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Medical survey of Marshallese people five years after exposure to fall-out radiation†

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SUMMARY

A medical survey of the Marshallese people in March 1959, five years after exposure to fall-out radiation, showed that the people had recovered from the acute effects of their radiation exposure and appeared to be generally in good health. The following specific statements can be made in regard to their radiation health status:

1. No illnesses or diseases were found that could be directly associated with acute radiation effects.
2. One case of cancer and three deaths have occurred, but with no direct relation to radiation effects.
3. Fertility does not appear to have been affected. The incidence of miscarriages and still-births appears to be somewhat higher than in the unexposed Marshallese, but a deficiency of vital statistics precludes definite conclusions as to whether or not this is a radiation effect.
4. Suggestive evidence of slight lag in growth and development of exposed children noted previously is being re-evaluated on the basis of better age data obtained during the past survey.
5. Blood-platelet levels are within the normal range, but somewhat below that for the unexposed population.
6. Only 12 cases show residual changes in the skin from beta-burns. None show any evidence of cancerous change.
7. Possible late effects of radiation, such as shortening of life-span, premature ageing, increased incidence of leukaemia and malignancies, increased incidence of degenerative diseases, opacities of the lens of the eyes, and genetic changes have not been observed. An attempt to measure ageing by a semi-quantitative clinical approach is presented.
8. The original body burdens of internally-absorbed fission products appears to be too low to have produced any acute or long-term effects.
9. The return of the people to the slightly contaminated island of Rongelap has caused some increase in body burdens of ^{137}Caesium, ^{65}Zinc and ^{90}Strontium. However, the levels are far below the accepted maximum permissible limits and it is not believed any untoward effects will result.

1. BACKGROUND

This discussion concerns a brief account of the present health status of the Rongelap people, who were exposed to the heaviest dose of radiation from accidental fall-out in March 1954 following detonation of an experimental nuclear device at Bikini in the Marshall Islands. An unpredicted shift in winds caused deposition of significant amounts of fall-out on four nearby inhabited Marshall Islands and on 23 Japanese fishermen aboard their fishing vessel, the Lucky Dragon (see figure 1). Sixty-four inhabitants of the island of Rongelap, 105 nautical miles away from the detonation, received the largest fall-out—an estimated dose of 175 r of whole-body gamma-radiation, indeterminate beta-ray dose to the skin from contamination of the skin and internal

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absorption of radioactive fission products. Eighteen Rongelap people away on a nearby island (Alinginae), where less fall-out occurred, received about 69 r with proportionately less contamination of the skin and internal absorption of radionuclides. Discussed in earlier reports (Cronkite, Bond and Dunham 1956, Conard, Meyer, Rall, Lowrey, Bach, Cannon, Carter, Eicher and Hechter 1958) were 28 American Servicemen on Rongerik Atoll who received about 70 r and 157 Marshallese on Utirik Atoll who received about 14 r. The exposed people were evacuated to Kwajalein in the Marshall Islands by air and sea about two days after the accident. Extensive examinations were carried out during the first three months after exposure, and these findings have been

