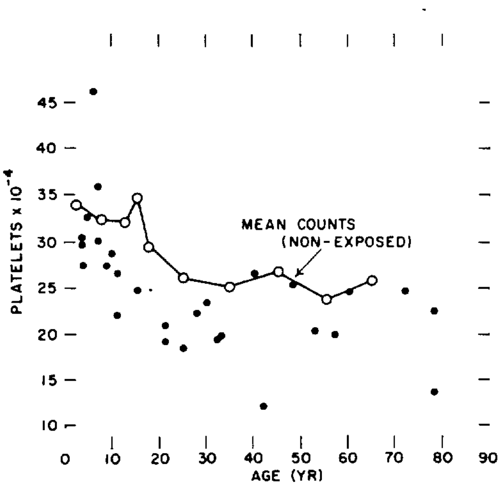

Figure 13. Platelets three years post-exposure, Rongelap males.

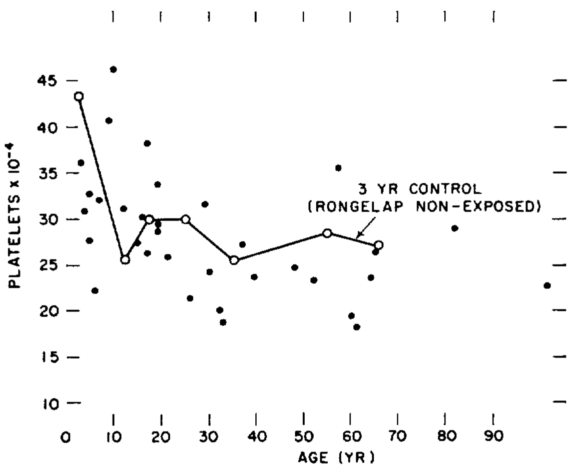

Figure 14. Platelets three years post-exposure, Rongelap females.

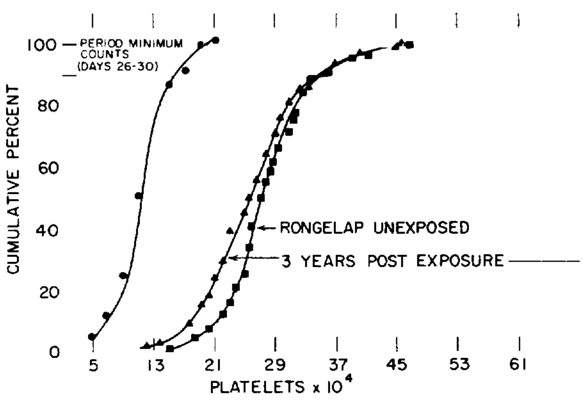

Figure 15. Platelets, cumulative, Rongelap, all ages.

dropped about 23% in the exposed population. However, the present controls had counts about equally below those of last year's control group.

The numbers of *lymphocytes* are slightly below the unexposed levels for both age groups (Table 6 and Figure 9). Figure 10 shows a greater distribution of counts below the mean control level. The cumulative distribution curve (Figure 11) shows the exposed counts to be still slightly displaced to the left of the unexposed counts. In the exposed group three people had absolute lymphocyte counts of less than 1500, compared to one in the unexposed group. There was a slight drop in the mean lymphocyte count this year compared with last year's (about 13%), but the count in this year's control population was similarly below that of last year's control population.

Eosinophils were elevated in both the exposed and the control groups. In the exposed groups 56% of the eosinophil counts were above 5%. In the unexposed group nearly as many (48%) showed counts above 5%.

Monocytes were at about the same level as in the unexposed group, but, as with the other white cells, the mean count was lower than last year's.

The mean *platelet* counts were slightly below the unexposed level (Table 6 and Figure 12). The greatest difference was seen in the males >10 years of age with mean counts about 18% below the unexposed level. These differences are apparent in Figures 13 and 14, which show the age distribution of individual counts around the unexposed mean curves. Figure 15 shows that the cumulative distribution curves in the exposed groups are still slightly displaced to the left. Two people (3.2%) in the exposed group had platelet counts below 150,000 (compared with four last year), and one (1.2%) in the unexposed group. Nine (14%) in the exposed group had counts less than 200,000, compared with five (5.9%) in the unexposed group. [There were three (2.3%) this low in the Utirik group.]

Basophils were about the same in the exposed and unexposed groups and showed little change since a year ago. Counts of basophils in 4000 white cells were carried out as a base-line study for leukemia. In studies on the Japanese exposed to the atom bombs[26] it was noted that early in the development of leukemia an increase in basophils in the peripheral blood occurred. No high counts were found in the exposed Marshallese (none over 1%).

The *hematocrit* values showed a tendency toward *anemia* in both the exposed and unexposed groups (Table 6). The males >15 years of age showed the greatest difference with a mean hematocrit of 38.7, which was 5.6% below the unexposed mean for this age group. There were 53% of the exposed and 46% of the unexposed people who had hematocrits of less than 37. As with the leukocytes, there was a drop in the hematocrit levels (5 to 10%) compared with the two-year level.

Reticulocyte counts. In the exposed group 15.7% showed reticulocyte counts of 3% or more. In the unexposed group 24.4% had values this high. In the Utirik group 64% had values of 3% or more. In no case were reticulocytes greater than 5% observed.

Sickling tests showed no sickling tendency in any of the people.

Blood groups. Examination of 137 blood samples from the Rongelap people (exposed and unexposed) showed the following: blood group O, 59%; A, 20%; B, 16%; and AB, 5%. The distribution of these groups was about the same in the exposed and unexposed people. All blood samples examined were Rh positive. There were no "V" groups characteristic of the Negroid race.[16] The distribution of these blood groups is similar to that seen in the Asiatic races.*

Bone marrow smears on four irradiated and four unirradiated people showed no abnormalities or deficiencies of cellular elements.

Counts in the Ailingnae group. As can be seen from Table 6, the 18 Ailingnae people showed a blood picture similar to that of the other exposed Rongelap people. WBC and neutrophils were as high as in the unexposed groups with slightly lower lymphocyte levels. The platelets in the males (but not in the females) were slightly below the unexposed level. The mean hematocrit values were slightly higher than in other exposed Rongelapese and about the same as in the unexposed group. This group also showed the same depression of leukocytes compared with last year's levels.

Counts in the Utirik group. It is apparent from Table 6 that the peripheral blood elements in the Utirik people were as high as or, in most cases, higher than the unexposed Rongelap level. This group is in fact more comparable with the two-year Rita control group.

Immune response: Primary and secondary tetanus antitoxin production. The data shown in Table 7 are expressed in international units of tetanus toxin neutralized by 1 ml serum. The average titer of the irradiated group was about three times less than the average titer obtained from the unirradiated group. However, the irradiated group had 25% greater response to the second stimulus than did the unirradiated group. Statistical analysis indicated that the difference in either case was not significant.*

Blood chemistry: Proteins. Total serum proteins as measured by specific gravity and refractometer showed unexpectedly high levels in both exposed and unexposed groups. There was no difference in total protein or electrophoretic pattern of proteins between the exposed and the unexposed people. The mean total serum proteins for the pooled groups are presented below:

Group	Falling drop method (sp. gr.)	Proteinometer (gms protein)
Exposed Rongelap	1.0303	7.99
Unexposed Rongelap	1.0312	8.36
Utirik	1.0294	7.67

Blood proteins of the sera from 37 people (19 exposed and 18 unexposed) examined electrophoretically showed the following mean distribution of albumin and the various globulin groups (expressed in grams based on the total proteins):**

		Globulin			
	Albumin	Alpha 1	Alpha	Beta	(
Marshallese	3.9	0.27	0.6	1.0	
Normal (American)	4.2–4.6	0.18–0.27	0.4–0.6	0.7–0.9	(

It can be seen that the increase in proteins is largely due to the gamma globulin fraction. Figure 16 is a representative pattern of one of the Marshallese with a normal American pattern superimposed.

*We are most grateful to Dr. Amos Cohan, Director, Knickerbocker Foundation, Inc., New York City, for carrying out the blood group studies.

*We are grateful to Dr. R.D. Stoner of Brookhaven National Laboratory for carrying out the serum titer determinations.

**We are indebted to Lt. D.R. Davis (MSC) USN of the Naval Medical School for the electrophoretic analyses.

Table 7

Tetanus Antitoxin Production

Primary antitoxin response			Secondary antitoxin response		
Individ. No.	International units tetanus antitoxin per ml serum	No. of MLD tetanus toxin neutralized by 1 ml serum	Individ. No.	International units tetanus antitoxin per ml serum	No. of MLD tetanus toxin neutralized by 1 ml serum
		Exposed Group			
4	0.00094	37	4	0.093	3750
10	0.0175	700	10	0.125	5000
27	0.0340	1400	27	0.219	8750
37	0.00047	18	37	0.063	2500
49	0.00031	12	49	0.047	1875
64	0.0	0	64	0.063	2500
74	0.0013	50	74	0.063	2500
80	0.00015	6	80	0.125	5000
Average	0.00695	278	Average	0.099	3984
		Range (0-1400)			Range (1875-8750)
		Unexposed Group			
828	0.015	600	828	0.093	3750
831	0.0	0	831	0.047	1875
833	0.030	1200	833	0.063	2500
834	0.00015	6	834	0.02	800
836	0.093	3750	836	0.203	8125
839	0.00008	3	839	0.047	1875
841	0.00011	4	841	0.040	1600
843	0.047	1875	843	0.093	3750
849	0.00015	6	849	0.063	2500
Average	0.0207	827	Average	0.074	2975
		Range (0-3750)			Range (800-8125)

Table 8

Isotope Body Burden – Marshallese

	Urine Cs^{137}, dpm/ml	Whole-body gamma spectroscopy	
		$\mu\mu C$ Cs^{137}/g K	mμC Zn^{65}
Exposed Rongelap (pooled)	0.054*		
Unexposed Rongelap "	0.012*		
Exposed Utirik "	2.396*		
Exposed Rongelap #9	0.090	69.0	73.0
" " #26	0.263	73.2	29.5
" " #40	0.207	95.5	62.1
" " #79	0.161	79.0	29.5
Utirik #2123	827.00	2720.0	229.0
" #2125	2.651	1610.0	482.0
Majuro control #10		65.0	29.5
U.S. (Chicago) mean		35.0	

*Mean value for samples.

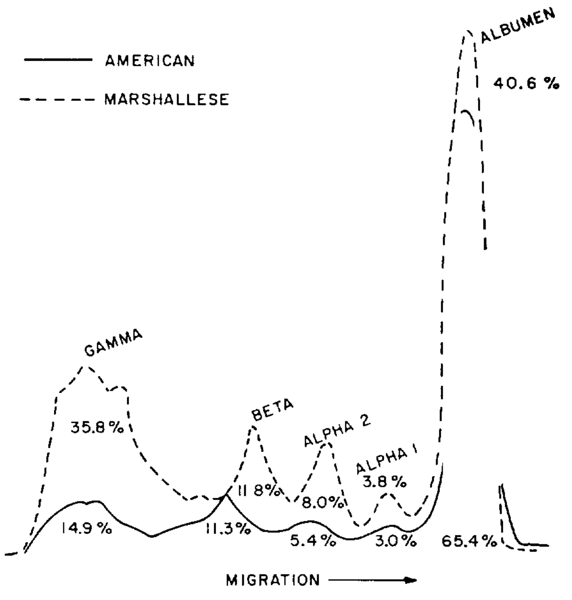

Figure 16. Blood proteins.

*Serum cholesterol examinations** on exposed populations showed a mean value of 169.5±8 mg percent, and a mean value of 196.6±7 mg percent in the unexposed population. There were no abnormally high readings in either group. Some of the values were slightly low.

*Serum creatinines** averaged 0.99±0.05 mg percent in the exposed and 1.03±0.03 mg percent in the unexposed group. There were no abnormal readings.

Body burden of radioactive isotopes: Radiochemical analysis of urine. The results available at present for regular chemical analyses of urine** and whole-body gamma-ray spectroscopy† are presented in Table 8. Figure 17 shows the gamma spectroscopy tracings.†† It was difficult to ascertain the 24-hr output in individual or pooled urine samples, since the samples were collected over a period of days; therefore, the data for the radiochemical analyses are presented in disintegrations per minute per milliliter (dpm/ml). Approximate calculations may be made based on an estimated daily urinary output of about 600 ml. Urine samples from exposed and unexposed Rongelap people collected over a 2-week period showed the former to have a mean activity of 0.054 dpm/ml, or roughly 7 dpm/24 hr in cesium-137 activity in the latter. In contrast the Utirik samples showed a mean value of 2.39 dpm/ml (roughly 1434 dpm/24 hr). Samples from several exposed Rongelap individuals who showed higher activity shortly after exposure also had high values (see Marshallese No. 26, 40, 9, and 79). Individual Utirik samples were considerably higher in cesium activity. Note that No. 2123 had 827 dpm/ml, which, though markedly higher than any other samples tested, is still calculated to be well below the tolerance level.

Radiochemical analysis for Sr^{90} showed only barely detectable levels, far below the tolerance level.

Whole-body gamma spectroscopy. The results of the whole-body gamma spectroscopy are shown in Table 8 and Figure 17.[10] It can be seen that the exposed Rongelap people have higher cesium levels than Americans, and the Utirik people have levels still higher. However, the estimated body burden of the Utirik people was 0.22 and 0.41 μC, values well below the accepted tolerance level (90 μC). Well-defined peaks for Zn^{65} were found on spectrographic analysis in all the Marshallese. Note (Table 8 and Figure 17) that these levels are much higher in the Utirik people.

Discussion

Three years have elapsed since the accidental exposure of the Marshallese people to radioactive fallout; therefore, the possible late effects of irradiation are receiving more consideration. However, persisting evidence of acute or subacute effects merits careful consideration. Earlier findings will be briefly reviewed in chronological sequence in order to give a clearer picture of the present status of the people. In this discussion the effects of radiation with respect to whole-body penetrating effects, superficial irradiation of the skin, and internal radiation from body burden of radioisotopes will be divided somewhat arbitrarily into

*We are grateful to Dr. Donald D. Van Slyke and Dr. L. Hankes of Brookhaven National Laboratory and Comdr. Demette (MC) USN of the Naval Medical School for their assistance in carrying out the cholesterol and creatinine determinations.

**We are grateful to Col. James Hartgering (MC) USA, Maj. Kent Woodward (MC) USA, and Lt. Ariel Schrodt of the Walter Reed Army Medical Research Institute for their assistance in carrying out the radiochemical analyses of the urine.

†We are indebted to M. J. Rose and Dr. C E. Miller of Argonne National Laboratory for doing the spectrographic analyses.

††This figure is taken from *Argonne National Laboratory Semiannual Report*, ANL 5755, January through June 1957.

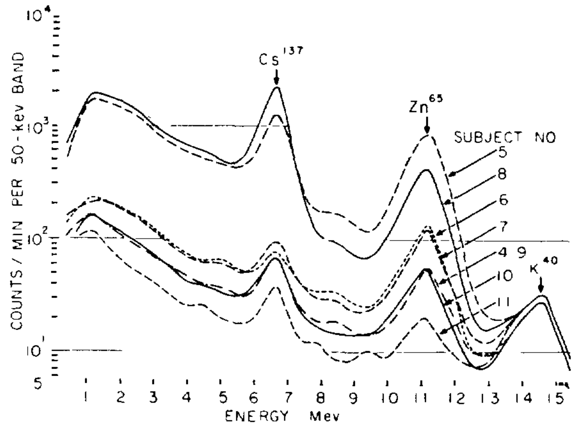

Figure 17. Net *in vivo* gamma-ray spectra of Marshallese.

acute or subacute effects and late or long-term effects. The discussion will concern largely the 64 Rongelap people who received the highest dose (175 r) of whole-body radiation.

ACUTE AND SUBACUTE EFFECTS

Penetrating Radiation

Symptoms. The only symptomatological evidence of acute effect from the penetrating radiation was the occurrence of anorexia and nausea, and in a few individuals vomiting and diarrhea, during the first two days after exposure. That these symptoms were unequivocally related to radiation is validated by the fact that they did not occur in the groups receiving lower exposure. Other than these early ones, however, during the three years of examinations there have been no symptoms that appeared to be related to radiation effects, except those associated with superficial irradiation to the skin.

Hematological effects. The early significant reduction of lymphocytes followed by depression of other leukocytes and platelets indicated that serious radiation exposure had occurred. Only a slight effect on erythropoiesis was observed in the form of a slight drop in the hematocrit levels during the first 6 to 8 weeks. The degree of the hematopoietic depression was consistent with the calculated dose of 175 r whole-body penetrating radiation.

Determination of degree of hematopoietic recovery during the past two years has been increasingly difficult because of problems in selection of unexposed "control" populations as outlined earlier; apparent changes in blood levels from year to year in different control groups; and closer proximity of the blood levels in the exposed groups to those in the unexposed population. The general lowering of leukocytes in the exposed group this year would be disturbing except that the unexposed group also showed similar lower counts when compared with the control population used last year. One must consider the possibility that a downward trend in the white blood cell level of the whole population may be occurring such as has been reported in the Japanese people over the past 10 years.[11] If this is true in the case of the Marshallese, it would not seem that such a trend had affected the more isolated Utirik people, whose blood levels were more comparable with those of last year's controls (Rita or B_2). Determination of white blood cell levels of these groups at the next annual medical survey at four years post-exposure will no doubt help clarify this issue.

It seems likely that a slight lag in recovery of lymphocytes and platelets does persist three years post-exposure when values for these elements are compared with the unexposed group levels. In contrast to the leukocytes, the platelets showed a slight increase over last year's values. Negative results in bone marrow examinations (carried out at 6 months and during this survey) do not negate the possibility of a slight degree of impairment of hematopoiesis, since a slight depression of elements noted would not be likely to be detectable in the bone marrow examinations.

The lower levels of hematocrits appear to parallel the reduction of leukocytes, and an explanation based on decreased erythrocyte production as a radiation effect does not seem likely, since erythropoietic depression was not a prominent feature of the radiation effects and hematocrits are also low in the unirradiated population. The slight anemic tendency may possibly be related to blood loss associated with chronic parasitic infestation and other forms of chronic infection. Nutritional deficiency such as iron deficiency, low dietary protein, or interference with absorption of vitamin B_{12} are possibilities, but there is no good evidence that these factors are involved. They will, however, be given careful consideration in the next survey.

Response to infection. The Marshallese experience has made it clear that nature has endowed human beings with a remarkable reserve margin of safety in protecting against infection. Even at the lowest ebb of hematopoietic depression, when the leukocytes and platelets in the Marshallese were about half their normal values, there was no detectable evidence of increased susceptibility to infection or increased tendency to bleeding. Indeed, at no time during the past three years has there been any increased incidence of diseases, infectious or noninfectious, in the exposed population compared with the unexposed groups. These people have sustained epidemics of measles, chicken pox, upper respiratory infections, and gastroenteritis, apparently without any greater incidence or severity of these diseases compared with unexposed groups. A limited study of immune responses at three years post-exposure showed that the antibody response to tetanus toxoid antigenic stimulus was not significantly different in the exposed and unexposed people. However, had this type of study been carried out soon after irradiation, it is possible that some degree of impairment of antibody production might have been demonstrated.

Metabolic effects: Weight changes. A possible effect of penetrating radiation noted during the first few months after exposure was a fairly constant weight loss of several pounds in many of the people, both adults and children. This occurred despite the fact that their appetites were good and their food consumption was greater than had been their custom. It is not known whether this weight loss represented an effect of radiation on metabolism or whether it was related to the change in environment.

Growth and development. It is difficult to evaluate the effects of the radiation exposure on growth and development because of the small numbers of children involved. The lag in growth and development as evidenced by differences in weight and height of the 4 to 10-year age group of exposed children was slight, and definite statements cannot be made at this time about the significance of these differences. However, the bone development studies seem to indicate a slight degree of retardation in the exposed group. Lag in growth and development was observed in the Japanese children exposed to the atomic bombs at Hiroshima and Nagasaki.[12] It was uncertain whether psychic and physical trauma or economic conditions might be responsible in the Japanese children. The slight effect on growth and development in the Marshallese was most probably due to the penetrating dose of gamma irradiation. Certainly external beta radiation would not contribute to the dose to the bones, and the internal adsorption of bone-seeking isotopes is not believed to have been large enough to have contributed significantly. The Marshallese children probably received a slightly higher dose than did the adults because of their shorter stature and thinner bodies in a field of radiation produced by the fallout. Even so, the dose of penetrating radiation received was probably too small to have produced a direct effect on the epiphyses. It would seem more likely that arrest of bone maturation might be from some nonspecific or indirect metabolic effect or possibly hormonal effect resulting from the radiation. Irradiation of the thyroid gland may have depressed thyroid hormone secretion and thus delayed bone growth. Further studies of thyroid activity are planned.

