# THE EFFECTS OF FALLOUT RADIATION ON MARSHALLESE CHILDREN*

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On March 1, 1954, native inhabitants of several atolls in the Marshall Islands were exposed accidentally to fallout radiation following the experimental detonation of a large thermonuclear device at Bikini Island. The heaviest fallout occurred on Rongelap Island, downwind and about 100 miles east of Bikini. Since that time the exposed people have undergone regular and intensive medical examinations, the results of which have been documented in a number of publications[1-4]. The present report will summarize the findings on the exposed Rongelap people who were children at the time of exposure. In particular, these findings will be compared to those noted in the exposed adult population.



## Fallout and Radiation Doses

At the time of the atomic bomb test, the fireball touched the surfaces of the earth and ocean. Tremendous amounts of incinerated particulate matter

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*The research was supported by the United States Atomic Energy Commission and, in part, by Public Health Service Research Career Award CA-02501 (to W.W.S.) from the National Cancer Institute.

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were sucked up into the cloud. Because of an unpredicted shift in wind direction, radioactively contaminated fallout was deposited on Rongelap, Ailingnae and Utirik atolls.

On Rongelap, the fallout was described as "snow-like" which coated the ground and vegetation and formed deposits on the hair and skin of the people. Less dense "mist-like" fallout was noted on Ailingnae. Ailingnae, some 40 miles south of Rongelap, was actually closer to Bikini but it was situated more out of the line of the cloud passage. No visible evidence of fallout was observed on Utirik, 250 miles from Bikini.

Fallout commenced on Rongelap and Ailingnae 4 to 6 hours after the detonation of the bomb. The radioactive cloud reached Utirik about 22 hours after the explosion. Evacuation of the contaminated islands was accomplished approximately 48 hours after the commencement of fallout[5].

Exposure to radiation involved whole body gamma dose from environmentally deposited radioactive fission products, superficial doses from beta and soft gamma radiation and doses from internal absorption (through inhalation and ingestion) of radionuclides.

The external whole body gamma dose has been computed to be 175 rad on Rongelap, 69 rad on Ailingnae and 14 rad on Utirik (Table I). Based on calculations from radiochemical urine analyses, it has been estimated that the thyroid gland accumulated about 11.2 uCi of $^{131}I$. In addition, the shorter-lived isotopes, $^{132}I$, $^{133}I$ and $^{135}I$, added considerably to the dose. The most probable dose to the thyroid gland of Rongelap Island children less than 4 years of age has been calculated to be in the range of 700 to 1400 rad[5,6]. Except for the thyroid gland, the dose from absorbed radioactive material appears to have been minimal with no discernible biological effects[7].

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Subsequent to the return of Rongelap people to their home island, the body burdens of $^{137}Cs$, $^{65}Zn$ and $^{90}Sr$ rose to low levels, but these reached equilibrium with environmental sources by 1961. No effects from these isotopes have been detected[8,9].

## Populations Under Study

A total of 64 men, women and children were present on Rongelap Island. The 18 who were exposed to fallout on Ailingnae were Rongelap inhabitants who had gone to the adjacent atoll for fishing. On Utirik Island, 157 Marshallese people received fallout radiation. In addition, 28 American servicemen on Rongerik Island and 23 Japanese fishermen on the boat, "Lucky Dragon," were subjected to sublethal doses of radiation from the fallout (Table II).

In the Rongelap group, 12 of the 64 were under 5 years of age, 18 were between 5 and 16 years, and 34 were over 16 years of age. Among these children, 19 were under the age of 10 years. Four fetuses were exposed in utero on Rongelap. In the Ailingnae group, 6 of the 18 were children, all under the age of 10 years. On Utirik, 63 of the 157 were children 15 years of age and younger. Fifty-four of the 63 were under 10 years of age.

