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CONTAMINATION OF SOFT TISSUES OF INFANTS AND CHILDREN WITH RADIOACTIVE FALLOUT AS EXEMPLIFIED BY ^{137}Cs AND ^{131}I*

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For possible presentation at a Conference on Pediatric Significance of Peacetime Radioactive Fallout to be held at San Diego, California, on March 14-16, 1966.

INTRODUCTION

The occurrence of radioactive fallout iodine-131 and cesium-137 in tissues of children represent two rather different circumstances. On the one hand, ^{131}I is a most important constituent of local fallout, is short-lived, and the radiological health significance of past releases has generally been due to acute dosages received by temperate zone populations residing near test sites or other origins. By comparison, cesium-137 is associated with the prolonged deposition of worldwide fallout, is long-lived, and is of greatest significance in arctic regions usually far removed from weapons testing locations. A discussion of both these radionuclides thus encompasses a variety of environmental factors, food habits of diverse population groups, and radiological health aspects. An extensive discussion of ^{131}I phenomena appears in the Hanford Symposium on the Biology of Radioiodine (Bustad, 1964) and in several Congressional Hearings (Joint Committee on Atomic Energy, 1962, 1963, 1965). I shall refer to these and other sources only briefly, principally because specific amounts of ^{131}I in human thyroids are generally not reported; rather, thyroid dose rates are calculated on the basis of ^{131}I levels in milk and fairly constant parameters (Eisenbud et al., 1963). This is often more practical than direct measurements

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(UNSCEAR, 1964). Discussion of these dose rates will be the topic of other speakers at this Conference.

Measurement of cesium-137 in infants and children of northern arctic regions has been an integral part of our studies, and I shall devote most of this paper to a discussion of the amounts, routes and rates of ^{137}Cs accumulation in Alaskan Eskimo and Indian populations.

Iodine-131

The radiological health importance of fallout radioiodine was first recognized about 1954 when it was reported in thyroids of dairy cattle (Van Middlesworth, 1954). Subsequent measurements of human thyroids defined milk as the principal source of ^{131}I and children as the critical population segment (Van Middlesworth, 1956; Comar, 1957). It is now generally accepted that children and infants less than two years of age are of most concern in appraising fallout ^{131}I because of (1) the relatively greater importance of milk in their total diet, (2) the small size of their thyroid glands increases the significance of absorbed radioiodine, (3) the cells at that stage of rapid growth are presumably more sensitive to radiation, and (4) the long post-irradiation life span during which delayed effects could appear. Eisenbud _et al_. (1963) have further delineated the critical age to about seven months on the basis of various parameters functionally related to age.

Thyroid glands of average United States infants and children were estimated to have experienced annual doses of about 0.1 to 0.2 rad from fallout ^{131}I during the late 1950's (Lewis, 1959). Estimates of the average ^{131}I dose to the thyroid of infants 6-18 months of age, based on the Federal Radiation Council model (FRC, 1961) ranged from 30 to 440 mrems in 1961 and from 30 to 650 mrems in 1962, based on sampling in the U. S. Public Health Service pasteurized milk network. A limited number of infants in localized areas conceivably could have received doses 10 to 30 times the averages (FRC, 1963). By comparison, the estimated dose to thyroids of 40,000 to 50,000 Utah children was a few rads on several occasions during the period 1952-1962, and during May, 1953, about 700 infants at St. George, Utah received an estimated average dose of 84 rads (Pendleton et al., 1963). This latter value is about five times the estimated maximum exposure received by English children immediately following the Windscale accident in October, 1957 (Dunster, Howell and Templeton, 1958), but only one-tenth that received by thyroids of three Marshallese children who 9-10 years later developed thyroid nodules (Conard and Hicking, 1965).

Radioiodine concentrations in human thyroids have usually been most important in the immediate area of release, but occasionally significant exposures have occurred at distant areas. The meteorological phenomena responsible for appreciable ^{131}I deposition have been described as (1) short range low-altitude air drift from small-yield atmospheric tests or venting of underground tests in Nevada; (2) subsiding air masses containing debris from USSR tests; and (3) scavenging of relatively fresh debris by falling precipitation (Machta, List and Telegadas, 1963). The first type of deposition has generally proved of most significance so far as thyroid exposure of general populations are concerned. An outstanding example occurred during July and August of 1962 in Utah. Initial appearance phases for ^{131}I in milk was assigned to a series of nuclear tests conducted at the Nevada Test Site during the period 6-17 July (Bostrom, 1962). Subsequent measurement of ^{131}I levels in milk reached a maximum on 20 July, and thyroid dosages to infants consuming one liter of the milk at peak concentrations were calculated to be 14 rad, compared to an average exposure of 1.0 rad (Pendleton, Lloyd and Mays, 1963; Pendleton et al., 1963). The importance of seasonal grazing or feeding of dairy cattle is emphasized by comparing these values with those reported in Norway following the deposition of ^{131}I from a Russian nuclear test during November 1962 (Hvinden, Lillegraven and Lillesaeter, 1964). Iodine-131 in milk from Norwegian cows on stored feed increased to nearly 0.1 nCi/liter when the radioactive cloud passed and contributed a thyroid dosage of about 40 mrad to infants' thyroids in the Trondheim area. Had the event occurred during the grazing season, it was estimated that the ^{131}I concentration in milk might have reached 10 nCi/l or more, corresponding to dosages of 5.0 rads or more to infants' thyroids. Consequently, the transfer of dairy cattle from grazing to stored feed is an obvious way of avoiding the potential biological hazard of ^{131}I. Field experiments within the Project Sedan (July 6, 1962) fallout pattern indicated that such a transfer of food source of dairy cattle for two weeks would avoid more than 85% of the ^{131}I risk (Martin, 1965), particularly to those populations residing near high fallout areas. The diversion of fresh milk into processing plants for conversion into other dairy products is another obvious method of reducing the radioiodine content, and was practiced during critical periods (Dunster, Howells and Templeton, 1958; Pendleton et al., 1963).