In utero effects and effects on pregnancy. Four women were pregnant at the time of exposure, two in the first, one in the second, and one in the third trimester. These pregnancies progressed uneventfully to normal-term deliveries. The babies all appeared normal in every way, and no microencephaly was present as has been reported in some babies irradiated *in utero* in Japan.[13,14] Since the event, nine other normal births have taken place. One miscarriage and two infant deaths have occurred, but this incidence does not seem greater than that in unexposed Marshallese people based on limited numbers of observations.

Fertility. It is entirely possible that a temporary loss of fertility may have occurred shortly after exposure in some of the people. However, careful investigation of the possible effects of the radiation exposure on fertility has not been possible. Comparison of the frequency of pregnancies in the exposed and unexposed groups does not indicate any detectable effect of radiation exposure on fertility. As pointed out, however, satisfactory vital statistics are lacking, and the numbers of individuals are too small to reach any definite conclusions. In a limited medical survey of the Central Pacific Islands carried out by the U.S. Navy in 1949 and 1950,[15] limited statistics on pregnancies in the Marshallese were reported. Pregnancies among the exposed Rongelap women during the past three years are within the range 18 to 32 per 1000 population reported in the above survey.

Psychic effects. The Japanese people exposed to the atomic bombings suffered acute psychic trauma from the horrifying experience they underwent and multiple injuries, burns, loss of homes, lack of food, disease, etc. In contrast, the Rongelap people were hardly aware of anything of great significance happening at the time of exposure, and it was with relative calm and rapid adjustment that they went to their new homes to living conditions generally superior to those they were accustomed to. It is true that they have suffered some nostalgia for their home island but always with the knowledge that they would return. (At the time of this writing they have returned to their home island and are living in completely rebuilt homes.) If there had been no hope of returning to their home island, the psychic effects might have been serious. There was little real concern expressed about their radiation exposure. It would seem, therefore, in the case of the exposed Marshallese that there has been little or no apparent psychic effect of this momentous event.

Superficial Beta Radiation Exposure

The acute phase of the beta burns of the skin was over by several months after exposure with satisfactory healing taking place. No further breakdown or development of chronic radiation dermatitis has been noted in any of these lesions.

It is of interest that about twice the incidence of pingueculae and pterygia had been noted in the exposed Rongelap people as in the unexposed groups during the past two years. Since many of the people received a certain degree of beta radiation to the mucous membranes of the eyes (as evidenced by lachrymation and burning during the first day or two), it is possible that this may have influenced the increased incidence of these abnormalities.

Internal Radiation Exposure

In an acute fallout situation, iodine-131 is probably the most important absorbed isotope to be considered during the early period. In the Marshallese, the 300 rep estimated to have been delivered to the thyroid glands (100 to 150 from I^{131} and 175 r from the gamma dose) was far too low to produce any acute effect. (Possible long-term effects of this dose will be discussed below.) The conglomerate of ingested isotopes delivered about 3 mC of radiation to the gastro-intestinal tract during the first day after radiation, but again this dose was too low for any acute effect. Internal concentration of other isotopes was far below any levels necessary to produce acute or subacute effects.

LATE EFFECTS

Investigations in animals and to a lesser extent in man have revealed certain late or long-term radiation effects. Some of the more fundamental of these are discussed below in relation to the Marshallese experience.

Penetrating Radiation

Premature aging and shortening of life span have been shown conclusively to occur in animals following irradiation.[16,17,19] Establishment of criteria for quantification of aging is notoriously difficult. Therefore, little or no data suitable for precise measurement of aging effects have been collected in the Marshallese. Accommodation tests of the eyes and audiometric analyses were carried out, but no detectable differences in these parameters were found in regard to age between the irradiated and unirradiated groups. As to premature aging, the senior author has observed these people at repeated intervals since their radiation exposure, and they do not appear to have aged faster or look older than similarly aged unexposed Marshallese persons. No doubt the subtle changes which occur with aging would be difficult to detect over this period of time.

Estimates of the shortening of life span in the human being have varied considerably in different reports.[20-23] In the Marshallese at three years post-exposure, only one of the 64 heavily exposed group had died. This compares favorably with five deaths among the 157 Utirik people who received the smaller exposure. Even though there are quite a few old people in the irradiated group, it is probably too soon to expect meaningful longevity data. However, it would appear that some of the upper estimates of life span shortening in human beings are too high (some investigators estimate 30 or more days per r), since it would seem that even in this small population more evidence of aging or life span shortening of this magnitude would have been noted. Data on longevity in the exposed Japanese people are not yet available.

Degenerative diseases. An increase in degenerative diseases has been reported to occur in irradiated animals as evidence of premature aging.[17,18] No such increase in degenerative diseases has been noted in exposed Marshallese compared with unexposed populations. Again, lack of vital statistics hampers evaluation.

Carcinogenesis and leukemia. Increased incidence of cancer in animals has been noted even with low doses of radiation.[18,24] Increased incidence of leukemia has been reported in the exposed Japanese populations.[25,26] In the exposed Marshallese no cancer (or leukemia) has been seen. Base-line studies have been carried out during the past two years for alkaline phosphatase levels of the neutrophils, and no consistent decrease of this enzyme indicative of early leukemia has been seen in any individuals. In addition, no increase in basophils in the peripheral blood (based on counts of 4000 white cells) has been noted. Decrease in alkaline phosphatase activity of neutrophils and increase in basophils were noted in Japanese cases that later developed full-blown leukemia.[25,26]

In view of reports of thyroid malignancy and leukemia in individuals who as young children had received moderate doses of irradiation over the thymic region,[27] the thyroid and its function are being studied in the Marshallese. The estimated dose of 300 rep to the thyroid from iodine-131 and gamma radiation is in the lower ranges reported to have resulted in malignancy. During the present survey, the exposed and unexposed people were screened for cholesterol levels of the sera. No abnormally high levels indicative of thyroid hypofunction were noted. (During the next survey it is planned to determine protein-bound iodine levels in all children.)

The incidence of leukemia and malignancy would be expected to be relatively low with the dose of radiation received by these people, and a significant number of cases would be seen only in a large population; therefore, the probabilities are good that such effects will not be observed in the Marshallese.

Ophthalmological effects: Visual acuity. In exposed teen-aged Japanese children, slight loss of visual acuity has been noted nine years after exposure.[14] No differences were found in visual acuity in the exposed and the unexposed Marshallese children.

Opacities of the lens. Radiation induced cataracts and polychromatic plaques of the lens have been observed in exposed human beings.[28,29] Careful slit-lamp observations revealed no such changes in the Marshallese. Even if such changes do develop, it is probably too early to expect them yet.

Genetic effects. Radiation induced mutations of the germ plasm in animals produce abnormalities in the offspring.[30,31] However, extensive studies by Neel et al.[32] in the first generation children of exposed Japanese people have failed to show any significant abnormalities. In the case of the Marshallese, no anomalies have been observed in the 13 babies born since the event. Unfortunately the product of the miscarriage and the two dead infants were not examined.

There are several factors which, offhand, would seem to make genetic studies in the Marshallese likely to be fruitful: 1) The people live together as a unit and thus are easily available from year to year for study. 2) They appear to be a rather homogenous race anthropologically, having lived in the Marshall Islands for about 2000 years with little outside intercourse. Intermarriage for such a period of time tends to produce genetic homogeneity. Height, skin color, and features are fairly uniform. 3) Consanguinous marriages are prevalent (first-cousin marriages on the maternal side only are indeed in good taste) and have produced a backlog of "bad" genes as evidenced by the high incidence of congenital anomalies. Radiation induced mutations would be likely to be reinforced by such marriages.

In spite of these factors, the small numbers of people involved in this study (compared to the large numbers in the Japanese studies) make it unlikely that these studies will be fruitful.

Superficial Irradiation of the Skin

Thus far there has been no indication of any premalignant or malignant change grossly or microscopically in any of the residual areas of scarring atrophy and pigment aberrations resulting from the beta burns. The complaint in some individuals of further epilation during the past year was not substantiated by physical examination. The residual skin lesions are being kept under close surveillance for possible malignant changes. Exposure to tropical sunlight, trauma, and high incidence of skin infections may enhance such changes.

Internal Radiation

Long-term effects of internally deposited isotopes from the fallout would result largely from the bone-seeking isotopes, of which Sr^{90} with a half-life of 28 years is by far the most important. Bone deposition does not impose a genetic hazard, since radiation is almost entirely confined to bones, with little or no gonadal irradiation. As with radium, Sr^{90} irradiation of the bone may result in osteoporosis, sarcoma, and possibly leukemia if deposited in sufficient amounts. The Sr^{90} activity of the Rongelap urine samples at two years post-exposure was calculated to be 0.6 d/m/24 hr, and of bone samples on the deceased to be 1.6 ± 0.06 d/m/g ash. Both values indicate the body burden of Sr^{90} to be well below the accepted tolerance levels and within the limits of American samples.

Cs^{137} is distributed generally in the soft tissues and so might cause some gonadal radiation and present a genetic hazard. However, the levels in the Marshallese, though several times higher than those found in Americans, are far below the tolerance level. It was estimated that the individual with the highest level of Cs^{137} probably received an additional amount of radiation equal to about one-fifth that ordinarily received as cosmic radiation.

It is quite reassuring that such low levels of body burden of radionuclides were reached so quickly, when one considers the extreme degree of contamination that these people lived with for two days with little or no effort to avoid internal deposition. The original body burdens have dwindled rapidly over the three-year period. Indeed, at this time such low levels are present that evaluation of the component due to the original fallout becomes difficult to differentiate from the added components due to subsequent world-wide fallout. The fact that the Cs^{137} level in the Marshallese man not exposed to the original fallout was nearly as high as that in the exposed Rongelap people makes it seem plausible that additional sources of fallout are now contributing more to the body burden than the original exposure. The relatively much higher levels observed in the Utirik people are due either to the fact that these people have been living continuously on their slightly contaminated island since four months after the accident, or that further fallout has occurred since the original event. Probably both factors are involved.

The presence of detectable Zn^{65} peaks on gamma spectroscopy is of interest, since this isotope is not a fission product. The isotope may have originated from metallic structures involved in the nuclear detonations. Zinc has been found to be concentrated in marine life.[33] The large consumption by these people of fish containing Zn^{65} would therefore account for the zinc peaks. Co^{60} has been found to be concentrated in clams in the Marshall Islands. Presumably since these are not eaten to any great extent, Co^{60} peaks were not detected.

REPATRIATION OF THE RONGELAP PEOPLE

The decision to move the Rongelap people back to their home island was made after careful consideration of the hazards associated with the slight residual contamination of the island to which the people would be subjected on a lifetime basis. The evaluation of the hazard resolved itself primarily into a consideration of the gamma dose and Sr^{90} levels. Extensive radiological surveys of Rongelap Atoll with radiochemical analysis of samples have been carried out by several agencies sponsored by the Atomic Energy Commission.[33,34] The results of the surveys have been summarized by Dunning.[35]

External gamma readings on the island at two years post-contamination showed levels (at 3 ft above the ground) varying from 0.2 to 0.5 mr/hr with an average of 0.4 mr/hr. However, since part of this dose was due to relatively recent fallout of slight degree (at that time), it was expected that the dose rate at the time of repatriation (July 1957) would be less than 30 mr/week, and at the end of the first year the accumulated dose would probably not exceed 0.5 rem with lower doses in succeeding years.

Radiochemical analyses of food sources of the island revealed that in spite of some degree of uncertainty, the estimated future body burdens of the Rongelap people would be less than 100 $\mu\mu$C Sr^{90} provided that land crabs (which selectively concentrate Sr^{90}) were eliminated from the diet. This is the value (100 sunshine units) that has been considered allowable by the U.S. National Academy of Sciences report. In view of the present low levels of body burden of radionuclides, and since the added radiation burden imposed by living on their home island was small, it was decided to allow the people to return.

CONCLUDING REMARKS

The increasingly widespread uses of radioactive sources in research and industry increase the possibility of exposure of people to various forms of ionizing radiation. Therefore, greater knowledge of such effects on human beings is badly needed. Considerable research is being carried out on effects of radiation on animals, but there are obvious limitations in extrapolating such data to the human species. Human experimentation, particularly with regard to whole-body radiation effects, is limited to therapeutic use of radiation in diseased people. Though such data are useful, they must be evaluated with caution. The most valuable information about human radiation effects, therefore, has come from people irradiated from atomic bombs such as the Japanese people of Hiroshima and Nagasaki and the Marshallese, from a few isolated laboratory accidents, and from individuals having ingested radium. The group of irradiated Marshallese people offers a most valuable source of data on human beings who have sustained injury from all the possible modes of exposure–penetrating radiation, beta radiation of the skin, and internal absorption of radioactive materials. The acute and subacute effects of these different forms of exposure have been well documented and for the most part have subsided. Even though, as pointed out, the radioactive contamination of Rongelap Island is considered perfectly safe for human habitation, the levels of activity are higher than those found in other inhabited locations in the world. The habitation of these people on the island will afford most valuable ecological radiation data on human beings. Since only small amounts of isotopes are necessary for tracer studies, the various radioisotopes present can be traced from the soil, through the food chain, and into the human being, where the tissue and organ distribution, biological half-lives, and excretion rates can be studied. Such investigations will be done by the use of whole-body gamma spectroscopy of the people and of sample materials, and by radiochemical analyses of soil, food, and human excreta.

Several factors favorably influence these studies on the Marshallese. The exposed and unexposed Rongelap people are interrelated and represent a remarkably homogeneous population. They live under the same environmental, sociological, and economic conditions and are likely to remain together as a group indefinitely. As contrasted with the Japanese, the dose of gamma radiation received is reasonably well established. Also in contrast to the Japanese, these people have been subjected to only minimal psychic and no physical trauma.

In view of these facts, continued medical surveys of the Marshallese people are anticipated on an annual basis.

Summary

Results are reported of a medical survey on the Marshallese people exposed to radioactive fallout three years previously. Examinations were carried out at Majuro in the Marshall Islands on 82 people from Rongelap who had been exposed to the heaviest fallout and on a comparison population of unexposed Rongelap people matched for age and sex. A Navy LST was used for the second phase of the examinations to examine 144 people of Utirik Island who received the least fallout.

The survey showed that all the irradiated Marshallese people were making satisfactory recovery from their radiation exposure. The following is a summary of the findings on the Rongelap people.

ACUTE AND SUBACUTE EFFECTS

Penetrating radiation

Diseases. In general the incidence of disease, infectious and noninfectious, was about the same in the exposed as in the unexposed group. No symptoms were present that could be related to radiation effects. Several interesting findings were noted in both the irradiated and unirradiated groups: the incidence of congenital anomalies was high; peptic ulcer and psychic disturbances were rare; the incidence of dental caries was very high; and intestinal parasitism was widespread.

Nutrition. Nutrition appeared to be as good in the exposed as in the unexposed groups.

Growth and development. In the exposed children from about 4 through 9 years of age there was a slight lag in bone maturation (based on x-ray studies of the left wrist), and these children were slightly shorter and weighed slightly less than unexposed children of the same age.

In utero effects, pregnancy, and fertility. Pregnancies are believed to have been in the normal range for the Marshallese with regard to number, course, and termination. No abnormalities were observed in the babies irradiated *in utero.*

Psychic effects. Little or no effect on the psyche related to their radiation exposure or displacement has been observed in the Rongelap people.

Hematological effects. Lymphocytes and platelets (mean population counts) continue to lag in complete recovery when compared with the unexposed group. There was also a downward trend of leukocytes compared with examinations a year ago. However, the unexposed comparison population had similarly lower levels compared with previous comparison groups. Hematocrits were low by our standards in exposed as well as unexposed people. The low values are believed to be related to widespread parasitism and chronic infections (skin and caries). These diseases may also be related to the high total serum proteins (average of about 8.0 g) with high gamma globulin fraction noted in most of the Marshallese.

Beta Lesions

Fifteen residual beta lesions showed varying degrees of mild atrophy, scarring, and pigment aberration. No chronic radiation dermatitis was noted.

A twofold greater incidence of pingueculae and pterygia was noted in the exposed group. It is not known whether radiation exposure to the eyes might have enhanced the development of such abnormalities.

Internal Radiation

No acute or subacute effects have occurred from internal deposition of fallout isotopes because of the low body burdens of radionuclides absorbed.

LATE EFFECTS

Penetrating Radiation

Premature aging and shortening of life span. One death (at the time of this survey) or 1.5% incidence compares favorably with 5 deaths or 3.0% mortality in the Utirik people (who received about 14 r). In general the exposed people did not appear older or seem to have aged faster than the unexposed Marshallese. From these observations it would appear that some of the higher estimates of radiation induced aging in the human being are too high.

Degenerative diseases. No increase in degenerative diseases was noted in the irradiated people compared with the unexposed populations.

Carcinogenesis and leukemia. No cancer or leukemia was seen. Examination of blood smears failed to reveal any consistent decrease of alkaline phosphatase activity of neutrophils or increase in basophils indicative of early leukemia.

Ophthalmological effects. No loss of visual acuity or appearance of opacities of the lens that could be related to radiation effects was seen.

Genetic effects. Genetic studies have not been carried out. However, no anomalies have been noted in the 13 babies born of irradiated parents since exposure.

Beta Lesions

Gross and microscopic studies of residual skin lesions revealed no premalignant or malignant changes.

Internal Radiation

Radiochemical analyses of urine samples and whole-body gamma spectroscopy for Cs^{137} revealed levels of this isotope several times higher than found in Americans, but far below accepted tolerance levels. Because of subsequent world-wide fallout, determination of the residue of the original exposure was difficult to differentiate from later absorption. Sr^{90} levels as of a year ago were far below tolerance levels. The body burden of isotopes had dwindled rapidly over the three years since exposure and is not considered to present any long-term hazard.

The Rongelap people were moved back to their home island in June 1957. The levels of contamination on the island are reduced sufficiently to allow safe habitation.

FUTURE PLANS

Future examinations of the Marshallese people will include studies of the subsiding acute and subacute effects; long-term effects of radiation on the human being; and valuable ecological radiation studies of the people related to the soil-food-human chain of small but detectable amounts of radioisotopes still present on the island.

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MEDICAL SURVEY OF RONGELAP PEOPLE, MARCH 1958, FOUR YEARS AFTER EXPOSURE TO FALLOUT

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CONTENTS

MEDICAL SURVEY OF RONGELAP PEOPLE, MARCH 1958, FOUR YEARS AFTER EXPOSURE TO FALLOUT

Background

This report presents the results of a medical survey carried out in March 1958 on the Marshallese people of Rongelap Atoll who were accidentally exposed to radioactive fallout in March 1954. The accident occurred following the detonation of a high yield thermonuclear device during experiments at Bikini in the Pacific Proving Grounds. An unpredicted shift in winds caused a deposition of significant amounts of fallout on four inhabited Marshall Islands nearby and on 23 Japanese fishermen aboard their fishing vessel, the Lucky Dragon (see Figure 1.) Sixty-four inhabitants of the island of Rongelap, 105 nautical miles away from the detonation, received the largest fallout exposure: an estimated dose of 175 r whole-body gamma radiation, beta burns and epilation from contamination of the skin, and slight internal absorption of radioactive material. Another 18 Rongelap people away on a nearby island (Ailingnae), where less fallout occurred, received only about half this exposure. Twenty-eight American servicemen on the island of Rongerik further away received about the same amount of radiation as did the 18 people on Ailingnae (about 70 r). Lastly, 157 Marshallese on Utirik, about 200 miles distant, received only about 14 r whole-body radiation. The fallout was not visible on this island and no skin effects were seen.

The exposed people were evacuated from these islands by plane and ship about two days after the accident and taken to Kwajalein Naval Base about 200 miles to the south, where they received extensive examinations for the following 3 months. In view of the generally negative findings on the American servicemen, they were returned to their duty stations. The Utirik people were repatriated to their home island, where the radioactivity was considered to be low enough for safe habitation. Because Rongelap Atoll was considered to be too highly contaminated, a temporary village was constructed for the Rongelap people on Majuro Atoll several hundred miles to the south, where they remained for the following 3½ years. In July 1957, after careful evaluation of remaining radiological hazards, Rongelap Island was found safe for habitation. A new village was constructed, and the Rongelap people were moved there by Navy ship. The present survey was therefore carried out at Rongelap Island.

SUMMARY OF PAST FINDINGS

Reports have been published on the findings of surveys made at the following times after exposure: initial examinations,[1] 6 months,[2] 1 year,[3] 2 years,[4] and 3 years.[5] The following is a brief summary of these findings.

