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.

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

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

*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

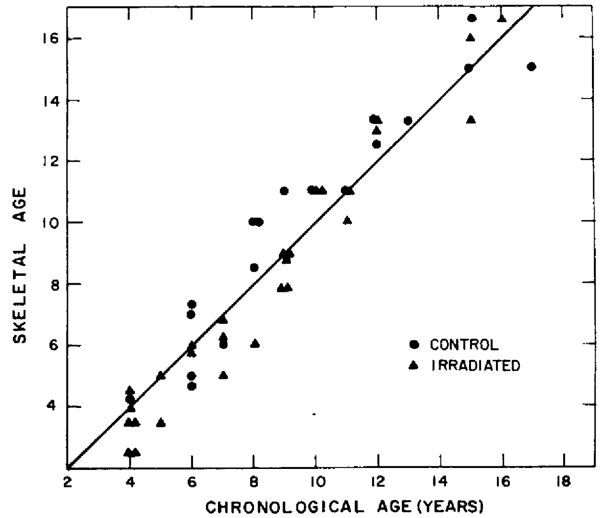

Figure 4. Skeletal maturation.

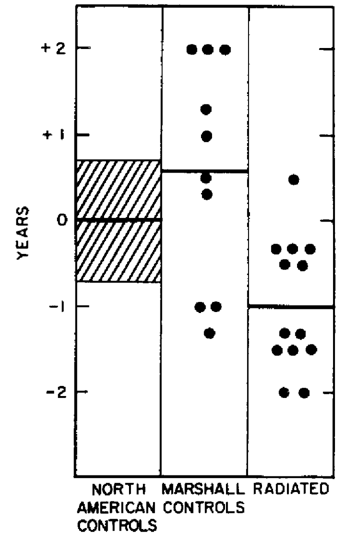

Figure 5. Deviation from normal bone age values, 4 to 9 years old.

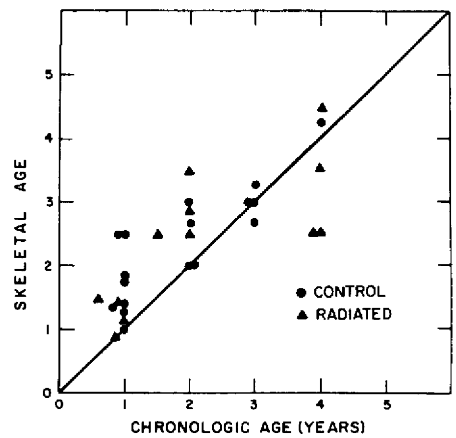

Figure 6. Skeletal maturation.

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

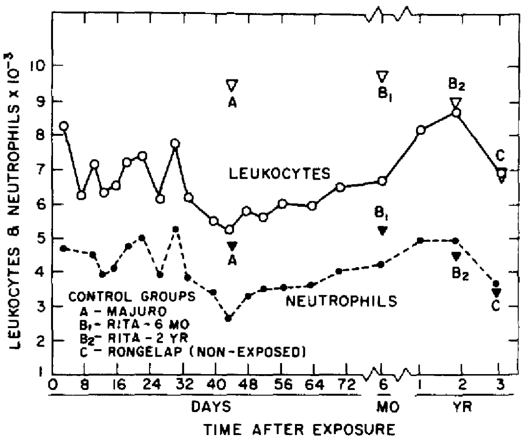

Figure 7. Leukocytes and neutrophils, Rongelap, age >5.

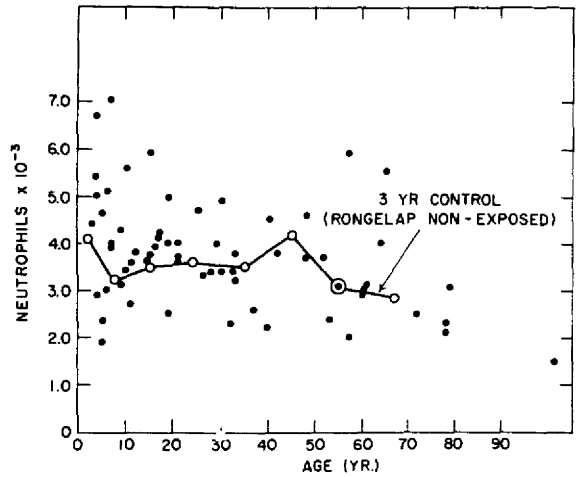

Figure 8. Neutrophils three years post-exposure, Rongelap, age >5.

