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EFFECT OF ACUTE FALLOUT RADIATION ON A MARSHALL ISLAND POPULATION*

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by

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DISCLAIMER

This paper summarizes the acute and residual effects of a localized fallout exposure on the people of Rongelap Island during the eight year period subsequent to their accidental exposure on March 1, 1954. The accident occurred following the detonation of a high-yield nuclear device during experiments at Bikini in the Pacific proving grounds, when an unpredicted shift in winds caused deposition of significant amounts of fallout on four inhabited atolls to the east. Also involved were 23 Japanese fishermen aboard their vessel, "The Lucky Dragon". This acute, localized type of fallout must not be confused with the so-called world-wide fallout where radioactive debris from bomb tests filters slowly down over large areas of the globe resulting in contamination of a chronic nature, which imparts very low levels of radiation.

The 64 inhabitants on the island of Rongelap, 105 nautical miles away from the detonation, received the largest exposure: an estimated dose of 175 r of whole body gamma radiation, contamination of the skin sufficient to result in beta burns, and slight internal absorption of radioactive materials through inhalation and ingestion. The fallout resembled a light snowfall. Another 18 Rongelap people away on a nearby island (Ailingnae) received less fallout exposure with an estimated gamma dose of about 69 r, minimal beta burns of the skin, and internal absorption of isotopes,* (See Figure 1).

The exposed people were evacuated by plane and ship about two days after the accident and taken to Kwajalein Naval Base about 150 miles to the south, where they received extensive examinations for the following

* There were also 28 American servicemen on the island of Rongerik, further to the east, who received about the same amount of radiation as did the Rongelap people on Ailingnae and 157 Marshallese on Utirik Island, about 200 miles further east, who received an estimated dose of 14 roentgens of whole body radiation. Following initial examinations, the people of Utirik were returned to their home island, which was considered radioactively safe and the American servicemen were returned to duty.

three months. Because Rongelap Atoll was considered to be too highly contaminated, a temporary village was constructed for the Rongelap people on Majuro Atoll several hundred miles to the south, where they lived until 1957, when after careful evaluation of the radioactive contamination situation, Rongelap Island was considered safe for habitation. The new village was constructed and the people were moved back (see Figure 2). A group of Rongelap people, who were relatives of the exposed people, but had been away from the Island at the time of the accident, moved back with the Rongelap people to their home island and have served as an ideal comparison population.

Annual medical surveys have been conducted on the Rongelap people by physicians and technicians representing Brookhaven National Laboratory under the Atomic Energy Commission as well as medical personnel of the Trust Territory of the Pacific Islands. Detailed medical reports of these surveys have been published (1-7).

Early Findings.

During the first 24-48 hours after exposure, about two-thirds of the Rongelap people experienced anorexia and nausea. A few vomited and had diarrhea. Many also experienced itching and burning of the skin and a few complained of lacramation and burning of the eyes. Following this, people remained asymptomatic for about two weeks after the accident, when skin lesions and loss of hair developed, due largely to beta irradiation of the skin. It was apparent when these people were first examined, a few days after exposure, that the lymphocytes were considerably depressed and that significant doses of radiation had probably been received. In addition to the whole body dose of radiation, and the beta irradiation of the skin, radiochemical analyses of the urine showed measurable amounts of radioactive materials had also been absorbed internally. Further effects of the radiation exposure on these people will now be summarized under penetrating irradiation, skin irradiation, internal irradiation, and residual effects.

Penetrating irradiation:

The most important findings indicative of significant exposure in these people was lowering of levels of the white blood cells and platelets of the peripheral blood. By three days after exposure, the lymphocytes showed depression to about half the level of the nonexposed Marshallese. The average level of these cells in the exposed population gradually increased over the ensuing years, (see Figure 3). However, recovery did not appear to have been complete through eight years. The other main type of white blood cell, the neutrophils, showed fluctuation of levels during the first month after exposure, and then gradually decreased to levels about half that of the unexposed group by 5-6 weeks (see Figure 4). These cells increased more rapidly than lymphocytes and reached near normal levels by one year. However, in ensuing years there was some evidence that these cells also had not completely recovered to the comparison population level. Platelets became depressed in the Marshallese to about 30% of the level of the unexposed people by the fourth week, which was followed by gradual recovery. However, in ensuing years, the level of platelets has consistently remained slightly below that of the comparison population (see Figure 5). The red blood cells never showed significant depression.

The dose of radiation received by the Rongelap people was not large enough to result in lowering of the white blood cell level sufficient to cause infectious processes, or of the platelets to cause bleeding. In fact, there were no complications that developed that could be related to their hematological disturbances, and no prophylactic or specific therapy for this radiation effect was necessary. The immunological response did not appear to be significantly impaired. During the first six months following the accident, they were exposed to outbreaks of upper respiratory infection, measles and chicken pox, with no greater incidence or severity than was observed in the unexposed population. During this period the people had no complaints (except for those related to the beta burns of the skin described below). A slight loss of weight was noted in over half the exposed people during the first six weeks, in spite of the fact that their diet was more than adequate. This may have been a radiation effect or on the other hand the possible effect of change of environment cannot be definitely ruled out. However, the Marshallese are used to travelling from island to island for extended periods of time so that they adjus t ed well to this change in environment and showed no great concern about their radiation exposure.

The dose of radiation received by the Rongelapese proved to be sublethal, since no deaths occurred which could be directly related to radiation effects. Based however on experience with degrees of hematological depression in animals and other human beings exposed to radiation, the hematological depression experienced by the Rongelap people indicated that their exposure was probably not far from the lethal range. Perhaps if they had received as little as 50 r more radiation, the serious complications of infections, bleeding, and even death might have occurred.

Beta irradiation of the skin:

Beta burns of the skin and epilation appeared about two weeks after exposure, largely on parts of the body not covered by clothing. About 90%

of the people had these burns and a smaller number developed spotty epilation of the scalp (see Figures 6 and 7). Most of the lesions were superficial; they exhibited pigmentation and dry scaling and were associated with little pain. Rapid healing and repigmentation followed. Some lesions were deeper with ulceration and were more painful (see Figure 8). Repigmentation of the lesions gradually took place in most instances, and the skin appeared normal within a few weeks. However, in about 15% of the people, deeper lesions, particularly noted on the dorsum of the feet, continued to show lack of repigmentation with varying degrees of scarring and atrophy of the skin. Regrowth of hair commenced at about three months after exposure and complete regrowth of normal hair had occurred by six months. Residual effects will be described later.

Internal radiation:

Shortly after the accident, radiochemical analyses of numerous urine samples of the exposed population showed internal absorption of radioactive materials, brought about largely through eating and drinking contaminated food and water, and to a lesser extent, through inhalation. During the first few days, when body levels were at their highest, the maximum permissible concentrations were approached or slightly exceeded only in the case of Sr^{89} and the isotopes of iodine. The concentrations were too low to result in any detectable effects. An important observation was that the body levels fell rapidly, so that by 2 and 3 years postexposure, they were far below the accepted maximum permissible level. By six months, activity in the urine was barely detectable. The

The return of the Rongelapese to their home island (which after careful survey was considered safe for habitation despite a persisting low level of radioactive contamination of soil, plants and marine life) was reflected in a rise in their body burdens of Cs^{137}, Zn^{65} and Sr^{90}. Body burdens of gamma emitting isotopes principally Cs^{137} and Zn^{65}, were measured in a whole body counter, a 21-ton steel room, which was constructed at BNL and taken to the Islands (see Figure 10). By 1961 the levels of Cs^{137} had apparently reached equilibrium at a value of about 13.7 muc, about one-fifth of the state maximum permissible levels for the general population. Zn^{65}, which had risen to about 9.9 muc in 1959, fell to 1.51 muc in 1961, far below the maximum permissible level. Body burdens of Sr^{90} were measured by radiochemical analyses of numerous urine samples and on a few bone samples obtained from several autopsies. The level of Sr^{90} in 1962 had reached 12.0 muc, about 5.7% of the maximum permissible level.