During the first 24 to 48 hr after exposure, about ⅔ of the Rongelap people experienced anorexia and nausea. A few vomited and had diarrhea. Many also experienced itching and burning of the skin and a few complained of lachrymation and burning of the eyes. Following this, these people remained asymptomatic until about 2 weeks after the accident, when cutaneous lesions and loss of hair developed due largely to beta irradiation of the skin. It was apparent when the people were first examined, a few days after exposure, that the lymphocytes were considerably depressed and that significant doses of radiation had probably been received. In addition to the whole-body dose of radiation and the beta irradiation of the skin, radiochemical analyses of the urine showed that significant amounts of radioactive material had also been absorbed internally. The effects of the radiation can best be summarized under three headings according to the mode of exposure: penetrating irradiation, skin irradiation, and internal irradiation.

Penetrating Irradiation

The changes in the peripheral blood of the more heavily exposed Rongelap people who received 175 r will be reviewed below (see Figures 7, 9, 12 and Tables 3, 4, 5). The changes in the Ailingnae and Utirik groups were similar but less marked. Certain unexplained fluctuations have occured from year to year in the peripheral blood levels of the comparison populations as well as of the exposed groups. Depression of the peripheral blood elements as represented by mean population levels occurred as follows.

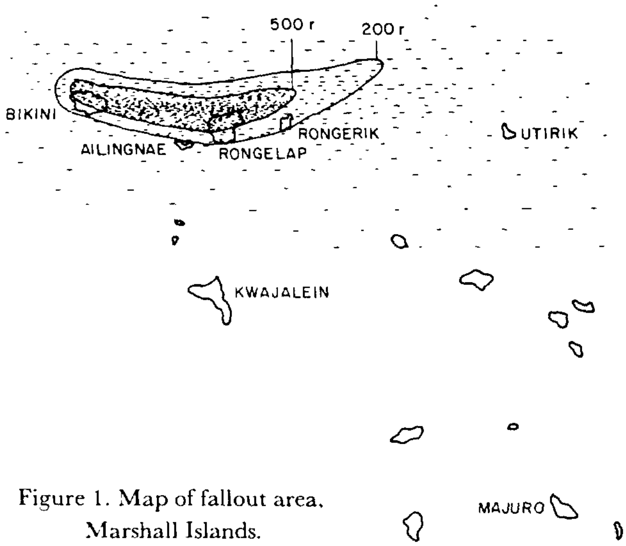

Figure 1. Map of fallout area, Marshall Islands.

Lymphocytes fell promptly and by the third day were about 55% of the control values in adults, and slightly lower in children. There was only slight recovery by six months. At 2 years, although further recovery was evident, the mean values of these cells were still found to be below the comparison population levels (75 to 80%). The 3-year examination showed that the lymphocytes were still somewhat below the level of the unexposed population.

Neutrophil levels fluctuated considerably during the first few weeks but fell gradually to a low of about 50% of control values by the 6th week after exposure. Slow recovery ensued, but at 6 months they were still slightly below the unexposed levels. However, by 1 year post-exposure they had returned to the level of the comparison population and have since remained so.

Platelets fell to about 30% of the unexposed values by the 4th week. By 6 months they had reached 70% of the controls; at 1 year the mean platelet count was still below that of the control population but higher than at the 6-month survey. Although further increases were apparent at the 2- and 3-year examinations, the levels were still below those of the comparison population.

Changes in hematocrit were not remarkable in any of the groups.

Clinical observations revealed no diseases processes or symptoms which could be attributed to radiation effects, aside from skin lesions, loss of hair, and early symptoms. The diseases encountered were no more severe or frequent in the irradiated than in the unirradiated population, even during the period of greatest depression of peripheral blood elements. Epidemics of chicken pox, measles, upper respiratory infections, and gastroenteritis have occurred, but apparently with no greater frequency or severity than in the unexposed populations. Two persons died in the exposed population. One was a 46-yr-old man with hypertensive heart disease which had been present at the time of exposure, who died two years after the accident. The second was a 78-yr-old man who died, three years after exposure, of coronary heart disease complicating diabetes. There was no apparent relationship between these deaths and radiation exposure, and mortality in the exposed group did not appear to have been greater than in the unexposed population.

It is difficult to evaluate the effects of exposure on fertility; however a number of apparently normal babies have been born, and there has been no discernible fall in the birth rate. Several miscarriages developed, but the incidence does not appear to be higher than in the unexposed populations. No opacities of the lens or other eye changes have been found that could be related to radiation. Studies on height and weight and bone age seemed to show a slight degree of retardation in growth and development in the exposed children. However, the small number of children involved, and a later finding that exact ages of some of the children were in doubt, permits no definite statements to be made.

Beta Irradiation of the Skin

No accurate estimate of the radiation dose to the skin could be made. Lesions of the skin and epilation appeared about 2 weeks after exposure, largely on parts of the body not covered by clothing. About 90% of the people had these burns and a smaller number developed spotty epilation. Most of the lesions were superficial; they exhibited pigmentation and dry, scaly desquamation and were associated with little pain. Rapid healing and repigmentation followed. Some lesions were deeper, showed wet desquamation, and were more painful; a few became secondarily infected and had to be treated with antibiotics. Repigmentation of the lesions gradually took place in most instances, and the skin appeared normal within a few weeks. However, in about 15% of the people, deeper lesions, particularly on the dorsum of the feet, continued to show lack of repigmentation with varying degrees of scarring and atrophy of the skin. At 3 years 14 cases continued to show some degree of residual skin change largely in the form of pigment aberrations with atrophy and scarring. Numerous histopathological studies have been made, and the changes found have been consistent with radiation damage. However, at no time have changes been observed either grossly or microscopically indicative of malignant or premalignant change.

The spotty epilation on the heads was short-lived, regrowth of hair occurring about 3 months after exposure and complete regrowth of normal hair by 6 months post-exposure. No further evidence of epilation has been seen.

An interesting observation was the appearance of a bluish-brown pigmentation of the semilunar areas of the fingernails and toenails in about 90% of the people beginning about 3 weeks after exposure. By 6 months, however, the pigmentation had largely grown out with the nail and had disappeared in most cases. The cause of this phenomenon has not been explained.

Internal Irradiation

Radiochemical analysis of numerous urine samples of the exposed population showed some degree of internal absorption of radioactive materials, probably brought about largely through eating and drinking contaminated food and water. Calculations of the body burdens of these materials, however, showed that the concentrations were too low to result in any serious effects, and the levels found at 2 and 3 years post-exposure were far below the accepted maximum permissible body level. The results of numerous radiochemical examinations of the urines over the past 4 years, and of gamma spectroscopy over the past 2 years, will be reviewed in greater detail below.

Present Survey

BACKGROUND MATERIAL

Organization

The medical team consisted of 8 physicians, 5 scientists, and 6 technicians from various laboratories in the United States. A Marshallese practitioner and 2 medical technicians from Majuro Atoll assisted the team, as did some of the Rongelap people (see Figure 2).

A group of six scientists from the University of Washington, headed by Dr. E.E. Held, accompanied the team to collect soil, marine, and plant

Figure 2. Medical team personnel.

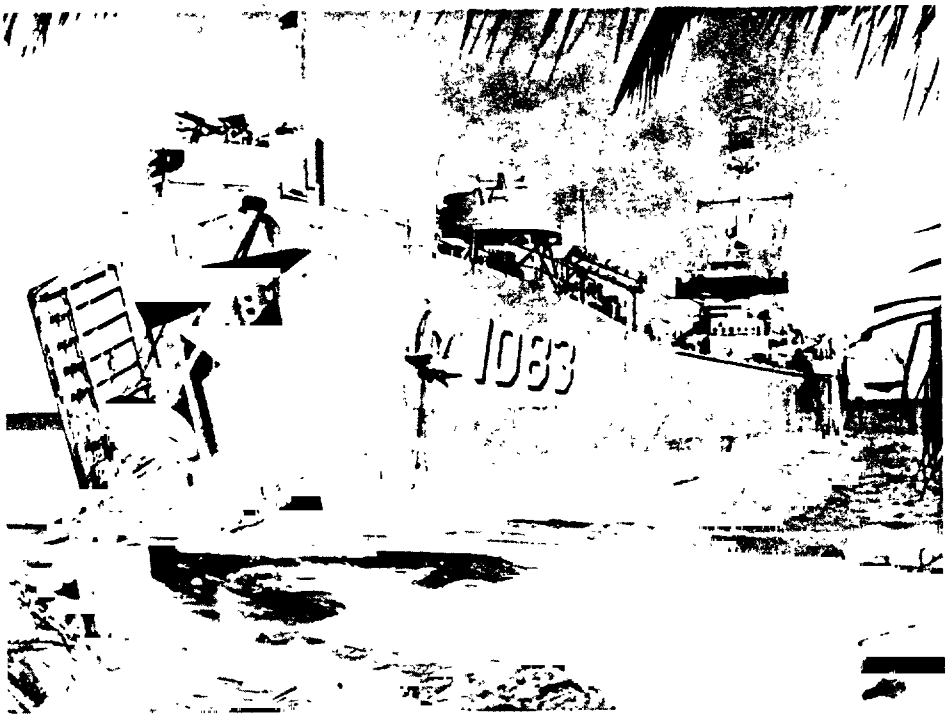

Figure 3. LST Plumas County beached on Rongelap Island.

Figure 4. Personnel decontamination station aboard LST.

Figure 5. Steel room used for whole-body gamma spectroscopy.

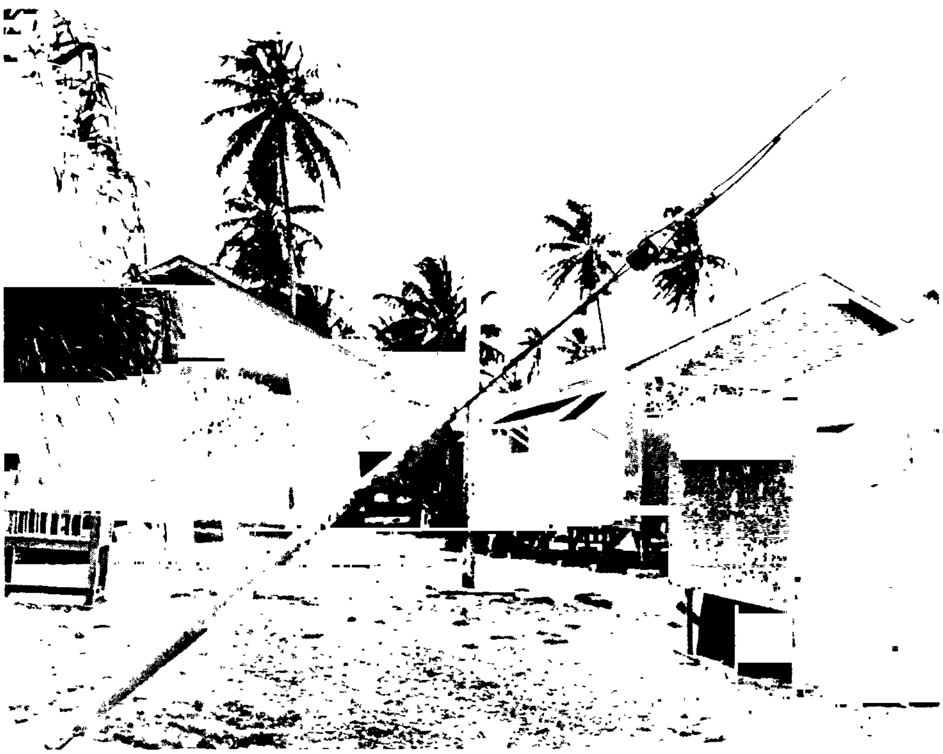

Figure 6. Dispensary and examination buildings, Rongelap Island.

samples for radiochemical analysis: These studies are not yet complete and have not been included in this report.

The Navy kindly furnished a ship for the expedition, an LST, the USS Plumas County (Figure 3). The LST picked up medical equipment for the survey, including a 21-ton steel room for carrying out whole-body counts on the Rongelap people, about the middle of February at Hawaii and proceeded to Kwajalein. The medical team staged in Hawaii and flew via military air transportation to Kwajalein, boarded the LST, and proceeded to Rongelap Atoll. At Rongelap the LST was beached for easy accessibility to Rongelap village.

The 21-ton steel room, constructed at Brookhaven National Laboratory for use in whole-body gamma spectroscopy on the Marshallese in this and future surveys, measured 5 ft 8 in. by 5 ft 8 in. by 6 ft 6¼ in., with 4-in.-thick walls and ceiling and a 2-in.-thick floor. The room had been set up in the tank deck of the LST along with two 100-channel analyzers, a 5-in. crystal, and other accessory electronics equipment. A dressing room and shower facility had also been constructed on the tank deck for decontamination of personnel prior to whole-body counts. (See Figures 4 and 5.)

The histories were taken, and the physical and laboratory examinations were carried out at Rongelap village in the dispensary, school building, and council house (see Figure 6). The examinations lasted 3 weeks.

Difficulties Associated with the Examinations

Several difficulties associated with carrying out the examinations as well as interpreting the findings should be pointed out.

1) The language barrier made examinations difficult since very little English is spoken by the Marshallese. However, there were sufficient English-speaking Marshallese to assist the medical team in most instances in carrying out the examinations.

2) The lack of vital statistics or demographic data on the Marshallese imposed a serious difficulty in interpretation and evaluation of the medical data. Records of births, deaths, etc., have been made by the health aides or magistrates of the villages and supposedly forwarded to the district administrator; however, such records have been poorly kept or lost in most instances and thus vital statistics are practically nonexistent. Trust Territory officials are now attempting to assemble such data.

3) It is unfortunate that many of the Marshallese, particularly in the older age group, are uncertain of their exact ages, largely because few written records of birth are maintained.

Comparison Populations

During the first 2 years, two separate groups of Marshallese people were used for comparison, each of comparable size to the exposed Rongelap group and matched in age and sex. However, this population was found to be unstable, with a large attrition rate over the 2 years, which made it unsatisfactory. At the time of the 3-year survey, it was found that during the preceding 12 months the Rongelap population at Majuro Atoll had doubled because of the influx of relatives who had come back from other islands to live with them. These people had been away from Rongelap Atoll at the time of the accidental exposure. This group matched reasonably well for age and sex and was of comparable size; moreover, since these people were of the same stock genetically, they proved to be uniquely appropriate to serve as a comparison population. This group was therefore used at the 3-year examination as a control and again during the present survey.

PROCEDURES

History and Physical Examinations

Histories were taken by a Marshallese practitioner with particular emphasis on the interval history during the past year.

Complete physical examinations were carried out including examinations of the children for growth and development, anthropometric measurements, and x-ray examinations of the left wrist and hand for bone development studies; special examinations of the skin with color photography for selected lesions; ophthalmological studies including slit-lamp observations, visual acuity, and accommodation; and EGC and x-ray examinations as deemed necessary.

Laboratory Examinations

Hematological examinations included three complete blood analyses with WBC, differential, platelet counts (phase microscopy), and hematocrit (microhematocrit method) done at about weekly intervals.

The following examinations of the blood were made to determine genetically determined traits.

These studies were of interest in evaluating the homogeneity of the Rongelap people and learning something of their anthropological background.

Blood grouping studies. Studies of the blood groupings and gene distributions in the blood of 129 Marshallese were carried out by Dr. L.N. Sussman of the Beth Israel Hospital, New York City. The following systems were studied: ABO, MN, Rh-Hr, and Duffy, Kell, and Diego factors.

Haptoglobin studies. The method of Smithies was used, in which electrophoresis is carried out with a starch gel slab as supporting medium.[6] This analysis was made on 126 Marshallese blood samples by Dr. B.S. Blumberg of the National Institutes of Health, Bethesda, Maryland.

Hemoglobin types. The determination of hemoglobin types was made on 45 Marshallese blood samples by the method of Smithies[6] (starch gel zone electrophoresis). These studies were carried out by Dr. R.L. Engle, Jr. and Dr. G. Castillo of the Cornell University Medical Center, New York, N.Y.

Plasma proteins. Plasma protein determinations were carried out on all sera by the proteinometer technique.

Thyroid metabolism. In view of the exposure of the thyroid glands to radiation from the internally absorbed radionuclides, the metabolic state of the thyroid gland was of interest. These studies were made by Dr. J.E. Rall at the National Institutes of Health, Bethesda, Maryland. Protein-bound iodine determinations were carried out on 36 people in the exposed group and 24 in the comparison population. Butanol-extractable iodine content was measured in three people in each group, and thyroxine-binding proteins were determined in 12 persons in the comparison population.[7]

Serum vitamin B_{12} concentrations. In view of the general tendency to anemia in the population, serum vitamin B_{12} contents were measured to see whether they could be related to anemia. These determinations were carried out on the sera of 44 exposed Marshallese and 58 unexposed by Dr. D.W. Watkin of the National Cancer Institute, National Institutes of Health, Bethesda, Maryland. The method used was a modification of the USP XV *Lactobacillus leichmannii* method developed specifically for vitamin B_{12} assay in serum.[8]

Intestinal parasite survey. The generally high eosinophil counts and tendency to low hematocrits noted in both the exposed and unexposed Rongelap people led to an intestinal parasite survey to see whether parasitism might be responsible for these findings. Because of the generally accepted view that blood pictures of anemia and eosinophilia are more likely to be associated with helminthic rather than with protozoan infections of the intestinal tract, the methods used were directed primarily to detecting the former. The Beaver method of egg counting[9] and formalin-ether concentration[10] was used to obtain quantitative information on helminth infections. This is a simple, direct technique which is also useful in revealing protozoan infections, particularly when trophozoites are present. In addition, all stools were concentrated by the formalin-ether method to pick up infections too light to be detected by direct examination. One stool specimen per person was examined in each of 69 exposed persons and 112 unexposed. Specimens were brought to the laboratory shortly after being passed, and were generally examined within 1 hr. The methods used probably revealed ⅓ to ½ of the protozoan infections and perhaps 80% of the helminth infections likely to be found in these individuals had they been subjected to repeated examinations.

Serum and food sodium and potassium determinations. Because the Marshallese seem to have generally lower blood pressures and in view of the possibility that salt intake bears a causal relationship to essential hypertension in humans,[11,12] correlations between salt intake and incidence of hypertension were investigated by Dr. L.K. Dahl of Brookhaven National Laboratory. A morning sample (before breakfast) of urine was obtained on 13 exposed and 14 unexposed persons and analyzed for sodium and potassium level by flame spectrophotometry. A sample prepared meal was also obtained for similar analysis of the several items.

Determination of Body Burdens of Radionuclides

Radiochemical urine analyses. Urine samples, 24-hr as well as cumulative, were collected from 15 Rongelap people for radiochemical analyses carried out under the direction of Maj. K. Woodward and Col. J. Hartgering at the Walter Reed Army Institute of Research, Washington, D.C.

Whole-body gamma-ray spectroscopy. During this survey about 200 people were examined in the whole-body counter (21-ton steel room constructed at Brookhaven National Laboratory and carried out to the Islands) for body levels of gamma emitting nuclides. Unfortunately, the data on these counts as well as considerable medical equipment were lost in the Pacific Ocean when the cargo had to be jettisoned from a plane which developed engine trouble. A return trip to Rongelap Island was made two months later (May 1958), and about 100 Rongelap people were again counted in the steel room. Details of the procedures used and the results will be described below.

FINDINGS

Living Conditions

During the past year the Rongelap inhabitants have become well adjusted to life in their new village, which was completely rebuilt, with well constructed houses far superior to the old ones. An interesting sidelight is that some of the people, particularly the older ones, prefer to live beneath their houses, probably because it is cooler and they prefer not to climb the steps.

During the 8 months since the people returned, copra production was being satisfactorily re-established, but it had not reached full capacity. The establishment of an agricultural program was proceeding disappointingly slowly. At this writing it is understood that the Trust Territory is sending a full-time agriculturist to implement this program.

Adequate water is available on Rongelap from the concrete water catchment cisterns from the roofs of nearly all the houses. Flies are quite prevalent. Most of the people still cook outdoors rather than in the screened cook-houses built for them. Scraps of food around the cooking area probably predispose toward flies. The screened-in latrines are a big improvement, and it is hoped that the children will make greater use of them. This point has been emphasized to the people in order that intestinal parasites may be better controlled. The island is heavily infested with rats and some sort of extermination program is indicated.

The diet is extremely limited in variety, although caloric intake appears to be adequate. The chief source of carbohydrate is rice and a small amount of flour. Protein is derived largely from fish with an occasional supplement of canned meat. The fat intake is mostly from coconut meat. Vitamins are obtained mainly from coconuts, pandanus (when available), and fish. In view of the importance of diet in relation to certain puzzling clinical laboratory findings, the following more detailed information is presented.

