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March 1956

BROOKHAVEN NATIONAL LABORATORY
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Introduction

Background

Following the experimental detonation of a nuclear device in the Marshall Islands on March 1, 1954, inhabitants of four nearby islands were accidentally exposed to significant amounts of radioactive fallout material. The exposed personnel were evacuated to Kwajalein Naval Station where they were studied and cared for during a three-month period. As a result of this study, it was found that the inhabitants of the two most remote of these islands (28 Americans on Rongerik, and 157 Marshallese on Utirik) had received only minimal effects from the fallout, and further examinations were not considered necessary. Accordingly, the American servicemen were returned to duty and the Utirik people were returned to their homes. However, the 82 Marshallese who were on the two nearest islands (Rongelap and Ailingnae) showed significant effects of exposure and required continued study at intervals. Since their home islands were not considered safe at that time for habitation, they were moved to an island in Majuro Atoll where homes were built for them and they have since been comfortably established.

The results of the initial examinations have been reported (1-3). Since this time, follow-up studies on the Rongelap people at Majuro have been carried out and reported at six months (4) and at one year postexposure (5). This report concerns the third follow-up study carried out at Majuro in March 1956, two years postexposure.

Summary of Past Findings

The following is a brief summary of the past findings which can be found in detail in references 1 to 5.

During the first 24 to 48 hours after exposure, about two-thirds of the Rongelap group 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 symptom-free until about two weeks after the accident, when skin lesions and loss of hair due largely to beta irradiation of the skin developed. The effects of the irradiation can best be summarized under three headings according to the mode of irradiation: a) penetrating irradiation, b) skin irradiation, and c) internal irradiation.

a) Penetrating Irradiation. The Rongelap people received an estimated whole-body dose of 175 r and the Ailingnae people 69 r of gamma radiation. Depression of peripheral blood elements occurred as follows in the Rongelap people:

Lymphocytes fell promptly and by the third day were 55 percent of control values (unirradiated Marshallese) in adults, and 25 percent in children. The cells showed only slight recovery by six months. At one year, there was further recovery but the cells were still below control levels.

Neutrophiles fluctuated considerably during the first few weeks but fell gradually to a low of about 50 percent 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 they had returned to the level of the control population.

Platelets fell to about 30 percent of the control values by the fourth week. By six months, they had reached 70 percent of controls; at one year the mean platelet count was still below that of the control popuiation but was slightly higher than at the six-month survey.

The depression of blood elements in the Ailignae group was similar to that in the Rongelap group except that it was less marked.

Changes in the hematocrit were not remarkable in either of the two groups.

b) Beta Irradiation of the Skin. No accurate estimate of the radiation dose to the skin could be made. Spotty lesions of the skin and epilation began to develop about two weeks after exposure. The lesions occurred 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 lesions 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. By one year, however, this type of pigmentation had been greatly reduced. Deeper lesions on the dorsum of the feet continued to show lack of repigmentation, with scarring in some cases, at one year. Histopathological studies of the skin showed changes consistent with radiation damage. A common finding 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 at six months showed considerable improvement but some persisting changes.

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

c) Internal Irradiation. Radiochemical analysis of numerous urine samples of the exposed personnel showed some degree of internal adsorption of radioactive materials, probably 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 cause any serious effect. Analysis of urine samples at six months after exposure showed only barely detectable radioactivity present in some cases.

Clinical observations revealed that aside from skin lesions, loss of hair, and early symptoms, no other symptoms or disease processes had been encountered which could be attributed to radiation effects. There had been no deaths, and the diseases encountered had been no more severe or frequent than in the nonirradiated population. This was true even during the period of the greatest depression of peripheral blood elements. It was difficult to evaluate the effects on fertility; however, a number of apparently normal babies had been born and further pregnancies had occurred. Ophthalmascopic examinations, including slit lamp observations, were made initially and at one year postexposure. No opacities of the lens or other eye changes were found that could be attributed to radiation.

Procedures

The 82 Rongelap and Ailingnae people, plus nine babies born since the accident, were examined. Of the 82 controls from Rita Village on Majuro examined during the six-month follow-up study, 57 were available and were re-examined.

Physical examinations were performed and interval histories were taken on all persons. Examinations included pelvic examination of all women and rectal examination when indicated. Height and weight were recorded for all persons and special growth and development measurements of children were taken as in the past.

Careful examination of the skin, including color photography and biopsies of selected cases, was carried out. Examination of the eyes included slit-lamp observations for opacities.

Hematological examinations included total WBC, differentials, platelet counts and hematocrit. In addition, cover slip smears were prepared and fixed. They were stained and examined for phosphatase in the neutrophiles.* These data will serve as a baseline should any leukemic change later appear. In addition, sufficient smears were taken on each individual for a 4000 WBC differential count for basophiles.

Approximately 57 liters of urine were collected at random from the irradiated population and precipitated for radiochemical analysis. The urinary sediment and a limited number of individual 24-hr samples were subjected to radiochemical analysis.** In addition, roentgenographs of the right femur on all children were obtained for studies of possible effects of skeletal deposition of radionuclides.

