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MEDICAL SURVEY OF MARSHALLESE TWO YEARS AFTER EXPOSURE TO FALL-OUT RADIATION

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• *Detonation of a nuclear device in 1954 resulted in the exposure of 82 people to fall-out radiation consisting of a whole-body dose of gamma radiation, beta radiation to the skin from radioactive material in contact with the surface, and internal radiation from radionuclides absorbed from food and drink. Gastrointestinal symptoms occurred during the first 24 to 48 hours after exposure and then subsided. Irritation of skin and conjunctiva was seen during the same period. No subsequent abnormalities were seen in the eyes, but the skin manifested epilation and spotty lesions beginning about two weeks after the exposure. Residual skin lesions were found in 15 subjects two years after the exposure. Hematological data show a progressive recovery from the initial damage. The general health of the exposed people was good, but the irradiated male children showed a mean deficiency of 5.33 cm. in height and 3.4 kg. in weight two years after the exposure. No comparable effect was seen in the girls. The quantitative data obtained from radiochemical analysis of the urine showed that these people are still excreting cerium-144, praseodymium-144, and strontium-90, but in amounts estimated to be well below permissible levels.*

This report concerns the medical follow-up survey of 82 Marshallese people two years after exposure to fall-out radiation. On Rongelap island, 64 people and, on Ailingnae, 18 people were exposed to the radiation on March 1, 1954, after an experimental detonation of a nuclear device some 100 miles away. Initial and follow-up studies on these people six months and one year after exposure have been reported. The following is a brief summary of previous findings, which can be found in detail in the previous reports.[1]

Background

During the first 24 to 48 hours after exposure, about two-thirds of the persons in 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 lachrimation and burning of the eyes. After this, the people remained symptom-free except for symptoms associated with skin lesions resulting from beta irradiations of the skin, beginning about two weeks after the accident. The effects of the irradiation can best be summarized according to the mode of irradiation under three headings: (1) penetrating irradiation, (2) skin irradiation, and (3) internal irradiation.

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: Lymphocyte levels fell promptly and by the third day were 55% of control values and in the children 25% of control values. These cells remained at this level, with only slight recovery by six months. At one year, there was further recovery, but they were still below control levels. Neutrophil levels fluctuated considerably during the first few weeks, but they 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 they had returned to the level found in the control population. Platelet levels fell to about 30% of the control values by the fourth week. By six months, the levels were still depressed to 70% of control levels, and at one year the mean platelet count was still below that in the control population, but it was slightly higher than at the six-month survey. The depression of blood elements in the Ailingnae group was similar to that in the Rongelap group except that it was less marked. Changes in the hematocrit had not been remarkable in either of the two groups.

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 the exposure. The lesions occurred largely on exposed parts of the body that were not covered by clothing. Most of the lesions were superficial and exhibited pigmentation and dry, scaly desquamation and were associated with little pain. Rapid healing and repigmentation followed. Some lesions were deeper, exhibiting wet desquamation, and were more painful, and 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 pigmentation of a grayish, dusky color and a thickening of the skin with "orange-peel" appearance. By one year, however, this type of pigmentation had greatly lessened. 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. Spotty transepidermal damage with atrophy and flattening of the rete pegs was a common finding, 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 with some persisting histopathological changes.

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Internal Irradiation.—Radiochemical analysis of numerous urine samples from the exposed persons showed some degree of internal absorption of radioactive materials, probably as a result of 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 six months after exposure showed that there was only barely detectable radioactivity remaining in some cases.

These studies revealed that, other than the occurrence of skin lesions, loss of hair, and early symptoms, there had been no other symptoms or disease processes encountered that could be attributed to radiation effects. There had been no deaths. The diseases encountered had been no more severe or frequent than in the nonirradiated population. This was true even during the period when the greatest depression of the peripheral blood elements occurred. It was difficult to evaluate the effects on fertility. A number of apparently normal babies had been born, however, and further pregnancies had occurred. Ophthalmoscopic examinations and slit-lamp observations were made initially and at one year after the exposure. No opacity of the lens or other eye changes were found that could be attributed to radiation.