Little of the body burden of the exposed group was due to their initial exposure, since at the present time there is little difference between the levels in exposed and unexposed population living on Rongelap Island. The body burdens are of small significance in terms of radiation hazard.

Residual effects:

Studies in irradiated animals and to a lesser extent in man, show that certain residual effects, some of which may not show up for years, are known to occur. In the Marshallese, such effects appear to have been minimal. Some of these possible effects as related to the Marshallese will be briefly reviewed.

Shortening of life span and premature aging, which have been noted largely in animal studies, have not been detected in the Marshallese. Quantification of certain aging criteria in the exposed and unexposed groups showed no apparent differences in aging in the two groups (10). The five deaths during the eight year period did not appear to be related to radiation exposure and the mortality rate was about the same in the exposed and unexposed groups.

Effects on fertility have not been apparent based on birth rate. The birth rate in the exposed and unexposed groups have paralleled one another. A degree of temporary sterility might be expected to have occurred during the early postexposure period but this could not be evaluated.

Miscarriages and stillbirths:

During the first five years after exposure, there appeared to be a slight increase in the number of miscarriages and stillbirths in the exposed women compared with the unexposed. During that period 35% of the births terminated in nonviable babies in the exposed women, compared with 23% in the unexposed group. The numbers of cases is too small and vital statistics on this subject too meager to allow for proper statistical evaluation of this finding.

Growth and development studies comparing exposed with unexposed children of the same ages have indicated slight retardation effects in the exposed children, believed to be associated with the acute radiation exposure (5-9). The amounts of fission products absorbed internally in the children is believed to have been too small to have caused an effect. These examinations have included a series of anthropometric measurements, the most useful being stature, weight and bone age (determined from radiographs of the wrist and knee).* Nonparametric statistical methods of analysis were used**. The boys exposed at ages 1 through 5 showed retardation of statural growth. This was most marked in those exposed at 15 to 18 months of age, (see Figure 11). Though weight gain appeared slightly retarded in this group, it was not statistically significant. The exposed girls on the other hand showed no significant differences of stature (Figure 12) or weight compared with the unexposed girls. Radiographic bone age studies showed that in both exposed boys and girls there was some retardation in skeletal maturation, the difference being more pronounced in the boys. The average skeletal maturation in the exposed boys was about 7 months behind their unexposed peers, whereas the exposed girls were only about five months behind (see Figure 13). The Japanese children exposed to the atomic bomb at Hiroshima and Nagasaki have also been reported to show slight retarded growth and development (11).

Since the dose of radiation received by the Marshallese children was considered less than is usually associated with direct effects of radiation on bone growth in clinical situations, we carried out an experiment on rats to see if an indirect factor was involved (12). The following is a brief summary of this study. Groups of weanling male rats were given 0-800 r of X-radiation, some of which had one leg shielded and some of which had one leg only exposed. Tibial bone growth was measured from radiographs taken at intervals for several months and direct and indirect effects were determined by subtracting growth rates under the different shielding conditions. Figure 14 shows that retardation of bone growth

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* These studies were carried out under the direction of Dr. W. W. Sutow, of the M.D. Anderson Hospital, Houston, Texas, and will be reported elsewhere in detail (13).

** We are grateful to Dr. Kenneth Griffith of the M.D. Anderson Hospital, Houston, Texas, for carrying out a statistical analysis in these studies.

was roughly dose dependent and that though some direct effect of radiation was apparent even with lower doses, the indirect effect (inhibitory effects on bone growth contributed from parts of the rat other than the leg) was about twice that of the direct effect. Since it was noted that there was an apparent correlation between weight loss and inhibition of bone growth, the effect of differences in food consumption was studied by pair-feeding experiments (feeding unirradiated rats the same amount of food eaten by irradiated mates). Figure 15 shows that the lowered food consumption of the irradiated rats appeared to account to a large extent for the growth retardation.

In the exposed Marshallese children, it had been noted that 23 of 31 below 16 years of age lost an average two pounds of weight during the first six weeks postexposure. There is no data on their food consumption during this period but from these data, it seems possible that certain indirect effects such as metabolic or hormonal, may have been induced by the radiation exposure in these children and have played a part in the retardation observed.

Cancer and leukemia studies have revealed only one case of cancer (in an exposed 60 year old woman) which occurred five years postexposure, too soon, it is believed, to be related to radiation exposure. No cases of leukemia have been seen.

Opacities or cataracts of the lens of the eyes which may occur as a late effect of radiation exposure has not been observed in the Marshallese. It is believed that their radiation dose was too low to produce such an effect.

Genetic effects have not been studied because of the small numbers of people involved. Among 37 children born of irradiated parents, one has shown a possible congenital defect. Children otherwise appear normal and healthy. The suggested evidence of increased miscarriages and still-births in the exposed women may have been related to a genetic effect.

Beta burns of the skin. By six years the only residual effects of beta radiation of the skin ~~was~~ were seen in about a dozen cases which showed various degrees of pigment aberrations, scarring and atrophy at the site of former burns. During the past several years, an increased number of pigmented nevi-like lesions have been noted in previously irradiated areas of the skin, but these have appeared to be quite benign (see Figure 9). No chronic radiation dermatitis or cancer of the skin has been noted.

Internal exposure. The body burdens of radionuclides in the Rongelap people have been far below the stated maximum permissible levels. Though there is no previous experience associated with the combination of whole body exposure with low levels of internal exposure, the internal doses are believed to have been too small to cause any obvious early or late effects. To date no effects have been noted in this group that clearly implicate internal exposure.

SUMMARY AND CONCLUSIONS

The medical findings on the people of Rongelap Island during the eight year period following their accidental exposure to radioactive fall-out have been reviewed. Sixty-four people were exposed to 175 r of penetrating gamma radiation and eighteen others on a nearby Island to about 70 r. In addition, beta burns of the skin occurred in ninety percent of the people and measurable amounts of radionuclides were absorbed internally. The penetrating whole body radiation caused transient anorexia and nausea followed by depression of certain blood elements, of which the white blood cells were reduced to about half and the platelets to about thirty percent of the unexposed population levels during the first six weeks. This was followed by the return of these elements toward normal, but with persisting lag in complete recovery to levels of the comparison population, even after eight years. No deaths or illnesses related to their radiation exposure occurred and no specific therapy was necessary. Numerous beta burns of the skin and spotty epilation of the scalp developed between two to six weeks postexposure, but these lesions healed rapidly and hair regrew by six months. Body burdens of radionuclides, even at the time of highest levels during the first week, were only slightly above the stated maximum permissible levels in the case of radioiodine and Sr^{89}. Rapid excretion of these elements occurred and at no time were there any obvious effects associated with this internal exposure.