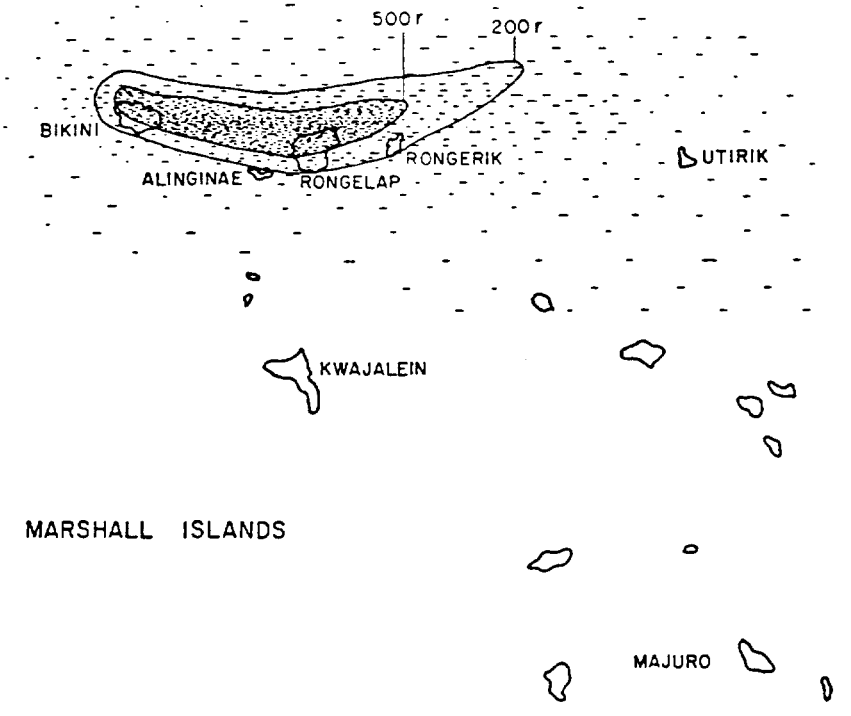

Figure 1. Map of fall-out area, Marshall Islands, March 1954.

reported in detail (Cronkite *et al.* 1956). In view of the radioactive contamination of their home island of Rongelap, the people were subsequently moved to a village provided for them at Majuro Atoll, where follow-up medical surveys were carried out and reported on at six months (Bond, Conard, Robertson and Weden 1955), one year (Cronkite, Dunham, Griffin, McPherson and Woodward 1955), two years (Conard, Huggins, Cannon, Lowrey and Richards 1957) and at three years (Conard *et al.* 1958). By June 1957 radioactivity levels on Rongelap were considered safe for habitation, and the people were returned to their home island. The four-year post-exposure survey (Conard, Robertson, Meyer, Sutow, Wolins, Lowrey, Urschel, Barton, Goldman, Hechter, Eicher, Carver and Potter 1959) was carried out at Rongelap Atoll. By 1956 a large group of unexposed Rongelap people (relatives) had joined the exposed Rongelap people and returned to Rongelap Island with them. This unexposed group has increased in size to 200 people and served as a much better comparison population group

than did the earlier comparison group of people, which was randomly selected at Majuro Atoll.

2. Findings

The latest findings are based on the annual medical survey carried out at Rongelap in March 1959 at five years after exposure. About 100 exposed people including their children and 200 unexposed people were examined. Since the data are not completely analysed, the statements made concerning this survey must be considered as preliminary in nature. The survey was conducted by a 20-man medical team from various institutions in the United States under the direction of Brookhaven National Laboratory†. The examinations included medical histories, complete physical examinations, and blood and other laboratory examinations. In addition body burdens are being determined from spectrographs of gamma-ray activity of 175 Rongelap individuals from numerous urine samples for radiochemical analyses.

2.1. *Acute effects of gamma-irradiation*

During the first 24 to 48 hours after exposure about two-thirds of the Rongelap people experienced anorexia, nausea, and a few vomited and had diarrhoea. Many also experienced itching and burning of the skin, and a few complained of lachrymation and burning of the eyes. Following this they remained asymptomatic until about two weeks after the accident, when

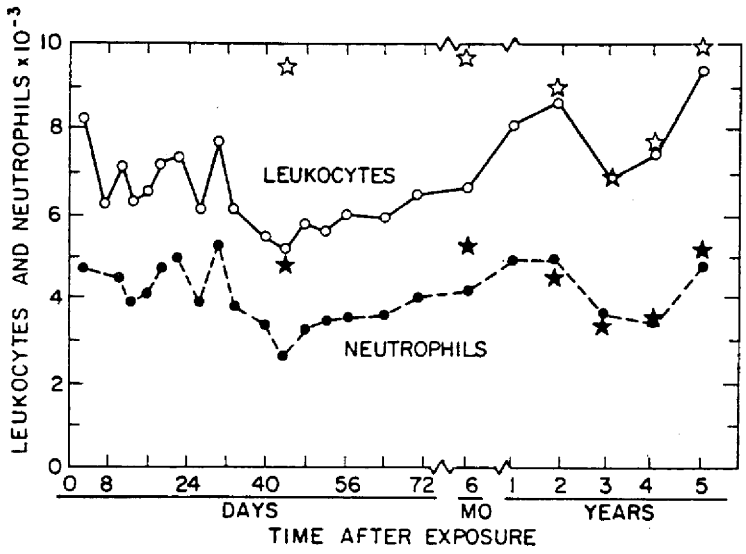

Figure 2. Mean neutrophil and white blood counts of exposed Rongelap people from time of exposure through five years' post-exposure. Stars represent mean values of comparison populations.

