Iodine-131 Dose from Soviet Nuclear Tests

Accumulation of iodine-131 in human thyroids was observed by in vivo procedures during the 1961 tests.

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The observation by Van Middlesworth (*1*) of the presence of iodine-131 in the thyroids of United States cattle during nuclear weapons tests in Nevada in 1953 was the first published indication that this radionuclide might be present in human foods during and immediately after tests. Van Middlesworth's report was followed by studies of Comar *et al.* (*2*), who measured the levels of iodine-131 in human and cattle thyroids from January 1955 through December 1956. Their studies indicated that the dose to human thyroids during the 23-month period of observation was about 0.01 rad. Later, Lewis (*3*) concluded, on the basis of published reports of the iodine-131 levels in milk, that the thyroid glands of average infants and children received a dose of 0.1 to 0.2 rad from May 1957 to September 1958. Subsequently Lewis (*4*) estimated that over the 5-year period prior to 1958 the average accumulated dose to the thyroids among 40 million children in the United States under the age of 10 years was 0.2 to 0.4 rad.

Lewis's observations attracted widespread interest because his calculated thyroid doses were considerably higher than earlier estimates of the doses to gonadal tissue and the skeleton by cesium-137 and strontium-90. These long-lived radionuclides were, until then, the only fission products that had been studied intensively in the biosphere.

Because iodine-131 has a short half-life (8 days), this radionuclide disappeared from the environment within a matter of weeks after the temporary moratorium on testing established in the fall of 1958. Thus, no new data became available prior to the resumption of testing by the U.S.S.R. in September 1961. In the intervening 3 years, however, the ease with which we can make environmental and human measurements of iodine-131 has greatly increased. This is due largely to the more general availability of gamma spectrometric equipment with which the direct determination of iodine-131 is a relatively simple procedure.

Following reports that radioiodine from the 1961 U.S.S.R. weapons tests was present in milk supplies in the United States, this laboratory began to undertake measurements of radioiodine in human thyroids. The first measurement was on an individual who died on 9 October, about 5 weeks after the Russians resumed testing and about 10 days after iodine-131 was first observed in dairy products in New York City. During the ensuing 10 weeks, a series of both postmortem and in vivo measurements was made on a total of 199 individuals.

Although considerable improvisation was necessary because no prior preparation had been made by us for this type of study, useful information about the presence of iodine-131 in humans was obtained. The data are presented in the hope that, in addition to the value of the limited conclusions which can be drawn from them, our observations will prove to be of value by guiding other investigators who may wish to undertake studies of this kind in the future.

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Methods of Measurement

During the period of observation, 179 thyroids were dissected at autopsy and were assayed for iodine-131. Most of these thyroids were made available through the cooperation of the Office of the Chief Medical Examiner of the City of New York, but a few were from hospital autopsy cases. Dissections were performed within 24 hours after death. In some cases the thyroids were weighed and counted the same day, whereas in others the thyroids were placed in a plastic container and frozen until they were counted (within a few days).

Dissected thyroids were counted by centrally locating the entire gland on the surface of a sodium-iodide crystal, 8 inches in diameter and 4 inches thick. Gamma spectra were obtained with an RIDL 400-channel analyzer, and the iodine-131 content of the gland was determined quantitatively by using the 0.36-Mev gamma peak. In most of the measurements, a 25-minute or 30-minute counting period was used.

The procedure was calibrated with a dilute carrier solution of known iodine-131 content. The radioactivity of the solution was determined by plating triplicate samples on copper, evaporating them to dryness, and counting in an internal flow counter. Under these conditions, it is known that no iodine is lost during drying. In the internal counter, for a weightless source of small diameter, the geometry factor is 0.50, there is no loss by absorption, and the backscatter factor for iodine-131 is 1.36 (*5*).

Using 10 milliliters of standard solution, we observed that the total counts in channels 40 to 50 (corresponding to the range 300 to 442 Kev) were raised by 5.0×10^5 counts per minute per microcurie. The efficiency remained constant over a circle of 3-centimeter radius so that no geometry correction for thyroid size was necessary. The iodine-131 content of the thyroids was subsequently estimated by using this ratio, and the radioactivity at counting time was extrapolated back to the time of death.