Residual effects have thus far appeared to be minimal. No effects such as life shortening, premature aging, loss of fertility, development of opacities of the lens of the eye, development of cancer or leukemia, or genetic effects have been detected. Slight increase in miscarriages and stillbirths in the exposed women was noted during the first five years. Because of the small numbers of the women involved, statistical analysis was not possible. Growth and development studies showed that the exposed children were slightly retarded in skeletal maturation. This was most prominent in boys exposed at less than five years of age, particularly those exposed at 15-18 months. These boys also showed slightly retarded statural growth. Studies on bone growth in young rats have shown that there is an indirect effect of radiation in addition to a direct effect, largely on a nutritional basis, that would seem likely to be the cause of the retardation of bone growth. These findings may have relevance in the case of the exposed Marshallese children, the majority of whom lost several pounds of weight during the six weeks period following exposure.

Based on the Marshallese experience, it is clear that in the case of acute fallout exposure from atomic bombs, the penetrating gamma radiation is the most serious hazard, and will likely be the major cause of serious illness and death. The skin burns produced by fallout may produce varying degrees of disability and complicate the course of radiation illness, but these lesions per se are not likely to be associated with any immediate serious consequences. The internal absorption of radionuclides in acute fallout situation appears to be the least serious of the hazards and it seems probable that before any serious internal acute effects can result from such exposure, a lethal dose of whole body minimum radiation would have been received by an individual. Recovery from the acute effects of fallout exposure does not insure against the possible development of residual or late effects of radiation.

Much has been learned from these studies of the effects of fallout exposure on the Marshallese and on the whole the results have been encouraging in pointing out the ability of human beings to withstand such exposure with so little in the way of acute or residual effects. Except for the skin burns, it seems unlikely that this population would have been aware of their exposure had they not been informed and made the subject of medical examinations. Even if they had received a dose of gamma radiation two to three times higher, most of these people probably could have been saved by vigorous treatment with antibiotics and blood derivatives. In view of the lack of knowledge about late effects of radiation in human beings, studies of this population probably will be continued indefinitely.

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LEGEND FOR FIGURES

Figure 1.	Map of fallout area (March 1, 1954) Marshall Islands.
Figure 2.	New village at Rongelap.
Figure 3.	Mean lymphocyte counts of exposed Rongelap people from time of exposure through eight year post-exposure. Stars represent mean values of comparison population.
Figure 4.	Mean neutrophil and white blood counts of exposed Rongelap people from time of exposure through 8 year postexposure. Stars represent mean values of comparison population.
Figure 5.	Mean platelet values of exposed Rongelap people from time of exposure through 8 year post-exposure. Stars represent mean values of unexposed comparison population.
Figure 6.	Extensive Beta burns in 13 year old boy at 45 days postexposure.
Figure 7.	Epilation in 7 year old girl at 28 days postexposure and re-growth of hair at six months.
Figure 8.	Ulcerating burn in 37 year old female at 28 days postexposure.
Figure 9.	Same case as in Figure 8 at 8 year postexposure. Note development of nevus-like lesions in area ofneck previously involved with beta burn.
Figure 10.	Marshallese subject leaving 21 ton steel room, following whole body gamma spectroscopy.
Figures 11-13.	Self-explanatory.
Figure 14.	Direct and indirect effects of X-irradiation on tibial bone growth in the rat.

Figure 15. Effect of reduced food consumption on tibial growth in rats.

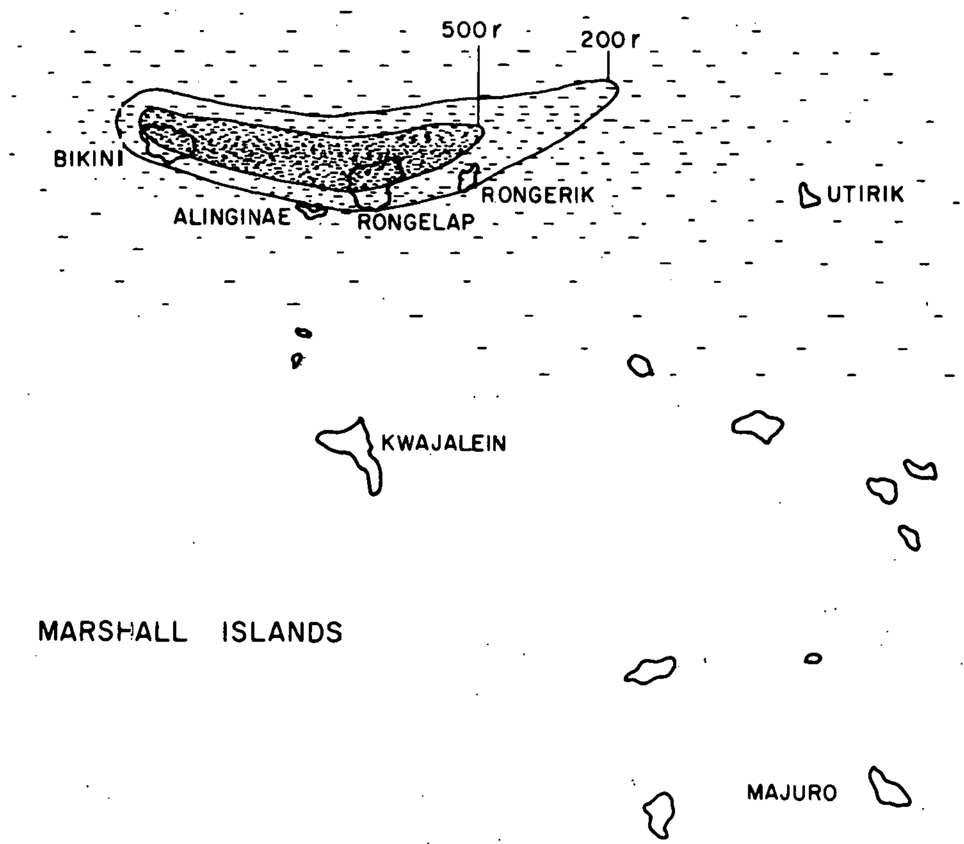
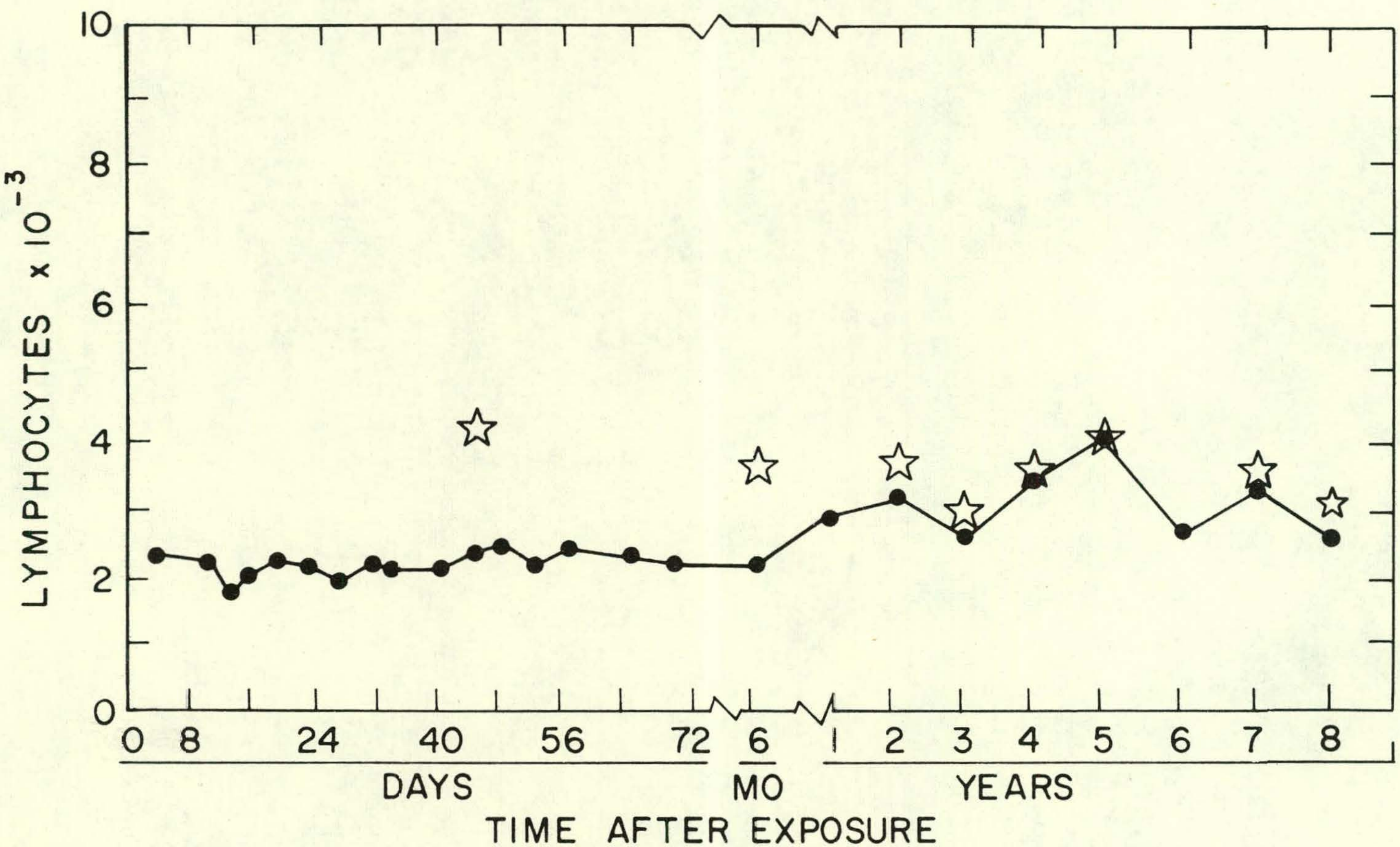