Present Findings

The present survey two years after exposure included examination of the exposed Marshallese (64 Rongelap and 18 Ailingnae people, along with 10 babies born to these people since the event) and, in addition, a control group of 57 unexposed Marshallese from Rita village on Majuro who were previously examined at the time of the six-month survey. In addition, control data on blood from another group of 127 unexposed Marshallese from Majuro, obtained at the time of the initial survey, was also used for comparison of hematological findings.

History During Interval and Clinical Findings.—Both the control and exposed groups had been in good general health during the previous 12 months. An epidemic of chickenpox, with no reported complications, involved a large percentage of both populations in the interim between the one-year and two-year examinations. One case of uncomplicated measles occurred in the Rongelap group during the year. In this period, five childbirths were reported among the Rongelap people and one in the control group. These infants have developed normally and are 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, recently after this survey (May 13, 1956), one death, which will be discussed below, occurred among the Rongelap people.

Physical examination revealed that the people of both the exposed and control groups appeared to be generally in good health and with good nutritional status. Clinical abnormalities were not unusual and were about equally distributed between the two groups. With the exception of the residua of skin lesions, none of the findings in the exposed groups could be attributed to the effects of irradiation. A 77-year-old man gave a history of paresis of the right upper and left lower extremities of nine months' duration, with gradual improvement in strength and function during the previous few months. Clinical findings substantiated a diagnosis of cerebrovascular accident. An 11-year-old boy had been hospitalized about a year previously with acute rheumatic carditis and cardiac decompensation. (This disease, though uncommon, does occur in the Marshall Islands.) The diagnosis of rheumatic heart disease with mitral stenosis and insufficiency was substantiated, and, at the time of examination, the boy was fully active without evidence of decompensation.

On May 13, 1956, a 46-year-old Rongelap man died suddenly after an illness of about one hour. The patient had been quite well until his present illness, except for two short illnesses, which occurred a year ago and four months previously, and were characterized by pyrexia (102-104 F [38.9-40 C]) headaches and bodyaches, general malaise, and a slight cough. In addition, he had complained occasionally of vague abdominal pain, but there were no associated physical findings present. Previous physical examinations had given essentially negative results except for hypertension (blood pressure 148/104 mm. Hg), which was present on the first examination, a few days after the radiation exposure occurred (2 years previously). The condition no doubt antedated the exposure. The present illness was characterized by acute onset of dyspnea, and the patient complained of abdominal pain. He died before he could be brought to the hospital. Autopsy and microscopic examination of tissues revealed myocardial hypertrophy (left side) and pericordial effusion with pulmonary and hepatic congestion; benign nephrosclerosis; and coronary artery arteriosclerosis. A diagnosis of hypertensive heart disease with congestive failure seemed justified. There was no apparent causal relationship with radiation effects, particularly since hypertension was undoubtedly present at the time of the radiation exposure.

Growth and Development: Growth and development, based on height and weight changes, were compared in nine males, between the ages of 3 and 15 years, and in nine females, between the ages of 5 and 19 years, from the exposed and control groups. Unfortunately, control data were only available from the six-month and the present survey for comparison, and the numbers were limited due to the inability to locate some of the previously matched control children. The irradiated male children, compared to matched controls at both six months and two years, showed a mean deficiency of 2.1 in. (5.33 cm.) in height and 6.5 lb. (2.9 kg.) at six months after exposure and 7.2 lb. (3.4 kg.) at two years. There was no real difference in the female children. Even though slight differences were noted between the irradiated and control male children, it is not possible to attach any significance to these differences because of the small number of children involved and uncertainties concerning the racial homogeneity of the two populations. Greulich and co-workers,[2] in surveys of Japanese children who survived the atomic bombings at Hiroshima and Nagasaki, noted retardation of growth and development in the exposed male children, when com-

pared with unexposed Japanese children, whereas there was little difference between the female children of the two groups.

Residual Radiation Lesions of the Skin.—Residual lesions were present in 15 of the Rongelap people, and only one residual lesion was observed among the 18 Ailingnae people. The latter group was exposed to considerably less fall-out, and they had developed much milder lesions.