The uncertainty in this procedure is thought to be no greater than ± 15 percent including the errors from counting and the fact that no self-absorption correction was made for variations in thyroid size. (Throughout this report the errors quoted correspond to a 90-percent confidence level.) The sensitivity of the method, considering counting statistics only, is such that for a 25-minute counting time and a background of 200 counts per minute the minimum amount of iodine-131 that can be detected 90 percent of the time is 23 pc (picocurie or 10^{-12} curie).

It soon became apparent to us that it should be feasible to undertake in vivo measurements by taking advantage of the shielding and gamma-ray discrimination available in the whole-body counter which the Atomic Energy Commission has made available for the use of this laboratory.

The in vivo measurements were made with two 3- by 2-inch sodium-iodide crystals placed so that the flat face of each crystal was in contact with the neck on either side of the trachea. The measurements were made in a room shielded by 7 inches of steel.

The problem of calibrating the in vivo iodine-131 measurements was considerably simplified by the opportunity afforded us to make measurements on cadavers prior to autopsy. After 30-minute counts by the procedure described above, the thyroids were dissected during regular autopsy and were then assayed for iodine-131.

In the gamma spectrometric determination of iodine-131 in dissected thyroids, no correction is required for the contribution to the iodine region from potassium-40 and cesium-137, since the quantity of these nuclides is insignificant. However, with in vivo measurements the contribution from potassium-40 and cesium-137 in the individual is appreciable, and a correction must be made. The Compton scatter contribution from these two isotopes to the iodine region was determined by using a Masonite phantom of the upper half of the body. From these measurements it was determined that the scattering contribution to the iodine region from each of these nuclides was equal to 30 percent of the counts appearing in the respective peaks. When the Compton scatter from potassium-40 and cesium-137 was subtracted from the iodine region, the calibration factor was 0.22 ± 0.04 count per minute per picocurie.

The sensitivity of the two-crystal, in vivio counting procedure is such that the minimum detectable amount is 16 pc at the 90-percent level for a 30-minute count at a background of 30 counts per minute. However, this does not account for the contribution of potassium-40 and cesium-137 which effectively increases the background. The minimum detectable amount of iodine-131 for the in vivo measurements varies depending on the size of the person being measured. From our measurements, the average contribution from potassium-40 and cesium-137 to the iodine region of the spectrum from children (8 to 12 years old) was 6 counts per minute, and the average contribution from adults was 11 counts per minute. For a 30-minute count, this would raise the minimum detectable amount to approximately 18 pc for the average child and approximately 20 pc for the average adult.