500r
200r
BIKINI
ALINGINAE
RONGELAP
RONGERIK
UTIRIK
KWAJALEIN
MARSHALL ISLANDS
MAJURO

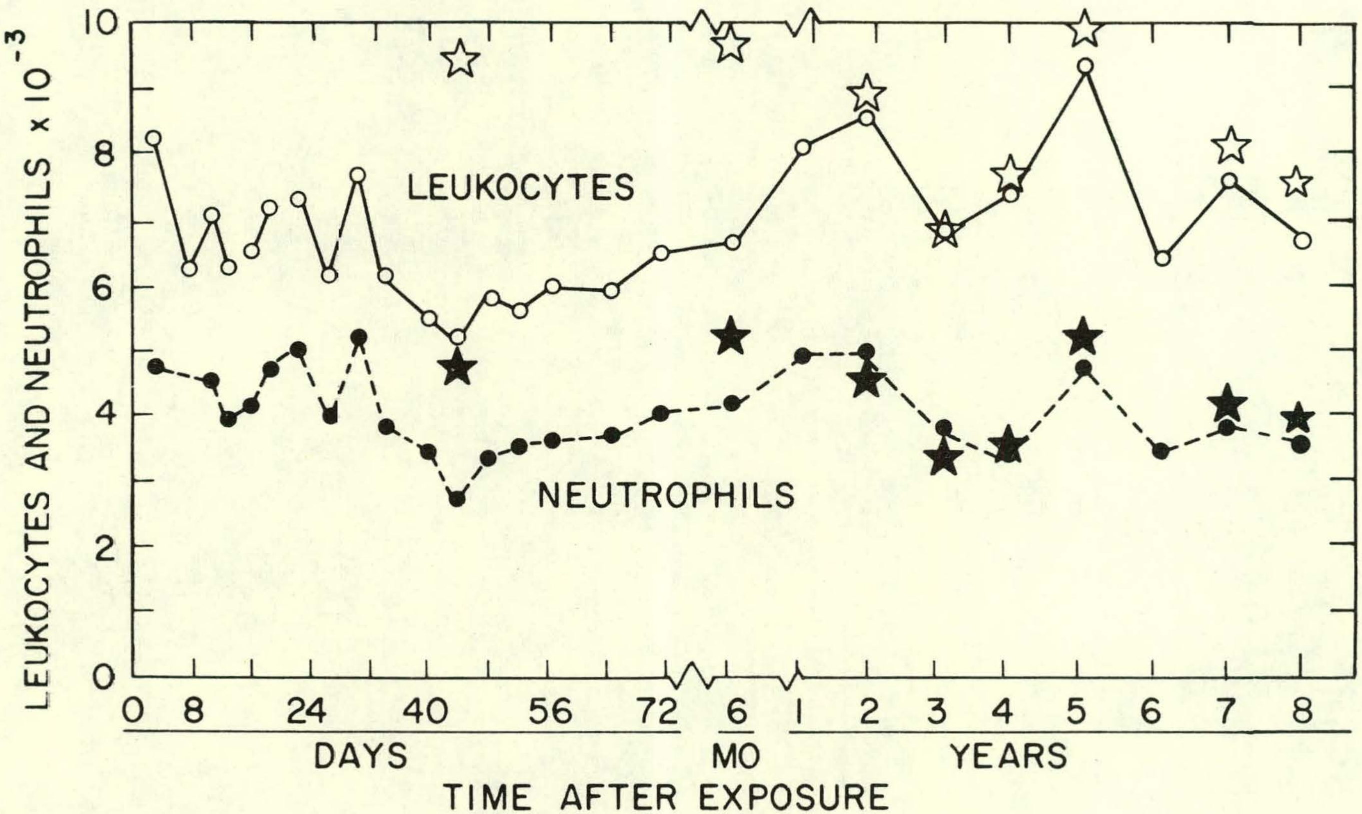
FIGURE 1

FIGURE 2



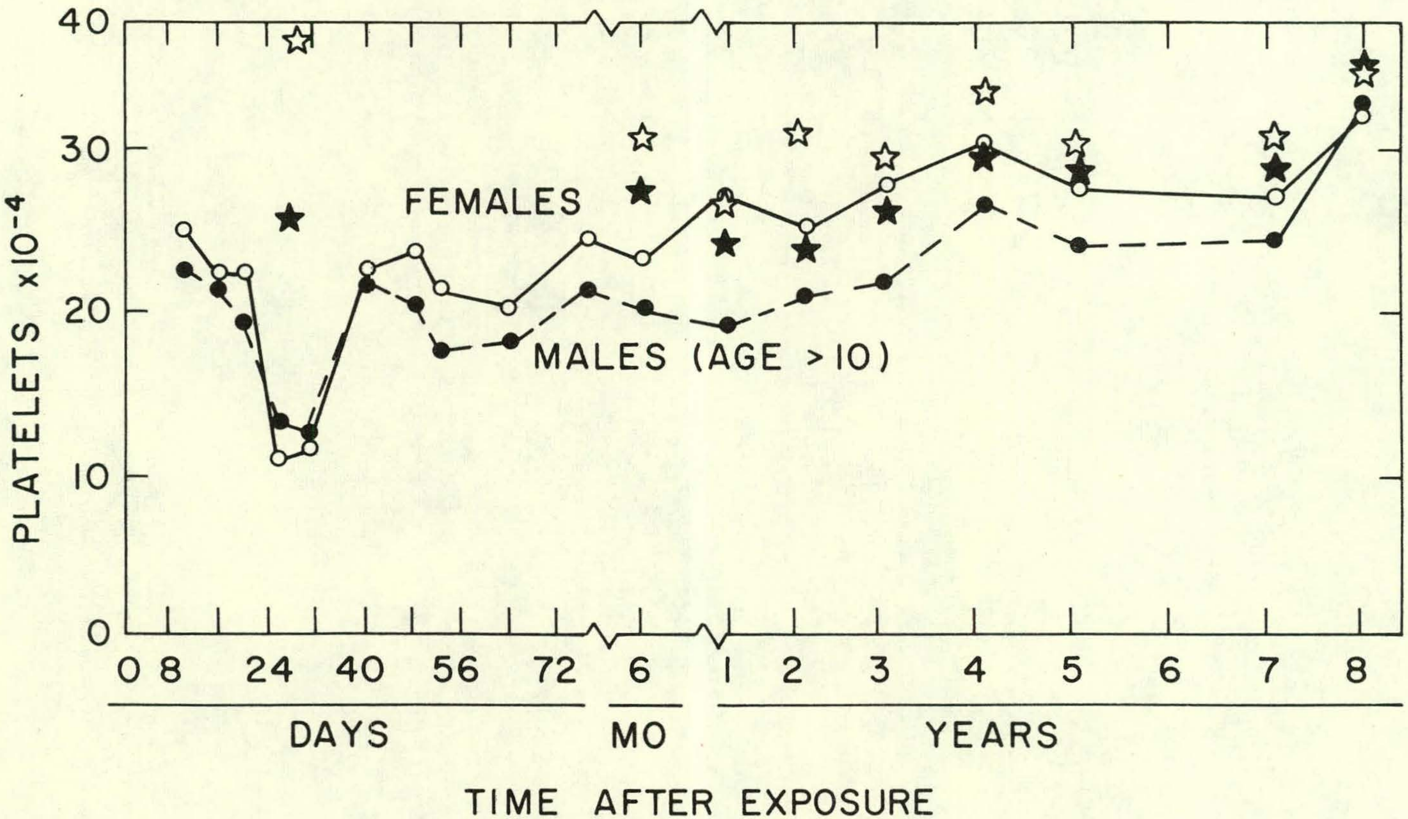
10
8
6
4
2
0
LYMPHOCYTES x 10^{-3}
0 8 24 40 56 72
6
1 2 3 4 5 6 7 8
DAYS
MO
YEARS
TIME AFTER EXPOSURE

FIGURE 3



LEUKOCYTES AND NEUTROPHILS x 10^-3
10
8
6
4
2
0
LEUKOCYTES
NEUTROPHILS
0 8 24 40 56 72 6 1 2 3 4 5 6 7 8
DAYS
MO
YEARS
TIME AFTER EXPOSURE

FIGURE 4



40
30
20
10
0
PLATELETS x10^-4
FEMALES
MALES (AGE >10)
0 8 24 40 56 72
6
1 2 3 4 5 6 7 8
DAYS
MO
YEARS
TIME AFTER EXPOSURE