cutaneous lesions and loss of hair developed, due largely to beta-radiation of the skin. It was apparent when the people were first examined, a few days after exposure, that the lymphocytes were considerably depressed and that significant doses of radiation had probably been received. The dose of radiation proved

† The material presented in this report represents findings by a large number of people who have participated in past surveys.

to be sub-lethal, since no deaths occurred which could be directly related to radiation exposure. However, it is probable that the dose was in the high sub-lethal range, judging by the degree of haemopoietic depression that

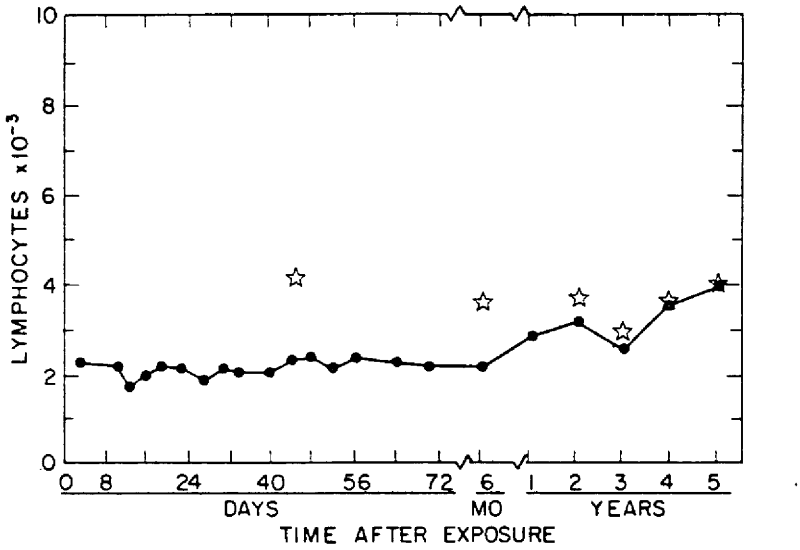

Figure 3. Mean lymphocyte counts of exposed people from time of exposure through five years' post-exposure. Stars represent mean values of comparison populations.

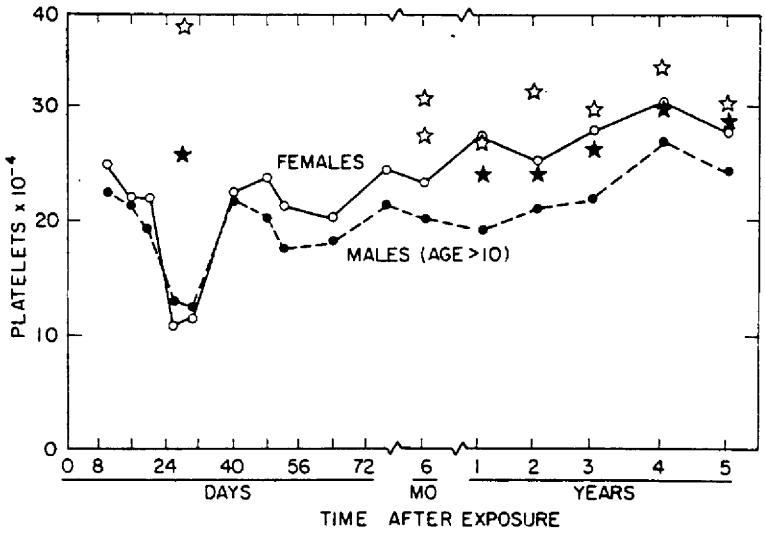

Figure 4. Mean platelet counts of exposed Rongelap people from time of exposure through five years' post-exposure. Stars represent mean values for comparison populations.

developed. In addition radiochemical analyses of the urine also showed that definite amounts of radioactive material had also been absorbed internally.

The changes during the past five years in the mean peripheral blood levels of the more heavily exposed group of 64 Rongelap people receiving approximately 175 r of whole-body radiation are shown in figures 2, 3 and 4. The white blood cell levels of the exposed group were depressed to about half the

level of the unexposed comparison population during the first two months, but did not result in any observable untoward effects in the people. No increased incidence of infection was observed, and no therapy (antibiotic or otherwise) was given specifically for their leukopenia. Mean blood-platelet levels were also significantly depressed to about 30 per cent of the unexposed levels by the fourth week. No bleeding associated with the platelet depression was noted, and no blood transfusions were necessary. Erythrocytes as measured by haematocrit levels were not significantly depressed.