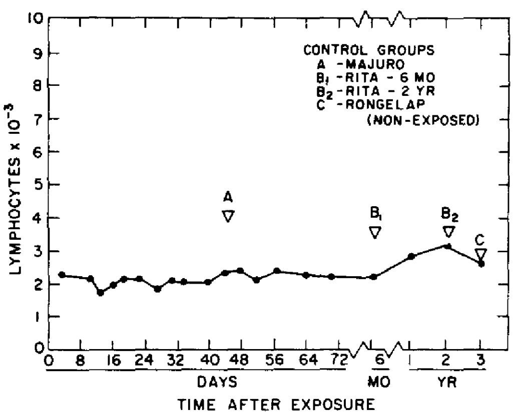

Figure 9. Lymphocytes, Rongelap, age >5.

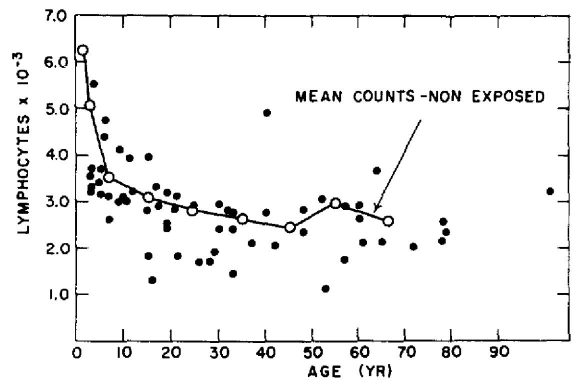

Figure 10. Lymphocytes three years post-exposure, Rongelap, age >5.

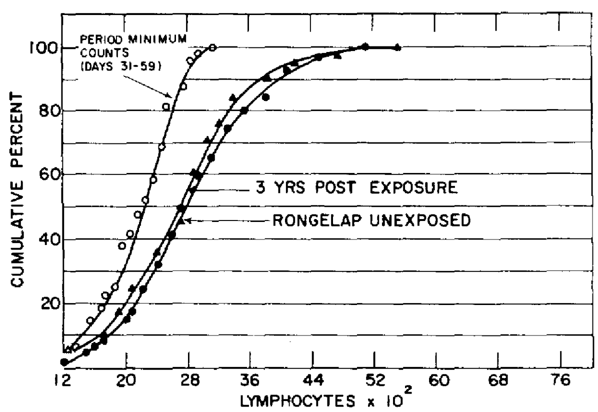

Figure 11. Lymphocytes, cumulative, Rongelap, age >5.

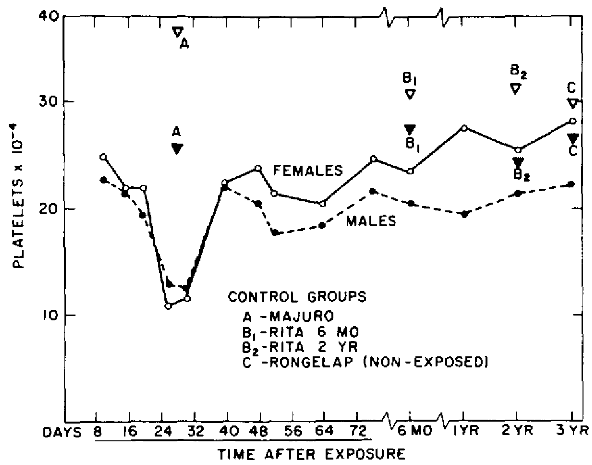

Figure 12. Platelets, Rongelap.

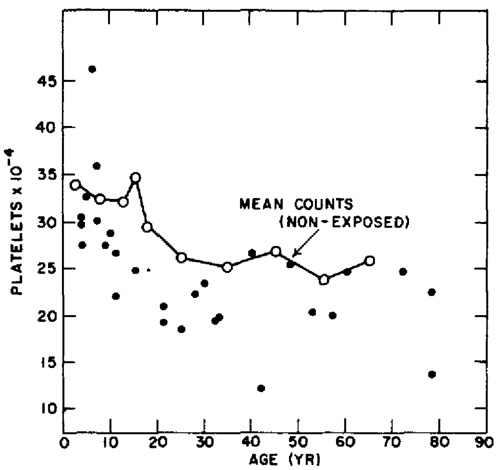

Figure 13. Platelets three years post-exposure, Rongelap males.