FIGURE 5

FIGURE 6

FIGURE 7

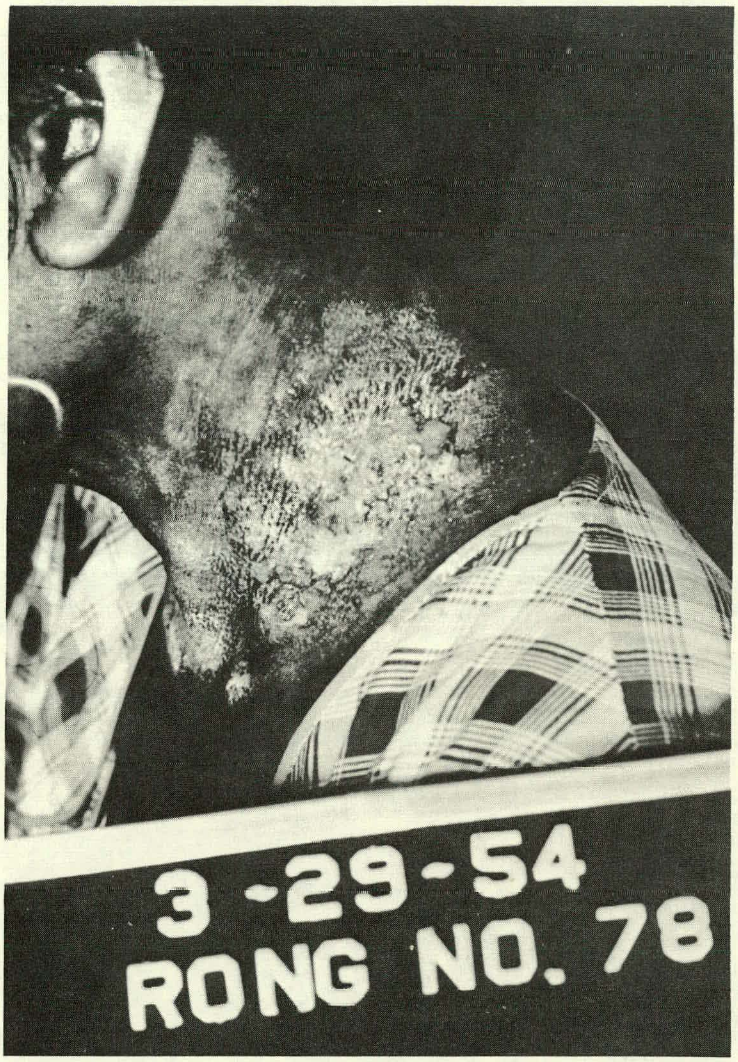


FIGURE 8

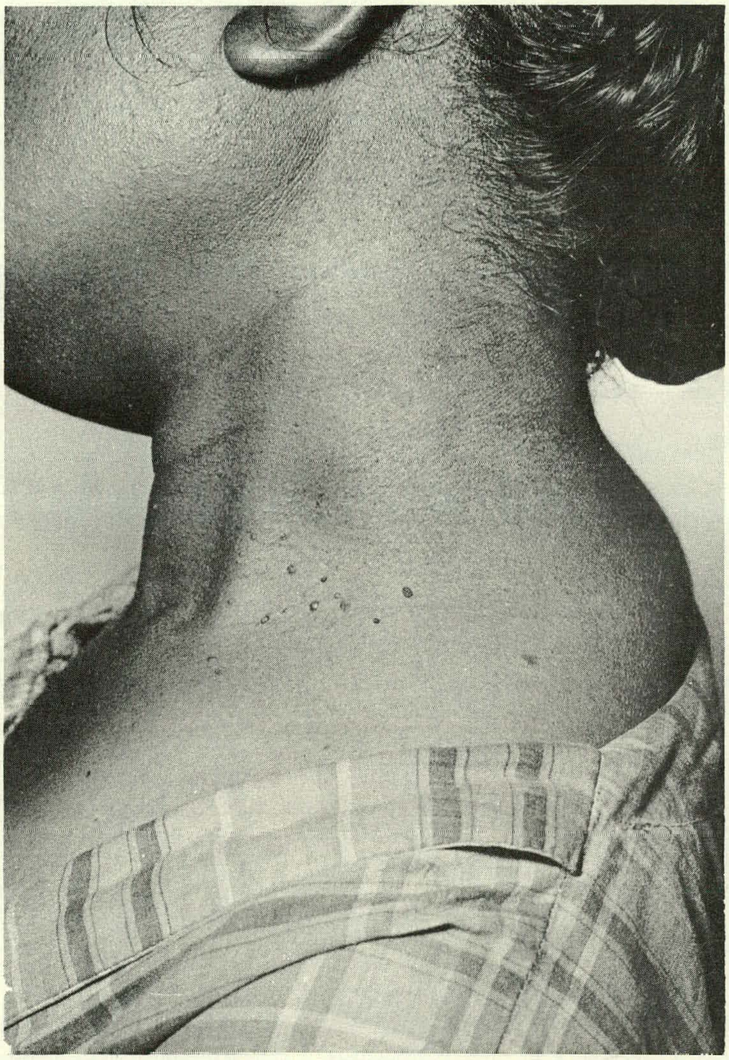


FIGURE 9

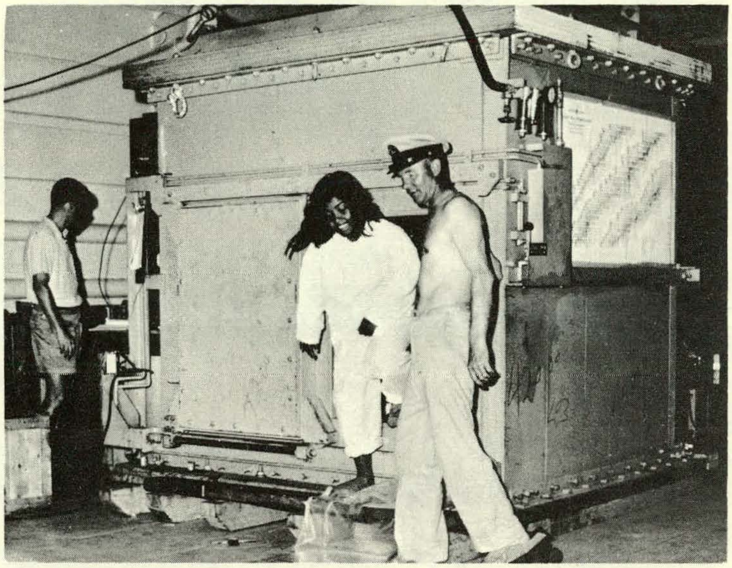


FIGURE 10

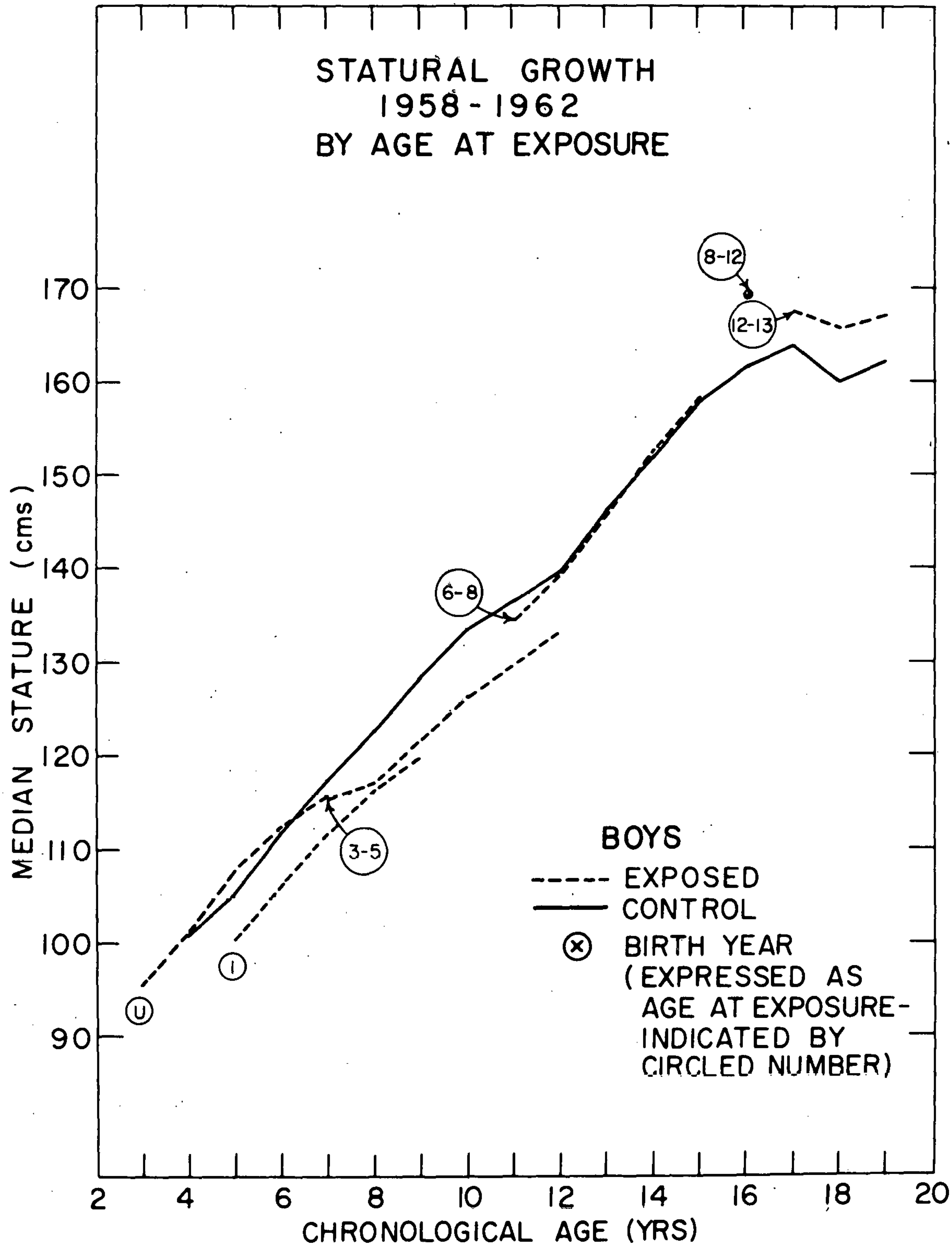

STATURAL GROWTH
1958 - 1962
BY AGE AT EXPOSURE
MEDIAN STATURE (cms)
170
160
150
140
130
120
110
100
90
2
4
6
8
10
12
14
16
18
20
CHRONOLOGICAL AGE (YRS)
8-12
12-13
6-8
3-5
1
U
BOYS
EXPOSED
CONTROL
BIRTH YEAR
(EXPRESSED AS
AGE AT EXPOSURE-
INDICATED BY
CIRCLED NUMBER)