Fish is the main source of protein. It is eaten fresh, dried, or salted, several times weekly and frequently daily. A great deal more is eaten fresh than otherwise. The liver is included. Among ***canned meats***, corned beef is well liked as well as salmon and sardines. About one can (perhaps two) is eaten weekly per person. ***Other meats*** include pigs and chickens which run loose on the island and are eaten on rare occasions. Clams (particularly the giant clams) are eaten when they can be found; however, they are not plentiful now. Land crabs are considered a delicacy, but eating them is forbidden at this time because of their high Sr^{90} level. (This is the only forbidden dietary item.)

Local plant products. Coconuts are an important item of the diet, eaten green or ripe. About three green coconuts per day are consumed per person, both milk and meat. Ripe coconut is eaten with meals either as such or grated onto rice and fish. ***Pandanus*** is available during the summer and fall. The fruit is eaten raw by sucking the sweet juice from the fibrous segments. The juice is also squeezed out and used to flavor arrow root flour and to make a candy known as "jenkum." This fruit is probably a major source of vitamin A and possibly C. ***Arrowroot*** is grated to form a starchy flour, which is cooked into a mushy, tapioca-like material. It is available principally in the winter months. ***Breadfruit***, a starchy fruit, is not abundant on Rongelap but is eaten when available. ***Rice, salt, sugar, flour, tea,*** and ***canned meats*** are imported. Rice is a mainstay eaten three times a day. Sugar is used to sweeten tea. A little salt is used in cooking rice and bread, but is usually in short supply and is rarely used on prepared food. Bread and pancakes are frequently eaten.

Interval Medical History

The general health of the Rongelapese has been good during this past year. Six children (4 exposed and 2 unexposed) presumably had infectious hepatitis during November and December 1957. No other major epidemics or diseases were reported. Abdominal pain and diarrhea were among the commonest complaints, and were probably associated with the eating of food kept several days without refrigeration. The large number of flies may also play a part in the prevalence of this condition. A complaint of night blindness of several months duration among 10 children and 1 adult was investigated and is reported below. Common colds, fungus infections of the skin, and impetigo were also common complaints for which the health aide was consulted.

During the past year healthy babies were born to 4 irradiated women and 6 unexposed women. The exposed and unexposed groups each contain 19 women of child-bearing age (15 to 44 years). Three miscarriages occurred in the exposed women, two at 3 months and one at about 6 months. In all three cases this was the second miscarriage since exposure. However, two of the women have had one normal pregnancy since the accident. One of the unexposed women had a miscarriage, and another had a full-term baby that died within a month, apparently of diarrhea of infancy. (Between the March survey and the return survey in May 1958, one exposed woman had a full-term baby that died shortly after birth of unknown cause.)

One death, presumably due to coronary thrombosis, occurred in July 1957, that of a 78-yr-old diabetic male. No autopsy was obtained. One unexposed 65-yr-old male died in January 1958, presumably of arteriosclerosis and senility. No autopsy was obtained.

Physical Examinations

Examinations showed the general physical condition of the people to be satisfactory. Grossly, nutritional status was also satisfactory, in spite of the dietary restrictions referred to above. However, 6 children (all in the unexposed group) showed mild to moderate degrees of hemeralopia when put through an obstacle course test at night. All were treated with vitamin A and recovered rapidly. This evidence of mild vitamin A deficiency is understandable after study of their diet. At that time of the year pandanus was not ripe and other sources of vitamin A were scarce.

Table 1 lists the major diseases noted in the exposed and unexposed people. The diseases found were present with about the same frequency in the unexposed and exposed groups. No malignant conditions were noted.

Physical examination of the children revealed few major medical disorders in either the exposed or unexposed groups. One exposed child had inactive rheumatic heart disease with evidence of polyvalvular involvement (reported previously). He showed no further evidence of decompensation such as had occurred 3 years previously and was able to keep up with other children in their play. Extensive molluscum contagiosum and superficial pustules on the legs were common. An occasional child had palpable cervical nodes, but tonsilar hypertrophy was uncommon. Xeroderma, cheilosis, and glossitis were not seen.

In the exposed adults, one case of auricular fibrillation of several years standing in a 50-yr-old male continued asymptomatic. The case of leprosy showed no progression of the lesions of the hands

Table 1

Incidence of Various Disease States Among the Marshallese (52 exposed adults and 55 unexposed adults examined)

	Exposed	Unexposed
CONGENITAL ANOMALIES		
Short 5th finger	1	2
Prominent ulnar styloid process	3	2
Congenital dislocated hip	0	1
Heberden's nodes	1	1
Adrenogenital syndrome	0	1
Pilonidal sinus	2	0
Hernia, umbilical	0	0
Congenital nystagmus	0	1
Congenital facial asymmetry	0	1
OTHER ABNORMALITIES FOUND		
Cheilosis	1	0
Tinea versicolor	4	7
Kyphoscoliosis	7	3
Impetigo and ecthyma	1	0
Healed yaws	1	1
Bronchitis	9	5
Hypertension	5	6
Arteriosclerosis, peripheral	2	1
Osteoarthritis	2	4
Obesity	2	2
Chronic cervicitis	0	2
Cystocele and rectocele	2	2
Emphysema	4	0
Uterine fibroids	0	2
Goiter	0	2
Hemorrhoids	0	1
Hepatosplenomegaly	1	0
Abnormal knee-jerks	0	1
Keloid	1	1
Leprosy	1	0
Functional heart disease	1	0
Rheumatoid arthritis	0	1
Ovarian cyst	0	1
Anal fistula	0	1
Dupuytren's contracture	0	1
Senile vaginitis	0	2
Hallux valgus	0	1
Leontiasis osseum	0	1
Urethral caruncle	1	0

and feet. Marked improvement was noted in the case of an 80-yr-old man who had suffered a cerebral accident 2 years previously; much of the unilateral paralysis had disappeared. Three other aged exposed people, two females, one supposedly 101 years of age and one 75, and one male 79, were obviously becoming more infirm. They rarely left the seclusion of the mats beneath their houses. Only one unexposed person was in this same age range, a male aged 84 who was still able to move about fairly well.

In April 1958, after the March survey, a death occurred in a 36-yr-old male from the Ailingnae group, which had received about 69 r of gamma irradiation from the fallout in 1954. He had complained in March of epigastric pain, anorexia, and loss of vigor. Physical examination at that time was essentially negative except for epigastric tenderness. A tentative diagnosis of peptic ulcer was made, although it could not be substantiated since x-rays were not available. He improved on an ulcer diet including canned milk. About 3 weeks later, after the survey team had left, he became acutely ill and was transferred to the Naval Hospital at Kwajalein, where he died the following day. The entire skin and mucous membranes of the mouth were covered with uniocular vesicles and bullae. Autopsy revealed acute bilateral pneumonia of unknown origin and passive congestion of the liver. A diagnosis of varicella was made. Microscopic examination of the skin lesions showed inclusion bodies typical of varicella.*

The striking thing about the physical examinations in both the exposed and unexposed people was the relative paucity of findings associated with degenerative diseases. While the group under observation is too small to permit any valid statistical analysis, the clinical impression was that diseases such as atherosclerosis and hyptertension were considerably less common and of lesser severity than in a comparable group of our population. Among the 114 people 50 years old or less, none had a blood pressure greater than 140/90. Among the 23 persons older than 50 years, 6 had pressures ranging from 160 to 220 systolic and 90 to 110 diastolic, and 2 had systolic elevations of 160 to 170 but diastolic pressures of 75 to 80. The groups were too small for these findings to be evaluated relative to American statistics, but it can be said that theblood pressures do not exceed those commonly found and probably are lower.

There was a general feeling that conditions like hernia, varicose veins, hemorrhoids, and vaginal prolapse were much less common than one might anticipate in examining a random group of people of similar age in our society. One interesting finding was a relatively high incidence of kyphosis. While this is common in older people in our own population, it was particularly striking in the Marshallese, because it appeared to be localized to the lower thoracic and lumbar region. Fungus infections of the skin, particularly Tenia versicolor, were widespread.

*We are grateful to Capt. B.E. Bassham, (MC) USN, for doing the autopsy, and to Dr. S.W. Lippincott and Dr. H.A. Johnson of Brookhaven National Laboratory for the histological examination.

Growth and Development Studies

Cross sectional data on height and weight and bone age determinations for the 2- and 3-year surveys gave an impression of lag in growth and development in the exposed children compared with unexposed children of the same age. However, in an attempt to obtain more accurate birth dates of the children for the 4-year survey, the ages of some of the children, previously thought to be well established, were found to be questionable. The absence of recorded birth information seriously complicates the determination of the accuracy of given chronological ages and dates of birth. More definitive evaluation of data will be possible when verification of birth dates is completed. Detailed geneological and biological histories are being compiled to establish the most probable birth date of each child. (Unfortunately, the 1958 roentgenograms of the wrist and knee, intended for assessment of osseous maturation, were lost at sea.)

In addition to cross sectional studies, longitudinal studies of incremental growth data and bone maturation studies over the period since exposure will be undertaken when the ages of the children are better established.

Ophthalmological Examinations

Table 2 shows the major ophthalmological findings. Generally the Rongelap people, exposed and unexposed, showed superior vision and accommodation. The majority of disorders were found in the conjunctiva, cornea, and lens. Irritation of the eyes from bright tropical sunlight and exposure to coral dust probably play a part in the high incidence of conjunctival and corneal defects.

Table 2

Ophthalmological Findings (% incidence)

	Exposed	Unexposed
Pterygium	30.5	16.3
Pinguecula	24.4	15.3
Corneal pigment	6.1	4.8
Corneal scars	9.8	8.6
Arcus senilis	29.2	12.5
Dacryocystitis	1.2	0.0
Phthisis bulbi	3.6	1.0
Nystagmus	0.0	1.0
Pannus	1.2	0.0
Strabismus	7.3	1.0
Molluscum contageosum	3.6	3.8
Argyll-Robertson pupil	1.2	0.0
Keratitic precipitates	1.2	0.0
Cataracts	12.1	0.0
Aphakia	6.1	2.9
Vitreous opacities	8.5	0.0
Retinal arteriosclerosis	10.7	9.6
Choroidal scars	4.8	1.9
Macular degeneration	2.4	0.0
Drüsen	1.2	2.4
Congenital anomalies	3.6	1.0
Macrocornea	15.9	14.4

Slit-lamp observations revealed no opacities of the lens in the exposed people like those seen in the irradiated Japanese.[13,14] Also, no differences between the exposed and the unexposed groups were noted in visual acuity or accommodation.[15] A high incidence of such conditions as pinguecula and pterygium has been noted in the exposed group. This finding may have no significance, but it is not known whether the exposure of the eyes to beta irradiation in 1954 from fallout could have played an etiological role.

It is of interest that no cases of glaucoma were noted. The incidence of myopia was very low, as was the incidence of retinal arteriosclerosis, squint, and deficiency in color vision. Of interest was the finding of a large number of adults and children with large corneas, and anomalies of the retinal vascular patterns.

Examination of the Skin

Twelve cases continued to show residual evidence of beta lesions of the skin. These were for the most part mild and consisted of slight atrophy and pigment aberration. A few lesions showed scarring and atrophy with slight adhesion of the skin to subcutaneous tissues, and lack of pigment formation. However, improvement was noted in most lesions and in no case was there any aggravation of the lesion or tendency to develop chronic radiation dermatitis, or any change that appeared to be malignant or premalignant. In view of the generally favorable progress of the lesions, no biopsies for microscopic study were taken on this survey.

Laboratory Examinations

Hematological – Routine. The basic hematological data are presented in Tables 3 to 6. The mean blood counts of the exposed people and of the various comparison populations are shown for the 4-year period since March 1954. In Figure 7 are plotted the mean of two separate absolute blood counts on the exposed groups carried out during the 4-year survey, along with mean levels for other post-irradiation intervals; the open circles represent the mean values for the comparison population. The blood data have been classified as in the past according to age and sex.* The following represent the findings on the more heavily exposed Rongelap group compared to those on the unexposed Rongelap people.

WBC. The mean WBC was slightly higher in both exposed and unexposed groups in both the <5 and >5 year age groups compared with the levels a year ago (see Table 3 and Figure 7). The exposed level is about the same as the control level.

The ***neutrophils*** showed a further slight decrease in the exposed group since a year ago (Table 3, Figure 7). These counts in most cases reached a peak at 1 to 2 years post-exposure and declined during the following 2 years. In fact the counts this year are the lowest since the maximum depression occurred at 6 weeks post-exposure. In spite of this observation, the counts show little difference (5% less) from those in the unexposed group. A scattergram (Figure 8) age distribution

	Sex	Age, yr	Rongelap	Ailingnae	Unexposed Rongelap
*Leukocytes:	both	<5	8	2	5
	both	>5	56	16	80
Platelets	M	<10	9	2	10
	M	>10	22	5	40
	F	all ages	33	11	34
Hematocrits:	M	<15	12	2	17
	M	>15	19	5	34
	F	all ages	33	11	34

of the counts compared with the mean curve of the unexposed neutrophil counts shows that children about 12 years of age and below have more counts below than above the mean curve of the unexposed children of the same age range. However, above this age the distribution of counts is about the same.

The mean of the ***lymphocyte counts*** shows an increase since last year's counts of 33% in the exposed groups (Figure 9). It is this increase in lymphocytes that accounts for the rise in the total white count noted above. The lymphocytes in the exposed group are at the highest point since exposure. However, a scattergram (Figure 10) shows that more of the counts in the exposed group are below than above the mean unexposed curve. An accumulative percentage distribution of the counts (Figure 11) shows the exposed curve still to be slightly displaced to the left.

Eosinophil and ***monocyte*** and ***basophil*** counts are about the same in the exposed as in the unexposed groups. The eosinophil counts were quite high in both exposed and comparison populations, but were about the same in the two groups. In their differential counts, 45% of the exposed and 55% of the unexposed had eosinophils of 5% or greater.

Mean ***platelet counts*** have shown further recovery this year in both sexes of the exposed group compared with last year's results (Figure 12). As

Table 3

Rongelap Group and Control Mean Blood Counts by Day and by Age

	WBC $(\times 10^{-3})$		Neutrophils $(\times 10^{-3})$		Lymphocytes $(\times 10^{-3})$		Platelets $(\times 10^{-4})$				Monocytes $(\times 10^{-2})$		Eosinophils $(\times 10^{-2})$	
Postexposure day	<5	>5	<5	>5	<5	>5	Male <10	Male >10	Female all ages	Total group	<5	>5	<5	>5
3	9.0	8.2	6.4	4.7	1.8	2.2	—	—	—	—	0.8	0.3	0.1	0.7
7	4.9	6.2	—	—	—	—	—	—	—	—	—	—	—	—
10	6.6	7.1	3.5	4.5	2.6	2.1	28.2	22.7	24.9	24.8	2.9	1.7	1.6	1.6
12	5.9	6.3	3.5	3.9	2.1	1.7	—	—	—	—	4.2	5.4	1.9	1.9
15	5.9	6.5	3.2	4.1	2.4	1.9	27.1	21.3	21.7	22.5	3.0	2.3	1.1	1.3
18	6.7	7.2	3.4	4.7	2.4	2.1	21.8	19.1	21.8	21.0	2.7	1.7	3.5	1.6
22	7.0	7.4	4.3	5.0	2.6	2.1	16.8	14.6	15.2	15.3	1.9	2.0	2.3	1.8
26	5.7	6.1	3.0	3.9	2.3	1.8	13.2	12.9	10.9	11.9	1.9	1.6	1.8	1.3
30	7.6	7.8	4.0	5.3	3.2	2.1	14.1	12.3	11.8	12.3	1.5	0.9	3.4	2.2
33	6.5	6.2	3.1	3.8	3.2	2.0	17.9	16.6	15.1	16.0	1.7	1.6	2.6	2.2
39	5.7	5.5	3.0	3.3	2.6	2.0	25.5	22.0	22.4	22.8	0.9	0.9	0.5	1.0
43	5.2	5.2	2.0	2.6	2.9	2.3	26.8	20.9	23.2	23.2	1.1	1.1	1.4	0.8
47	5.9	5.8	2.6	3.3	3.1	2.4	24.6	20.6	23.9	23.1	1.0	1.0	1.1	0.5
51	6.7	5.6	2.6	3.5	3.4	2.1	22.1	17.5	21.2	20.3	2.5	1.6	0.8	0.7
56	7.0	6.0	3.5	3.5	3.7	2.4	—	—	—	—	1.7	1.2	—	—
63	7.7	6.0	3.9	3.6	3.7	2.3	23.1	18.2	20.2	20.1	0.5	0.9	0.3	0.6
70	7.6	6.5	3.8	4.0	3.3	2.2	—	—	—	—	—	—	3.4	1.9
74	—	—	—	—	—	—	26.2	21.7	24.7	24.1	—	—	—	—
6-mo survey	8.5	6.6	4.6	4.2	3.6	2.2	24.4	20.3	23.2	22.6	1.4	1.1	2.5	1.6
1-yr survey	10.1	8.1	4.7	4.8	4.6	2.8	26.6	19.5	27.6	24.9	0.7	1.3	6.7	2.8
2-yr survey	11.8	8.6	5.9	4.8	4.7	3.1	30.0	21.4	25.5	24.7	2.7	1.5	9.6	5.3
3-yr survey	8.6	6.9	4.1	3.7	3.7	2.7	32.0	22.1	28.1	—	1.2	0.7	6.4	4.5
4-yr survey	8.9	7.5	3.3	3.4	4.6	3.6	32.5	27.1	30.8	—	1.5	1.1	7.9	4.0
Majuro controls	13.2	9.7	4.8	4.8	7.4	4.1	41.2	25.8	36.5	33.4	2.0	2.0	9.5	4.7
Rita controls, 6 mo	10.7	7.6	5.4	5.2	4.7	3.7	35.0	27.3	30.9	30.4	1.9	1.7	4.2	4.8
Rita controls, 1 yr	—	—	—	—	—	—	37.5	24.5	29.4*	27.6	—	—	—	—
Rita controls, 2 yr	14.0	8.9	7.0	4.4	5.6	3.6	35.5	24.2	31.2	29.5	1.4	1.5	12.8	6.6
Rongelap controls, 3 yr	9.8	6.9	4.0	3.4	4.7	2.9	32.6	26.9	30.0	—	1.4	0.7	6.2	4.0
Rongelap controls, 4 yr	11.2	8.0	4.0	3.6	6.2	3.7	38.8	30.7	34.0	—	2.3	1.1	7.0	4.5

*Excluding pregnancy

with the lymphocytes, the platelet counts are the highest yet attained since exposure. However, the unexposed group also showed an increase in mean platelet count compared with last year; but the exposed group levels are still significantly below the unexposed (males, <10, −16%; >10, −11%; and females, all ages, −9%). This is also borne out by the following findings: (1) 22% of the exposed group have levels below 250,000 compared with only 7% in the unexposed people; (2) the scattergrams (Figures 13 and 14) show more counts below than above the unexposed mean curve in both sexes; and (3) the accumulative percentage distribution curve (Figure 15) is displaced to the left of the unexposed curve.

Erythropoietic function as evidenced by hematocrit levels shows little difference between the exposed and the unexposed groups, and neither group shows significant change since last year. The exposed males >15 years of age continue to show slightly lower hematocrit values than do unexposed males of the same age (see Table 6). However, the other blood elements in this group of males do not appear lower than in the unexposed group. A general anemic tendency in the Marshallese (combined exposed and unexposed groups) is borne out by the finding that 78% of the females have hematocrits of 36% or less and 54% of the males have hematocrits of 38% or lower.

Counts in the Ailingnae group. From Table 4 it can be seen that the counts in the 18 people of this group averaged nearly the same for the various blood elements as did the counts in the more heavily exposed group. Lymphocyte levels and platelet levels in the males were slightly lower, however. These same differences were noted at the time of the 3-year survey.

Individual counts. In reviewing the individual peripheral blood counts, lower levels were found in more exposed individuals than in the unexposed group. Those showing generally lower counts in the two groups are listed in Table 7.