Following this early depression, the blood elements slowly recovered, some elements faster than others. The neutrophils were first to reach comparison population levels by about one year post-exposure (figure 2). The lymphocytes returned more slowly, and even at two and three years' post-exposure the mean levels were slightly below the unexposed mean levels (figure 3). By four years they had reached the unexposed levels and remained so at the time of the five-year survey. Platelet levels showed the slowest recovery (figure 4). A rapid recovery trend followed the early depression, after which there was slower increase with mean levels remaining consistently below the unexposed mean population level. At the five-year survey the males were about 13 per cent and the females 11 per cent below the corresponding mean levels of the comparison population, though the individual platelet counts were within the normal range. The mean red blood count, haemoglobin and haematocrit levels, were about the same in the exposed as in the unexposed group.

The 18 Rongelap people who had received about 70 r at Alinginae Island showed less severe early haemopoietic depression, but have also shown a similarly slow recovery rate of lymphocytes and platelets, as noted in the more heavily exposed group.

The incidence of diseases, infectious or non-infectious, has remained about the same in the exposed as in the unexposed population. Three deaths have occurred: one in a 46-year-old man during the second year after exposure from hypertensive heart disease which had been present at the time of exposure; the second in a 78-year-old man, at three years after exposure, of coronary heart disease complicating diabetes; and the third in a 36-year-old man, at four years after exposure, of acute varicella.

During the first six weeks over half of the exposed people lost weight, even though their diet was satisfactory and appetites good during this period. This possibly reflects an effect of radiation exposure on general metabolism. However, factors associated with a change in environment cannot be ruled out as being responsible.

There were no abnormalities noted at birth in four babies irradiated *in utero*; two in the first trimester, one in the second trimester, and one in the third trimester.

The five-year survey revealed that the people were generally in a good state of health and nutrition. The incidences of diseases were about the same in the exposed and unexposed groups. One case of ovarian cancer developed during the past year in a 61-year-old exposed woman.

2.2. *Late effects of gamma-radiation*

Late effects of radiation exposure constitute an important part of the examinations in the Marshallese. Very little is known about such effects in

human beings. From experiences with the Japanese exposed at Hiroshima and Nagasaki and from animal studies, certain late effects of radiation may possibly develop in the Marshallese. Results of observations for such effects will be presented accompanied by appropriate discussion related to findings of others.

2.2.1. *Shortening of life-span*

Thus far the three deaths in the exposed group represent about the same death rate as has been observed in the Marshall Islands as a whole over the same period of time (about seven deaths per 1000 per year).

Numerous investigators have reported shortening of life-span of animals exposed to acute and chronic radiation (Blair 1956, Bennett, Chastain, Flint, Hansen and Lewis 1953, Brues and Sacher 1952, and others). Chronic exposure of radiologists in the United States was reported to result in life-shortening compared with other physicians (Dublin and Spiegelman 1948, Warren 1956). In view of the above findings, some life-shortening may be expected in the Marshallese, though in view of the small size of the population a number of years will no doubt be required before such an effect of radiation can be evaluated.

2.2.2. *Premature ageing and degenerative diseases*

From observations over the past five years the impression is that the exposed Marshallese do not appear to have aged faster or appear older than unexposed Marshallese of the same age. No doubt the subtle changes which occur with ageing would be difficult to detect over this period of time. The incidence of degenerative disease has been about the same in the exposed as in the unexposed group.

An attempt is also being made to study ageing from a more quantitative clinical approach. Certain criteria usually associated with ageing that can be easily obtained on physical examination are recorded as nearly quantitatively as possible, either by direct measurement or estimation of degree of severity of criteria in a scale from 0 through 4+. Though the work is in the early stages and only preliminary analyses have been carried out, it might be of interest to outline some of the criteria which are being investigated.

Skin: Special calipers with spring tension have been designed for measurement of (*a*) looseness and (*b*) elasticity. Looseness is measured in millimetres height of the fold of skin anteriorly at the junction of the neck and chin. Elasticity or resilience of the skin is determined by clamping a fold of skin on the back of the hand for one minute, releasing the calipers and measuring the time in seconds for retraction of the fold to the normal skin level. (*c*) Senile changes in the skin, such as keratosis, pigment changes, and warts (0–4+).