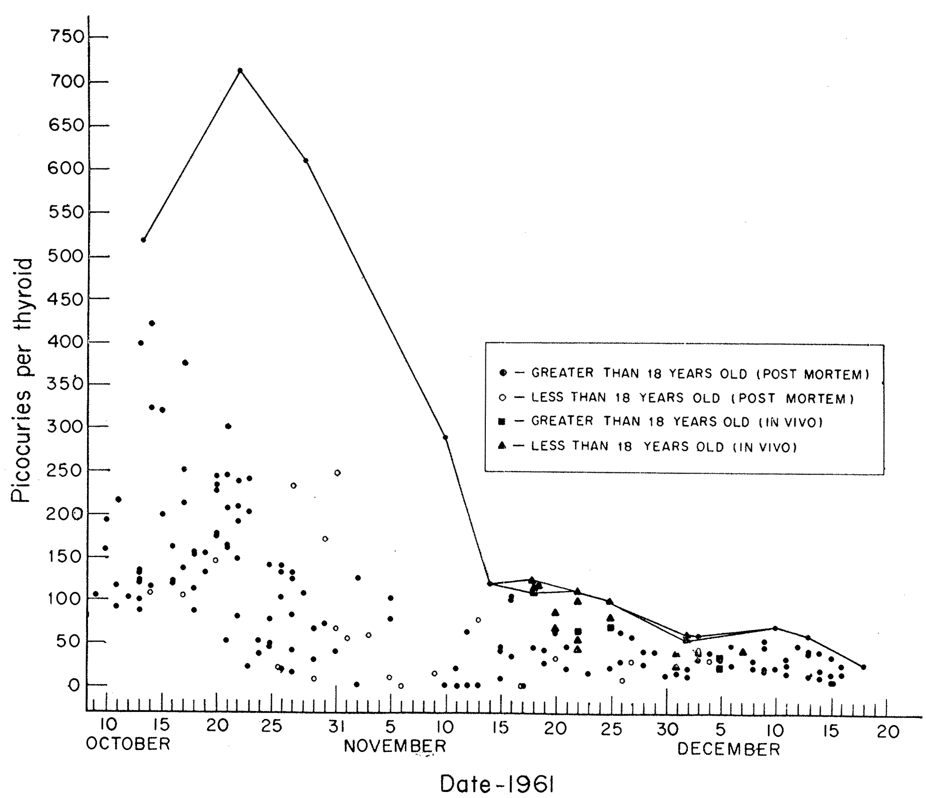

Fig. 1. Observed amounts of iodine-131, in picocuries per thyroid, for the period from 9 October through 18 December 1961.

Findings

On the first day of sampling, 10 October, eight thyroids were dissected from patients who had died on 9 and 10 October. Four of these became available from a hospital, and the remaining four were Medical Examiner's cases. The four hospital cases averaged 39 pc per thyroid, whereas the Medical Examiner's cases ranged from 110 to 295 pc, with a mean of 200 pc per thyroid. These few data suggested that hospitalized cases might be less representative of the general population with respect to thyroidal radioiodine than are the cases which come to the attention of the Medical Examiner. The latter include a large fraction of sudden deaths in which there is more apt to be a history of normal nutrition than is true for individuals who die in hospitals. Subsequent samples were therefore limited primarily to Medical Examiner's cases. Hospital cases were relatively few and were included in this study only if the history indicated that the individual had been a normally active person with a high probability of normal dietary habits and no thyroid disease. The same criteria were used in selecting Medical Examiner's cases.

During the latter part of our study, when we had developed the method of in vivo measurement, we observed that milk-drinking subjects selected from among the laboratory staff and their children tended to show higher iodine-131 burdens than cases referred to the Medical Examiner. A comparison of various groups of cases is given in Table 1.

In Fig. 1 are plotted the observed amounts of iodine-131 in picocuries per thyroid for the period from 9 October through 18 December. It is immediately apparent that the highest values

Table 1. Comparison of total iodine-131 burdens of various groups.

Subjects			Dates examined	Thyroid burden (picocuries)
Source	Condition	No.		
Adults (October)				
Office of the Chief Medical Examiner	Postmortem	20	9–15 Oct.	200 ± 130
Hospitalized cases	Postmortem	4	10 Oct.	39
Adults (November to December)				
Office of the Chief Medical Examiner	Postmortem	26	18 Nov.–7 Dec.	38 ± 17
Laboratory staff	In vivo	6	18 Nov.–5 Dec.	57 ± 33
Children (November to December)*				
Office of the Chief Medical Examiner	Postmortem	4	18 Nov.–7 Dec.	26 ± 11
Children and friends of staff	In vivo	18	18 Nov.–7 Dec.	77 ± 31

* Under 18 years of age.

were observed early in the sampling period. The maximum values were reported during the month of October with a progressive diminution until 18 December, at which time sampling was discontinued. The same data are plotted in Fig. 2 as picocuries per gram of thyroid. When presented in this way there is an obvious difference between the iodine-131 concentrations in the thyroids of children and adults. During the period 9 to 31 October, the mean thyroid burden for individuals over 18 years of age was 170 ± 136 pc, compared with 115 ± 84 pc for individuals less than 18 years of age. The large standard deviations reflect the considerable scatter seen in Fig. 1. For the 13 children and 77 adults sampled during this period, the differences in the total iodine-131 burden of the two groups is not statistically significant, although the data suggest that on the average the total iodine-131 content of adults is higher than that of children.