Table 4

Ailingnae Group and Control Mean Blood Counts by Day and by Age

Postexposure day	WBC ($\times 10^3$) <5	WBC ($\times 10^3$) >5	Neutrophils ($\times 10^3$) <5	Neutrophils ($\times 10^3$) >5	Lymphocytes ($\times 10^3$) <5	Lymphocytes ($\times 10^3$) >5	Platelets ($\times 10^4$) Male <10	Platelets Male >10	Platelets Female all ages	Platelets Total group	Monocytes ($\times 10^2$) <5	Monocytes >5	Eosinophils ($\times 10^2$) <5	Eosinophils >5
3	6.0	7.0	3.0	5.0	2.8	2.2	—	—	—	—	0.8	1.6	0.5	0.4
7	5.5	6.8	—	—	—	—	—	—	—	—	—	—	—	—
10	6.3	7.3	4.2	4.2	1.9	2.2	22.5	22.6	20 9	21.5	3.8	2.1	2.6	1.6
12	6.3	7.6	1.8	4.7	3.1	2.2	—	—	—	—	3.4	5.8	4.4	2.6
15	7.1	7.0	2.3	4.5	4.2	2.2	29.0	20.2	24 6	23.9	3.7	2.6	2.3	1.4
18	6.8	7.8	2.9	5.0	3.5	2.4	27 5	21.7	24.9	24.3	2.3	1.5	3.2	2.3
22	8.9	8.7	5.3	5.4	2.7	2.9	23.5	17 0	22.9	21.3	1.5	2.4	5.8	2.4
26	8.4	7.0	4.8	4.4	3.2	2.2	20.0	13.8	17.4	16.7	2.3	2.4	0.6	1.6
30	9.6	8.6	5.3	6.2	3.7	2.0	19 5	12.8	18.2	16.8	1.9	1.9	4.1	2.0
33	7.7	7.8	3.3	5.2	3.5	2.2	24.0	15.8	22.7	17.6	2.8	2.2	6.0	1.9
39	7.5	6.2	2.9	4.2	4.7	1.9	26.5	20.8	27.0	25.2	1.1	1.7	2.7	1.6
43	6.9	6.5	2.7	3.6	3.9	2.7	28.0	19.6	25.3	24.0	0.6	1.4	2.8	0.6
47	7.3	6 7	3.5	3.8	3.4	2.7	27.0	20.0	26.1	24.5	2.2	1.9	1.5	0.7
51	8.4	6.3	3.8	3.6	4.0	2.2	32.0	18.2	25.0	23 9	2.7	2.8	2.2	1.0
54	4.6	6.3	2.8	3.5	3.2	2.5	37 0	19.8	23.8	24.2	1.5	1.9	1.8	0.8
6-mo survey	7.7	6.5	4.8	3.9	2.7	2.2	25.2	19.2	23.9	22.7	1.1	1 4	1.5	2.2
1-yr survey	11.1	7.8	4.2	4.7	6.5	5.6	38.7	21.4	28.3	27.5	1.0	1.1	1.7	2.2
2-yr survey	11.0	9.1	4.9	5 1	4.8	3.2	51 2	17.4	26.4	26.7	3.6	1.4	9.6	6.4
3-yr survey	12.1	7 0	5.5	3.9	5.6	2.6	40.8	22.4	31.2	—	3.0	0.7	5.3	3.7
4-yr survey	11.5	7.5	2.8	3.7	7.0	3.3	33.2	24 7	33.6	—	2.2	1.1	12.6	4.2
Majuro controls	13.2	9.7	4.8	4.8	7.4	4.1	41.2	25.8	36.5	33.4	2.0	2.0	9.5	4.7
Rita controls, 2 yr	14.1	8.9	7.0	4.4	5.6	3.6	35.5	24.2	31.2	29.5	1.4	1.5	12.8	6.6
Rongelap controls, 3 yr	9.8	6.9	4.0	3.4	4.7	2.9	32.6	26 9	30.0	—	1.4	0 7	6.2	4.0
Rongelap controls, 4 yr	11.2	8.0	4.0	3.6	6.2	3.7	38 8	30 7	34.0	—	2.3	1.1	7.0	4.5

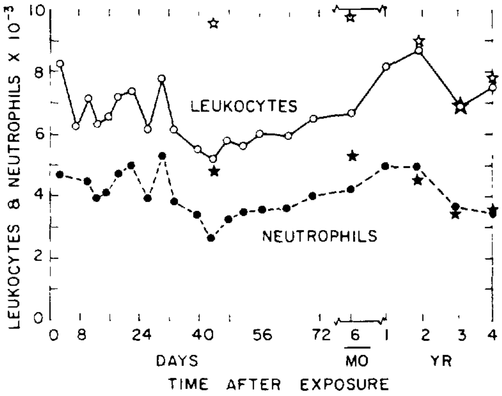

Figure 7. Mean neutrophil and white blood cell count of exposed Rongelap people from exposure through 4 years post-exposure. Stars represent mean value of control population.

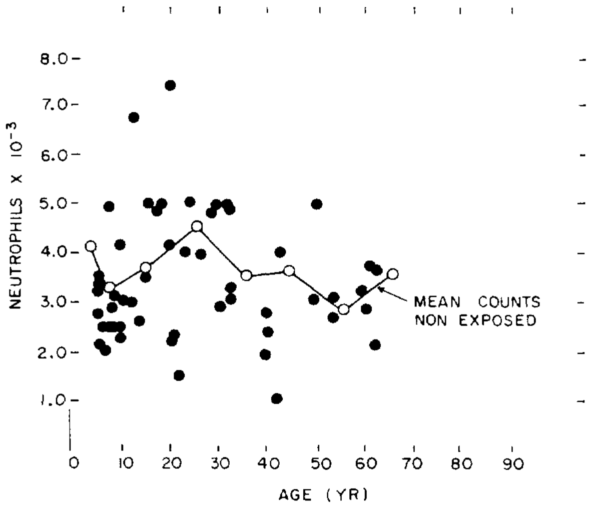

Figure 8. Neutrophil scattergram of individual counts plotted against age; Rongelap, age >5, 4 years post-exposure. Open circles represent mean counts of comparison population.

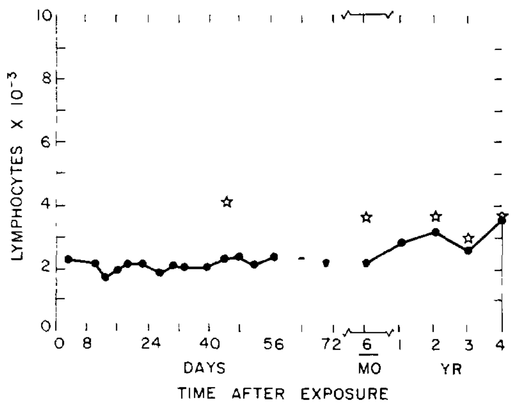

Figure 9. Mean lymphocyte values for exposed Rongelap people from exposure through 4 years post-exposure. Stars represent mean values of control population.

Table 5

Hematocrits

	Rongelap			Ailingnae		
Postexposure day	Male <15	Male >15	Female all ages	Male <15	Male >15	Femal all ag
22	37.5	43.9	39.0	37.5	43.7	39.2
26	36.3	41.6	37.5	36.5	43.2	36.8
30	37.9	42.2	37.1	36.0	44.6	36 7
33	37.4	42.2	36.8	35.5	43.8	37.3
39	37.8	42.4	37.4	35.0	45.6	37.4
43	37.3	41.8	37.6	36.0	45.2	36.8
47	39.0	43.4	38.3	—	46.5	40.2
6-mo survey	38.0	41.7	38.2	37.5	40.1	37.3
1-yr survey	37.5	41.1	36.9	33.0	44.6	36.2
2-yr survey	38.7	41.2	38.1	35.7	44.4	37.5
3-yr survey	35.6	38.7	35.4	37.5	40.6	36.5
4-yr survey	35.6	41.0	35.8	36.1	43.1	35.7
Majuro controls	39.6	46.0	39.9	39.6	46.0	39.9
2-yr controls	38.9	42.1	39.8	38.9	42.1	39 8
3-yr controls	35.6	41.0	35.9	35.6	41.0	35.9
4-yr controls	35.5	42.8	35.1	35.5	42.8	35.1

Table 6

Mean Blood Count by Age and Sex
for the Exposed and Control Groups, 1958

	Rongelap		Ailingnae		Unexposed Rongelap	
WBC (×10⁻³)						
4 – 5	8.9 (7)*	±1.4**	11.5 (1)		11.2 (4)	±1
>5	7.5 (48)	±1.6	7.5 (15)	±1.8	8.0 (68)	±1
Neutro (×10⁻³)						
4 – 5	3.3	±0.9	2.8		4.0	±1
>5	3.4	±1.2	3.7	±1.0	3.6	±1.
Lymph (×10⁻³)						
4 – 5	4.6	±1.2	7.0		6.2	±1.
>5	3.6	±1.1	3.3	±1.2	3.7	±1
Mono (×10⁻²)						
4 – 5	1.5	±1.0	2.2		2.3	±1
>5	1.1	±0.6	1.1	±0.9	1.1	±0
Eosin (×10⁻²)						
4 – 5	7.9	±5.2	12.6		7.0	±3
>5	4.0	±2.1	4.2	±4.7	4.5	±3.
Platelets (×10⁻⁴)						
Males 4 – 10	32.5 (8)	±8.6	33.2 (2)		38.8 (7)	±6
>10	27.1 (18)	±5.8	24.7 (4)	±2.3	30.7 (33)	±5
Females > 3	30.8 (29)	±7.0	33.6 (10)	±7.4	34.0 (32)	±5
Hematocrit						
Males 3 – 15	35.6 (11)	±1.5	36.1 (2)		35.5 (14)	±1
>15	41.0 (15)	±2.4	43.1 (4)	±2.8	42.8 (26)	±2
Females > 4	35.8 (29)	±1.5	35.7 (10)	±3.8	35.1 (32)	±2

*Number of individuals.
**Standard deviation.

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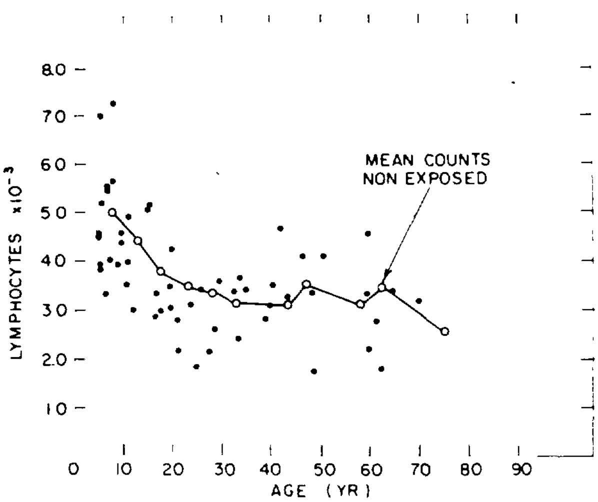

Figure 10. Lymphocyte scattergram of individual counts plotted against age; Rongelap, age >5, 4 years post-exposure. Open circles represent mean counts of comparison population.

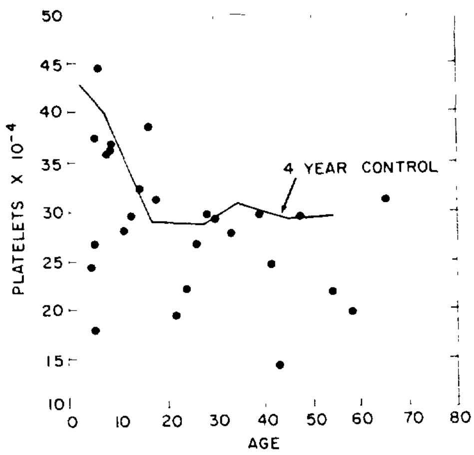

Figure 13. Platelet scattergram, males, of individual counts plotted against age. Solid line represents values for control population.

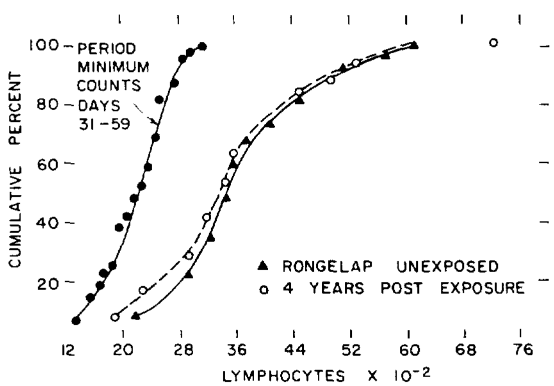

Figure 11. Cumulative distribution curve, Rongelap lymphocytes, age >5.

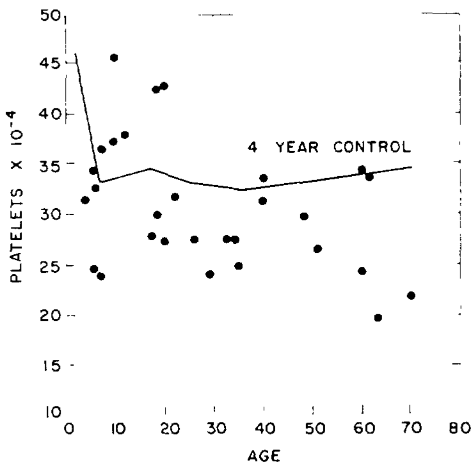

Figure 14. Platelet scattergram, females, of individual counts plotted against age. Solid line represents values for control population.

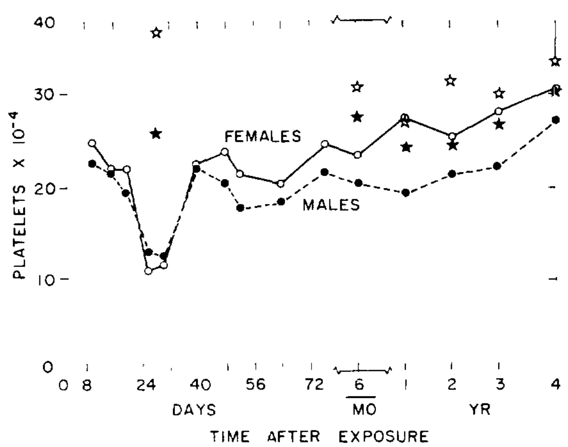

Figure 12. Mean platelet values for exposed Rongelap people from exposure through 4 years post-exposure. Stars represent mean values for control populations.

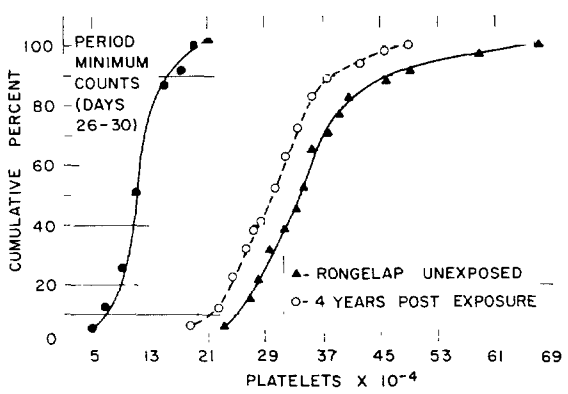

Figure 15. Cumulative distribution curve, Rongelap platelets, all ages.

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Hemopoietic reserve. It was of interest to determine whether the hemopoietic reserve of the exposed Marshallese was equal to that of the unexposed group. Means were sought to stimulate or challenge the marrow in regard to white cellular elements, erythroid cells, or platelets, but no feasible methods have been found. However, advantage was taken of a possibility that effects of the natural stress of menstruation and childbearing in the women 15 to 45 years of age might be reflected in differences in levels of their peripheral blood elements. The blood levels in this group of females were compared with those in the same age group of unexposed females, and the differences were then compared with the differences between exposed and unexposed men in the same age groups. Irradiated women and men, 15 to 45 years of age, were found to show the following percentage differences from the unexposed women and men of the same age group: neutrophils, females −5%, males +3%; lymphocytes, females −6%, males −15%; platelets, females −6%, males −7%; hematocrit, females +2%, males −6%. From these data, it did not appear that exposed women showed any lower levels of peripheral blood elements than did the exposed men compared with the unexposed groups, and the stress of these female functions did not appear to cause any noticeable effect.

Hematological Studies of Genetically Determined Traits. Blood grouping studies. The following is taken from a report by Sussman et al.[16] on blood groupings in the Rongelapese.

1) ABO System:

The groupings in this system were as follows.

Group	No.	%	Gene Frequency	
O	75	58.1	0.762	$p_r=0.789$
A_1	24	18.6	0.114	$q_r=0.116$
A_2	0	0		
B	19	15.0	0.093	$r_r=0.095$
A_1B	10	7.4		
A_2B	1	0.8		

The unusual finding of a single A_2B was verified by testing with several absorbed B antisera, as well as with the lectin of *Dolichos biflorans.*[17] The total absence of A_2 genes in Eastern Asia, Australia, and Indonesia has been repeatedly noted.[18,19] Inquiry into the family background of the single A_2B native failed to reveal any significant information leading one to suspect admixture.

2) MN System:

This blood group system was distributed as follows.

	No.	%	Gene Frequency
M	8	6.2	0.14
MN	20	15.5	
N	101	78.3	0.86

The low frequency of the M gene has been noted in the Marshall Islanders by many investigators.[20] The frequencies obtained in this study are among the lowest encountered.

3) Rh-Hr System:

A most unusual distribution was noted in this system. Tests were performed with anti Rh_0 (D), rh′ (C), rh″ (E), hr′ (c) and hr″ (e) sera. The results are as follows.

Phenotype	No.	%	Chromosome Frequency
Rh_1Rh_1	126	97.7	$R^1=98.5$
Rh_1rh	3	2.3	

The chromosome frequency of 98.5% for R^1 is the highest reported for any ethnic group. The complete absence of any rh negative persons in these and related series leads one to suspect that the true genotype of the bloods giving a positive reaction with anti hr′ (c) serum is most probably R^1R^0. The occasional finding of an Rh_0 person by Simmons[20] supports this interpretation. In the present series of 125 there were no bloods that reacted with rh″ (E) antiserum.

Table 7

Case No.	Age	Sex	WBC ($\times 10^{-3}$)	Neut. ($\times 10^{3}$)	Lymph. ($\times 10^{3}$)	Plate. ($\times 10^{3}$)	H
				Exposed			
68	53	M	4.6	2.2	1.7	199	3
73	22	M	4.7	2.3	2.1	198	4
12	23	F	4.5	1.6	2.8	316	3
16*	42	M	4.5	2.2	1.8	247	4
58	63	F	5.6	2.2	3.2	219	3
30	63	F	5.5	3.7	1.7	197	3
11	54	M	5.6	3.2	2.2	218	3
				Unexposed			
878	39	M	5.0	2.2	2.2	229	3
854	58	F	5.1	2.2	2.7	383	4

*Ailingnae.

Table 8

ABO, MN, Rh-Hr, and Duffy-Kell-Diego Frequency Among Marshallese and Polynesians

	ABO system								MN system				
		Group				Gene frequency			Type			Gene frequency	
	No.	O	A	B	AB	p_r	q_r	r_r	M	MN	N	m	n
Marshallese (present study)	129	58.1	18.6	15	8.2	0.789	0.116	0.095	6.2	15.5	78.3	0.14	0.86
Marshallese (Simmons[20])	678	52.2	21.4	121.1	5.3	0.723	0.135	0.134	(10)	(19)	(71)	0.22	0.78
Polynesians (Simmons and Graydon[21])	138	39.1	60.9	0	0	0.626	0.374	0.10	19.6	47 8	32.6	0.435	0.565

	Phenotype Rh-Hr				Gene frequency			Duffy, Kell, Diego		
	Rh_1Rh_1	Rh_1rh	Rh_2	Rh_1Rh_2	R^1	R^2	R^0	Fy^a+	K+	Di^a+
Marshallese (present study)	97.7	2.3	0	0	0.985	0	0.15	89.2	0	0
Marshallese (Simmons[20])	90.6	0.7	0.3	8.0	0 951	0.04	0.006	100	–	–
Polynesians (Simmons and Graydon[21])	19.6	0.7	29.7	50.0	0.449	0.543	0.007	74.6	0	0

4) Duffy System:

In this system 89.2% Duffy (Fy^a) positive bloods were found. A previous report of 100% Duffy (Fy^a) positive reactions[20] (in 30 specimens that had been stored for 16 months) indicates a need for verification and clarification.

5) Other Systems:

Kell tests were 100% negative as previously reported. Diego* tests were 100% negative.

The failure to demonstrate the Diego factor in any of the studies conducted in this area of the world is noteworthy. To date its absence in Polynesians,[21] Maoris,[22] and now in Marshallese becomes a significant finding in view of its occurrence in Mongoloids, Eskimos, and Amerindians,[23-25] to whom Heyerdahl[26] credits the population of the Polynesian Islands.

The gene frequency comparisons with other reports from this area are shown in Table 8.

The above findings indicate a rather homogenous population of the Marshall Islands with extremes of gene frequencies. With some reservations because of the relatively small samplings, the following facts are of interest in the blood groupings of the Marshallese.