The above examinations were carried out with the aid of several interpreters and English-speaking Marshallese nurses.

Interval History and Clinical Findings

Interval History

Both the control and exposed (Rongelap and Ailingnae) groups were in good general health during the past 12 months. An epidemic of chicken pox (with no reported complications) involved a large percentage of both populations in the period between the one- and two-year examinations. One case of uncomplicated measles occurred in the Rongelap group during the year. Five childbirths were reported among the Rongelap people and one in the control group; the infants developed normally and were free of any apparent abnormalities. Five Rongelap women and three women in the control group currently have uncomplicated pregnancies. One child and an adult in the exposed group were seriously ill during the past year and their cases will be discussed later. Two Rongelap children had been treated recently for intestinal parasites. At the time of this survey no deaths in either group had been reported during the past year. However, on May 13, 1956, one death, which will be reported below, occurred among the Rongelap people.

Clinical Findings

In general, the people of both the exposed and control groups appeared to be in good health and nutritional condition. Tables 1 and 2 list the positive clinical findings, which were about equally distributed between the two groups. None of the clinical findings in the exposed group, with the exception of residua of skin lesions, could be attributed to the effects of irradiation. A few findings were noted during the two-year study which were not recorded on previous examinations. With the exception of the cases discussed below in further detail, it was not believed that these additional findings represented recent pathological developments.

A 77-year-old man, #46, gave a history of paresis of the right upper and left lower extremities of nine months' duration with gradual improvement in strength and function

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*These studies were carried out by Dr. W.C. Moloney and Miss Lila Fliegelman of the Boston City Hospital.

**Radiochemical analysis was carried out by Lt. A.G. Schrodt (MSC) USA, and Pvt. A. Burstein, USA, of Walter Reed Institute of Research, and Dr. John Harley and Mr. Edward Hardy of the New York Operations Office of the AEC.

Table 1. Clinical findings in adults (20 years and older).

Findings	Exposed group No. of findings	Control group No. of findings
Cardiac pathology		
Cardiomegaly	3	8
Aortic valvular dis.	2	5
ASHD	2	4
Skeletal disease		
Arthritis	3	1
Kyphoscoliosis	3	-
Sacroiliac pain	-	1
Infectious disease		
Congenital syphilis	-	1
Leprosy	1	-
Neurological disease		
Cerebrovascular accident	1	-
Genito-urinary findings		
Urethral caruncle	1	-
Cystocele	2	-
Pregnancy	3	1
Diabetes	-	1
Oral pathology		
Leukoplakia (buccal mucosa)	-	1
Papilloma - tongue	-	1
Desquamation - tongue	-	1
Hepatomegaly - unexplained	-	2

Table 2. Clinical findings in children (19 years and younger).

Findings	Exposed group No. of findings	Control group No. of findings
Rheumatic heart disease	1	-
Functional cardiac murmurs	4	2
Pregnancy	2	2
Upper respiratory infection	1	1
Cervical lymphadenopathy	-	4
Hepatomegaly - unexplained	1	1

during the past few months. Important physical findings included: BP 190/66; generalized diminution of deep tendon reflexes; marked weakness and limitation of motion of the right upper and left lower extremities with some muscular atrophy of the involved parts; and inability to walk without aid. These findings can best be explained on the basis of a cerebrovascular accident.

The second case was that of an 11-year-old boy, #76, who was hospitalized in January 1956 with acute rheumatic fever and cardiac decompensation. He improved on salycilate and digitalis therapy and was discharged two weeks after admission. Present findings include cardiomegaly with regular sinus rhythm and grade 2 systolic and grade 3 diastolic apical cardiac murmurs. The diagnosis of rheumatic heart disease

with mitral stenosis and insufficiency was substantiated. At the time of examination, the boy was fully active without evidence of decompensation.

On May 13, 1956, a 46-year-old Rongelap man (#25) died suddenly after an illness of about one hour. He had been quite well except for two short illnesses occurring a year ago and four months ago characterized by pyrexia (102 to 104°F), headaches and bodyaches, general malaise, and slight cough. In addition, he had complained occasionally of vague abdominal pain but there were no associated physical findings. Previous physical examinations had been essentially negative except for hypertension (BP 148/104) which was present on the first examination two years ago, a few days after radiation exposure, and which no doubt antedated the exposure. The present illness was characterized by acute onset of dyspnea with complaint of abdominal pain. The health aide observed that his abdomen was boardlike. He died before he could be brought to the hospital and autopsy was delayed until about 20 hours after death because of religious rites.* The heart was reported to be enlarged with pericardial effusion and the presence of vegetations on the mitral valve. There was pulmonary and hepatic congestion and what appeared to be a fatty degeneration of the pancreas. Tissues were sent to Brookhaven National Laboratory for histological evaluation. Unfortunately the tissues were poorly fixed; autolysis had occurred in most specimens because of the length of time elapsing between death and autopsy, and the use of insufficient fixative. A summary of the histopathological findings follows:** The sections examined microscopically indicated that the patient had benign nephrosclerosis (hypertension) with myocardial hypertrophy (presumably, left). Coronary artery arteriosclerosis was present. Evidences of heart failure were noted in the presence of recent pulmonary edema and passive congestion, acute, of liver and spleen. No evidence of rheumatic heart disease, acute or inactive, was noted and no valvular vegetations were observed. The specimen of pancreas was autolyzed.