FIGURE 11

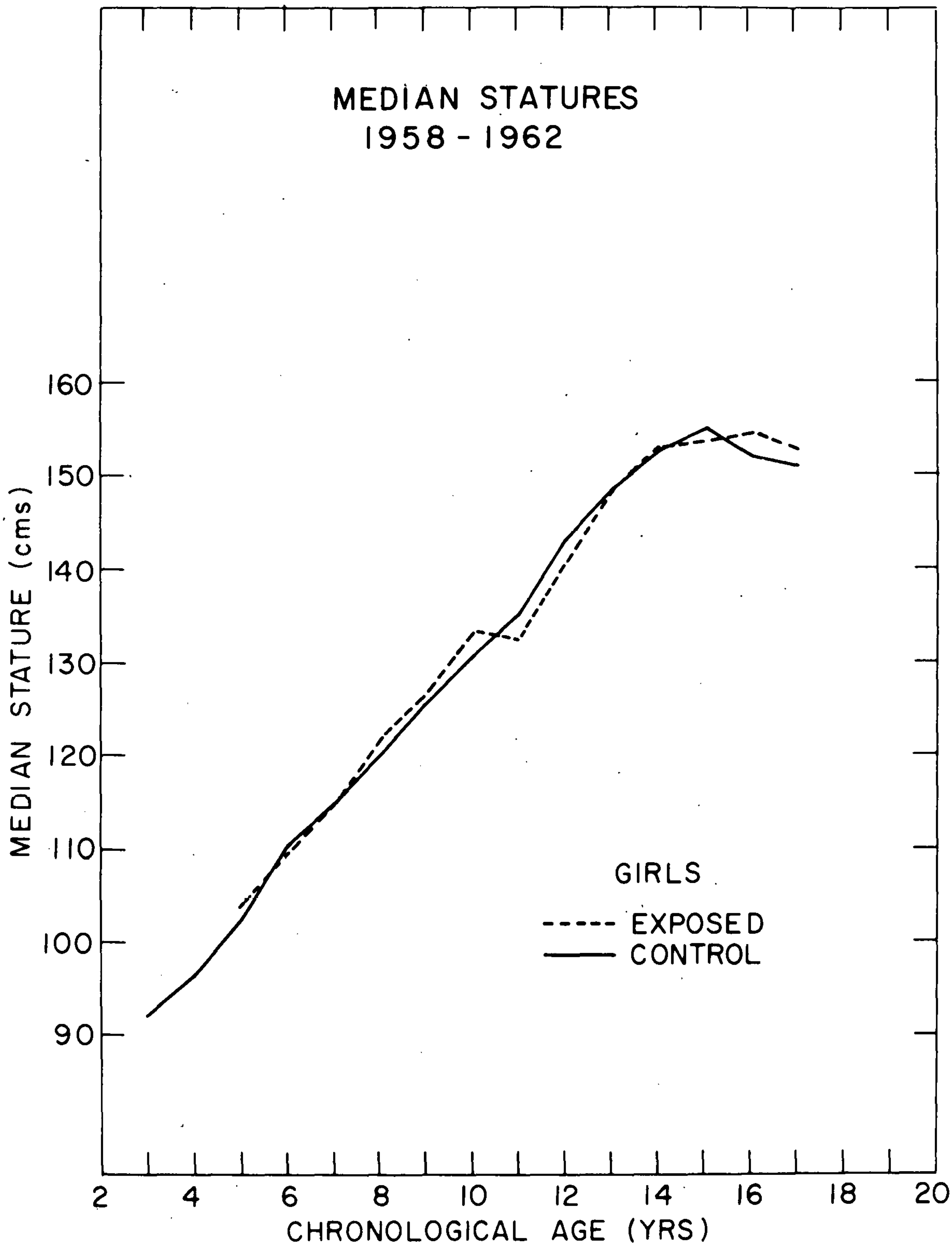

MEDIAN STATURES
1958 - 1962
MEDIAN STATURE (cms)
160
150
140
130
120
110
100
90
2
4
6
8
10
12
14
16
18
20
CHRONOLOGICAL AGE (YRS)
GIRLS
EXPOSED
CONTROL