Rongelap was considered to be habitable in 1957. At that time the people were transferred back to their home island. When repatriation took place, a group of about 200 unexposed people also moved to Rongelap. This non-exposed group, mostly relatives and former inhabitants of the island, has served as the comparison population for the continuing studies of the exposed people. Among the non-exposed group, 48 were under 10 years of age in March 1954 and 8 were between 10 and 15 years of age[10].

## Examinations

Following the intensive medical studies initially, followup examinations of the Rongelap and Ailingnae people have been conducted at 6 months and then at annual intervals in March. Systematic and comparable examinations of the Rongelap unexposed population were started in 1958 and have been conducted at least biennially. People on Utirik have been seen at less frequent intervals. The pediatric surveys have also included examination of all children born after March 1954 to parent or parents exposed to the fallout and to parents in the unexposed control group. The children of exposed parents now number 88 and children of non-exposed parents number 121.

## Early Effects

The acute early effects of fallout radiation involved primarily the skin, the hair, the gastrointestinal system and the hematopoietic tissues. During the first 2-day period following exposure and before evacuation from the island, itching and burning of the skin were noted. Anorexia and nausea with some vomiting also occurred. These symptoms subsided promptly within a few days with no recurrence. A tabulation of incidence of these symptoms (Table III) suggests that the gastrointestinal manifestations were more frequent and more severe among younger children than among older children and adults[11].

Radiation burns resulting from deposits of fallout material on the skin developed about 2 weeks after the exposure. Hyperpigmentation, desquamation, depigmentation, and, in severe cases, ulceration followed. Spontaneous healing and repigmentation occurred during the next few weeks. The skin lesions were more extensive in the younger children. Some variation in the anatomical distribution of the burns was recorded among several age groupings[12,13].

Epilation, generally spotty in nature, began 2 to 3 weeks after exposure. Regrowth of hair started at about 3 months and was complete by the sixth month. The new hair seemed normal in color, texture and abundance. Both the frequency and the severity of epilation were more marked among children as compared to those among adults (Table IV). Thus, 100% of children under 5 years of age showed some degree of epilation, 90% of them moderate to severe degree. Only 27% of those over 16 years of age manifested epilation[12,14].

In respect to hematologic findings and particularly as they relate to age (Table V), the following observations have been made[13, 14]:

(a) At maximum depression of lymphocytes (3rd day), the values were lower in those under 5 years of age (25% of normal) than in those over 5 years of age (55% of normal). Recovery was more rapid in the younger age group and age differences became less marked after the fourth week.

(b) Platelet values (as percent of control values) during the first 12 months were consistently lower among those under 10 years of age as compared to those over 10 years of age. Maximum depression occurred by 30 days.

(c) Granulocyte values dropped during the second week and showed a second drop during the 5th week. By 12 weeks, the levels had returned nearly to the control range. Although the patterns of change were the same, the values for children under 5 years of age were below those of the older age groups throughout most of the first year of observation.

(d) Complete recovery to normal levels of peripheral blood elements was slow. Mean levels for platelets, granulocytes and lymphocytes remained slightly, but consistently, below the control levels during the followup surveys until the 11th year (1965). These differences were statistically significant at various examinations. In 1965, the mean counts for all blood elements reached control values. Inspection of the mean values calculated for children aged 15 years or younger at the time of each examination showed essentially the same pattern of variation from the control values, reaching control values in 1965[3].

## Late Effects

The significant late effects of the fallout radiation have been the retardation of growth and the development of thyroid abnormalities among the Rongelap children exposed at young ages.

Longitudinal anthropometric data, including skeletal age assessments, have been accumulated on these children. Analyses of these measurements showed, in the exposed boys only, a slight but consistent retardation in body size (expressed as stature) during growth from the 4th through the 16th year as compared to the statural growth curve of the unexposed boys. This difference, however, was not statistically significant. No difference in the growth curves was noted among girls[15]. Further examination of the data suggested that the retardation noted in the boys was most marked among those who were 5 years of age or younger at the time of the fallout[15]. (For growth and development studies, because of the relatively small numbers of children in the various age groups, the Ailingnae and Rongelap populations have been combined.)