Cesium-137

Since 1962 we have measured ^{137}Cs body burdens in native populations at several locations in northern Alaska (Figure 1). The subjects can be separated into distinct ethnic groups, or peoples of common traits or customs, on the basis of their food habits, location and cultural background. Eskimos of northern Alaska represent two major ecological groupings, the inland and the coastal peoples (Spencer, 1959). The food gathering cultures of these people differ considerably; the inland people, of which the Anaktuvuk Pass residents are the sole remaining village, rely upon caribou for most of their food, while coastal Eskimos utilize marine mammals extensively and caribou and/or reindeer moderately. Intergradations of both cultures occur among Eskimos inhabiting villages along the Noatak and Kobuk river systems in northwestern Alaska. The Athabascan Indian villages of Fort Yukon and Arctic Village provided comparison of ^{137}Cs body burdens in natives who utilize moose as a major food source during fall and winter months, with groups who rely upon caribou and reindeer during those seasons. Dietary habits of each person were determined at the time of counting, and samples of indicated important domestic and native foods were obtained and evaluated as a source of radionuclides.

Average ^{137}Cs body burdens of the various ethnic groups maintained the same general ranking during 1962 and 1963 (Table 1). Body burdens were directly related to food habits, specifically to the amount and constancy of caribou and reindeer consumption; greatest amounts occurred in Anaktuvuk Pass residents and lowest amounts were found in Fort Yukon residents (Hanson and Palmer, 1964; Hanson, Palmer and Griffin, 1964). Persons between 21 and 50 years of age usually contained greater amounts of ^{137}Cs than did children or older people. Comparison of body burdens among members of 152 families from the several villages showed the following ratios:

Husband	2
Wife	1
Child - local school student	0.8
Child - boarding school student	0.6

These ratios resulted from several factors. Husbands estimated they consumed about 50% more food than did their wives, and they have a higher proportion of muscle tissue, the principal concentration site of ^{137}Cs. The lower values in children compared to parents are ascribed to less consumption of native foods and because of an apparent discrimination against cesium in favor of potassium (Onstead, Oberhausen and Keary, 1962). Boarding school students who attended high schools or colleges in other parts of Alaska or other states usually contained lower ^{137}Cs body burdens than students who attended local grammar schools and consumed caribou and reindeer typical of their family diet while living at home. The ^{137}Cs body burdens in boarding school students usually increased during the summer as they consumed caribou and reindeer meat as part of the normal family diet, thus modifying the above ratios later in the summer.

During 1964 and 1965 we defined the seasonal cycle of ^{137}Cs body burdens of Anaktuvuk Pass residents by performing measurements at about two-month intervals, and by corresponding measurements of caribou meat typical of the native diet (Hanson and Palmer, 1964). Cesium-137 body burdens in the Anaktuvuk Pass people showed a recurring seasonal pattern with lowest values during January of each year and maxima during July (Figure 2). This pattern results from the Eskimo practice of killing a substantial number of caribou when the animals migrate near the village twice yearly. These slaughter periods occurred at crucial times in the seasonal pattern of ^{137}Cs concentrations in caribou flesh. Animals killed during fall months (late August to early October) were migrating from summer ranges on the Arctic Slope where their food consists principally of fresh green vegetation containing low ^{137}Cs concentrations. This meat is stockpiled for use throughout the winter and is supplemented by killing animals near the village, and which contain increasing ^{137}Cs concentrations as the winter diet of lichens asserts its influence. Caribou leaving the winter range are usually slaughtered in large numbers during late May and the meat stored in underground cellars ("caches") dug into the permafrost. These animals contained greater ^{137}Cs concentrations in their flesh than animals killed at other times of the year because of the extended winter period of lichen utilization.

Maximum ^{137}Cs body burdens during 1964 and 1965 occurred in Anaktuvuk Pass Eskimos about two to three months after the people began to utilize the main spring kill of caribou. The relationship between the ^{137}Cs levels in caribou flesh, the estimated consumption of caribou meat by the people, and the human body burdens is shown in Figure 3. Cesium-137 body burdens responded directly to changes in ^{137}Cs level in the diet; increases occurred following the utilization of spring-killed animals and decreases accompanied a shift to fall-killed caribou.

Comparison of ^{137}Cs concentrations in various age categories of Anaktuvuk Pass residents showed a consistent relationship, with increasing amounts of ^{137}Cs with an increase of age and body weight (Figure 4). Children (3-14 years old) usually contained about half as much ^{137}Cs per kilogram body weight as adults (>21 years old), and minors (15-20 years old) contained about 70% as much as adults. These results reflect the greater consumption of caribou, a greater proportion of muscle and less discrimination against cesium with increasing age.

Comparison of males and females of the three age categories showed that males generally contained greater ^{137}Cs concentrations per kg body weight than females (Figure 5), and the difference was most pronounced in the adults and minors. Male and female children contained almost identical concentrations, with a suggestion of a slightly greater value in males. A scatter-plot of male and female body burdens during the maximum concentration period of July 1964 is shown in Figure 6, with an eye-fitted curve for the two sexes. This indicated that the differences in male and female ^{137}Cs body burdens were unimportant until the age of about twenty, males then contained consistently more ^{137}Cs than females, maximum difference occurred at about the age of 40, and the two curves tended to converge during advanced age. Similar results were observed during the 1965 seasonal maximum.