1) The extremely high frequency of the O gene (78.9%).
2) The extremely low frequency of the M gene (14%).
3) The highest incidence of the R^1 chromosome yet reported (98.5%).
4) The presence of 10.8% of Duffy (Fy^a) negatives.
5) The absolute absence of Kell and Diego factors.
6) A single example of A_2B in this area.

The investigations of numerous authors, compiled and summarized by Mourant,[18] most nearly relate these blood groupings to those found in Southeast Asia and Indonesia, where relatively frequent B genes are found, a high N frequency exists, and a similar high frequency of the R^1 chromosome is seen.

The absolute absence of the Diego factor, the extremely low incidence of the M gene, and the unusually high R^1 chromosome frequency of the

*We are indebted to Dr Philip Levine who supplied the anti Di^a serum and Dr Miguel Lavrisse who supplied the Di^a positive cells for control

Marshallese more nearly resemble the blood groupings of the people of the Western Islands of Indonesia than those of the Amerindians. Too great a generalization of population origin, however, cannot be drawn from such a relatively small study group.

Haptoglobin studies. Results of the haptoglobin studies are taken from a report of Blumberg et al.[27] With the starch gel method of electrophoresis there are three distinct patterns of haptoglobins.[6] In type 1–1, there is one haptoglobin travelling near the beta globulin region; in type 2–2, there are three haptoglobins travelling between the alpha and beta globulins; and in type 2–1, there are four haptoglobins. One of these appears to be the same as in type 1–1 and the other three migrate slightly further than the three haptoglobins of type 2–2. It has been shown that these haptoglobin patterns are genetically determined, and they also appear to have a physiological function associated with hemoglobin transport.[28,29]

Occasionally an individual is found who has no haptoglobin at all. It is not yet clear if this type is genetically or environmentally determined. In the Marshallese, one such individual was found, and he was excluded in computing the phenotype frequencies. The actual incidence of the haptoglobin types was as follows.

Type	No.	%
1–1	51	40.48
2–1	54	42.86
2–2	20	15.87
0–0	1	0.79
Total	126	100.00

The Marshall Islanders have a very high incidence of the 1–1 type of haptoglobin, and incidence of the $H_p{}^1$ gene exceeded only by that of the Yorubas of Nigeria.[30] The Alaskan Eskimos have a low incidence of this type. There appears to be a *prima facie* relationship with latitude; populations from areas near the equator have a high incidence of 1–1 and a low incidence of 2–2, persons in high latitudes the reverse, and populations from temperate climates intermediate values. There is, of course, no evidence that the relationship is more than coincidental. Another possible correlation is diet; the Artic people live primarily on a protein diet (sea mammals, fish, and caribou), while the Nigerians have a diet with a high carbohydrate content. Further studies are required to confirm or reject this association. The haptoglobin system represents one of the best examples of genetic polymorphism yet described in humans. A study of its incidence in various people may help in elucidating the selective factors that maintain its balance in the population.

Hemoglobin types. In the 45 Marshallese blood samples analyzed, hemoglobin A_1 was found to be a little more diffuse than in the control samples. There was also an increased smearing of the hemoglobin behind the A_1 zone. However, the hemoglobins were considered to be normal, and the above findings were believed to be due to possible denaturation which caused increased diffusion and smearing of the hemoglobin during electrophoresis.

Serological and Urine Studies. Serum proteins. As noted in the past, the serum protein levels were elevated in both exposed and unexposed people. The mean level of the exposed group was 7.6 g, and of the unexposed group 7.8 g. Electrophoretic studies last year showed the gamma globulin to be elevated.

Tests of thyroid function. The following was reported by Dr. J.E. Rall. The level of serum protein-bound iodine in both groups was significantly above the normal range (see Table 9). The Normal PBI in man in the United States by this technique ranges from 3.5 to 7.5 μg%. There appeared to be no correlation of PBI with either age or sex. The ages of those examined ranged from 6 to 83. The total iodine of these sera averaged 1.0 μg% above the PBI, which is a normal value and an indication that contamination with iodine was not contributing to the elevated PBI values. To determine whether the PBI might consist of other organic but not thyroidal iodine, butanol extractable iodine tests were performed on 6 sera. These values were at the upper limit of normal (normal range 3.2 to 6.4 μg%). To delinate further these findings, thyroxine-binding capacity studies were performed on selected sera by methods previously described.[7] In 12 cases the values averaged 0.26 μg thyroxine/ml serum and ranged from 0.186 to 0.32. The normal value is 0.20 μg/ml, but inadequate data are available to define precisely whether the values in these Marshallese individuals were significantly different from normal. It can, however, be calculated that the level of thyroxine-binding protein is insufficient to cause an elevation of serum thyroxine (presumably to maintain a normal level of free thyroxine) as seen in these subjects. Contamination of the sera with

Table 9

Group	No. people	Av PBI*	Range	No. people	Av BEI	No. people	Av TBC**†	Range
Radiated	36	9.93	6.0 — 13.6	3	6.6			
Control	24	10.4	7.2 — 16.4	3	6.2	12	0.26	0.18 — .32

*As μg/100 ml serum.
**As μg thyroxine bound (maximal)/ml serum.
†No difference was noted between radiated and control groups, therefore they were not separated for these values.

an organic iodinated material could account for these data, but no source of such contamination is apparent. It must therefore be concluded, pending further study, that the Marshallese showed elevated serum protein-bound iodine levels which may or may not represent thyroid hormone.

Sodium and potassium determination in urine and food samples. Preliminary data on the sodium and potassium determinations in the urine and food samples of the Marshallese indicate that there may be some correlation between the suggestive evidence of hypotension in the people and salt intake. However, further analyses will be made before a final conclusion is reached.

Serum vitamin B_{12} concentrations. The following was reported by Dr. D.W. Watkin. Table 10 shows the mean levels of vitamin B_{12} found in the Marshallese sera along with data on American subjects. The former were all significantly higher than the latter.

The reason for this increased vitamin B_{12} level in the Marshallese serum is not apparent. The possibility of contamination of the samples with bacteria producing vitamin B_{12} must be considered, but no such contamination was grossly evident. Increased B_{12} concentrations in United States medical practice are usually associated with myeloproliferative diseases, liver disease, and frequent parenteral administration of large doses of B_{12}. Increased concentration of B_{12}-binding protein is usually observed in myeloproliferative diseases. The origin of this protein is not known. Perhaps in the Marshallese increased concentrations of B_{12}-binding protein may normally occur.

Table 10

Means, Ranges, Standard Deviations, and Standard Errors of the Means of Serum Vitamin B_{12} Concentrations in USA Normal Subjects, in Exposed Marshallese, in Unexposed Marshallese, and in All Marshallese Examined

Group	No. people	Mean, $\mu\mu g$/ml	Range, $\mu\mu g$/ml	SD, $\mu\mu g$/ml	SE of mean, $\mu\mu g$/ml
;A normal	31	533	260– 850	166	30
arshall, exposed	44	667	305–1250	260	39
arshall, unexposed	58	811	194–1705	327	43
arshall, total	102	749	194–1705	308	30

Survey for Intestinal Parasites. In Table 11 are listed infections found in the two main groups examined. For most parasites the incidence in exposed and unexposed populations was close enough to be considered the same. There were more infections with small race *Entamoeba histolytica* and with hookworm in the unexposed group, and more infections with *Trichomonas hominis* in the exposed group. For the three major pathogens found, the over-all infection rates were *E. histolytica* 18.2%, hookworm 5.5%, and *T. trichiura* 34.3%.

Of the 69 exposed individuals who had stool examinations, 40 had eosinophil counts of 5% or more, and 29 had levels of < 5%. Among the unexposed individuals, there were 60 cases on whom both stool examinations and eosinophil counts were available. Of these, 34 showed eosinophilia, 26 did not. The incidence of eosinophilia of >5% in the over-all population was 50%. The incidence of *Trichuris* was determined in these groups, and it was found that in both exposed and unexposed populations more of the eosinophilia cases had *Trichuris* infections than those with no eosinophilia (Table 12). However, about half the cases with eosinophilia showed no helminth infections at all.

Since infection rates for both exposed and unexposed groups were similar, the following analyses are based on pooled results for both groups.

Table 13 presents the age distribution of infections found. *E. histolytica* was found in 4.6% of 43 children 5 years old or younger. In the 6 to 12 year group, detected infections went up to 23.3%. The

Table 11

Relationship of Radiation Exposure to Infection With Intestinal Parasites

Organism	Exposed (69 cases)	Unexposed (112 cases)	Totals (181)
Entamoeba histolytica	14 (20.3)*	19 (16.9)	33 (18.2)
Entamoeba histolytica (small race)	2 (2.9)	10 (8.9)	12 (6.6)
Entamoeba coli	25 (36.2)	35 (31.3)	60 (33.1)
Endolimax nana	14 (20.3)	35 (31.3)	49 (27.1)
Iodamoeba butschlii	—	3 (2.7)	3 (1 7)
Giardia lamblia	5 (7.2)	9 (8.0)	14 (7.7)
Chilomastix mesnili	4 (5.8)	4 (3.6)	8 (4.4)
Trichomonas hominis	24 (34.8)	30 (26.8)	54 (29.9)
Hookworm	2 (2.9)	8 (7.1)	10 (5.5)
Trichuris trichiura	21 (30.4)	41 (36.7)	62 (34.3)
No parasites	11 (15.9)	30 (26.8)	41 (22.7)

*The number in parentheses is the percent.

highest incidence, 26.8%, was found among adults in the 21 to 50 age group. The other two intestinal amebae, *Entamoeba coli* and *Endolimas nana* occurred much more frequently in the youngest age group, 23.3 and 18.6% respectively, and both showed increases among the older individuals. Among flagellates, the *Giardia lamblia* incidence was highest in the young children and almost nonexistent after the age of 12. *T. hominis* showed a high, relatively unchanged incidence in all age groups.

Of the two helminths found, hookworm showed a steady rise in incidence, from 2.3 to 12.5%, with ages up to 50. No infections were found after 50 years of age. *T. trichiura* occurred in 30.2% of the children 5 years old or less, and in 66.7% of the 6 to 20 year group. In the older age group, 21 to 50, the incidence dropped to 16.1%, rising again after 50 to 31%.

Table 14 shows a breakdown of infections according to sex, with a further division into two age groups, less or more than 13 years of age. Division into the two age groups was made on the basis that both sexes probaly engaged in similar pursuits up to puberty, but that afterwards their daily routines probably differed. Older males had higher incidences than older females, or similar ones, for all parasites except *T. trichiura*, the incidence of which was about half as great in males. Among younger males, incidences tended to be lower than among young females, except that of *E. coli*, which was distinctly higher in the males.

Although differences in incidence of various parasites occurred in exposed and unexposed groups, there is no convincing indication that radiation had anything to do with the variations. In most instances differences can be accounted for by sampling errors in the relatively small numbers of cases studied. In addition, the two groups are not precisely comparable. The unexposed or control group consisted of individuals who had lived on different islands before joining the exposed population of Rongelap. Environmental sanitation had not necessarily been the same for the two groups.

The environment on the coral atolls and the customs of the inhabitants are such that it was not expected that any trematode or cestode infections would be found. However, the complete absence of *Ascaris* in the face of a 34.3% incidence of *Trichuris* was unexpected. Life cycles of both these nematodes in the external environment are such that they are customarily found together. The history of Marshallese association with other peoples, Europeans, Japanese, and Americans, makes it likely that they have been exposed to *Ascaris*. Thus, one is led to the possibility that the external environment on Rongelap Atoll may be unfavorable for *Ascaris* even though very suitable for *Trichuris*. It was not possible to obtain stools from any of the few dogs on the island in order to check for dog ascarids. Several dried pig droppings were examined at one time and no *Ascaris* was found in them. However, in the absence of more epidemiological and experimental information, one can only guess the reasons for the lack of *Ascaris*. Soil moisture, salinity, *p*H, porosity, etc., may all play some part in this unusual picture.

The fact that half the cases with eosinophilia showed no helminthic infections at all suggests other significant factors causing this blood picture besides parasitic infections. On the other hand, the greater incidence of *Trichuris* among Marshallese with eosinophilia than among those without eosinophilia indicates that infection with that helminth may have been a contributing factor in its incidence.

The incidence of parasites in all age groups indicates that fecal contamination is widespread and that infections are acquired early in life. Although individual Marshallese were generally neat and clean in appearance, their simple sanitary facilities and rural life make it likely that fecal contamination is a continuing affair. The concentration of

Table 12

Relationship of Eosinophilia to Infection With Intestinal Helminths

Organism	Exposed population: Eosinophilia (40 cases)	Exposed population: No Eosinophilia (29 cases)	Unexposed population: Eosinophilia (34 cases)	Unexposed population: No Eosinophilia (26 cases)	Combined population: Eosinophilia (74 cases)	Combined population: No Eosinophilia (55 cases)
T. trichiura	14 (35.0)*	7 (24.1)	17 (50.0)	7 (26.9)	31 (41.9)	14 (25.5)
Hookworm	1 (2.5)	1 (3.4)	5 (14.7)	2 (7.7)	6 (8.1)	3 (5.5)
No helminths	26 (65.0)	21 (72.4)	13 (38.2)	19 (73.1)	39 (52.7)	40 (72.7)

*The number in parentheses is the percent.

Giardia in children conforms to the usual picture for the incidence of this parasite. It would be unwise to ascribe special reasons for differences in infections between the sexes. Not enough individuals were examined, differences show no simple pattern, and the unsettled living conditions of these people during the past few years undoubtedly upset their usual daily routine.

Body Burdens of Radionuclides

Background. Studies of the internally deposited radioactive materials in the Marshallese population exposed to fallout were included in the initial examination in 1954 and have continued to be part of the subsequent re-evaluations. Until the 1957 examination, however, only indirect methods for assaying the body burden, namely urine analyses and extrapolation from animal data, were used. In the 1957 and 1958 examinations, the more direct method of whole-body gamma-ray spectroscopy was added to the procedure.[5]

As documented in the previous reports,[1-5] most of the radioactivity found in the urine specimens obtained during the first 24 days was accounted for by a few relatively short-lived nuclides, I^{131}, Sr^{89}, Ba-La^{140}, and other rare earths. Further analyses of stored 24-day urines performed 2 years later (after decay of the short-lived nuclides) showed that the samples contained averages of 12 d/m/l of Sr^{90} and 174 d/m/l of Cs^{137}. Low levels of Ce-Pr^{144} were found in the pooled specimens in 1956. In specimens obtained in 1957, the Sr^{90} level had decreased to between 0.34 and 1.41 d/m/l. The Cs^{137} concentration had been down to

Table 13

Relationship of Age of Individuals to Infection With Intestinal Parasites

Organism	Age: 1 – 5 (43 cases)	6 – 12 (30 cases)	13 – 20 (15 cases)	21 – 50 (56 cases)	51 and older (29 cases)
E. histolytica	2 (4.6)	7 (23.3)	2 (13.3)	15 (26.8)	5 (17.2)
E. coli	10 (23.3)	10 (33.3)	5 (33.3)	20 (35.7)	14 (48.3)
E. nana	8 (18.6)	4 (13.3)	7 (46.7)	18 (32.1)	9 (31.0)
G. lamblia	8 (18.6)	2 (6.7)	0	1 (1.8)	1 (3.4)
T. hominis	13 (30.2)	11 (36.6)	3 (20.0)	17 (30.4)	8 (27.6)
Hookworm	1 (2.3)	1 (3.3)	1 (6.7)	7 (12.5)	0
T. trichiura	13 (30.2)	19 (63.3)	11 (73.3)	9 (16.1)	9 (31.0)
No parasites	17 (39.5)	3 (10.0)	2 (13.3)	11 (19.6)	5 (17.2)

8 individuals whose age and sex were unknown are not included.

Table 14

Relationship of Sex of Individuals to Infection With Intestinal Parasites

Organism	Male: <13 yr (41 cases)	Male: 13 and over (49 cases)	Female: <13 yr (32 cases)	Female: 13 and over (51 cases)
E. histolytica	5 (12.2)	10 (20.4)	6 (18.7)	12 (23.5)
E. coli	14 (34.1)	22 (44.9)	6 (18.7)	17 (33.3)
E. nana	6 (14.6)	20 (40.8)	6 (18.7)	14 (27.5)
G. lamblia	5 (12.2)	1 (2.0)	5 (15.6)	1 (2.0)
T. hominis	14 (34.1)	11 (22.4)	10 (31.3)	18 (35.3)
Hookworm	0	6 (12.2)	2 (6.3)	2 (3.9)
T. trichiura	18 (43.9)	10 (20.4)	14 (43.8)	19 (37.3)
No parasites	9 (22.0)	8 (16.3)	11 (34.4)	10 (19.6)

8 individuals whose age and sex were unknown are not included.

33 d/m/l in 1956 but rose to between 137 and 370 d/m/l in 1957 (presumably because of slight fallout from a test series).

As part of the 3rd annual survey, several of the Marshallese people were brought back to Argonne National Laboratory for whole-body gamma-ray spectroscopy studies.[5,31] At that time the presence of Zn^{65} as an internally deposited radioisotope was first noted, and the importance of similar studies on the entire Rongelap population was recognized. Since it was not feasible to bring large numbers of Marshallese back to the States for such a study, it was decided that for the 4th annual survey the necessary equipment would be transported to Rongelap. (In view of the frequency of breakdown of the complex electronic equipment even under laboratory conditions, and the severe additional stresses associated with transportation and tropical conditions, complete spare units of the major electronic items were taken, as well as complete sets of spare tubes and other small components.)

Equipment and Procedures. The 1957 measurements at Argonne indicated that, although a good shield would be needed to lower the background, there would be enough radioactivity in the Rongelap subjects to make the shielding requirements less stringent than the criteria used at Argonne for very low body burdens. Accordingly, a steel room was used similar in design to the one at Argonne,* but with the walls and top only 4 in. thick and with the bottom only 2 in. thick. The steel deck of the LST and the water underneath were expected to compensate for the relatively thin bottom shield. With outside dimensions of 5 ft 8 in. by 5 ft 8 in. by 6 ft 6¼ in., the steel room weighed 21 tons.

The crystal found to be most useful as a detector was a sodium iodide (thallium activated) crystal in the form of a right cylinder 5 in. in diameter and 5 in. deep.

Within the steel room the subjects sat in a semi-reclining chair in a position similar to that used at Argonne.[32-34] The crystal, photomultiplier tube, and preamplifier were suspended above the subject's abdomen. The signal was conducted from the preamplifier to a linear amplifier outside the room and subsequently analyzed with a 100-channel pulse height analyzer. Commercial models* of the analyzer designed by Chase[35] were used. A fan and a phonograph contributed to the subject's comfort within the steel room.**

Before entering the steel room, the subjects took a shower bath and donned paper overalls and slippers. A special facility had been constructed aboard the ship for the shower and dressing station. The subjects were usually counted for 10 minutes.

In order that direct comparisons of body burdens with urinary excretion rates could be made, individual, rather than pooled, 24-hr urine specimens were obtained. The radiochemical analyses of the urines were conducted at the Walter Reed Army Institute of Research.***

One of the subjects died, and in this case the additional comparison of bone radionuclide concentration with whole-body and urine data was made.

The gamma-ray spectral data and most of the electronic equipment from the March 1958 trip were lost at sea, but prominent Cs^{137} and Zn^{65} peaks had been observed in the field, and it was felt that the expedition had proved the feasibility of conducting such measurements under field conditions. As soon as possible, therefore, the lost equipment was replaced and a second survey was conducted in May. By then, however, the 1958 series of weapons tests had begun at Eniwetok. This added to the difficulties because the steel room was taken to Rongelap by ship from Eniwetok, and it was not discovered until arrival at Rongelap that the ship being used (an LCU) was sufficiently contaminated with radioactivity to raise the background enough to interfere with the measurements. In fact, the deck underneath the steel room had been painted with a nonskid paint which evidently included radioactive sand from Eniwetok. The use of a paint remover and generous washing down of the ship reduced the background from 50,000 to 20,000 cpm, which, though still very high, did permit the measurements to be made. In March the background had been 1200 cpm.

*The authors wish to express their gratitude to Dr. C.E. Miller, Dr. L.D. Marinelli, and Mr. J.E. Rose of Argonne National Laboratory for generous assistance in planning the steel room, including their supplying drawings of the Argonne iron room

*Technical Measurements Corp., New Haven, Conn.

**Additional information on gamma-ray spectroscopy and sources of data may be found in references 79 to 90.

***We are grateful to Col. James Hartgering, (MC) USA, Maj. Kent T. Woodward, (MC) USA, and Lt. Ariel Schrodt of the Walter Reed Army Medical Center; Dr. John Harley and Mr. Edward Hardy of the New York Operations Office of the AEC; and Dr. Stanton H. Cohn of Brookhaven National Laboratory for assistance in the radiochemical analyses.