Growth and Development

Heights and weights based on sex and age were compared in exposed and control children (19 years of age and younger), using the data taken in the six-month and two-year surveys. Unfortunately only nine children of each sex could be matched with the controls, since not all the control children were available for re-examination. Nine males between the ages of 3 and 15 years and nine females between the ages of 5 and 19 were compared. When there were several children of the same age, the means for each age were used to calculate the over-all mean differences for the total group. The mean differences in height and weight of the exposed children compared to the controls were as follows:

	Males		Females	
	6-mo survey	2-yr survey	6-mo survey	2-yr survey
Height, in.	-2.1	-2.1	-0.1	-0.5
Weight, lb	-6.5	-7.2	+2.0	-0.2

Even though slight differences were noted between the irradiated and control children, it is not possible to attach any significance to these differences because of the small

*Dr. A. Hicking in charge of the Marshall Islands Memorial Hospital performed the autopsy.
**The histopathological findings are those of Dr. S.W. Lippincott of Brookhaven National Laboratory.

number of children involved and uncertainties concerning the racial homogeneity of the two populations. The greatest differences generally noted were between the ages of 7 through 10 years. There was no apparent difference in physical fitness between the irradiated and control children.

Greulich et al. (6), in the growth and development surveys of Japanese children who survived the atomic detonations at Hiroshima and Nagasaki, noted retardation of growth and development in the exposed male children when compared with unexposed Japanese children, whereas there was little difference between the female children of the two groups.

Skin Findings

General

The observed incidence of diseases of the skin was not excessive considering the tropical environment. Such diseases occurred with about the same frequency in the control and in the irradiated population. Impetigo, as has been noted in the past, was

Table 3. Residual skin lesions

Case No.	Sex	Age	Description
2	M	4	Mottled depigmentation of the anterior neck folds and around the anus.
11	M	53	Depigmentation of the left antecubital fossa.
17	F	6	Hyperpigmented and depigmented spots in the left antecubital fossa.
24	F	17	Slight depigmented areas on dorsum of feet.
25	M	46	Area of depigmentation and scarring over dorsum of right foot and depigmentation to a lesser extent on the left foot.
26	M	15	Depigmentation and hyperpigmentation of the right antecubital fossa. Scarred, depigmented lesion on right foot between first and second toes with hypertrophic changes in the skin and atrophy.
27	M	31	Small depigmented area in right antecubital fossa.
39	F	18	Hyperpigmentation, depigmentation, and hyperkeratosis of the back of the neck and to a lesser extent in the antecubital fossae. Small areas, not yet completely repigmented, over the dorsum of both feet.
49	F	19	Slight mottled increased pigmentation of the neck. A few areas on the dorsum of the feet not fully repigmented.
59	F	37	Hyperpigmentation and hyperkeratosis of the neck.
63	F	41	Mottled pigmented and depigmented areas on the back of the neck, left check, and forehead. Pigmented hyperkeratotic band on the left wrist and thumb.
67	F	17	Areas on dorsum of feet not yet completely repigmented.
76	M	13	Small depigmented scar on dorsum of left foot with adherence to the subcutaneous tissues.
78	F	40	Increased pigmentation and hyperkeratosis of the back of the neck.
79	M	48	Depigmented, scarred lesion on back of left ear with atrophy of the skin and fixation to cartilage. No evidence of breakdown of this lesion at present.

very prevalent in the babies and young children. However, by 8 to 10 years of age the children appeared to acquire resistance, since the disease was much less prevalent beyond those ages. Numerous pox scars were found on those individuals who had chicken pox during the past year. An itching, papular lesion over the arms, legs, and back was occasionally seen and, except for distribution, resembled scabies; this disease may have been due to the copra mite. In some individuals, small oval areas of depigmentation of the skin were noted, possibly residual from fungus infection. One case of leprosy in the Rongelap group, #77, who had lost the fingers of both hands and the toes of the right foot (except the big toe), showed hyperkeratosis and fissuring of the stumps of the hands. Indolent ulcers were present on the soles of both feet. Because of his deforming disease, this young Marshallese man secluded himself and led a lonely existence; he presented a real problem in psychological adjustment.

Residual Radiation Lesions of the Skin

Residual lesions were present in 14 of the Rongelap people, and only one residual lesion was observed among the 18 Ailingnae people. The latter were exposed to considerably less fallout and had developed much milder lesions.

Table 3 summarizes the residual skin lesions. The majority of all lesions showed improvement; almost all the early superficial lesions were completely healed, without any apparent residual changes. Figure 1 shows an early superficial lesion of the neck, and Figure 2 shows the completely healed appearance of the lesion two years post-exposure. Lesions which showed dusky, grey hyperpigmentation during the first year after exposure (mostly on the back of the neck) showed less hyperpigmentation and in most cases the pigmentation developed a more normal "mahogany" color. All residual

Figure 1 (Left). Superficial beta lesion of the back of the neck about six weeks after exposure. Note areas at sides of neck which have desquamated contrasted to the center region which shows hyperpigmented thickening of the skin which gradually desquamated also. Case #24, F, age 15.