Comparison of ^{137}Cs body burdens from one summer to the next showed pronounced increases of about 50 per cent from 1962 to 1963 and a doubling between 1963 and 1964, followed by a decrease of 30 per cent from 1964 to 1965. This reflects the pattern of ^{137}Cs concentrations in caribou flesh at Anaktuvuk Pass, which forms the food base of the people. Amounts in lichens, which determine the ^{137}Cs concentrations in caribou flesh, have shown a steady but less spectacular increase with time. This points out that the 30% decrease from 1964 to 1965 was as inconsistent with the trend in the lichens as was the abrupt increase during the spring of 1964, and emphasizes the importance of caribou behavior on winter range to the determination of ^{137}Cs levels in the Eskimos. During the winter of 1963-1964 the caribou wintered farther south of Anaktuvuk Pass than normal and the spring kill by the natives must have consisted of animals from areas where ^{137}Cs concentrations in lichens were greater than those at Anaktuvuk Pass or of animals that were eating lichen species which contained greater ^{137}Cs concentrations than those we sampled. We have noted a 2- to 3-fold difference among ^{137}Cs concentrations of several lichen species (Hanson, Watson and Perkins, 1966). These important differences in ^{137}Cs concentrations in the food base of the caribou and the people are due to factors which have not been sufficiently well identified to permit reliable prediction of future levels. Current studies of ^{134}Cs and ^{85}Sr retention following artificial application to natural lichen communities in Alaska (Hanson, Watson and Perkins, op. cit.) showed that cesium is more tenaciously retained by lichens than is strontium, and suggests that present levels of ^{137}Cs in the biota of northern Alaska may be maintained for some time to come.

In terms of radiological health, whole-body radiation dosage to the Anaktuvuk Pass people from ^{137}Cs body burdens measured during the year 1964, the period of maximum values, were calculated from various formulae (Bertinchamps and Cotzias, 1958; ICRP, 1953; Maycock _et al_., 1960; NCRP, 1953). Estimated averages ranged from 135 to 150 millirems, which were about 30 per cent of the amount suggested as a Radiation Protection Guide for this population group (Federal Radiation Council, 1965).

The maximum individual exposure among all Anaktuvuk Pass adults was about twice the average value stated above (about 300 mrems) and was also within values recommended by the Federal Radiation Council.

The amounts of ^{137}Cs in Anaktuvuk Pass Eskimos are about the same as those reported in Swedish and Finnish Reindeer Breeder Lapps (Lidén and Naversten, 1964; Miettinen, 1964), and slightly less than those in reindeer breeders in northern regions of the Soviet Union (UNSCEAR, 1964). This agreement of enhanced ^{137}Cs body burdens among arctic peoples indicates the circumpolar situation is primarily due to the effective transfer of this fallout radionuclide through the lichen to caribou (reindeer) to man food web. In general, ^{137}Cs body burdens of arctic peoples are several orders of magnitude greater than those of North American and European inhabitants of the regions between 30 and 60 degrees north latitude, which area receives about five times as much fallout deposition as the arctic regions. The important effect of ecologic factors in regulating the human dietary level of ^{137}Cs in these regions is emphasized by comparing the estimated average daily intake of ^{137}Cs by children under 18 years of age. The U. S. Public Health Service Institutional Diet Sampling Program estimated that the average daily intake of ^{137}Cs via diet of children under 18 years of age was 29 picocuries per day during 1961 and about 49 picocuries during 1962 (USPHS, 1963). Our estimates of ^{137}Cs ingestion by Anaktuvuk Pass children during the same periods were about 800 pCi/day and 3,500 pCi/day, respectively. The body burdens of temperate zone populations generally lag behind fallout deposition rates by times varying from about nine months to two years (UNSCEAR, 1964). This suggests that the period of maximum values should now be past. Our recent results indicate that the concentrations of fallout radionuclides in arctic ecosystems may be significantly influenced by the retention of ^{137}Cs in lichens, and emphasizes the need for more study of this environment before our prediction capability is adequate.

SUMMARY

Fallout ^{131}I in children's thyroids has resulted from local fallout associated with nuclear weapons tests and the Windscale reactor accident. Milk is recognized as the principal means of transport into human populations, and very young children are considered to be the critical age group so far

as exposure hazards are concerned. Environmental factors influence the deposition of the ^{131}I and the subsequent rate of transfer to dairy cattle and into humans. Maximum exposures within the continental United States have generally occurred among Utah children. During the period 1952-1962, some 40,000 to 50,000 of these children were estimated to have received thyroid doses from ^{131}I of a few rads on several occasions, and during 1953 about 700 infants at St. George, Utah received an estimated dose of 84 rads. This was about five times the maximum dose received by English children immediately following the Windscale accident and about one-tenth the ^{131}I dose estimated to have resulted in thyroid nodules in a few Marshallese children several years following exposure.

Cesium-137 is most important in arctic regions, where whole-body burdens are several orders of magnitude greater than those of temperate North America and Europe. This results from ecologic factors which facilitate the effective transfer of ^{137}Cs through the lichen to caribou (reindeer) to man food web. The distribution of ^{137}Cs body burdens within Alaskan native populations showed important influences of ethnic background and cultural practices of the people. Maximum values were consistently found in those persons who consumed the greatest amounts of caribou flesh, and reflected the seasonal cycle of ^{137}Cs concentrations in caribou flesh. Adults contained the greatest ^{137}Cs whole-body burdens and concentrations, minors (15-20 years old) contained median amounts and children (less than 15 years old) contained the least. Comparison of male and female ^{137}Cs body burdens at times of the seasonal maximum indicated there was no difference between the sexes until about the age of twenty, males then contained consistently more ^{137}Cs than females, maximum difference occurred at about the age of 40, and then the difference decreased with advancing age.

Whole-body radiation dosage to the Anaktuvuk Pass people from ^{137}Cs body burdens during 1964, the period of maximum values, were calculated to be about 30 per cent of the amount suggested as a Radiation Protection Guide for that population group.

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TABLE 1. Cesium-137 body burdens of various age categories and ethnic groups of northern Alaska during 1962 and 1963.