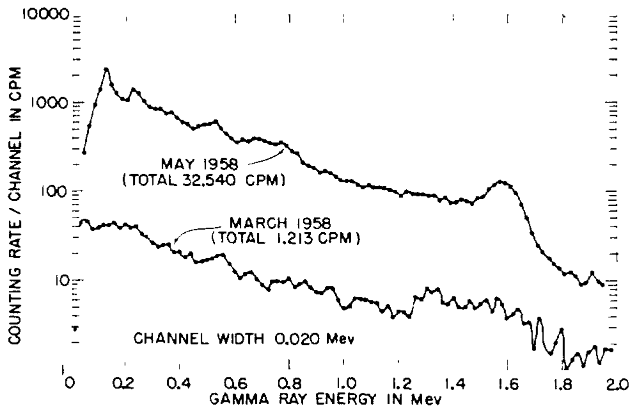

Figure 16. Background counting rates at Rongelap Atoll.

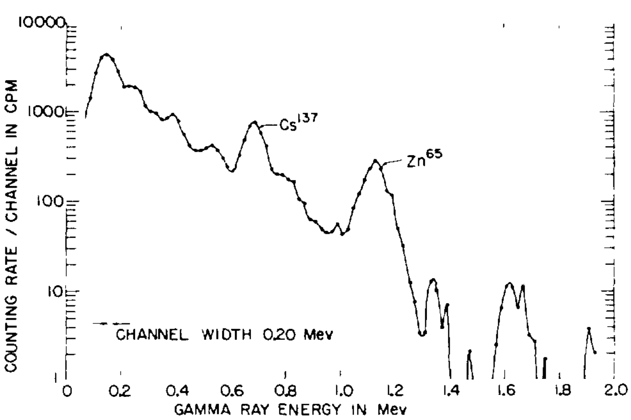

Figure 17. Rongelap subject #50, May 1958, total 43,260 cpm above background.

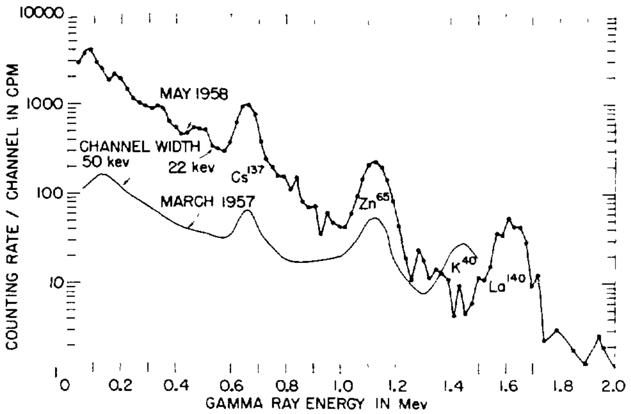

Figure 18. Rongelap subject #79. total 66,974 cpm above background (analysis No. 4).

Findings. Figure 16 compares the background gamma-ray spectrum of March 1958 with that of May 1958. (A few background data, plant and marine specimens, and data on one of the American subjects had been carried separately and hence were not lost at sea.) In addition to its being high, the May background shows a peak at 1.6 Mev, which was attributed to Ba-La^{140}. Except for this one peak, the background spectrum is essentially continuous. This, plus the fact that external procedures were effective in reducing the background, whereas cleaning the inside of the steel room and removal of unnecessary articles from within the room were ineffective, indicated that the contaminating radioactivity was outside the room.

Figure 17 shows the net gamma-ray spectrum of a representative Marshallese subject after appropriate correction for analyzer dead time and subtraction of the background. The Cs^{137} and Zn^{65} peaks are seen to be prominent, and in this case there is also a net peak at 1.6 Mev which has been attributed to Ba-La^{140} and which obscures the K^{40} peak. The latter was not a constant finding, but even in the spectra without it, the K^{40} peak was usually obscured by the high background. It had been hoped that the spectra could be examined for other peaks, but, since the method of analysis requires the high energy peaks and their associated Compton scattering spectra to be subtracted out first, the difficulties introduced by the high background, the 1.6 Mev peak, and the masking of the K^{40} peak render the entire procedure very uncertain. Similar difficulties prevented examination of the spectrum for possible contributions from Sr^{90} bremsstrahlung. If future surveys show the presence of additional nuclides, the 1958 data may be re-examined. For the present, however, only the Cs^{137} and Zn^{65} values, based on peak heights, are reported here.

Figure 18 shows the spectrum for another subject in 1958 compared with his spectrum in 1957. Because of the narrower channel width used in the 1958 study, the activities are even higher relative to the 1957 levels than the graph indicates.

The body content of Cs^{137} and Zn^{65} and the urinary concentrations of Cs^{137}, Zn^{65}, K^{40}, and Sr^{90} are presented in Table 15. Since the urine specimens were obtained in March, they may not correspond strictly to the body data obtained in May. The subjects are divided into groups on the basis of their island of residence. The data are presented in this way rather than on the basis of exposure

Table 15

Internal Deposition and Urinary Concentrations of Radioisotopes in Marshallese People

Case Number*	Age (yr)	Sex	Weight (lb)	Body Cs^{137} (mμC)	Body Zn^{65} (mμC)	Urine Cs^{137} (μμC/l)	Urine Zn^{65} (μμC/l)	Urine K^{40} (μμC/l)	Urine Sr^{90} (μμC/l)
				RONGELAP RESIDENTS					
1	58	F	148	442	485				
6	5	M	38	317	544				
7	41	M	129	—	—	2161	161	83	1.56
8	5	F	38	384	138				
9	27	M	135	—	—	1222	99	57	3.78
11	54	M	118	425	147				
12	22	F	120	397	235	2897	261	109	1.53
14	29	F	135	688	532				
15	10	F	58	580	152				
16	43	M	118	552	526				
17	7	F	48	466	135				
18	25	F	108	600	397				
19	9	M	48	370	118				
20	11	M	63	425	108				
23	8	M	52	601	226				
28	3	F	28	312	117				
30	63	F	102	507	361				
31	36	M	138	—	—	3362	236	190	1.20
32	8	M	43	739	320				
34	49	F	112	611	329				
35	17	M	123	905	412				
36	11	M	75	758	262				
37	24	M	134	569	379				
40	33	M	128	495	452	2254	147	72	6.10
41	48	M	126	365	446	2225	106	—	5.29
45	36	F	108	300	223				
47	12	M	77	697	573				
49	20	F	142	671	594				
50	38	M	164	723	829				
66	34	F	111	—	—	2391	22	121	3.09
73	22	M	160	1200	300	5534	145	—	5.62
74	20	F	138	498	300				
79	43	M	137	950	644	3684	120	173	1.97
80	50	M	132	326	429				
82	54	M	131	735	176				
820	9	M	56	471	129				
822	12	M	69	312	220				
823	14	M	95	495	255				
825	16	F	101	—	—	9839	334	234	10.13
830	19	M	141	543	417	5119	549	162	6.69
831	18	M	113	865	420	7276	303	120	2.71
833	25	M	120	649	326				
834	24	M	121	1268	455				
836	25	M	118	923	532	6964	87	319	2.52
840	28	M	142	951	476	3363	1251	113	4.02
842	34	M	130	913	411				
843	29	F	110	—	—	2070	74	57	1.66
851	50	F	158	302	115				
852	54	F	92	567	488				
856	59	M	120	702	241				
875	41	M	136	673	373				
878	58	M	188	617	317				
881	26	M	165	913	743				
882	25	M	123	432	444				
885	18	M	135	827	667				
910	55	M	143	921	723				
915	61	M	—	516	220				
917	40	M	175	1256	811				
918	60	M	209	1165	588				
927	63	M	155	605	335				
933	54	M	169	856	455				
935	60	M	—	639	576				
939	10	M	86	634	397				
940	8	M	54	399	120				

*Numbers >100 are in group exposed to fallout in 1954; numbers <100 are in unexposed group.

Table 15

Internal Deposition and Urinary Concentrations of Radioisotopes in Marshallese People

Case Number*	Age (yr)	Sex	Weight (lb)	Body Cs^{137} (mμC)	Body Zn^{65} (mμC)	Urine Cs^{137} (μμC/l)	Urine Zn^{65} (μμC/l)	Urine K^{40} (μμC/l)	Urine Sr^{90} (μμC/l)
944	33	M	150	955	491				
945	38	F	120	611	432				
947	50	M	—	639	173				
957	50	F	—	290	241				
958	26	M	125	885	335				
963	40	M	145	1770	417				
964	32	M	—	601	185				
966	26	M	—	944	229				
967	14	M	103	1154	438				
971	14	M	93	1053	344				
1001	6	M	—	357	44				
1006	5	M	40	242	532				
1008	47	M	175	798	543				
	Average			666	374	4024	260	139	3.86
				ENIAETOK RESIDENTS					
4	42	M	150	793	185				
21	7	F	44	453	162				
22	21	F	86	490	273	5864	341	209	5.99
24	17	F	109	469	191				
26	16	M	148	807	461	4291	220	134	2.09
33	5	F	39	553	188				
39	19	F	116	—	—	13011	155	—	NDA
76	15	M	97	805	215	11603	235	70	2.84
818	7	M	47	712	209	7605	99	26	6.37
819	9	M	66	762	294				
838	25	M	132	397	317	1850	322	94	3.51
855	53	F	145	680	214	3147	119	99	2.45
860	68	M	123	741	285				
865	25	F	98	562	493	4625	317	143	4.09
872	14	M	103	921	379	7666	194	164	1.26
873	39	M	140	846	335				
874	11	M	105	681	417	6086	130	78	3.19
876	20	F	117	—	—	2883	161	27	3.29
877	20	M	130	883	502	3281	231	127	1.95
880	37	M	158	1106	658				
887	12	M	130	673	244	11627	395	183	4.66
1010	38	F	—	933	385				
	Average			713	320	6426	225	113	3.47
	Grand Average			677	361	5139	243	134	3.70
				FORMER EBEYE RESIDENTS					
828	18	M	103	523	211				
849	39	M	204	861	544	3845	939	280	5.00
883	46	M	142	—	—	3356	268	167	2.70
973	49	M	—	238	76				
989	10	M	20	317	26				
	Average			485	214	3601	604	224	3.85
				AVERAGE LEVELS UNEXPOSED AND EXPOSED 1958					
Unexposed				747	384	5282	305	135	3.93
Exposed				578	325	4654	173	104	3.42
				AVERAGE LEVELS PER KG BODY WEIGHT FOR ISLAND GROUPS					
Rongelap				2.7	1.5	14.4	0.9	0.5	0.14
Eniaetok				3.0	1.3	26 1	0 9	0.5	0.15
Ebeye				2.4	1.1	9.4	1.6	0.6	0.10

*Numbers >100 are in group exposed to fallout in 1954; numbers <100 are in unexposed group.

or nonexposure to fallout in 1954, since the body burdens of the two groups are indistinguishable (see mean values for the two groups at the end of Table 15), and the present environmental contamination appears to be the important factor in determining their present body burdens. The island of Eniaetok (about 10 miles north of Rongelap Island) where some 50 Marshallese were living is slightly more contaminated than Rongelap Island itself where the majority of the people live. The Eniaetok group, however, had moved to Rongelap about a month prior to arrival of the team for the whole-body gamma analysis, and the lack of appreciably higher body burdens of this group is probably influenced by this fact. The Ebeye group had also moved to Rongelap Island from an uncontaminated island about three months prior to the May determinations, which probably accounts for the fact that their body burdens approach the Rongelap levels.

Samples for Sr^{90} analysis were taken from a vertebra and from the ileum of the 35-yr-old Rongelap man (No. 31) who died in April 1958. The results indicated a concentration in these bones of 3.7 $\mu\mu C$ Sr^{90}/g calcium.*

Analysis for Sr^{90} was carried out on 7 premolar and molar teeth (pooled) removed in May 1958 from Rongelap residents (exposed and unexposed). A value of 0.95 $\mu\mu C$ Sr^{90}/g calcium was found. This is considerably lower than the bone values found in case No. 31, as would be expected, because of the relatively slower turnover rate of strontium in teeth compared with bones.

A summary of the data on urinary excretion of radionuclides by the Rongelap people for the past 4 years is presented in Figure 19, and on estimated body burden in Figure 20.

Discussion of Body Burdens. In a discussion of the body burdens of the Marshallese it is well to recall the following historical points: (1) For the first 2 days after the accident in 1954, the people lived in a highly contaminated environment with little or no effort to avoid ingestion of fallout materials. This was reflected in their initially high urinary level of radionuclides. (2) For the following 3 years (until July 1957) they lived on a relatively uncontaminated island at Majuro Atoll, during which time the radiochemical urinalysis showed a rapid decrease of radionuclide concentrations. (3) In July 1957 they returned to Rongelap, which had been carefully surveyed for radioactivity and was considered to be safe for their habitation. However, low levels of activity do remain on the island, and these low levels are reflected in the increased body burdens and urinary concentrations observed.

In Table 15 the urine concentrations are expressed in $\mu\mu C/l$. Since 1 $\mu\mu C/l$ corresponds to 2.22 d/m/l, the 1958 concentrations of Cs^{137} are increased by factors of up to 100 over the 1957 concentrations, and that of Sr^{90} is increased by a factor of about 20 (see Figure 19). As previously noted (Figure 18), gamma spectroscopy shows a concomitant increase in the Cs^{137} and Zn^{65} body burden levels in 1958 over those seen in 1957 (see also Figure 20).

Considerable individual variation in body burdens is apparent, but the various groups in Table 15 are not greatly different from one another. There is some correlation of body Cs^{137} and Zn^{65} with body weight, but the variation is great. The correlation of body burden with urinary concentrations of Cs^{137} and Zn^{65} is not very good. The high urinary Cs^{137} level in Eniaetok residents is not matched by much higher body burdens of Cs^{137}.

Using the average values and an estimated 24-hr urine volume of 1450 ml, division of the urinary excretion rates by the body burdens indicates that 1.05% of the body burden of Cs^{137} is excreted daily, but only 0.106% of the body burden of Zn^{65} is excreted daily. It is not known whether the people are in metabolic equilibrium with the radionuclides in this environment. However, taken as steady-state values and assuming only urinary excretion, these figures would indicate biological half-times of 140 days for Cs^{137} and 110 days for Zn^{65}, values considerably at variance with the 17 days for Cs^{137} and the 23 days for Zn^{65} quoted in the recommendations of the National Subcommittee on Permissible Internal Dose.[36]* A value of 145 days for Cs^{137} has been calculated by Anderson.[37] The shorter value for the Cs^{137} biological half-time can probably be explained as being due to prompt excretion of recently ingested cesium. The zinc data, on the contrary, suggest an unusual retention, which could, for example, result from a deficiency of this element, but there are no data at hand to support such a theory.

The body burdens of Sr^{90} appear to be well below the maximum permissible levels (100 Sr^{90}

*This analysis was obtained through the Health and Safety Laboratory, AEC, NYO.

*However, the new Handbook values soon to be published indicate a biological half-time for Cs^{137} of 70 days.[91]

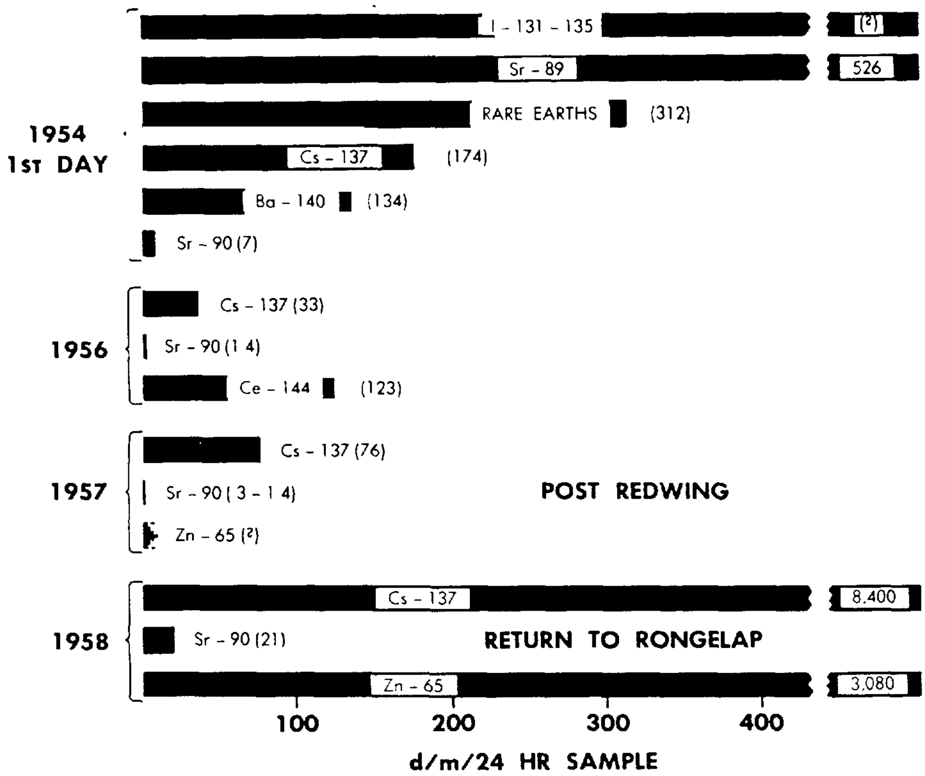

Figure 19. Urinary excretion of isotopes by Rongelap people.

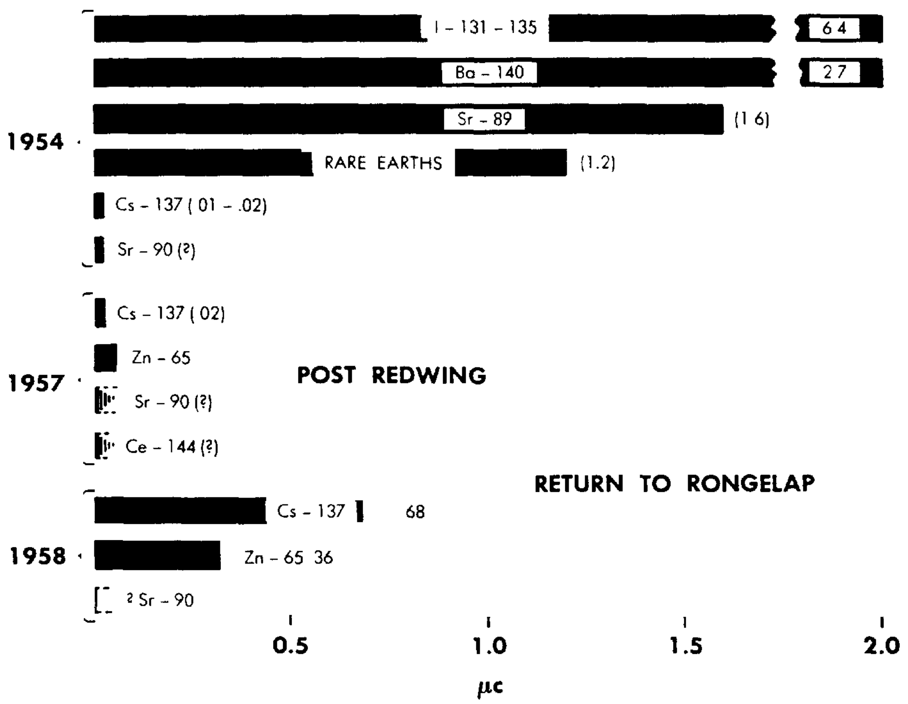

Figure 20. Estimated body burden of isotopes of Rongelap people.

units for populations at large) based on analysis of a small sample of bones from the Rongelap man who died in April 1958, if this sample is representative. Since children may have levels higher than those of adults by a factor of 10, their values may be as high as about ⅓ of the stated maximum permissible concentration (30 to 40 $\mu\mu C$ Sr^{90}). However, this estimate is based on bones of American children and, since consumption of milk by the Marshallese children is practically nil compared with that by American children, this extrapolation may not be valid. Based on urine analyses for Sr^{90} excretion, the average 1958 level was 3.42 $\mu\mu C$ Sr^{90}/l urine, or about half the level found during the first month post-exposure (6.2 $\mu\mu C$ Sr^{90}/l urine). It is not known whether the body burdens of Sr^{90} in the Rongelap people have yet attained equilibrium with their environment, and this point will be carefully followed in future studies.