Figure 2 (Right). Same case as Figure 1 two years after exposure, showing complete healing of lesion.

depigmented lesions continued to show varying degrees of repigmentation; in some cases repigmentation was complete. The lesions showing the most residual change were in case #25, case #26 (see Figures 3 to 6), and case #76 of the dorsum of the feet, and of the ear in case #79 (Figure 8). These lesions showed varying amounts of scarring and atrophy of the skin with some adherence of the skin to the subcutaneous tissues. The center of the ear lesion was fixed to the underlying cartilage. However, even in these lesions there was no evidence of degradation or breakdown of the tissues, and in no case was surgical repair considered necessary at this time. Although

Figure 3. Beta radiation lesions of the feet four weeks after exposure. There is a weeping ulceration between first and second toes of right foot. Note desquamation of both feet. Case #26, M, age 12.

Figure 4. Same case as Figure 3 six months after exposure. Note healing except for persisting depigmentation at sites of deeper lesions.

Figure 5. Same case as Figure 3 one year after exposure. Some repigmentation has occurred in depigmented lesions noted at six months.

Figure 6. Same case as Figure 3 two years after exposure. Further repigmentation has occurred. There is atrophy and scarring of the skin with some adherence to subcutaneous tissues at site of deepest lesion between first and second toes of right foot.

it was believed possible that these lesions might not respond well to trauma, all biopsy lesions healed per primam. There was no evidence that the intense sunlight to which these people were exposed had adversely affected any of the lesions. There appeared to be no evidence of any change which would suggest malignancy.

Histopathology

Biopsies were taken from 15 lesions showing residual changes. The following stains were used on all biopsies: 1) hematoxylin and eosin; 2) Mallory, for connective tissue; 3) Verhoeff, for elastic tissue fibers; 4) phosphotungstic acid hematoxylin, for fibrils; 5) Mayer's mucicarmine stain, for mucin; and 6) Rinehart's acid mucopolysaccharide, for mucopolysaccharide. Comparison was made with control biopsies taken from the neck, antecubital fossa, and dorsum of the foot of nonexposed Marshallese. At the time special staining of sections from earlier biopsies were not available. However, a detailed description of comparative changes between the two-year and earlier sections will be given in a future report.

The following changes were noted in the two-year postexposure sections of the biopsies:

1. No neoplastic lesions were present.
2. No epidermal cellular alterations suggestive of a precancerous condition were seen.

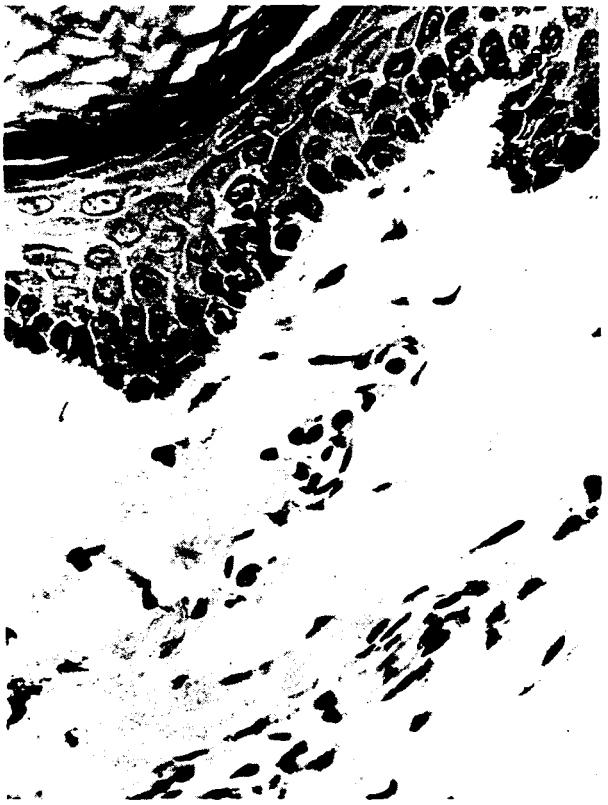

Figure 7. Section from lesion of back of neck, 512X. There is some loss of pigment in the basal layers of the epidermis and telangiectasis in the dermis. Case #39 (Table 3).