Location	Average ^{137}Cs body burden in nanocuries: Children (4-14 years) 1962	Children (4-14 years) 1963	Minors (15-20 years) 1962	Minors (15-20 years) 1963	Adults (>21 years) 1962	Adults (>21 years) 1963
Anaktuvuk Pass	(19) 230	(39) 280	(12) 340	(13) 500	(39) 450	(44) 640
Kotzebue	(40) 47	(28) 46	(26) 50	(22) 55	(112) 150	(102) 120
River Villages*	(10) 63	(12) 49	(7) 64	(7) 92	(35) 150	(16) 150
Coastal Villages**					(8) 100	
Barrow	(52) 16	(47) 25	(57) 17	(34) 26	(248) 55	(119) 65
Little Diomede	(3) 9		(1) 12		(15) 29	(1) 44
Point Hope	(44) 13	(37) 22	(34) 14	(27) 24	(80) 19	(76) 40
Fort Yukon		(9) 9		(25) 21		(56) 37

* Ambler, Kiana, Kobuk, Noatak, Noorvik, Selawik and Shungnak

** Deering, Elim and Kivalina

() Number of persons

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FIGURE 1. Map of Alaska showing locations of native villages and whole-body counting operations.

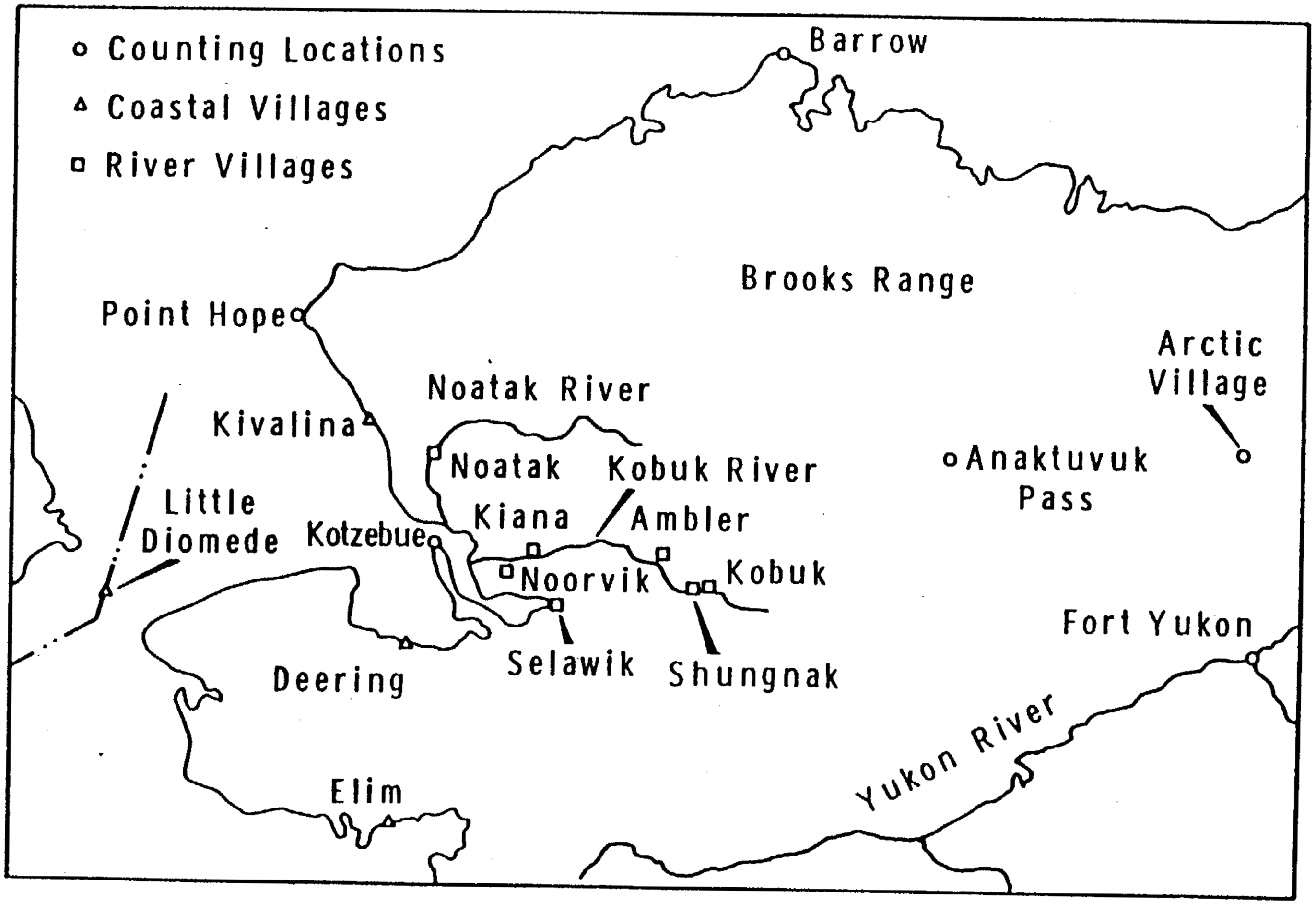
FIGURE 2. Cesium-137 in caribou flesh and Eskimos at Anaktuvuk Pass, Alaska during the period May 1962 - March 1965. Arrows on abscissa indicate major killing periods of caribou for food supplies.

FIGURE 3. Seasonal changes of average ^{137}Cs body burdens, ^{137}Cs intake, and caribou flesh intake of 26 control natives at Anaktuvuk Pass, Alaska.

FIGURE 4. Cesium-137 body burdens of various age categories of Anaktuvuk Pass, Alaska residents, 1962-1965.

FIGURE 5. Cesium-137 body burdens of males and females of age categories at Anaktuvuk Pass, Alaska residents, 1962-1965.

FIGURE 6. Cesium-137 body burdens of Anaktuvuk Pass Eskimos during July, 1964 as a function of age and sex.