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When this youngest age group was considered separately (Figure 1), a significant retardation in statural growth was shown among the boys. These children were smaller than both the control boys and those exposed at older ages. Girls exposed at similar young ages had normal statural growth curves. No significant difference in weight curves were found between exposed and control children for both boys and girls.

Although there were individual cases in which the skeletal maturation lagged markedly behind expected norms (particularly in the hypothyroid subjects), the overall curves for exposed and control children showed no statistically significant differences.

In 1963 a nodule was palpated in the thyroid gland of a 13-year old girl who was exposed to fallout on Rongelap at the age of 3 years 4 months. A total thyroidectomy was done. The surgical specimen showed multiple nodules with cystic and hemorrhagic changes. The histological diagnosis was adenomatoid goiter. During the next 5 years, thyroid nodules have developed in an additional 14 of the 19 Rongelap children who were under 10 years of age at time of exposure to the fallout (Table VI). Two other children in this age group manifested frank hypothyroidism, making the total incidence of thyroid abnormalities 90% among this group of 19 children[16, 17].

Up to the conclusion of the 1969 survey, operative procedures have been carried out in 12 children with thyroid nodules. In all instances, multiple benign adenomatous lesions were found. No malignant changes have been noted in any of the specimens.

The pattern of thyroid-nodule development suggested several relationships to age and developmental status of the exposed children. Almost all of the tumors appeared to develop during the adolescent period (Figure 2). For

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comparable ages at exposure, the tumors were first noted at chronologically earlier ages among girls, consistent with the normal earlier occurrence of adolescent changes in girls. The "latent period" between radiation exposure and tumor development for 13 of the 15 lesions was 10 to 13 years.

[illegible] in the age range comparable to the 19 exposed children. No nodules have been noted in the 4 children exposed in utero and in the 6 children exposed in Ailingnae. Among the original 45 subjects exposed to fallout on Rongelap at ages greater than 10 years, three abnormalities of the thyroid gland have been found up through the 1969 examination. These abnormalities consisted of mixed papillary and follicular carcinoma in one, and adenomatoid goiter in two.

In the Ailingnae group of 12 who were older than 10 years of age at exposure, a tumor (neurofibroma) lateral to the thyroid gland has been found in one adult. Among the 54 children exposed at Utirik to fallout at ages under 10 years, no thyroid abnormality has occurred. Of the 59 Utirik people exposed at ages greater than 10 years and in whom adequate palpatory thyroid studies were done, two had nodules. Three of 133 unexposed Rongelap inhabitants, older than 10 years of age in March 1954, have nodular thyroid glands.

In the fall of 1965, the routine administration of thyroid hormone to the Rongelap exposed people was begun. This regimen was intended to decrease, if possible, the further development and progression of the thyroid nodules. The immediate effect of thyroid hormone has been the sudden marked spurt in the growth and development of the hypothyroid children, manifested most dramatically in statural gain and accelerated skeletal and sexual maturation.

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## Discussion

Age differences in the acute and late manifestations of injury following exposure to radiation fallout have been documented in the Rongelap population. The severity and frequency of several abnormal findings appeared to be correlated inversely with chronological age, that is, more severe in the younger subjects. The data, however, do not indicate whether the differences are due to increased biological sensitivity of the tissues of young children or to dose differences.

Observations during the annual surveys indicate that the children wear less clothing and that they spend considerably more time in the open, away from houses and overhead protection, than do adults. Young children play on the open ground with great frequency. Thus, during the two days before evacuation, they would have had greater and more prolonged contact with fallout material and would have been closer to the surface deposits than would adults. Moreover, the physical sizes of the children were such that they would have received a greater dose at midline than adults receiving the same air dose. These factors no doubt contributed to the skin lesions and greater depression of blood elements in children compared to adults. The greater incidence of thyroid abnormalities in the children was probably related not only to increased radiation dose to the children's glands, but also to the greater proliferative activity of the growing gland with lack of replacement of injured cells.