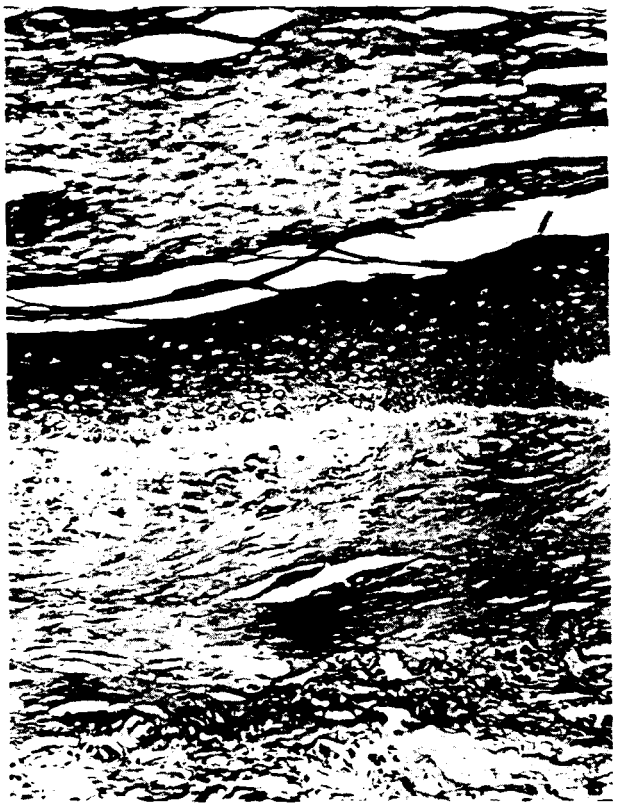

Figure 8. Section from ear lesion, 512X. There is a heavy deposition of collagen in the papillary and reticular layers of the dermis. Case #79 (Table 3).

3. In some sections acanthosis, absence of pigment in the basal layer, and atrophy and benign dyskeratosis were noted occasionally in the stratum spinosum of the epidermis.
4. The papillary layer of the dermis frequently showed distinct degenerative alterations in the collagen, characterized usually by homogenization of the latter and what appeared to be an alteration in the distribution of mucopolysaccharide when compared with control sections. Occasionally mucin was seen in areas of degeneration in the dermis.
5. Capillary dilatation was noted in the dermis and in one case in the hypodermis (Figure 7). Medial degeneration in an artery was noted in one case.
6. A single case showed increase in heavy dense bands of collagen in both the papillary and reticular layers of the dermis (Figure 8).

Most of these changes were consistent with previously reported late radiation changes in the skin.

Hematological Findings

Control

The control data* consisted of the hematological data on 134 Marshallese on Majuro Atoll obtained in April 1954, and data on another group of 82 Marshallese from Rita Village on Majuro taken in September 1954 and again in this survey. These control populations had been matched for sex and age with the exposed population.

Results

The hematological findings are presented in Tables 4 through 6 and Figures 9 through 13. As in the past, the groups were divided according to age and sex in order to make appropriate comparisons of the various blood elements.** Babies born since exposure were not included in the comparative studies so that there were fewer individuals in the younger age group.

Leukocytes. In both the Rongelap and Ailingnae people, the mean total leukocytes and mean absolute neutrophile counts, as in the one-year examinations, were equal to the control means in both the <5- and >5-year age groups (Tables 4 and 5, and Figure 9). However, there were some people who had neutrophile counts slightly below normal (10 with counts of 2500 or below in the exposed groups compared with two in the control group). The fact that none of these people had had comparably low counts at the one-year examination tended to make the finding less significant. The mean of the exposed groups was brought up to the control level by the presence of slight neutrophilia in some individuals. This effect is represented in Figure 10 by a slight change in slope of the neutrophile cumulative distribution curves.

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*Only 57 of the Rita group were available for examination during the present survey.

**The people were divided as follows:

			Rongelap	Ailingnae
Leukocytes:	both sexes	<5 years	6	2
	both sexes	>5 years	58	16
Platelets:	male	<10 years	9	2
	male	>10 years	22	5
	female	all ages	33	11
Hematocrits:	male	<15 years	12	2
	male	>15 years	19	5
	female	all ages	33	11

Table 4. Rongelap group and control mean blood counts by day and by age.

Postexposure day	WBC ($\times 10^3$) <5	WBC ($\times 10^3$) >5	Neutrophiles ($\times 10^3$) <5	Neutrophiles ($\times 10^3$) >5	Lymphocytes ($\times 10^3$) <5	Lymphocytes ($\times 10^3$) >5	Platelets ($\times 10^4$) Male <10	Platelets ($\times 10^4$) Male >10	Platelets ($\times 10^4$) Female all ages	Platelets ($\times 10^4$) Total group	Monocytes ($\times 10^2$) <5	Monocytes ($\times 10^2$) >5	Eosinophiles ($\times 10^2$) <5	Eosinophiles ($\times 10^2$) >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
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

*Excluding pregnancy.

Table 5. Ailingnae group and control mean blood counts by day and by age.