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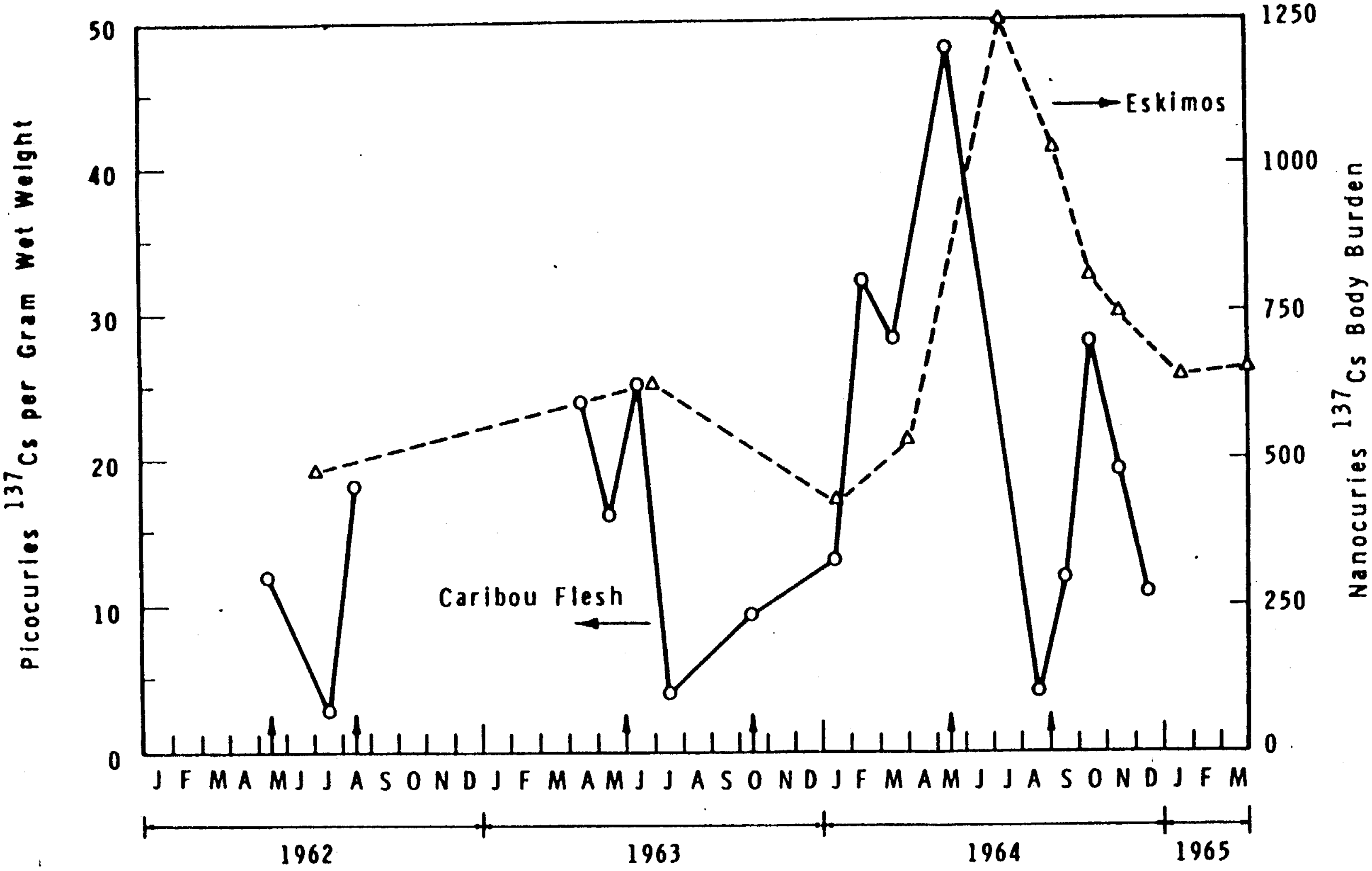
CESIUM-137 IN CARIBOU FLESH AND ESKIMOS AT ANAKTUVUK PASS DURING THE PERIOD MAY 1962 - MARCH 1965. ARROWS ON ABCISSA INDICATE MAJOR KILLING PERIODS OF CARIBOU



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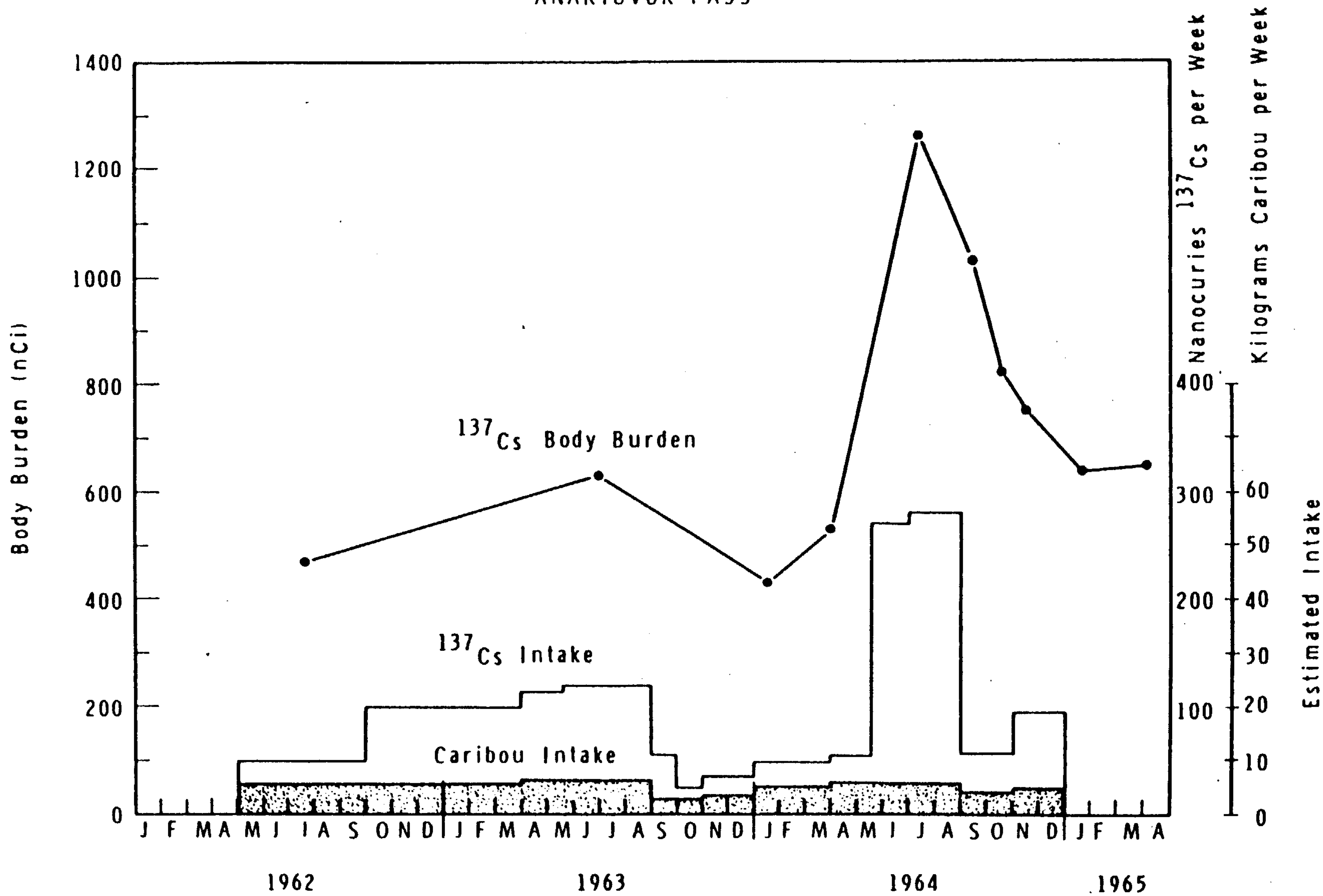
AVERAGE ^{137}Cs BODY BURDENS AND ^{137}Cs INTAKE OF 26 CONTROL NATIVES AT ANAKTUVUK PASS