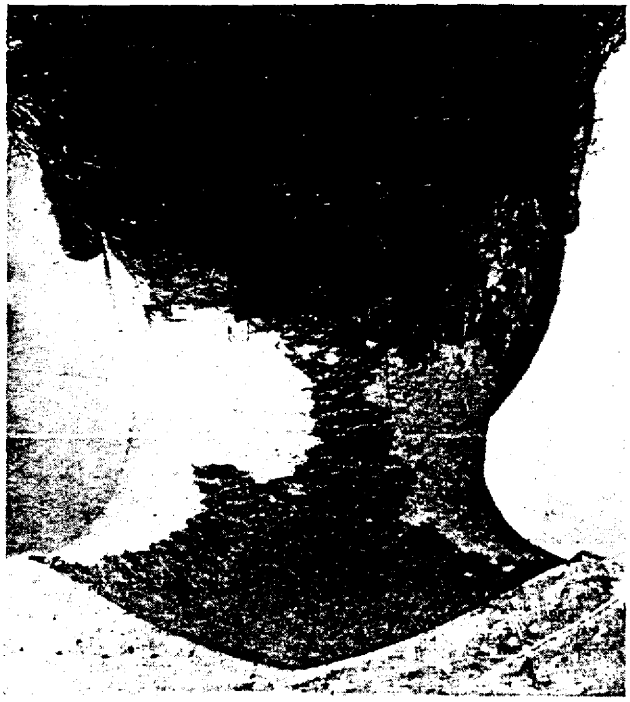

Fig. 1.—Photograph showing superficial lesion due to beta radiation of back of the neck in a 15-year-old girl about six weeks after exposure. Note areas at sides of neck that have desquamated as contrasted to the center region, which shows hyperpigmented thickening of skin, which gradually desquamated also.

The majority of all lesions showed improvement. Almost all of the early superficial lesions were completely healed at this time, without any apparent residual changes. Figure 1 shows an early superficial lesion of the neck, and figure 2 shows the completely healed appearance of this lesion at the time of this study. Lesions that showed dusky, gray hyperpigmentation during the first year after exposure (mostly on the back of the neck) showed less hyperpigmentation, and in most cases there had developed a more normal mahogany color. All residual depigmented lesions continued to show varying degrees of repigmentation, and in some cases repigmentation was complete. The lesions showing the most residual change were those in three cases of lesions of the dorsum of the feet and one lesion of the ear. These lesions showed varying amounts of scarring and atrophy of the skin, with some adherence of the skin to the subcutaneous tissues (fig. 3 and 4). The center of the ear lesion was fixed to the underlying cartilage. Even in these lesions, however, there was no evidence of degradation or breakdown of the tissues, and in no case was surgical repair considered necessary at the time of this study. Although it was believed possible that these lesions might not respond well after trauma, all biopsy lesions healed per primam. There was no evidence that the intense sunlight to which these people are exposed had adversely affected any of the lesions. There appeared to be no evidence of any change which would suggest malignancy.

Biopsy specimens were taken from 15 residual lesions. Comparison was made with control biopsy specimens taken from the neck, the antecubital fossa, and the dorsum of the foot from nonexposed Marshallese. Specially stained sections from earlier biopsy specimens were not yet available at the time of writing. A detailed description of comparative changes in the present sections with earlier sections, however, will be made the subject of a future report.

The following changes were noted in the two-year postexposure biopsy sections: 1. No neoplastic lesions were present. 2. No epidermal cellular alterations suggestive of a precancerous lesion were seen. 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 collagen 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 patient, in the hypodermis. Medial degeneration in an artery was noted in one patient. 6. The biopsy specimen from a single patient showed increase in heavy dense bands

Fig. 2.—Photograph in same patient as figure 1 two years after exposure showing complete healing of lesion.

of collagen in both the papillary and reticular layers of the dermis. Most of these changes were consistent with late radiation changes in the skin previously reported.

Hematological Findings.—As in the past, the groups were divided according to age and sex in order to make appropriate comparisons of the various blood elements.

The divisions were as follows: leukocyte counts in persons under 5 years of age (6 from Rongelap and 2 from Ailingnae) and in persons over 5 (58 from Rongelap and 16 from Ailingnae); platelet counts in males under 10 (9 from Rongelap and 2 from Ailingnae), in males over 10 (22 from Rongelap and 5 from Ailingnae), and in all females (33 from Rongelap and 11 from Ailingnae); and hematocrits in males under 15 (12 from Rongelap and 2 from Ailingnae), in males over 15 (19 from Rongelap and 5 from Ailingnae), and in all females (33 from Rongelap and 11 from Ailingnae).