However, when expressed as picocuries of iodine-131 per gram of thyroid, the values for children under 18 years of age tend to sort from the adult values and are, in general, higher than the values for adults. This is largely due to the effect of the very much smaller thyroid mass in the child, as can be seen from the data of Table 2, in which the mean weight of the adult thyroid is 17.3 ± 6.4 grams. This is somewhat less than the value of 20 grams used by the International Commission on Radiation Protection and the National Committee on Radiation Protection for the purpose of calculating the thyroid dose in the standard man (*6*).

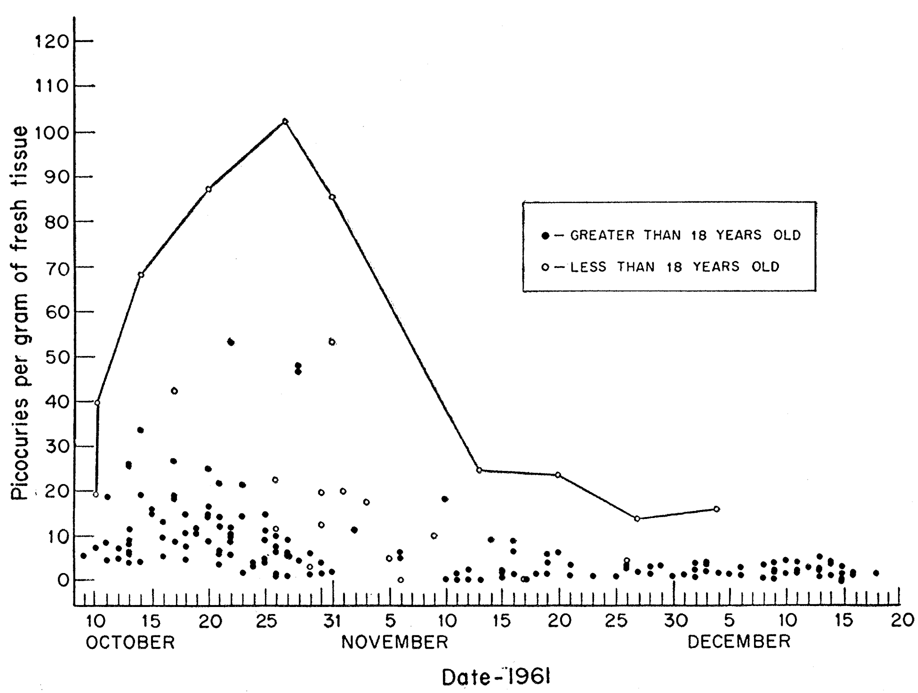

Fig. 2. Observed concentrations of iodine-131, in picocuries per gram of thyroid, for the period from 9 October through 18 December 1961 (plotted from the same data used for Fig. 1).

The variability in both the total thyroid burden of iodine-131 and in the iodine-131 concentration per gram of thyroid may be attributed either to physiological factors that are beyond the scope of this study or, to differences in the daily intake of iodine-131 from the environment. In humans iodine-131 can be absorbed during respiration or can be ingested with food or water. In New York City the latter route can be ruled out because of the enormous dilution which occurs in the reservoir system, the delay in time between the reservoir and the tap, and physical, chemical, and biological mechanisms which tend to remove the iodine between the reservoir and the tap. Similarly, measurements made in this laboratory during the period covered by this study indicated relatively negligible amounts of radioiodine in foods other than milk.