Postexposure day	WBC ($\times 10^3$) <5	WBC ($\times 10^3$) >5	Neutrophiles ($\times 10^3$) <5	Neutrophiles ($\times 10^3$) >5	Lymphocytes ($\times 10^3$) <5	Lymphocytes ($\times 10^3$) >5	Platelets ($\times 10^4$) Male <10	Platelets ($\times 10^4$) Male >10	Platelets ($\times 10^4$) Female all ages	Platelets ($\times 10^4$) Total group	Monocytes ($\times 10^2$) <5	Monocytes ($\times 10^2$) >5	Eosinophiles ($\times 10^2$) <5	Eosinophiles ($\times 10^2$) >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
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

Table 6. Hematocrits

	Rongelap			Ailingnae		
Postexposure day	Male <15	Male >15	Female all ages	Male <15	Male >15	Female all ages
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
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

The mean absolute lymphocyte level was slightly increased over the one-year level. However, the mean level was still somewhat below the mean control level (75 to 80 percent) in both age groups in the Rongelap and Ailingnae people (Tables 4 and 5). In the exposed groups, six people had lymphocyte counts of 1500 or below; none in the control group were this low. Five of the six had also shown low counts at one year and before. The cumulative curves in Figure 11 show the progressive changes in absolute lymphocytes at different postirradiation times compared with the Majuro controls.

Monocytes in both exposed groups showed an increase over the one-year level and were about equal to the two-year Rita control level, but were somewhat below that of the Majuro controls.

Eosinophiles showed an increase over the one-year level in both groups and were slightly above the Majuro control level, but slightly below the two-year Rita control level in the Rongelap group. A considerable number of individuals in both the exposed and control groups showed eosinophilia. Since it was thought that parasitic infestation might have been responsible, stool examinations on 10 Rongelap people with high eosinophile counts were done, but no ova or parasites were found. The eosinophilia might have been due to trichinosis or some obscure cause.

Platelets. The mean platelet level in the Rongelap males showed a slight increase over the one-year level, but in the females it showed a slight decrease (Table 4) so that the mean of the combined groups was about the same as at one year (Figure 12). The cumulative distribution curves of platelets for the Rongelap group (Figure 13) showed little difference at one and two years, whereas the difference between six months and one year was readily apparent. The less-exposed Ailingnae group showed no increase in the mean platelet level at two years compared to one year except for the younger males (Table 5). In both exposed groups, the platelet levels were between 70 and 85 percent of the control levels, depending on which control group was used for comparison. At this examination, there were four individuals with platelet counts below 150,000; the lowest count was 68,000. Three of the four had previously shown low counts. Only one control individual of all control groups had a platelet count below 150,000.

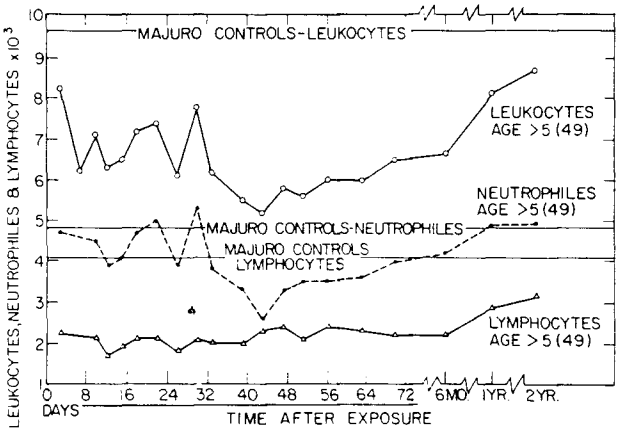

Figure 9. Rongelap leukocytes, neutrophiles, and lymphocytes.

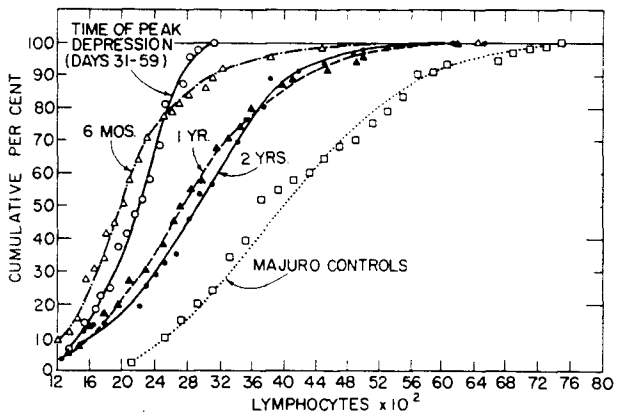

Figure 11. Rongelap lymphocytes, cumulative, age >5.

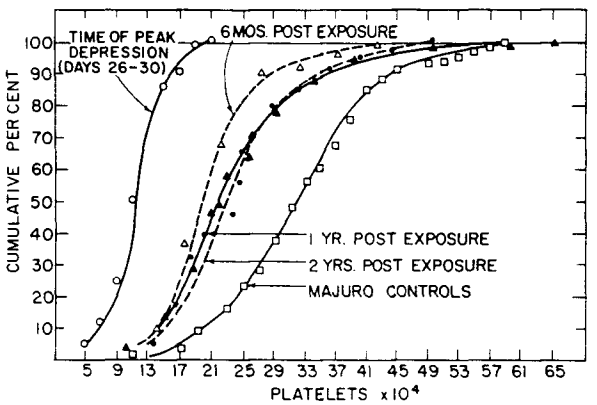

Figure 13. Rongelap platelets, cumulative, all ages.