In both the Rongelap and Ailingnae people, the mean total leukocyte level and mean absolute neutrophil counts, as in the one-year examinations, were equal to the control mean levels in both the under-5 and over-5 age groups (fig. 5). There were some people, however, who had neutrophil counts slightly below normal (10 with counts of 2,500 or below per cubic millimeter in the exposed groups as compared with 2 in the control group). None of the people with these lower counts had comparably low counts at the one-year examination, however, which tends to make the finding less significant. The mean level in the exposed groups was brought up to the control level by the presence of slight neutrophilia in some individuals.

The mean absolute lymphocyte level was slightly increased over the one-year level. The mean level was still, however, somewhat below the mean control level (75-80%) in both age groups in the Rongelap and Ailingnae people (fig. 5). In the exposed groups, six people had lymphocyte counts of 1,500 or below

Fig. 3.—Photograph showing beta-radiation lesions of the feet in 12-year-old boy four weeks after exposure. There is a weeping ulceration between first and second toes of right foot. Note desquamation of both feet.

per cubic millimeter as compared to none in the control group. Five of the six had shown low counts also at one year and before. The mean monocyte levels in both exposed groups showed an increase over the one-year level and were about equal to the two-year levels in the Rita controls but were somewhat below those in the Majuro controls.

The mean eosinophil levels showed an increase over the one-year level in both groups and were slightly above the mean level of the Majuro controls, but, in the Rongelap group, they were slightly below the two-year levels in the Rita controls. 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

Fig. 4.—Photograph in same patient as in figure 3 two years after exposure showing that further repigmentation has occurred. There is atrophy and scarring of skin with some adherence to subcutaneous tissues at site of deepest lesion, between first and second toes of right foot.

eosinophil counts were done, but no ova or parasites were found. The eosinophilia might be due to trichinosis or some obscure cause.

The mean platelet level in the Rongelap males showed a slight increase over the one-year level, but in the females the mean level showed a slight decrease so that the mean of the combined groups was about the same as at one year (fig. 5). The less-exposed Ailingnae group showed no increase in the mean platelet level at two years compared to that at one year, except for the younger males who showed an increased level. In both exposed groups, the platelet levels were between 70 and 85% of the controls (depending on which control group was used for comparison). There were four individuals, all in the Rongelap group, with platelet counts below 150,000 per cubic millimeter. (The lowest count was 68,000.) Of the four, three had previously shown low counts. Only one person in the control groups had a platelet count of below 150,000 per cubic millimeter. The delay in the return to normal of the lymphocyte and platelet levels is similar to that reported in follow-up studies of Japanese casualties two years after the atomic bombings.[3] In both exposed groups the hematocrit levels were not remarkably different from the control levels.

Special examination of blood smears from both exposed and control groups, stained for alkaline phosphatase, have been carried out. No significant findings in regard to a leukemic process were found, but this examination yields good base-line data on these populations for future examinations. Differential counts on 4,000 white blood cells showed no cases in which the proportion of basophils was increased.

Ophthalmic Examinations.—Ocular disorders were about as common in the exposed as in the control population. All lens opacities and cataracts could be classified as congenital, presenile, or senile. There were no opacities that resembled those due to effects of radiation. It is not known whether or not the whole-body dose of 175 r of gamma radiation received by the Rongelap people may 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 is consistent with that which might

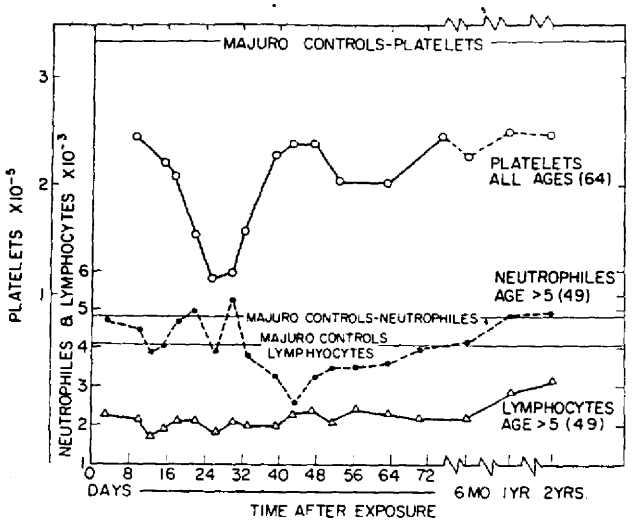

Fig. 5.—Graph showing effect of whole-body radiation (175 r) on blood elements in Rongelap people.

be expected when their racial background and the climatic conditions under which they live are taken into consideration.