Of the two remaining sources, milk and air, it appears that milk is of overriding importance, and there is presumptive evidence that much of the variability observed in Figs. 1 and 2 can be explained by differences in the milk intake. Near the end of our period of observation, when we had the definite impression that the better nourished children among those who came to autopsy had the highest amounts of iodine-131 in their thyroids, and after we had developed the in vivo procedure described above, nine adults were recruited for measurements from the laboratory staff. Six of these subjects drank varying amounts of milk, ranging from about 1 pint to more than 1 quart per day. These six individuals averaged 57 ± 33 pc per thyroid. Sixteen children—normal, healthy boys who admitted drinking about a quart per day—contained 83 ± 29 pc per thyroid. Three adults who used no milk other than the relatively small amount of fresh milk that might be used in cooking contained 4.3 ± 4.9 pc per thyroid. This is a significant difference, although only at the 5-percent confidence level because of the small number of nonmilk drinkers included in the study.

During October, when our subjects contained as much as 300 to 700 pc, the milk in New York City averaged about 100 pc/lit. (*7*). The iodine-131 content of the thyroid of an individual ingesting a given amount of iodine-131 per day may be estimated by assuming that 30 percent of ingested iodine reaches the thyroid and that the effective average life of this isotope in the thyroid is 11 days (*6*). The equilibrium thyroid burden would be about 330 pc for an individual consuming 1 quart of milk per day containing 100 pc of iodine-131.

Thus, the range of observed thyroid values can possibly be explained by variations in the daily intake of milk, although an additional source of variability would be in the fraction taken up by the thyroid. According to Oliner *et al.* (*8*), this might vary from 18 to 50 percent in normal children. Unfortunately, it was impractical to obtain either dietary histories or measurements of iodine uptake for the cases in this series.

During this period of observation the average concentration of radioactivity in outdoor air was measured daily, but only the concentration of beta-emitting dust was obtained. In early October, the daily concentrations ranged from 2 to 18 pc/m^3 and averaged 8 pc/m^3. If the bomb debris is assumed to have been 2 $\pm$ 1 week old, the iodine-131 contribution to the total beta activity of a well-mixed cloud of fission products would have been approximately 5 percent. On this basis, if one assumes that an individual inhaled 20 cubic meters in a 24-hour day, about 8 pc/day of iodine-131 would have been inhaled, of which 23 percent would have reached the thyroid (*6*). The daily intake would thus be 1 to 2 pc/day, and the equilibrium thyroid burden would be no higher than about 20 pc. From this reasoning it is evident that the observed amounts of iodine are consistent with the assumption that milk is the principal source of iodine-131 from weapons testing, and that the amount inhaled is of secondary importance.

Additional evidence for an association between the concentration of radioiodine in milk and the amounts of radioiodine in the thyroids is to be found from the data presented in Fig. 3, which has been constructed from the data of Figs. 1 and 2. It will be observed that the latter figures are characterized by a number of high values that seem at first glance to form upper envelopes to the scatter diagrams. A broken curve has been drawn through these points in both Figs. 1 and 2. Semilog plots of these points in Fig. 3 show that both the total thyroid content of iodine-131 and the concentration of iodine-131 in thyroid tissue rose to peak values toward the end of October and then diminished exponentially until the values began to approach the lower limits of detection in mid-December. The slope of the decay curve for the total thyroid content of iodine-131 is not significantly different from the curve representing thyroid concentration. The measured daily concentrations of iodine-131 in milk are also plotted in Fig. 3. These values reach a peak somewhat sooner than the thyroid values, and after a plateau lasting throughout October, the milk concentrations of iodine-131 diminish exponentially with a slope that is not significantly different from the slopes of the thyroid curves.

Interestingly, the data determining the curves in Fig. 3 are from different groups of subjects: the cases included on the curve of maximum thyroid radioiodine concentration are all children, whereas the cases included on the curve of maximum thyroid radioiodine content are all adults. This can be seen by inspection of Figs. 1 and 2.

If one assumes that the cases studied included heavy milk drinkers and nonmilk drinkers, as well as individuals who were intermediate between the two extremes, the upper envelopes can be

Table 2. Average thyroid weights at various ages. The average thyroid weight of all adults (over 18 years old) is as follows: total average, 17.3 $\pm$ 6.4 g (N = 152); male, 17.5 $\pm$ 6.3 g (N = 110); female, 16.7 $\pm$ 6.8 g (N = 42).