Clinical and laboratory data indicated that total destruction of the thyroid gland occurred in two youngsters. That partial destruction of the glands may have resulted in others is suggested by increased TSH levels, lowered thyroxine values, reduced uptake of radioiodine and the inability of the thyroid glands to respond to further TSH stimulation[3, 17]. The timing of the nodule development suggests that growth stresses associated with adolescence could have been a precipitating factor in nodule formation. However, the nodules occurred early in adolescence in the younger exposed children and late in adolescence in those who were older at exposure.

The finding of thyroid nodules in so many subjects raises the question of the existence of goitrogenic factors unrelated to radiation. However, the overwhelming concentration of the nodules within a specific age-exposure category would seem to eliminate such possibilities as familial goiter or environmental factors other than fallout radiation. The lack of development of thyroid abnormalities in children of same ages of less heavily exposed groups (6 Ailingnae and 54 Utirik children) as well as in 48 unexposed children all living in the same or similar environment substantiates the above conclusion.

Although no thyroid cancer has been detected as yet in the Rongelap children, the risk of malignancy should be considered increased. It is now 15 years from time of exposure, well within the 3 to 27 year latent period for cancer development reported in the literature[18, 19, 20]. The subjects are in the late teens and early twenties where the peak incidence of radiation-related thyroid cancers has been noted[18, 19]. The physical doses of radiation to which the thyroid glands of the Rongelap children were subjected are higher than those doses which have been associated with late development of cancer[18, 20, 22]. It is possible that in the Marshallese children the latent period may be prolonged compared with reported cases[21] since exposure was largely due to radioiodines. Under conditions of the fallout, the dose to the thyroid gland was received over a period of hours.

Thyroid cancer has developed in one adult. Although this single occurrence is not definitive evidence, the possible relationship of carcinogenesis to fallout radiation must be seriously evaluated. The effect of exogenously administered thyroid hormone on the risk of cancer of the thyroid gland in the irradiated human is unknown. However, the suppression of nodule formation in the irradiated thyroid gland of the rat has been reported[23].

The early clinical and endocrinologic evaluations had not delineated clearly the mechanism for growth failure in some of the Rongelap children[15]. Later studies have demonstrated abnormalities that indicate, with increasing probability, that the growth retardation has been the result of hypofunction of the thyroid gland in these children[16, 17]. The significant growth spurt in the most retarded children following administration of thyroid hormone can be considered strong corroborative evidence.

TABLE I

ESTIMATED RADIATION DOSE

IN MARSHALLESE POPULATIONS

| Population | Gamma dose (rads) | Thyroid dose (I, rads) |
|---|---|---|
| RONGELAP | | |
| Age < 10 yrs. | 175 | 700-1400 |
| Age > 10 yrs. | 175 | 160 |
| AILINGNAE | | |
| Age < 10 yrs. | 69 | 275-550 |
| Age > 10 yrs. | 69 | 55 |
| UTIRIK | | |
| Age < 10 yrs. | 14 | 55-110 |
| Age > 10 yrs. | 14 | 15 |

TABLE II

MARSHALL ISLAND POPULATIONS

| | Age in 1954 | | |
|---|---|---|---|
| | Under 10 yrs | 10-15 yrs | 16+ yrs |
| Rongelap exposed | 19 | 11 | 34 |
| Rongelap exposed (in utero) | 4 | 0 | 0 |
| Ailingnae exposed | 6 | 0 | 12 |
| Utirik exposed | 54 | 9 | 94 |
| Rongelap unexposed | 48 | 8 | 125 |