Analysis for Internal Radioisotopes

Radiochemical analysis of 57 liters of chemically treated pooled urine from Roneglap people showed that the precipitate contained radioactive strontium (Sr^{90}) in the amount of 64 ±4 disintegrations per minute, with a like amount of radioactive yttrium (Y^{90}). The greatest activity, present in the amount of 700 ±10 disintegrations per minute, was identified as due to radioactive cerium (Ce^{144}) and radioactive praseodymium (Pr^{144}). Earlier studies had shown that the average 24-hour urine output of the Marshallese was 580 ml. Thus the 57 liters represented about 100 24-hour samples, which gave the following values in disintegrations per minute per 24-hour sample: Sr^{90}, 0.6 and Ce^{144} and Pr^{144}, 7.0. These values are estimated to be well below the maximum permissible body burdens of these isotopes and when biological and physical half lives are taken into consideration agree fairly well with the original estimates of body burden two years ago.

Radiochemical analysis of bone samples taken from the Marshallese man who died revealed Sr^{90} in the amount of 1.6 ±0.06 disintegrations per minute per gram of ash, which is well below the accepted tolerance limit and is in the range of activity for this isotope found in the bones of Americans. Examination of roentgenograms of femurs of exposed children revealed no bone defects from possible deposits of radionuclides.

Summary

The medical survey of the Rongelap people two years after exposure to fall-out radiation shows that the people appear to have been generally in a good state of health and nutrition and are making satisfactory recovery from their radiation exposure. Serious illness had occurred in two individuals, but neither of these illnesses nor clinical findings in other individuals can be attributed to radiation effects. One death, which was due to hypertensive heart disease, occurred in May, 1956, in a 46-year-old Rongelap man. The cause of death could not be correlated with radiation effects. Previous examinations show that the disease was undoubtedly present at the time of exposure to fall-out radiation.

There is evidence of continued improvement of hemopoiesis. The mean lymphocyte count, which was slightly increased over the one-year levels, was still found to be slightly below the mean control count. The mean platelet level is about the same as that found at one year after exposure and is still slightly below the control level. The mean neutrophil count, as at one year after exposure, was up to the control level. 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 abberations are still evident in 15 cases, and, in 4 of these, there is also scarring with some adherence of the skin to the subcutaneous tissue. There is, however, no gross evidence of tissue breakdown or malignant change in any of these lesions, and surgical repair is not considered necessary at the time of this study. Histological examination of skin biopsy specimens from sites of radiation lesions show 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 that 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 radioactive cerium (Ce^{144}) and praseodymium (Pr^{144}), with only slight activity due to radioactive strontium (Sr^{90}). The body burden of these isotopes is estimated to be well below the permissible levels. Examination of bone specimens taken from the patient who died shows no radiation that can definitely be associated with fall-out deposition in the bones. Studies of roentgenograms of the femurs of the exposed children show no evidence of any bone defects from possible deposits of radionuclides.

C. P. A. Strome, HMC, W. K. Border, HMC, J. W. Hamby, HM 1, W. G. Clutter, HM 1, L. D. Snow, HM 1, and C. D. Severson, HM 2, Navy technicians from the Naval Medical Research Institute, Bethesda, Md., assisted in technical phases of this study.

Dr. S. W. Lippencott of Brookhaven National Laboratory made the histopathological evaluations of skin biopsy specimens.

Dr. W. C. Moloney and Miss L. Fliegelman of the Boston City Hospital carried out the alkaline phosphatase analysis of blood smears.

Lieut. A. G. Schrodt, MSC, and Pvt. A. Burstein, U. S. Army, of Walter Reed Institute of Research, Dr. J. Harley and Mr. E. Hardy of the New York operations office of the Atomic Energy Commission, and Dr. S. Cohn of the Naval Radiological Defense Laboratory, San Francisco, carried out the radiochemical analyses.

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