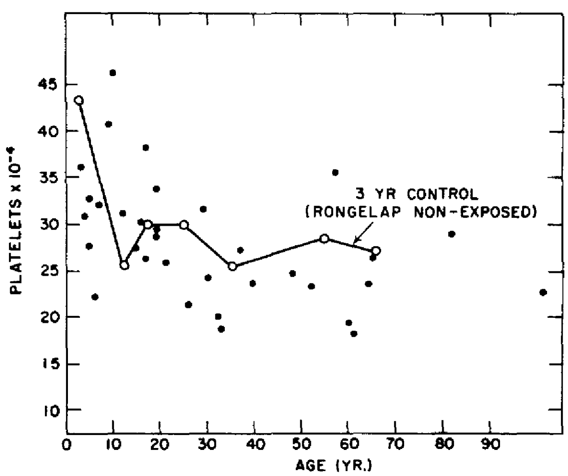

Figure 14. Platelets three years post-exposure, Rongelap females.

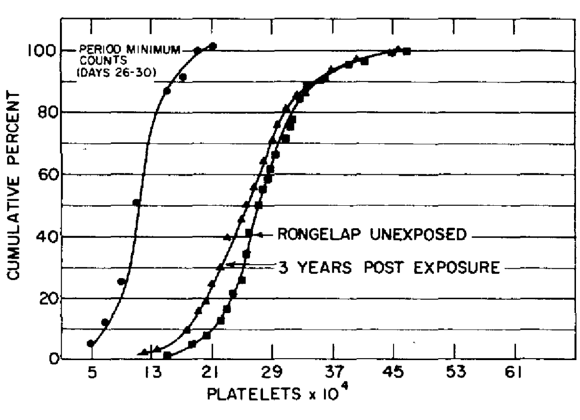

Figure 15. Platelets, cumulative, Rongelap, all ages.

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.[36] 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	$m\mu C$ 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.

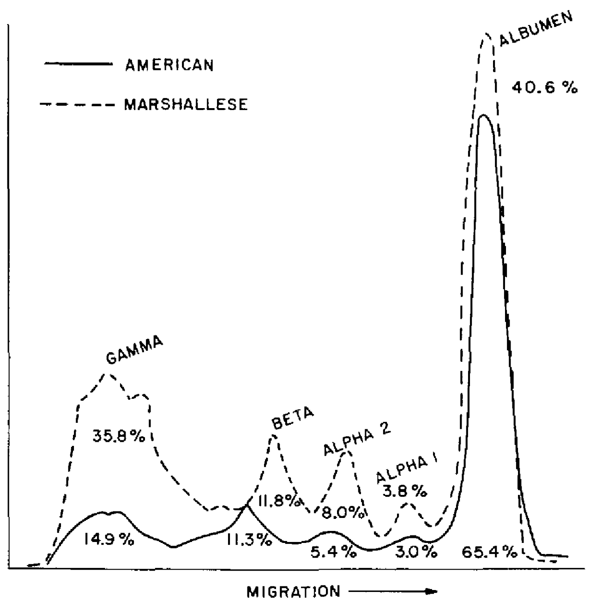

Figure 16. Blood proteins.

*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.

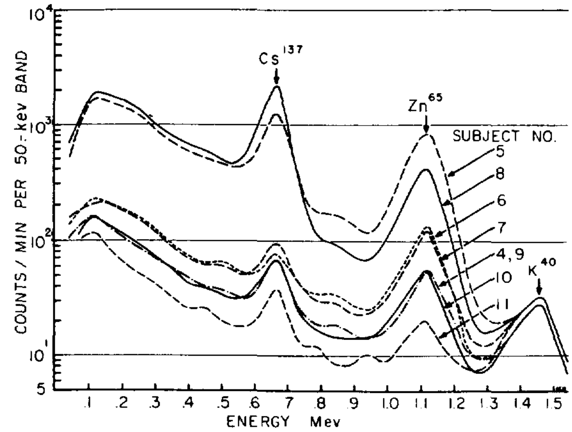

Figure 17. Net *in vivo* gamma-ray spectra of Marshallese.

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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