Eyes: (*a*) Visual accommodation measured in dioptres, (*b*) arcus senilis (0–4+).

Hearing: Loss of hearing at 4000 frequency.

Cardiovascular: (*a*) Peripheral and retinal arteriosclerosis (0–4+), (*b*) systolic and diastolic blood-pressure readings.

Vigour: (*a*) Vital capacity of lungs height, (*b*) hand-grip strength, as measured with a hand dynameter in kilograms.

Neuromuscular function: Number of depressions of the key of a hand tally (blood counter) in one minute.

A preliminary study of the data by plotting the values for each age criteria against age (at five-year intervals above 20 years) showed no consistent differences between the exposed and unexposed groups. However, the numbers of people are not large, and no statistical treatment of the data has yet been done. A general idea of the trends of several of these ageing criteria may be obtained from figure 5. After further testing of the age dependence and variability of the data, a uniform scoring system will be applied and the criteria weighted to

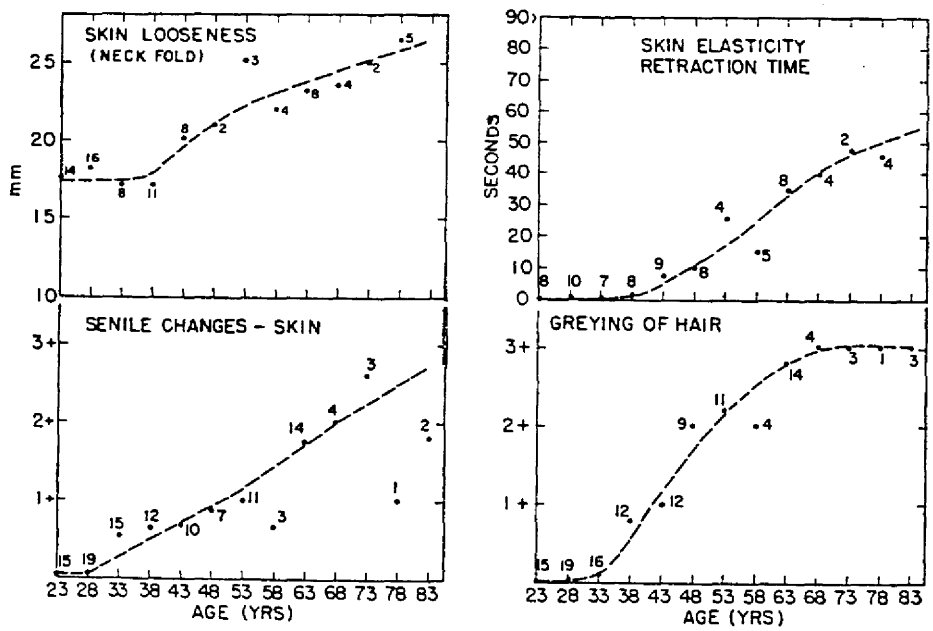

Figure 5. Plots of ageing criteria against age at five-year intervals.

obtain a total score on each individual which may approximate their ' biological age ' for a comparison with their actual age. Further criteria may be added. Particularly needed are further tests of functional status or vigour which can be measured. It is not known if the type of criteria chosen are necessarily associated with ' radiation senescence ', but the approach is believed worth investigating, since many animal studies indicate late radiation changes that closely resemble advanced or premature ageing (Blair 1952, Cassarett 1956, Alexander 1957, Comfort 1959).

2.2.3. *Malignancies, leukaemia*

One case of ovarian cancer (verified by biopsy at operation) in a 61-year-old exposed female was noted during the past year, the first case of malignancy noted in either the exposed or unexposed group. There is no reason to incriminate radiation in the aetiology of this case, particularly in view of the early time of appearance.

Since leukaemia is the earliest type of neoplasia associated with radiation to develop, examinations in the Marshallese have included blood smears, stained for alkaline phosphatase of neutrophils and basophil counts in 4000 white cells per individual. No evidence of decreased alkaline phosphatase of neutrophils

or increased basophil counts indicative of incipient leukaemia was noted. An increased incidence of leukaemia has been reported in radiologists (March 1947, Ulrich 1946, Warren 1956), in children receiving therapeutic radiation in infancy for thymic enlargement (Simpson and Hempelmann 1957), in children exposed *in utero* from diagnostic x-ray examinations of the mothers (Stewart, Webb, Giles and Hewitt 1956), in patients receiving x-irradiation for treatment of ankylosing spondylitis (Court-Brown and Doll 1957) and in survivors of the atomic bombs in Japan (Maloney and Kastenbaum 1955). Though the incidence of leukaemia in the exposed Japanese was significantly increased, the total incidence was low. Therefore, since the exposed Marshallese population is small, it does not seem likely that leukaemia will be observed as a result of their radiation exposure.