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TABLE III

NAUSEA AND VOMITING

RONGELAP GROUP

| Age at Exposure | Number | Incidence | |
|---|---|---|---|
| | | Nausea | Vomiting |
| 5 years and younger | 13 | 85% | 38% |
| Over 6 years | 51 | 44% | 4% |

TABLE IV

EPILATION

RONGELAP GROUP

| Severity of Epilation | Incidence (%) | | |
|---|---|---|---|
| | Age 0-5 yrs (13) | Age 6-15 yrs (13) | Age 16+ yrs (38) |
| Slight (1+) | 7.6 | 38.4 | 13.8 |
| Moderate (2+) | 38.6 | 30.7 | 5.5 |
| Severe (3+) | 53.8 | 23.0 | 8.3 |
| TOTAL | 100.0 | 92.1 | 27.6 |

TABLE V

MEAN BLOOD COUNTS AT PEAK DEPRESSION

RONGELAP GROUP

| | Percent of Control | |
|---|---|---|
| | Age under 5 yrs | Age over 5 yrs |
| Neutrophiles | 56% | 64% |
| Lymphocytes | 25% | 55% |
| Platelets | 23% | 34% |

TABLE VI

THYROID LESIONS

| Population | Incidence of Thyroid Lesions* | |
|---|---|---|
| | Age 10 yrs (in 1954) | Age 10 yrs (in 1954) |
| | % | % |
| Rongelap -- exposed | 89.5 (17/19) | 8.8 (3/34) |
| Ailingnae -- exposed | 0 (0/6) | 12.5 (1/8) |
| Utirik -- exposed | 0 (0/40) | 3.4 (2/59) |
| Rongelap -- unexposed | 0 (0/48) | 2.3 (3/133) |

*Calculated on basis of numbers of people examined for thyroid status.

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SUMMARY:

In March 1954, 82 people of Rongelap Island in the Marshall Islands were accidentally exposed to sublethal doses of fallout radiation during the atomic bomb testing program. Sixty-four of these people received about 175 rads whole-body gamma-ray exposure and 18 received about 69 rads. Additional radiation exposure occurred from radioactive material deposited on the skin and hair and from ingested radionuclides. This report summarizes the medical findings in the exposed children over a 15-year period as compared with findings in the adults.

Early nausea with vomiting and diarrhea occurred in both children and adults. The depression of leukocyte and platelet levels that developed was more pronounced in the children. Beta burns of the skin and epilation were more severe in the children but in all age groups healing was rapid with minimal scarring and regrowth of hair was complete. Growth and development appeared to be slightly retarded in some exposed children compared to non-exposed children. This growth lag was particularly prominent in boys who were less than 5 years of age at time of exposure. No acute effects were noted in connection with the internal absorption of radionuclides.

It has been calculated that the thyroid gland had absorbed about 11 microcuries of $^{131}I$ and that the thyroid glands of young children in the heavily exposed group received doses of 700 to 1400 rads. In 1963, a thyroid nodule was found in a 12-year old girl. During the next 5 years 17 cases of thyroid abnormalities (15 with nodules, 2 with hypothyroidism) were detected, all among a group of 19 children who were exposed at less than 10 years of age. No thyroid nodules have been noted in 48 unexposed children

of the same ages living on the same island and in 60 children exposed to lesser doses. Only three thyroid abnormalities have been documented among the heavily irradiated group of adults. Thyroid surgery on 12 children and two adults revealed adenomatoid goiter in all cases except for one 40-year old woman who had a malignant tumor. Atrophy of the thyroid gland and marked growth retardation with growth spurts subsequent to thyroid hormone administration were seen in the two hypothyroid boys. It has become increasingly evident that thyroid injury associated with fallout exposure has resulted in deficiency of thyroid function.