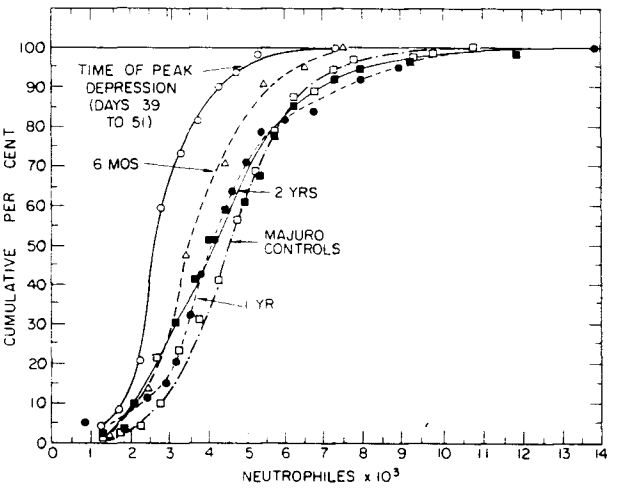

Figure 10. Rongelap neutrophiles, cumulative, age >5.

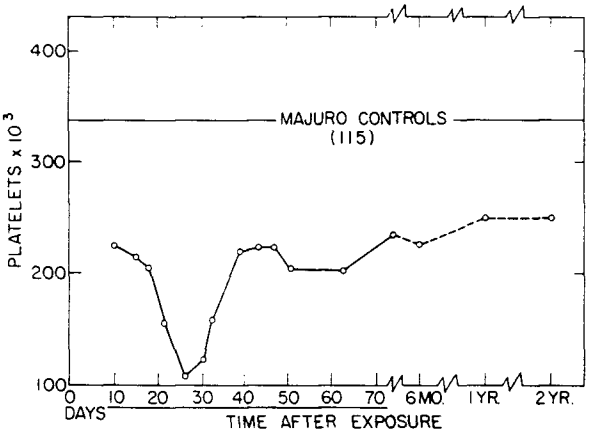

Figure 12. Rongelap platelets, pooled data, 64 people.

Hematocrits. In both exposed groups the hematocrit levels were not remarkably different from the control levels (Table 6).

Special examination of blood smears, stained for alkaline phosphatase, was carried out on both exposed and control groups. No significant findings in regard to a leukemic process were reported but this examination yielded good baseline data on these populations for future examinations. In this connection basophile counts based on a 4000 cell count of each individual showed no significant increase in basophiles in any exposed individual.

Ophthalmic Examination

Results

Ocular disorders were observed in 45 of the 91 Rongelap people, and in 24 of the 57 controls. These disorders are presented in Table 7 and are summarized as follows:

a) Pterygii were the most common, occurring in 27 percent of the Rongelap and 18 percent of the control people.

b) Pengueculae occurred in 19 percent of the Rongelap and 11 percent of the control group. The greatest incidence was in the 40 to 60 age group.

c) Cataracts were found in 16 percent of the Rongelap and 11 percent of the control group. Of the cataracts noted in the Rongelap group, 14 percent were of the senile type and occurred at an average age of 60.4 years. Two percent of the cataracts were of the congenital type. In the controls, all were of the senile type and occurred at an average age of 65.3 years.

d) Corneal Pigmentation was observed in a large number of both the Rongelap and control people and was considered to be a racial characteristic. The remainder of the ocular disorders found (arcus senilis, strabismus, corneal scars, healed choroiditis, retinopathy, etc.) were about equally distributed in the Rongelap and control groups.

There were three cases of cataracts (two in the Rongelap group and one in the control group) which caused severe impairment of vision and necessitated surgical removal. A pterygium was also removed from one of the Rongelap people.

All lens opacities and cataracts could be classified as congenital, presenile, or senile. There were no opacities that resembled those due to the effects of radiation. It was not known whether or not the whole-body dose of 175 r of gamma radiation received by the Rongelap people would result in opacities of the lens at a later date. The incidence of cataracts and other ocular disorders observed in the Rongelap and control people was consistent with what might be expected when their racial background and the climatic conditions under which they live were taken into consideration.

Analysis for Internal Radioisotopes

Radiochemical analysis of 57 liters of chemically treated pooled Rongelap urine showed that the precipitate contained strontium-90 in the amount of 64 $\pm$ 4 disintegrations/min, with a like amount of yttrium-90. The greatest activity, present in the amount of 700 $\pm$ 10 disintegrations/min, was identified as due to cerium-144 - praseodymium-144. Earlier studies had shown that the average 24-hr urine output of the Marshallese was 580 ml. Thus the 57 liters represented about 100 24-hr samples which gave the following values in disintegrations/min/24-hr sample: strontium-90, 0.6; and cerium-144 - praseodymium-144, 7.0. These values were estimated to be well below the maximum permissible body burdens of these isotopes and, when biological and physical half-lives were taken into consideration, agreed fairly well with the original estimates of body burden two years earlier.

Table 7. Incidence of eye disorders in Rongelap and control populations.