Age (years)	All cases No.	All cases Thyroid weight (grams)	Males No.	Males Thyroid weight (grams)	Females No.	Females Thyroid weight (grams)
0–9	23	2.0 ± 0.8	18	2.1 ± 0.9	5	2.0 ± 0.8
10–19	6	14.6 ± 4.9	4	13.9 ± 3.4	2	16.0 ± 9.1
20–29	31	17.6 ± 5.6	21	18.0 ± 5.0	10	16.7 ± 6.8
30–39	48	19.2 ± 7.3	31	20.1 ± 6.8	17	17.4 ± 8.1
40–49	28	16.0 ± 6.6	22	15.7 ± 7.2	6	17.0 ± 4.2
50–59	20	17.2 ± 6.7	15	17.9 ± 6.6	5	15.2 ± 7.6
60–69	13	14.9 ± 2.6	12	15.0 ± 2.6	1	13.0
70–	8	13.4 ± 5.4	7	13.3 ± 5.8	1	14.2

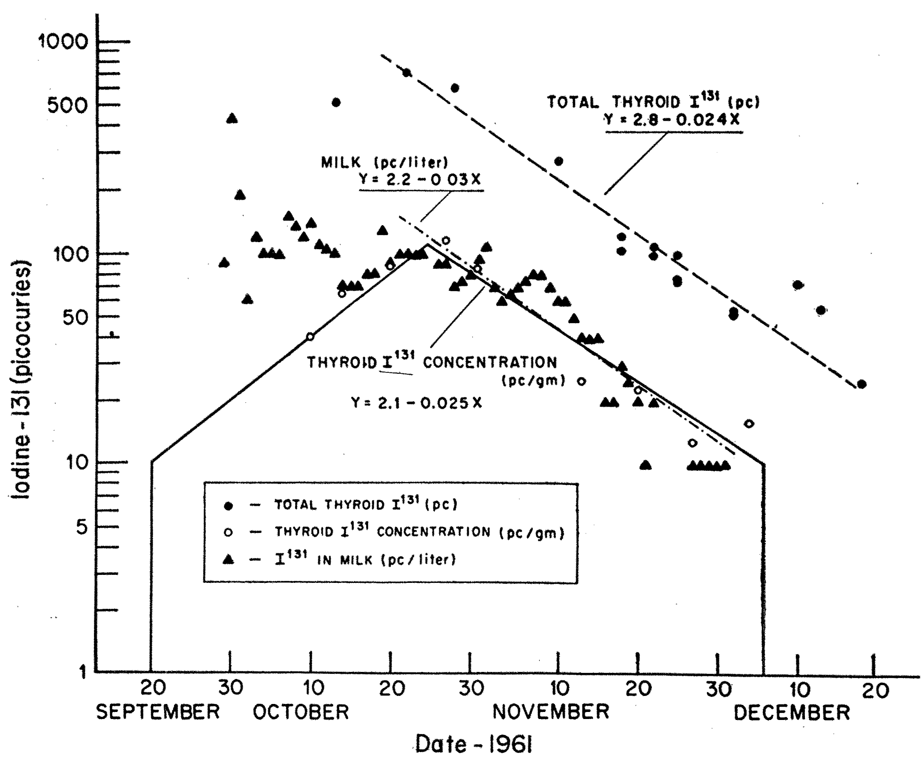

Fig. 3. Semilog arithmetic plots of the curves drawn in Fig. 1 (iodine-131 content, upper dashed line) and Fig. 2 (iodine-131 concentration, lower dashed line). Area under solid line provides an estimate of the iodine-131 dose to the milk-drinking population (see text). Measured daily concentration of iodine-131 in milk is also shown (see key). Y is measured in picocuries and X in days since 9 October 1961.

interpreted as being representative of the thyroid uptake of the milk-drinking population. The upper envelope of Fig. 2, as drawn in Fig. 3, may therefore be used to estimate the integrated exposure of thyroid to iodine-131 during the period of study.