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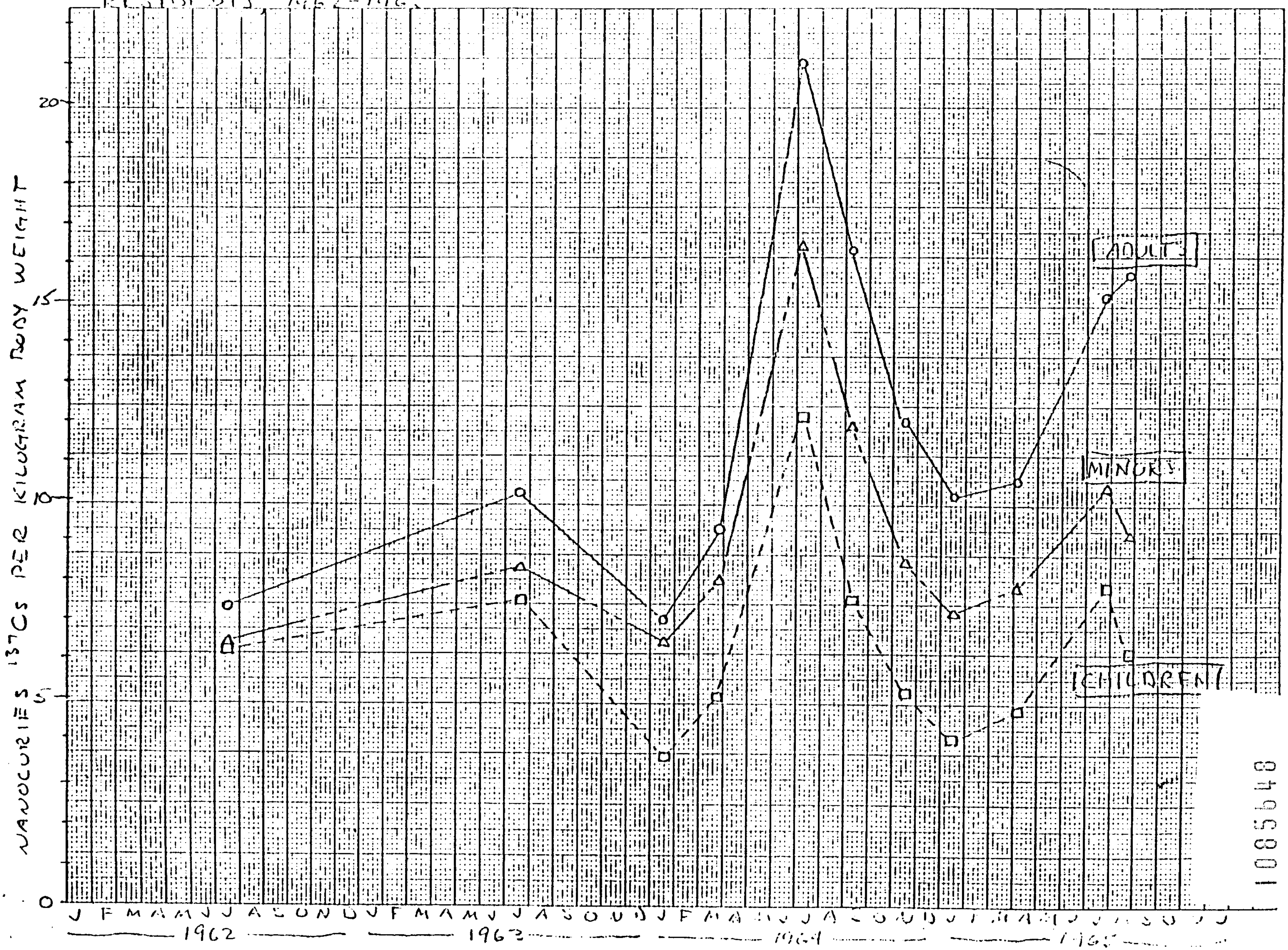
CESIUM-137 BODY BURDENS OF VARIOUS AGE CATEGORIES OF ANAKTUVUK PASS, ALASKA RESIDENTS, 1962-1965