Although the rapid rise of the Ebeye people's values toward those of the other Rongelap residents suggests that equilibrium values have been approached, the daily excretion rates indicate that equilibrium with the environmental values cannot be assumed. In any event, the increase in activity between the 1957 and 1958 surveys and the similarity of the results for the exposed and unexposed groups indicate that most of the radioactivity seen is the result, not of the initial contamination, but of more recent ingestion of food containing radionuclides. It is known from other studies[38-44] that the soil and food plants on Rongelap contain low levels of fallout products. Eating of land crabs has been proscribed because of their relatively high Sr^{90} content. Among other foods the pandanus fruit shows the highest Sr^{90} content, but this fruit represents a relatively small part of the diet. Other plant foods such as coconuts and breadfruit have relatively low levels of Sr^{90} activity. These plants also contain low levels of Cs^{137}.

Calculations of the radiation dose rates on the basis of existing data are subject to much uncertainty, but have been attempted because of the great interest in this facet of the problem. Using the assumptions accepted in the United Nations report,[15] the 3.8 $\mu\mu C$ of Sr^{90}/g calcium found in the one subject autopsied corresponds to a dose rate of 9.5 mr/year to the bone, and a dose rate of only 3.8 mr/year to the bone marrow. Similar calculations for Cs^{137} and Zn^{65} give a total of about 120 mr/year from the known internally deposited radioisotopes. This is to be compared with the dose rate from natural sources,[16] of which 44 mr/year are attributed to K^{40}, radium, and mesothorium distributed internally and 134 mr/year to cosmic rays and local external gamma sources. From local external gamma sources the Rongelap people as measured in March 1958 were receiving about 250 mr/year and in August 1958, 500 mr year. (The latter increase was due to slight additional short-lived fallout from a then current test series and the integrated dose for the year might be expected to be $<$500 mr.)

Discussion

ACUTE AND SUBACUTE EFFECTS

The results of the medical survey on the Rongelap people 4 years after exposure to fallout show that the people have largely recovered from the acute and subacute effects of their exposure and are making satisfactory readjustment to their repatriation on Rongelap Atoll.

The acute effects of radiation that were observed early in these people were indicative of significant exposure. Findings unquestionably related to their exposure were early gastrointestinal symptoms and significant depression of the peripheral blood elements commensurate with the calculated dose of 175 r penetrating gamma radiation, beta burns of the skin and epilation from skin irradiation, and the acquisition of a low level body burden of radionuclides. In addition certain other findings were possibly related to their exposure such as (1) loss in weight of several pounds in most of the people during the first several months after exposure and (2) suggestive evidence of a slight lag in growth and development of exposed children during the first 3 years based on studies of height and weight and bone development. (A reevaluation of these studies is necessary in view of uncertainty in ages of some of the children.)

Other acute and subacute effects of whole-body irradiation which have been reported to occur have not been observed in the Marshallese. (1) Fertility, based on comparison of frequency of pregnancies, did not appear to be affected; (2) no deleterious effects were noted on the course of pregnancies; and (3) the four *in utero* irradiated babies appeared normal. It should be reiterated that completely negative statements cannot be made based on these findings because of the paucity of vital statistics in the Marshallese and the small numbers of people involved.

No diseases, infectious or noninfectious, have developed which could be related directly to radiation effects. The incidence of diseases in the exposed people noted during the 4-year survey, as in previous surveys, remained about the same as found in the unexposed comparison population. A limited survey of immune responses of the exposed group at 3 years post-exposure[7] showed that the antibody response to tetanus antigenic stimulus was not significantly different from the response in the unexposed group.

Three deaths have occurred in the exposed people. The first was in a 46-yr-old man who died of hypertensive heart disease 1 year post-exposure. He had had the disease at the time of irradiation. The second occurred in a 78-yr-old man at 2 years post-exposure. He was a diabetic of long standing and died apparently of coronary heart disease. A third occurred in April 1958, after the present survey, in a 35-yr-old man from the group that received 69 r, due to pneumonia complicating a severe case of chickenpox. In none of these cases was there any direct evidence that death was due to radiation exposure.

Lag in recovery of some of the peripheral blood elements of the exposed people over the 4-year period since exposure is in sharp contrast to the much more rapid recovery seen in animal studies, but generally conforms to the recovery pattern seen in the Japanese exposed at Hiroshima and Nagasaki. In the Marshallese the myelocytic series showed earliest recovery (by 1 year post-exposure), with lymphocytes and platelets exhibiting much slower recovery. The present hematological examinations reveal that the mean leukocyte level has virtually recovered to the control level, but more individuals had lower counts than in the unexposed group. Thrombocyte production still does not appear to have recovered completely as evidenced by the lower mean levels in the exposed people both individually and as a group. As has been pointed out, however, the slightly lower peripheral blood level of these elements has not impaired in any observable way their resistance to disease.

There has been considerable speculation as to whether there is a lowered reserve hemopoietic capacity in the marrow of the exposed people. The effect of the natural stresses of childbearing and menstruation in women 15 to 45 years of age was examined by comparing differences between the mean peripheral blood element levels of this group and the corresponding group of unexposed women with differences between levels in exposed and unexposed men of the same age group. No significant differences were seen.

It might be questioned whether or not the present low body burden of radionuclides might contribute to delayed recovery of hemopoietic function. Admittedly little is known of possible effects of such low level exposure on the marrow, particularly if, as in the case of the Marshallese, a significant dose of penetrating radiation has been previously received. However, it is not believed that the small amount of additional radiation imposed on the marrow from this source would be sufficient to retard hemopoietic recovery.

Hematological examination at 3 years post-exposure revealed a drop in the mean leukocyte counts compared with 2-year levels in both the exposed and unexposed people. The possibility was considered that a population trend downward in leukocyte counts was occurring such as has been seen in Japan.[17] However, this does not seem to be the case, since leukocyte levels this year are not further depressed compared with previous levels.

The acute effects of the beta irradiation of the skin subsided rapidly, and only 12 cases still show residual scarring and pigment abberation. It is possible that the acute stage of the beta burns may have caused some of the fluctuation observed in the white blood cell count. In those showing epilation, complete regrowth of hair occurred by 6 months post-exposure.

No acute effects of the internal absorption of radionuclides were observed.

LATE EFFECTS

Late effects of radiation exposure have not been seen, but certain of the more fundamental of these effects that have been observed in animals and to a lesser extent in man will be mentioned in relation to the Marshallese.

Shortening of life span[18-32] has not been evident. The 3 deaths that have occurred in the exposed population do not appear to indicate a higher mortality rate than seen in the comparison populations. From these observations it would appear that some of the higher estimates of life shortening per roentgen may be too high.

Premature aging[18,33] is difficult to assess. From observations over the past 4 years the impression is that exposed people neither have aged faster nor appear older than similarly aged unexposed Marshallese. No doubt the subtle changes which occur with aging would be difficult to detect over this period of time. During the 4-year survey, data were collected in an attempt to obtain semiquantitative estimates of biological age by scoring the degree of certain criteria such as greying of the hair, skin looseness, skin retractility, arcus senilis, retinal arteriosclerosis, accommodation, blood pressure, etc. These data have not yet been completely analyzed.

Degenerative diseases[54-56] have not been found to be increased in the exposed people. No ***malignancies*** have been detected. In the irradiated Japanese an increased incidence of leukemia has been noted.[57-59] There have been no cases of ***leukemia*** or ***leukemia tendency*** noted in the Marshallese. (No cases have shown decrease in alkaline phosphatase of neutrophils, nor have increased levels of basophils been noted.) Since the incidence of malignancy or leukemia would be expected to be relatively low with the dose of irradiation received, and since such a small population is involved, the probabilities are good that such effects will not be observed in the Marshallese.

Ophthalmological changes related to late effects of radiation[13-15] have not been seen. Slit-lamp observations over the past 4 years have revealed no polychromatic plaques or cataracts. No differences were found in visual acuity in the exposed and unexposed children.

Genetic effects.[60,61] No specific studies for genetic effects have been conducted. Of the 18 babies born to irradiated parents and living at the time of examination, none showed any abnormalities. In view of the generally negative findings in the studies of the first-generation offspring of the irradiated Japanese,[62] it is unlikely that genetic studies in this group will be fruitful.

Beta irradiation. No late effects of beta irradiation of the skin such as chronic dermatitis or premalignant changes have been found in the Marshallese.

FINDINGS COMMON TO BOTH EXPOSED AND UNEXPOSED GROUPS

Certain findings common to both exposed and unexposed Rongelap people may have possible significance in relation to their state of health and future prognosis. Clinical laboratory examinations have revealed a complexity of findings difficult to evaluate. Principal among these is the anemic tendency in the population at large. Hematocrit values of 38% or less were found in 54% of the men, and of 36% or less in 78% of the women. Also possibly related to this finding was the increase in reticulocyte counts (>3%) in about 20% of the people noted during the 3-year examination. The following have been considered as possible etiological factors:

1) Nutritional deficiency, such as low dietary proteins or iron deficiency. Although the diet is extremely limited and fish supplemented by small amounts of other meats are about the only source of proteins, there is no good evidence that such a deficiency exists. In fact the blood proteins are high (average 7.8 g%). It is not known whether the diet is deficient in iron. Blood smear examinations did not reveal any obvious microcytosis of red cells. The nature of the anemic tendency will be further investigated in the next survey by carrying out serum iron determinations and running Price-Jones curves of the red blood cells. Poor absorption or deficiency of vitamin B_{12} is apparently not a factor since the levels of B_{12} in the serum were surprisingly high. (Experience with *Diphyllobothrium latum* infestation suggests that parasitism of the gastrointestinal tract should be associated with low vitamin B_{12} serum concentrations.) The relatively high values of serum vitamin B_{12} are puzzling, and no immediate explanation is apparent.

2) Intestinal parasitism is very prevalent, 72% of the people showing stools positive for ova and parasites. However, examination of these stools for occult blood showed positive tests in only 10 people. Chronic blood loss from this source does not seem likely; also, anemia is not usually associated with the parasites found in these people.

3) Chronic infections, particularly skin diseases and dental caries, may play an etiological role in the production of the anemic tendency. The high plasma protein levels with high gamma globulin component may be a reflection of such infectious processes.

The presence of eosinophilia in the population is another puzzling problem. (About half the people show eosinophils >5% in their differential counts with quite a few values as high as 20 and 25%.) Offhand, it might seem that the high incidence of intestinal parasites might account for the high eosinophil counts. However, as pointed out, most of the types of parasites found are not usually associated with a consistent eosinophilia, and indeed a large group of individuals with high eosinophil counts had stools negative for parasites. However, the greater incidence of eosinophilia among Marshallese with stools positive for *T. trichiura* indicates that infection with this helminth may be a contributing factor, but this does not entirely explain the generally high incidence noted. Possibly chronic infections, particularly fungus infections of the skin, may be partly responsible. Another possibility is trichinosis infestation, which has to be considered seriously in view of the large number of rats on the island and the presence of swine (used to a small extent for meat) roaming freely. On the next survey serological tests for trichinosis antigen will be carried out.

An unexpected finding was that the level of serum protein-bound iodine in these people was significantly above the normal range. Butanol-extractable iodines on 6 cases also showed values at the upper limit of normal, but thyroxine-binding capacity determinations on 12 cases gave data inadequate to define precisely whether the slight elevations were significantly different from normal. However, it could be calculated that the level of thyroxine-binding protein was insufficient to cause the elevation of serum thyroxine (presumably to maintain a normal level of free thyroxine) noted in these people.

The study of genetically determined traits has proved most interesting in helping to establish the anthropological background of the Marshallese people and the homogeneity of the population under study. Interesting findings in the studies of blood groupings were the high frequency of the O gene (78.9%), the extremely low frequency of the M gene (14%), the highest incidence yet reported of the R′ chromosome (98.5%), the presence of 10.8% of Duffy (Fy^a) negatives, the absence of Kell and Diego factors, and a single sample of the A_2B group. These groupings most closely resemble those of the people of Southeast Asia and Indonesia. Haptoglobin studies showed a very high incidence of the 1 − 1 type and the Hp′ gene exceeded only by that of the Yorubas of Nigeria. No unusual hemoglobin types were noted. These findings suggest a rather homogenous population.

RADIATION ECOLOGICAL STUDIES

It seems appropriate to discuss the Marshall Island data as part of the world-wide fallout problem. There has been much concern expressed both in scientific journals and in popular articles about the hazard from fallout, particularly Sr^{90}. The general situation as of mid-1957 has been reviewed by Robertson and Cohn,[63] with the conclusion that existing levels of radiation from fallout add little to the environmental radiation hazard. Eisenbud and Harley[64] present data indicating that in the United States Sr^{90} continues (in 1958) to be deposited at a rate of 11 to 54 mC/mi^2. The average for the rest of the Northern Hemisphere is 16 mC/mi^2, which is about twice the value for the Southern Hemisphere. Kulp and Slakter[65] conclude that the diet of an average U.S. citizen in 1957 contained about 6.5 $\mu\mu$C Sr^{90}/g calcium, which corresponds to an equilibrium base level of 1.6 $\mu\mu$C/g if the discrimination factor between diet and bone is 4. Finkel,[66] in an appraisal of the potential Sr^{90} danger based on data from animal experiments, concludes that the minimum effective dose in man may be a burden of from 5 to 10 μC Sr^{90}, in close agreement with an estimate of 6 to 15 μC based on the radium method of extrapolation. Hindmarsh et al.[67] have re-evaluated the relative hazards of Sr^{90} and Ra^{226}. Their conclusion is that the currently accepted maximal permissible dose figures for Sr^{90} are substantially correct. Brues[68] reviews the arguments upon which is based the fear that very low doses of Sr^{90} might produce a "very low (but in absolute numbers appreciable) incidence of leukemia" and concludes that the present data fail to indicate a linear relationship for dose and effect at low doses. He further emphasizes the fact that there are other theories of the etiology of cancer, and that their existence weakens the arguments of those who would assign unrealistically high probabilities to the role of single mutations as being the cause of cancer.

Gilliam and Walter[69] have studied the trends in the mortality from leukemia. In most age groups the death rate has been increasing exponentially since 1921, with doubling times of about 15 to 20 years for most age groups. The younger age groups, however, have recently shown a tendency to level off, or, in the authors' words, since 1940 there has been "a distinct tendency toward a decline in the rate of increase." This tendency is more definite with decreasing age, and in the age group 0 to 1 year there has been an actual decline in the death rate from leukemia. If leukemia follows from exposure to an environmental factor, the mortality data suggest that exposure of the population to this factor has decreased recently.

Schwartz and Upton[70] have considered the role of ionizing radiation in the general incidence of leukemia and lymphomas. Among other factors considered are age, race, sex, geographical location, climate, genetic factors, constitutional factors, and other extrinsic agents such as chemicals and infectious agents. These authors consider the increase in radiation background from all causes (medical, dental, fallout, etc.) to be "clearly not sufficient to account for the tremendous rise in the recorded incidence of leukemia. . ." Burnet[71] points out that the present peak of incidence of leukemia at age 3 to 4 is a relatively recent development and suggests the possibility that exposure to some new mutagenic agent at the time of birth is the cause. He cites data which indicate that at most 5 to 10% of leukemia incidence in the United States can be ascribed to radiation from all sources, and points out that the etiology of the other 90% is unknown.

Other constituents of fallout have not received as much publicity as Sr^{90}, but their study has not been neglected.[72-78] Anderson[72] reports an extensive series correlating Cs^{137} and K^{40} levels in people and in milk supplies. He states that the importance of Cs^{137} relative to Sr^{90} is increasing. The levels in both people and milk representing various locales in the United States ranged up to 60 $\mu\mu C$ Cs^{137}/g K, with fairly good correlation between the two levels. These results are consistent with those reported by Miller and Marinelli,[78] who have further data suggesting a rather uniform distribution of fallout in the Northern Hemisphere.

The significance of low doses of radiation has not been evaluated fully, the chief reason being the absence of positive data on low-dose effects, particularly in humans. Perhaps more subtle methods will be found by means of which low-dose effects can be documented, but it is to be hoped that the radiation dose can be maintained below the level at which effects appear with any method.

In the meantime, the Rongelap people provide an interesting group of subjects exposed to a level of radiation appreciably above the world average. Present indications are that the body burdens of radionuclides will not reach levels which, from known data, will result in morbid processes. As pointed out before, the development of leukemia associated with their exposure to a sublethal dose of gamma radiation in March 1954, based on experiences with the exposed Japanese,[57-59] is held to be improbable, particularly in view of the small number of people involved. The superimposition of the low level body burdens from environmental contamination would not seem likely to be sufficient to increase this possibility substantially.

The habitation of these people on Rongelap Island affords the opportunity for a most valuable ecological radiation study on human beings. Since only small amounts of radioisotopes are necessary for tracer studies, the various radionuclides present on the island can be traced from the soil through the food and into the human being, where the tissue and organ distributions, biological half-times, and excretion rates can be studied.

Summary

The medical survey of the Rongelap people in March 1958, 4 years after exposure to accidental fallout radiation, was carried out at Rongelap Island, to which these people had been returned in July 1957 after the radiation level of the island was declared safe for habitation. They were adjusting satisfactorily to life in their newly reconstructed village.

No apparent acute or subacute effects were found at this time related to the gamma dose of 175 r received, with the possible exception of hemopoietic findings indicating a persisting lag in complete recovery of platelet levels of the peripheral blood. In the males these mean levels were 11 to 16% and in the females 9% below the corresponding mean levels of the comparison population. The lymphocytes had recovered to a level about the same as in the comparison population, although many of these counts were lower than in the latter group. The stress of childbearing and menstruation did not appear to be reflected in any lowered hemopoietic reserve in the exposed women, based on comparative studies of the levels of peripheral blood elements. The suggestive incidence, previously reported, of slight lag in growth and development of the irradiated children at 2 and 3 years after exposure, based on height, weight, and bone age studies, needs re-evaluation in the light of the finding that the ages of some of the children were not as firmly established as previously thought. History and physical examinations revealed no clinical evidence of any illnesses or findings during the past year or at the time of the present survey which could be related to whole-body exposure.

Two deaths occurred in the exposed and one in the unexposed group since the last survey. The deaths in the exposed group did not appear to be related to radiation exposure. Diseases, infectious and noninfectious, were as common in the exposed as in the unexposed people. Nutrition appeared good except for slight hemeralopia in several children ascribed to vitamin A deficiency. The birth rate was about the same in the exposed as in the unexposed group, and the babies appeared normal.

No late effects of exposure were noted. Shortening of life span has not been observed. The death rate has been about the same in the exposed as in the unexposed population. Premature aging of the irradiated group has not been grossly visible. No radiation opacities of the lens or differences in visual acuity have been noted. No malignancies have been observed, and the incidence of degenerative diseases was about the same as in the unexposed group examined. Genetic studies have not been carried out, but no difference in the incidence of congenital abnormalities has been noted in the first-generation children of the exposed compared with the unexposed populations.

The only residual effects of beta irradiation of the skin were seen in 12 cases which showed varying degrees of pigment abberation, scarring, and atrophy at the site of deeper burns. In no case was there evidence of chronic radiation dermatitis or premalignant or malignant change in the lesions.

The return of the Rongelapese to their island (which has a persisting low level of radioactive contamination) is reflected in a rise in their body burdens and increased urinary excretion of certain radionuclides. Estimates of these body burdens of radionuclides were determined by gamma spectroscopy and by radiochemical analyses of urine samples. These estimates showed that the body burden of Cs^{137} had increased by a factor of 100 and of Sr^{90} by a factor of 10, with some increase in Zn^{65} also, since the return to Rongelap. However, the levels were well below the accepted maximum permissible levels. Analysis of bone samples on one of the men who died showed 3.7 Sr^{90} units/g calcium. Further detailed studies on the radiation ecological aspects of these surveys, including examinations of the food and human metabolism of these isotopes, is in progress and will be an important part of future investigations.

The survey team devoted considerable attention to other medical studies in the Marshallese not directly related to radiation effects but possibly having some bearing on prognosis. Findings in these studies were common to both the exposed and unexposed populations. An extensive intestinal parasite survey showed that the people were infected with many types of protozoa and helminths, although this finding did not entirely account for the generally higher incidence of eosinophilia. Among other findings that need further explanation are the general anemic tendency, the high plasma protein levels with increased gamma globulin, and the high levels of serum protein-bound iodines and vitamin B_{12}. It is hoped that some of these problems will be solved in future surveys.

Another group of investigations concerned the anthropological background of the Marshallese based on studies of genetically determined traits. Among these were determinations of various blood groups and of hemoglobin and haptoglobin types. These studies are shedding some light on the origin of these people and on the homogeneity of the population being investigated. Their blood groups resemble most closely those of people from Southeast Asia and Indonesia, and the population appears to be relatively homogenous.

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