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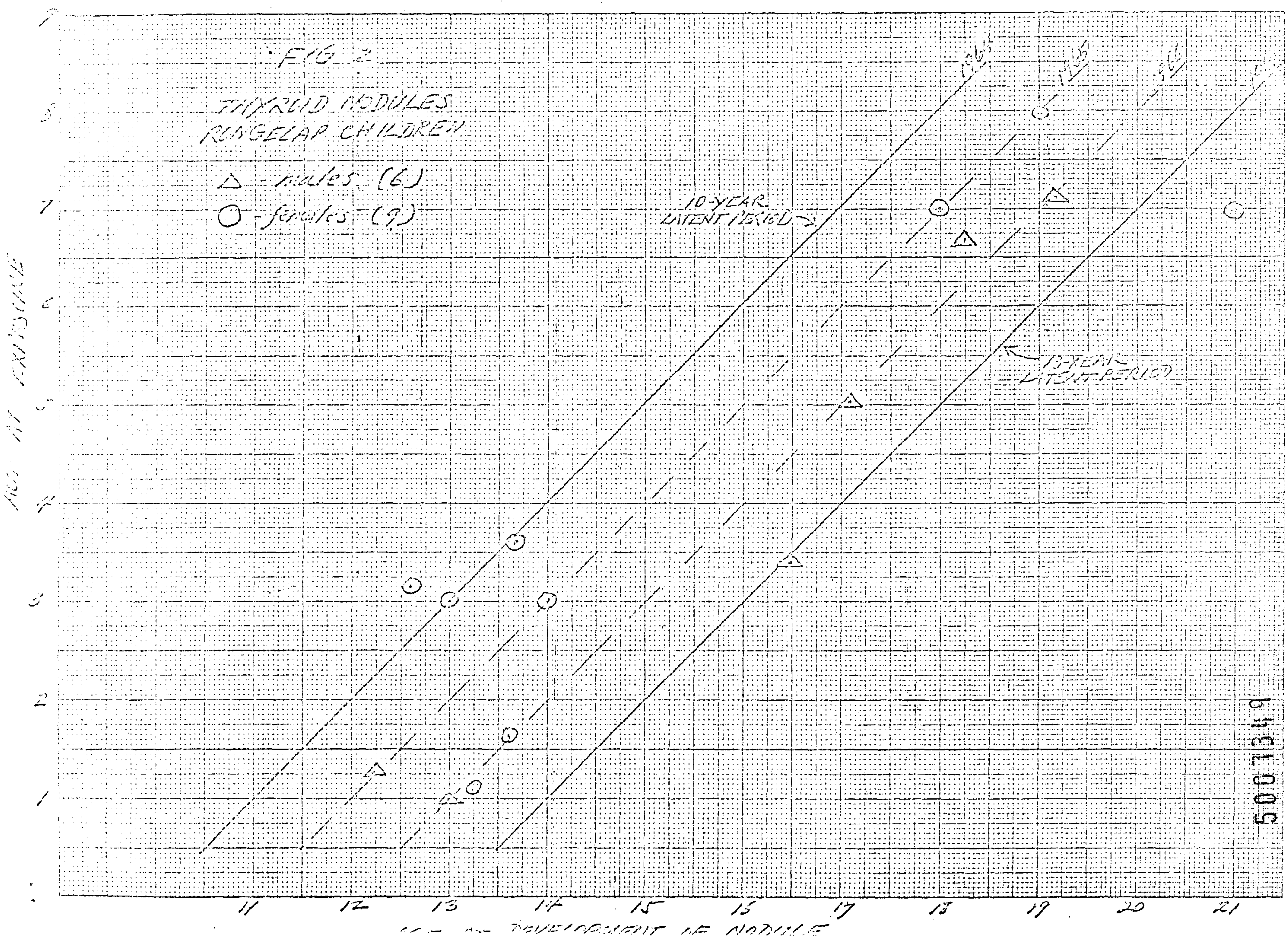
FIG 2
THYROID NODULES
RONGELAP CHILDREN
△ - males (6)
○ - females (9)
10-YEAR LATENT PERIOD