2.2.4. *Cataracts*

During the past five years repeated slit-lamp ophthalmological observations in the Marshallese revealed no opacities typical of the radiation-induced type. The induction of opacities of the lens by radiation is a well-established fact in man. In the Japanese exposed to the atomic bombs, opacities of the lens, including about 10 severe cataracts, have been observed (Cogan, Martin and Kimura 1949, Sinsky 1955). Merriam and Focht (1957) on the basis of clinical cases of radiation-induced opacities calculated that 200 r was the minimum dose of gamma- or x-radiation resulting in lens opacities. Therefore, the dose of radiation received by the Marshallese may be too low to result in such changes.

2.2.5. *Reproduction*

It has long been recognized that reduced fertility may be induced by ionizing radiation in man by relatively small doses, possibly even in the dose range that the Marshallese received. Transient effects on fertility may have taken place in this group, but such effects were not observed. Studies such as sperm counts were not feasible. No amenorrhoea was noted in the exposed women. Birth rate during the past five years in the exposed group was not reduced and, if anything, appears to have been higher than in the unexposed comparison population or in the Marshallese people generally. Therefore, the degree of sterility that may have been induced was not detectable based on these findings.

A somewhat greater prevalence of miscarriages and still-births has been noted in the exposed women but, due to the paucity of vital statistics in the Marshallese and the small number of people involved, the data are not readily amenable to statistical analyses.

2.2.6. *Growth and development*

Anthropometric measurements on the Marshallese children have revealed findings, previously reported (Conard *et al.* 1957), which were interpreted as suggestive of a slight lag in growth and development in the exposed children during the first few years after exposure. However, certain inconsistencies in the ages of the children were found, and the data are being re-evaluated based on more exact age data obtained during the last survey. The results of this evaluation are not complete enough to make any statements at this time. Such an effect would not be inconsistent with the findings of Greulich *et al.* (1953)

and Reynolds (1952) who reported slight growth retardation and delayed maturation in the Japanese children following exposure to the atom bomb.

2.2.7. *Genetic effects*

Specific studies for genetic effects of their radiation exposure have not been conducted in the Marshallese. The babies born of irradiated parents have shown no gross abnormalities that can be detected on routine physical examinations. In view of the generally negative findings in the first-generation offspring of the irradiated Japanese reported by Neel and Schull (1956), it is unlikely that genetic studies in the Marshallese will be fruitful.

2.3. *Effects of beta-irradiation of the skin*

About 90 per cent of the people in the more heavily exposed Rongelap group developed beta-burns of the skin beginning about two weeks after exposure. A lesser number of people also developed spotty epilation of the scalp. The burns occurred as a result of fall-out deposition on parts of the body not covered by clothing. Most of the burns were superficial and healed within a few weeks. About 15 per cent of the people, however, had deeper burns which healed with some atrophy, scarring, and pigment aberration. Complete regrowth of normal hair occurred in all cases by six months. Gross and microscopic descriptions of the lesions were given in detail in the earlier reports. The past survey revealed that there were 12 cases which showed residual atrophy, scarring and pigment aberrations at the site of deeper lesions. However, none showed evidence of pre-malignant or malignant change.

2.4. *Internal irradiation*

The Rongelap people lived under conditions of severe radioactive contamination for two days following the accident until they were evacuated from their island. This was reflected in significant absorption of radioactive materials, mostly from ingestion of contaminated food and water. Radiochemical urine analyses during the first 24 days showed internal levels of isotopes which were roughly estimated as follows in microcuries: $^{131-135}$Iodine, 6·4; ^{89}Strontium, 1·6; ^{140}Barium, 2·7; rare earths, 1·2; and smaller amounts of ^{137}Caesium, ^{90}Strontium, and ^{144}Ce–Pr. Radioiodine probably delivered a dose of 100–150 rep to the thyroid glands of the people, but absorption of isotopes was too small to result in any acute effects. Rapid diminution of body levels of these isotopes occurred, so that by six months urinary activity was barely detectable.