Eye disorders	Rongelaps*	Percent	Controls**	Percent
1. Arcus senilis	13	14.2	6	10.5
2. Chalazion	3	3.2	-	-
3. Ptosis	-	-	1	1.7
4. Nerve VII paralysis	2	2.0	-	-
5. Conjunctivitis	2	2.0	1	1.7
6. Foreign bodies imbedded in the lids	1	1.1	-	-
7. Strabismus	6	6.4	2	3.5
8. Phthisis bulbi	1	1.1	1	1.7
9. Pinguecula				
a. unilateral	3	3.2	1	1.7
b. bilateral	5	5.2	4	7.1
10. Pterygium in one eye and pinguecula in the fellow eye	9	9.6	1	1.7
11. Pterygium				
a. unilateral	5	5.2	4	7.1
b. bilateral	11	12.1	4	7.1
12. Pterygium, 3 or more	-	-	1	1.7
13. Corneal pigmentation	3	3.2	-	-
14. Corneal scars	1	1.1	1	1.7
15. Pannus	1	1.1	-	-
16. Interstitial keratitis	-	-	1	1.7
17. Argylle-Robinson pupil	1	1.1	-	-
18. Ectropion uveii	-	-	-	-
19. Aphakia	1	1.1	2	3.5
20. Cataracts				
a. Congenital	1	1.1	-	-
b. Senile	6	6.4	2	3.5
1. Incipient	8	8.4	4	7.1
21. Congenital remnants of the hyaloid system				
a. Hyaloid remnants	1	1.1	-	-
b. Mittendorf dot	1	1.1	-	-
22. Drusen	1	1.1	1	1.7
23. Retinal scars, healed	1	1.1	-	-
24. Choroiditis, healed	3	3.2	1	1.7
25. Vitreous floaters	6	6.4	3	5.3
26. Macular degeneration	1	1.1	2	3.5
27. Retinopathy, arteriosclerotic	2	2.0	1	1.7
28. Retinopathy, diabetic	-	-	1	1.7

*Total: 91; with pathology: 45 (49%); without pathology: 46.
**Total: 57; with pathology: 24 (42%); without pathology: 33.

Radiochemical analysis of bone samples taken from the Marshallese man who died revealed strontium-90 in the amount of 1.6 ± 0.06 disintegrations/min/g ash, well below the accepted tolerance limit and in the range of activity for this isotope found in the bones of Americans.

Examination of radiographs of femurs of exposed children revealed no bone defects from possible deposits of radionuclides.

Summary and Conclusions

The medical survey of the Rongelap people two years after exposure to fallout radiation shows that the people appear to have been in a generally good state of health

and nutrition and are making satisfactory recovery from their radiation exposure. Serious illness has occurred in two individuals but neither these illnesses nor clinical findings in other individuals can be attributed to radiation effects. One death in May 1956, that of a 46-year-old Rongelap man, was due to hypertensive heart disease. Previous examinations had shown that the disease was undoubtedly present at the time of exposure to fallout radiation.

There is evidence of continued improvement of hemopoiesis. The mean lymphocyte count is slightly increased over the one-year levels, but is still slightly below the mean control count. The mean platelet level is about the same as found at one year after exposure and is still slightly below the control level. The mean neutrophile count at one year after exposure had reached the control level. The delay in complete recovery of lymphocytes and platelets is similar to that reported in the two-year follow-up studies of the Japanese casualties of the atomic bombings (7, 8). Evidence from the Marshallese experience indicates that the lowered levels of these blood elements have not lowered the resistance of the people to disease, and the present levels are not considered to represent a serious condition.

Residual changes in the skin from the beta irradiation continue to show improvement. Pigment aberrations are still evident in 15 cases and in four of these there is also scarring with some adherence of the skin to the subcutaneous tissue. However, there is no gross evidence of tissue breakdown or malignant change in any of these lesions, and surgical repair is not considered necessary at this time. Histological examination of skin biopsies at sites of radiation lesions shows residual effects of radiation damage, but no evidence of premalignant or malignant changes.

Ophthalmological survey reveals that there are no radiation-induced lens opacities, and the incidence of ocular lesions is similar in exposed and control populations.

The radiochemical analysis of the urine of the Rongelap people shows measurable activity which is largely due to cerium-144 - praseodymium-144 with only slight activity due to strontium-90. The body burden of these isotopes is estimated to be well below the permissible levels. Examination of bone specimens in the case of the one man who died shows no radiation that can be definitely associated with fallout deposition in the bones. Studies of radiographs of the femurs of the exposed children show no evidence of any bone defects from possible deposits of radionuclides.

Recommendations

Continued medical surveys of the Rongelap people on a yearly basis are recommended, particularly since certain blood elements have not completely recovered, and continued observations of residual radiation effects on the skin are desirable.

The following studies are proposed for the next medical survey (three years post-exposure). In view of the errors associated with single blood examinations and the consequent difficulties of interpretation, it is desirable that several blood examinations be carried out over a period of several weeks on both Rongelap and control populations. Routine history and physical examinations, growth and development studies on the children, and special skin examinations with photography and biopsy of selected lesions should be included. Baseline electrocardiographs should be carried out on all people over 40 years of age and complete routine urine analysis should be carried out on all personnel. In addition, radiochemical urine analysis should be repeated with additional samples from unexposed people. It is also recommended that a geneticist accompany the survey team to initiate baseline genetic studies.

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