13-YEAR LATENT PERIOD
1
2
4
6
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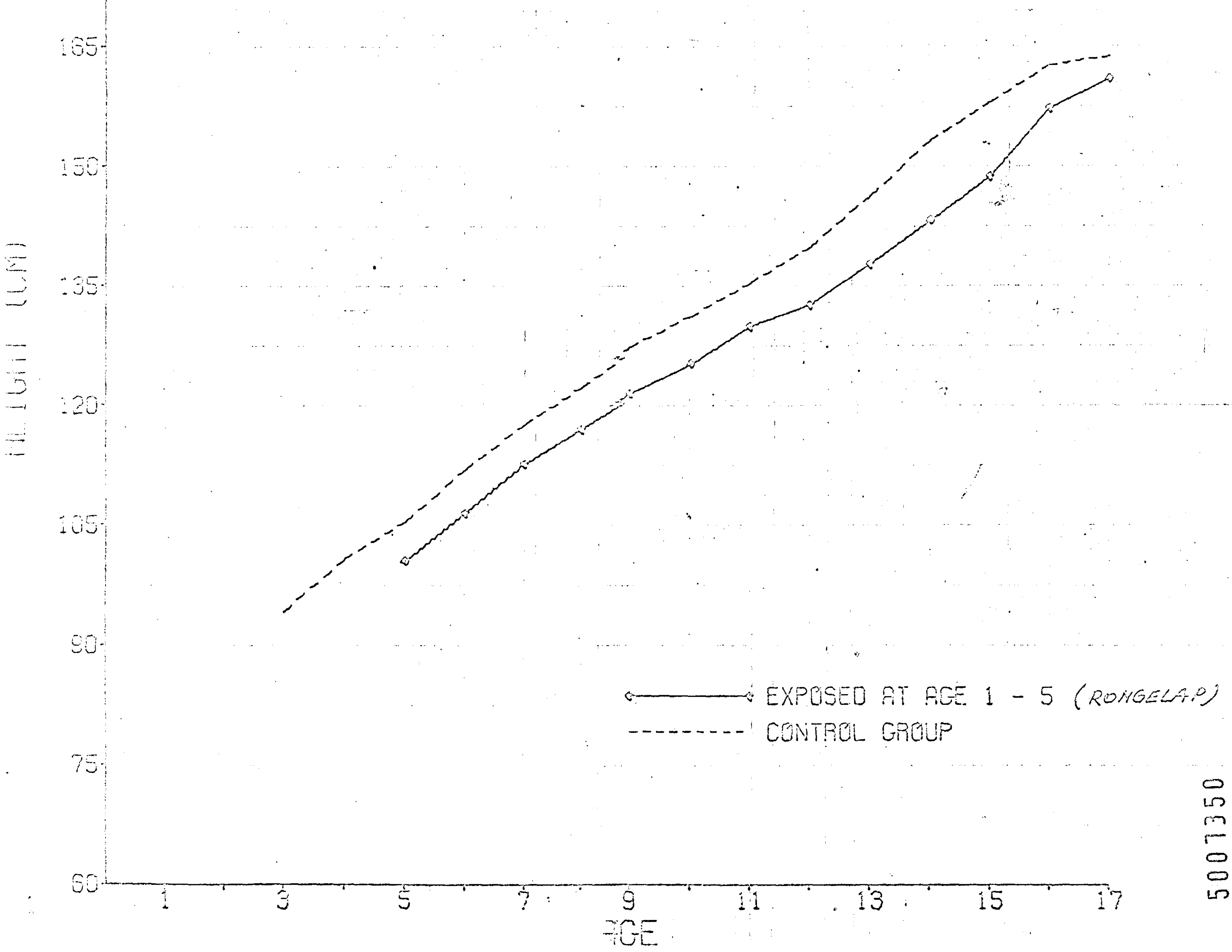
HEIGHT - M (1967)

FIG. 1.

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