Relatively late in the period of observation we endeavored to determine whether the stable potassium iodide prescribed for some children suffering from bronchial asthma is effective in suppressing the thyroid uptake of iodine-131. Five children, 9 to 15 years old, were selected by our laboratory from the allergy clinic. Three children who had for some months been on a daily dose of about 1.5 grams of potassium iodide were found to carry 11 $\pm$ 4 pc of iodine-131, compared with an average of 31 $\pm$ 13 pc for two children who were suffering from bronchial asthma, but who did not receive potassium iodide. These data are too few to be more than suggestive of the possibility that the stable potassium iodide had in fact suppressed the accumulation of iodine-131 in the thyroids of the three children observed.

Among the cases in our series were a mother and full-term male infant, both of whom died during delivery. The thyroid of the mother contained 27 pc of iodine-131 per gram compared with 42 pc/g for the child. The thyroid weights were 14.0 and 2.5 grams, respectively.

Discussion of Findings

The data collected during this survey were far from sufficient to permit us to define the distribution of thyroid doses in the population of New York City. However, it is possible to estimate the dose received by the most exposed portion of the population, which we assume to be those who drink the most milk and who are represented by the data which form the curve of thyroid concentrations versus time in Fig. 3. The area under this curve provides an estimate of the dose to the thyroids of the milk-drinking portion of the population. The dose delivered to the thyroid by a sustained iodine-131 burden of 1 pc/g can be estimated as follows:

$$1\ \text{pc/g} = \frac{(2.22\ \text{dis/min})(0.189\ \text{Mev/dis}) \times (1.6 \times 10^{-6}\ \text{ergs/Mev})(1440\ \text{min/day})}{100\ \text{ergs}} = 9.7\ \mu\text{rad/day}$$

The area under the curve for thyroid concentration in Fig. 3 can be shown to be 3400 picocurie days, and the total dose to individuals whose thyroid burden followed the rise and fall of the concentration illustrated by this curve would therefore be 33 millirads. This dose was delivered between 20 September and about 10 December. The areas under the tails of the curve prior to 20 September and after 5 December might add another 10 percent or so. The dose to milk-drinking children may therefore be taken to have been about 40 millirads during this period.

The dose delivered to children in the New York area during this period of observation was somewhat higher than the values reported by Comar and his associates for the period January 1955 through December 1956. The human thyroid burdens in that study ranged below 10 pc/g, and the total dose received during the 23-month sampling period was estimated to be 10 millirads. In May 1955, when human thyroid burdens in their study reached their highest values, only 11 out of 101 samples had burdens greater than 10 pc/g. In our series we found that in October 1961, 48 percent of ninety thyroids had burdens of more than 10 pc/g, and only 1 out of 13 children observed during this period had burdens of less than 10 pc/g.

The higher values during our survey can possibly be explained entirely by the higher levels of milk contamination, but there is no way of ascertaining whether this is so, inasmuch as very few milk samples were analyzed during the 1955–56 study. Contrary to Comar's findings, there was evidence in our study that thyroids which became available in the hospital contained less radioiodine than the thyroids obtained through the Medical Examiner's laboratory. The difference may be explained by the different source of subjects used.

The in vivo method of estimating thyroid radioiodine burdens is preferable to the postmortem procedures because of the obvious advantages of being able to follow the same individuals during a period when their diet can be kept under observation. The in vivo method also offers the opportunity for a controlled experiment in which one could study the effect of various doses of potassium iodide in modifying the uptake of radioiodine present in the diet. Unfortunately, so much of the brief period in which observations could be made was occupied by methods development that relatively few in vivo measurements were obtained by us. It is clear that additional studies, should the opportunity present itself once again, would be invaluable in permitting a better understanding of the mechanisms by which radioiodine passes from the atmosphere to man. Such knowledge is valuable not only for a better understanding of the potential hazards of the military uses of nuclear weapons, but also for a more quantitative understanding of the effects of nuclear accidents and the methods by which their consequences can be minimized (*9*).

References and Notes

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