Only the indirect method of body-burden estimation, based on urinary-excretion rates, was available until three years' post-exposure, when a direct method of measuring body levels of gamma-emitting isotopes was possible through the use of crystal detectors and a spectrum analyser in conjunction with a thick-walled steel room to lower background radiation. This made it possible to measure directly very low levels of isotopes. Several Marshallese were measured by this procedure at the Argonne National Laboratory in 1957. Later a steel room, constructed specifically for these surveys (figure 6), was taken aboard Navy vessels to Rongelap for the four- and five-year surveys where a large number of Rongelap people have been measured.

Rongelap Island remains slightly radioactively contaminated, but is considered safe for habitation. This is reflected in some increase in body levels of radionuclides since the return of the people to their island. Based on gamma-spectroscopy and urinary-excretion rates of isotopes, it has been estimated that during the first year after their return ^{137}Cs increased by factors up to 100 resulting in a body burden of 0·68 μc. ^{65}Zn (which is selectively absorbed by

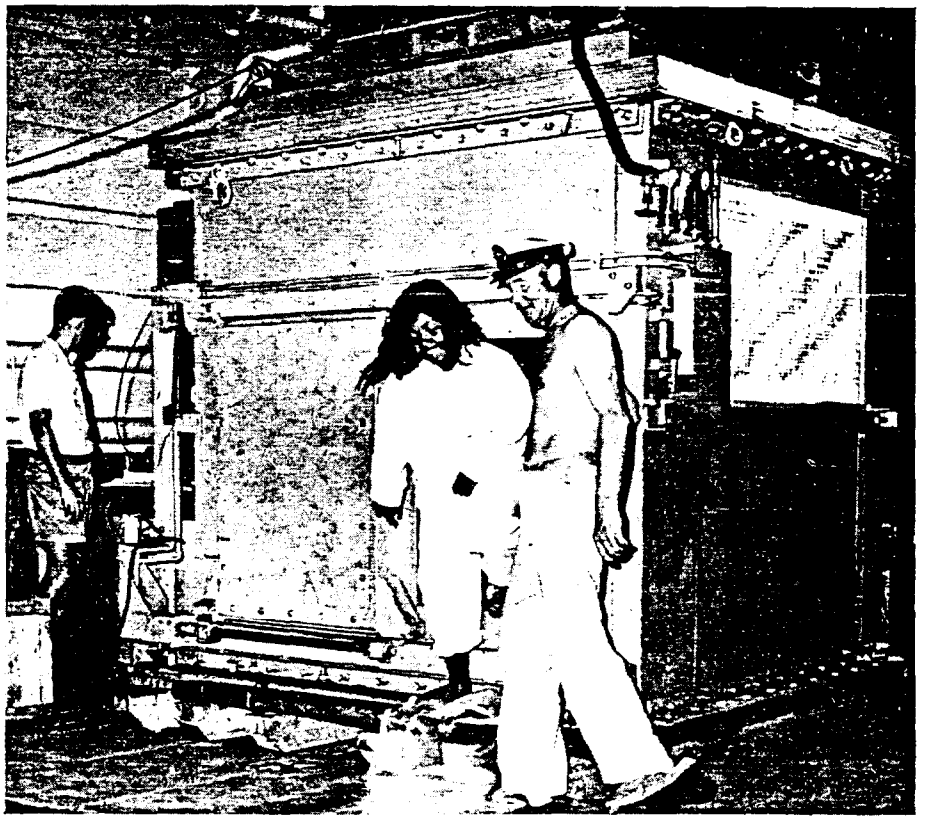

Figure 6. Steel room used for gamma spectroscopy.

the fish, a main item of the Rongelap diet) increased concomitantly to an estimated mean body burden of 0·36 μc. Excretion rates of ^{90}Sr increased by a factor of about 20. Increase in body burdens of isotopes occurred equally in unexposed and exposed populations, and the levels in the exposed group are about the same as in the unexposed group living there.