FIGURE 12

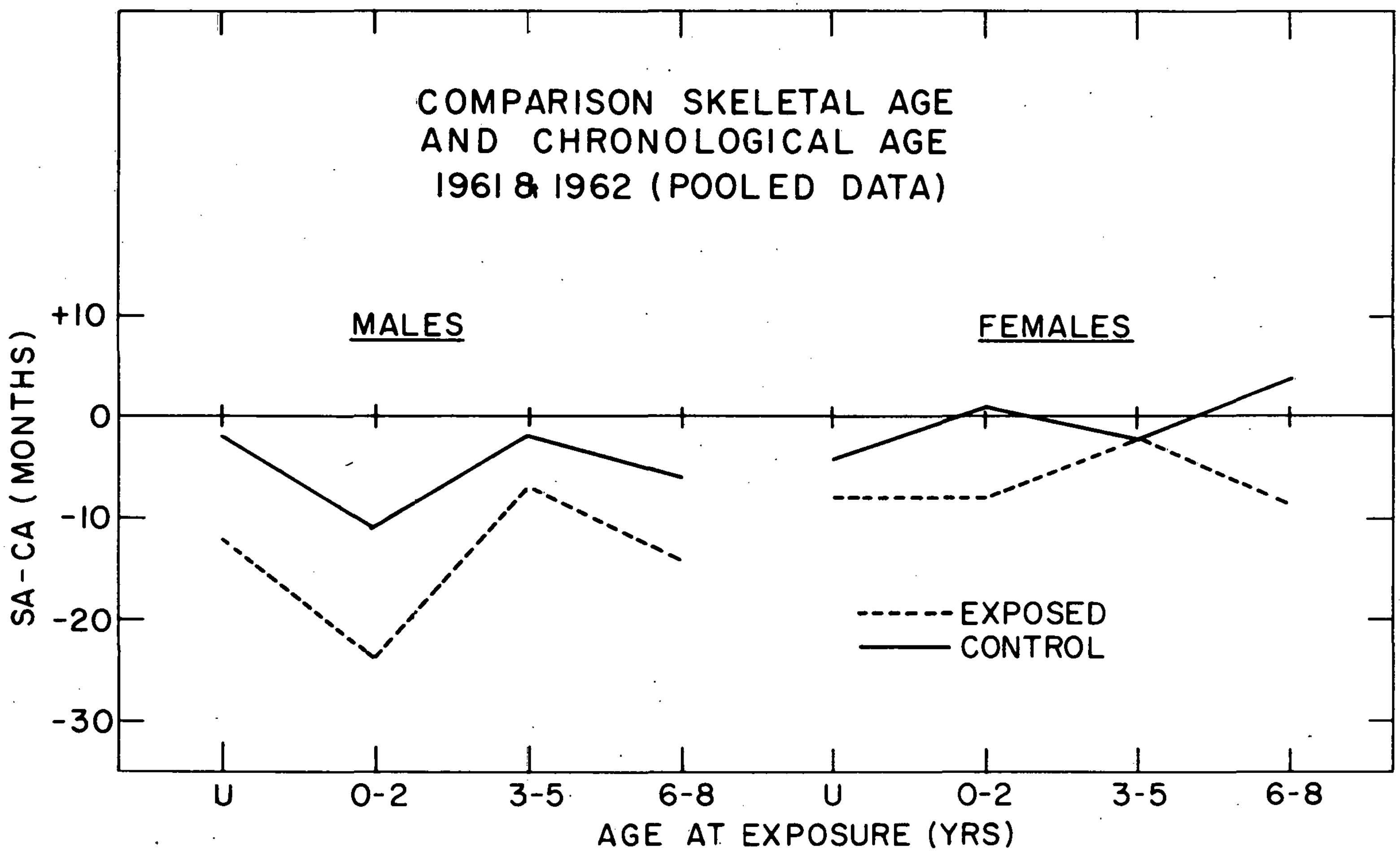

COMPARISON SKELETAL AGE
AND CHRONOLOGICAL AGE
1961 & 1962 (POOLED DATA)
MALES
FEMALES
+10
0
-10
-20
-30
SA-CA (MONTHS)
EXPOSED
CONTROL
U
0-2
3-5
6-8
U
0-2
3-5
6-8
AGE AT EXPOSURE (YRS)

FIGURE 13

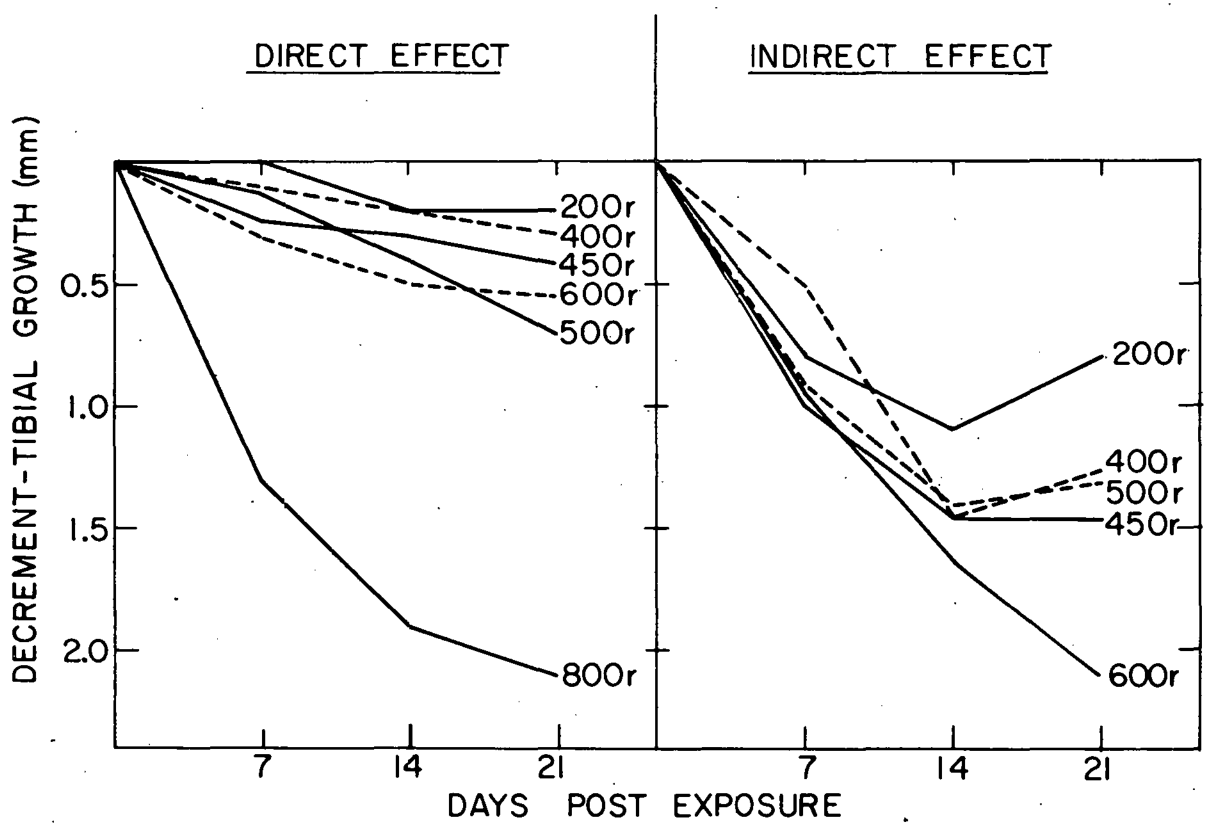

DIRECT EFFECT
INDIRECT EFFECT
DECREMENT-TIBIAL GROWTH (mm)
0.5
1.0
1.5
2.0
200r
400r
450r
600r
500r
800r
200r
400r
500r
450r
600r
7
14
21
7
14
21
DAYS POST EXPOSURE

FIGURE 14

TIBIAL GROWTH DECREMENT AND WEIGHT LOSS IN RATS RECEIVING 600 RADS (HIND LEGS SHIELDED) AND PAIR-FED RATS COMPARED WITH STRESSED CONTROLS

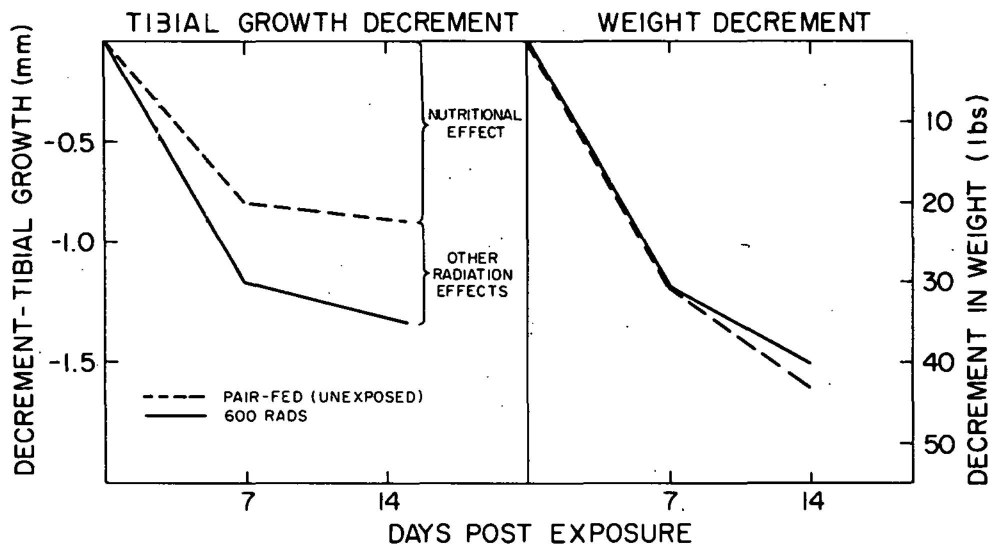


FIGURE 15