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CESIUM-137 BODY BURDENS OF MALES AND FEMALES OF AGE CATEGORIES AT ANAKTUVUK PASS, ALASKA

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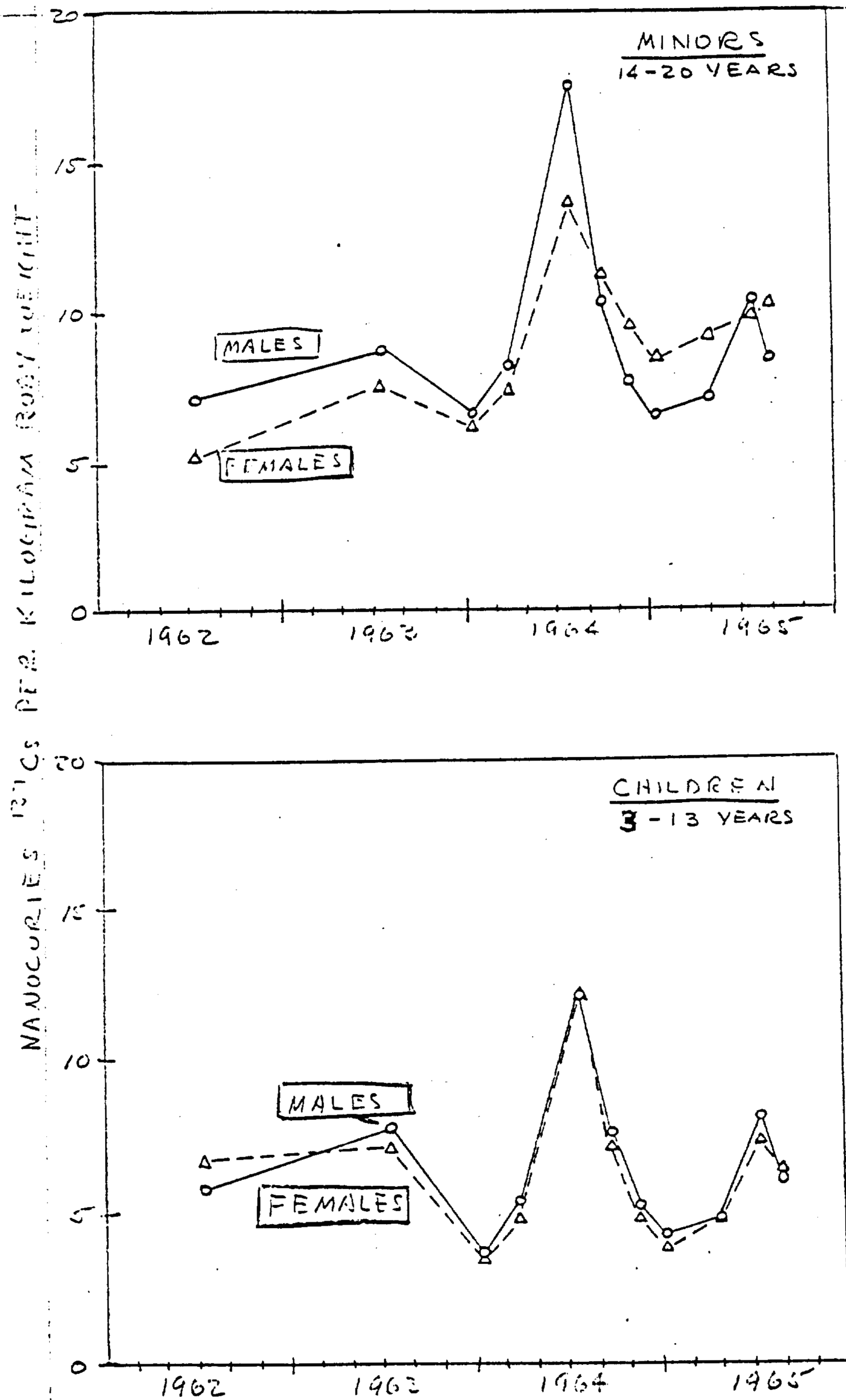