Based on preliminary analyses of data from the most recent survey period, eight to twenty months after the return to Rongelap, it appears that the people have begun to attain an equilibrium with their lightly contaminated environment. The ^{137}Caesium levels appear to be slightly lower than the year before while ^{65}Zinc has increased slightly. The ^{90}Strontium analyses, unfortunately, are not available yet. The body burdens estimated above are far below the maximum permissible levels; ^{137}Caesium is about 2 per cent and ^{65}Zinc about 1 per cent of the MPL. In figure 7 the increase in body levels of isotopes is shown in the spectrographs of a Rongelap man before 1957 and 20 months after returning

to Rongelap. The background radiation resulting from residual contamination on the island presently averages about 0·04 mr/hr which represents a dose of only about 0·35 r/yr.

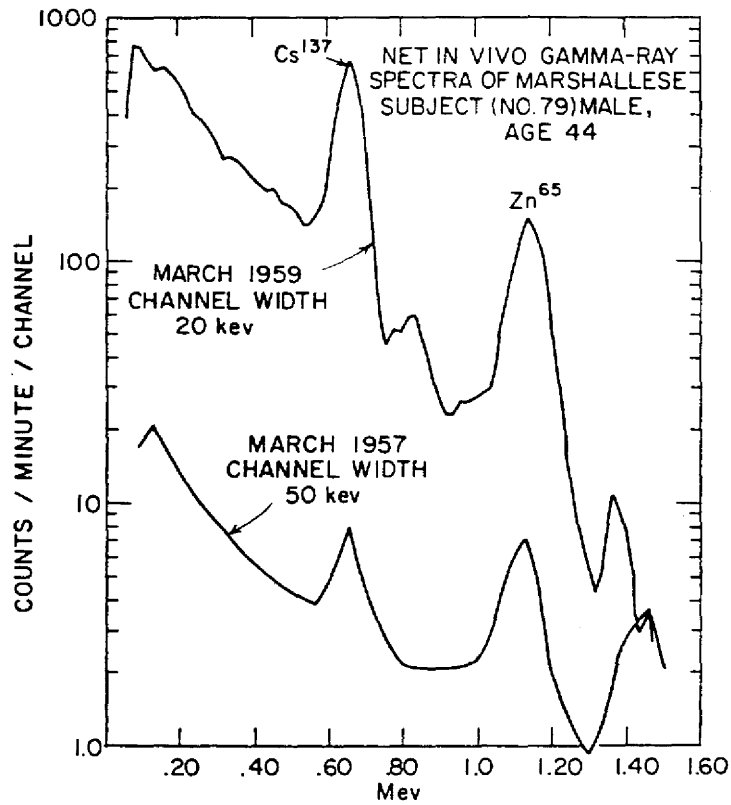

Figure 7. Gamma-ray spectroscopy of Rongelap man in March 1957 and March 1959.

3. Present status

It is apparent that the Rongelap people have recovered from the acute effects of their radiation exposure, and emphasis in the examinations is now directed toward possible late effects of irradiation, about which little is known in man. No acute effects have been observed related to the internal absorption of radionuclides, and no late effects are expected, either from their initial intake or subsequent low levels acquired from living on the slightly contaminated island of Rongelap. However, the habitation of these people on the island affords the opportunity for a most valuable radiation ecological study. Since only small amounts of radioisotopes are necessary for detection with present sensitive measuring equipment, the various isotopes present on the island can be traced from the soil through the food and into the human being, where tissue and organ distributions, biological half-lives and excretion rates can be studied.

Acknowledgments

The success of a mission of this type depends on the assistance of many individuals and organizations. The author wishes to express his sincere appreciation to those who participated and others too numerous to mention

whose efforts contributed to the successful completion of the survey. Particular gratitude is expressed to Dr. C. L. Dunham and his staff of the Division of Biology and Medicine of the Atomic Energy Commission, Dr. L. E. Farr and many others at the Brookhaven National Laboratory, the Department of the Navy and Trust Territory officials for their enthusiastic support.

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Discussion

Boeri:

You said, in the beginning of your report, that, among the acute effects, losses of weight were generally observed, in spite of good appetite. You added that the affected individuals had ingested some contaminated material. Your

hypothesis was that the loss of weight was due to a probable metabolic effect, if I understood it correctly.

This seems to me an important point. Do you exclude that weight losses could have been due to lesions of the intestinal mucosa, possibly from the ingested material ?

Conard:

It does not seem likely that such an effect was responsible for the weight loss in the Marshallese people since the dose to the gastrointestinal tract was too low and, if such an effect did occur, it should have been recovered from after the first week or so when the weight reduction was continuing. The radioactive material was probably eliminated from the gut by the 3rd or 4th day.