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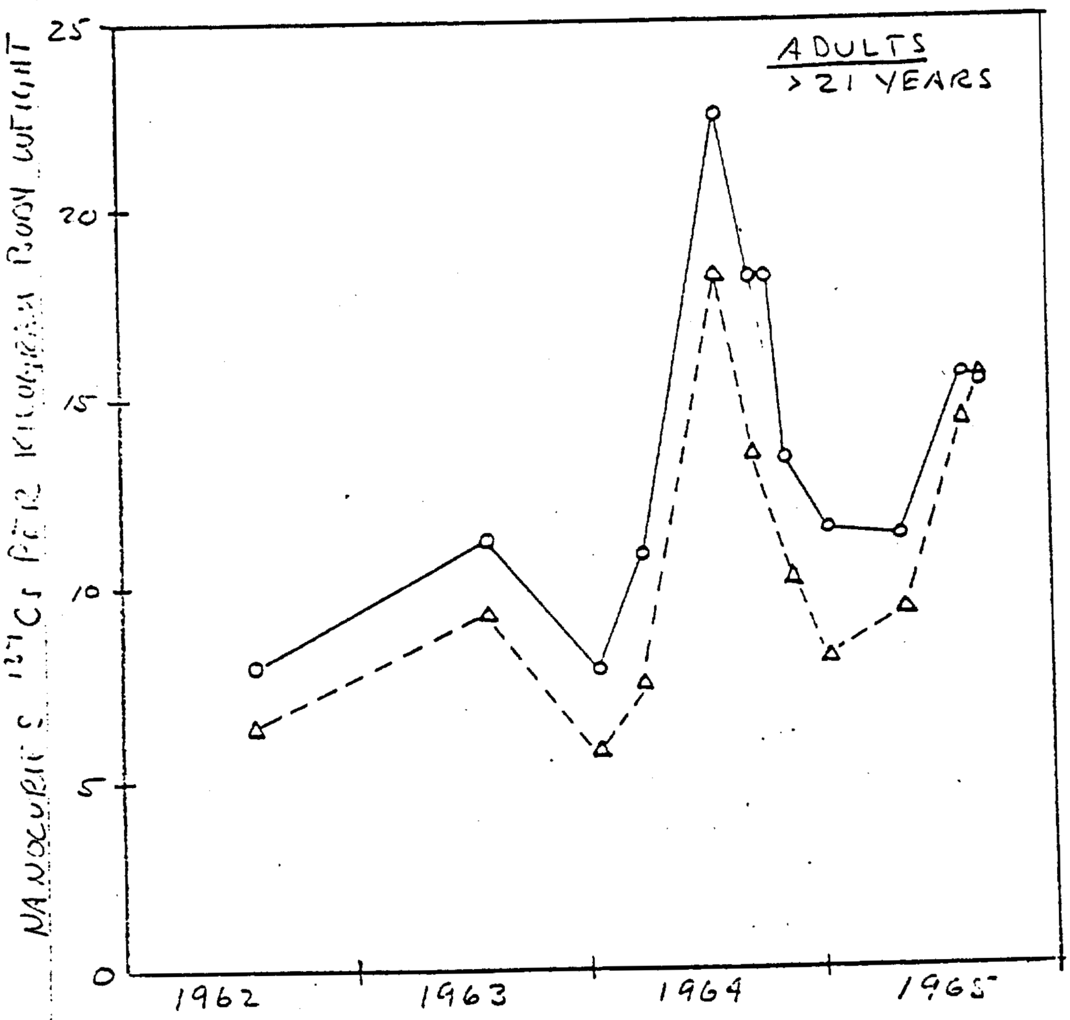

ADULTS
> 21 YEARS
NANOCURIES 137Cs PER KILOGRAM BODY WEIGHT
25
20
15
10
5
0
1962
1963
1964
1965

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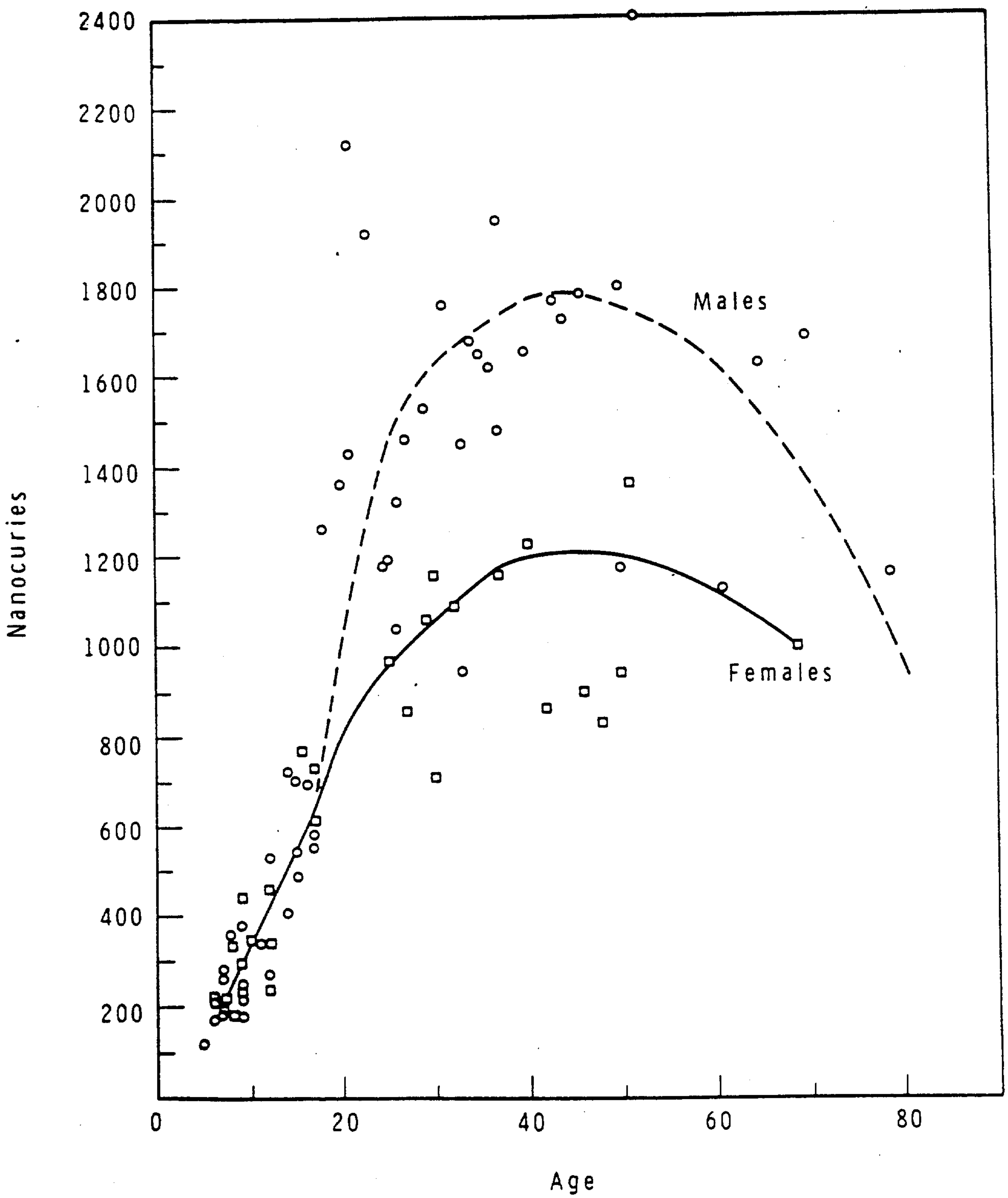

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