THYROID RADIATION DOSES FROM FALLOUT

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Absorbed doses of radiation from fallout, when averaged over yearly periods and over large numbers of individuals, have usually been assumed to be well below the corresponding doses from natural background sources. Although this assumption may be valid for most body organs, it is unlikely to have been valid for the thyroid glands of the average infant and child in the U.S. The purpose of this note is to point out that for the last few years such thyroids probably have received an annual radiation dose (chiefly, from the beta-rays of radioiodine) that is approximately equal to the annual dose which they receive from natural background radiations.

The radioiodines in fallout (chiefly, iodine-131, with a half-life of 8.05 days) pose a special hazard to infants and children. This arises in part because radioiodine tends to concentrate in fresh cow's milk[1, 2]—a major item in the diet of young people. Upon ingesting milk contaminated with radioiodine, human beings are expected to concentrate the isotope in their thyroids. Moreover, for the same amount of iodine-131 orally ingested, the average infant receives, according to estimates by Halnan and Pochin,[3] about 18 times the thyroid dose that the average adult receives.[4] This 18-fold increase results from the smaller size and possibly somewhat higher iodine uptake[3, 5] of the infant thyroid, and from the almost complete absorption of the iodine-131 beta-rays even within the small infant gland. Finally, there is evidence that the thyroid gland of infants and children is especially sensitive to radiation-induced carcinogenesis.[6]

Estimates of fallout doses to thyroids of infants and young children can be made by considering measurements of radioiodine activity levels in milk. Recently, Campbell *et al.*[7] have published such data for milk samples taken once a month at a sampling station in each of five metropolitan milksheds in the U.S. The radioiodine activities of such samples fluctuated widely with time and with locality. For a one-year period ending June, 1958, the over-all average for the five milksheds was 150 $\mu\mu$c per liter. From a more recent report,[8] it may be calculated that for a 16-month period ending September, 1958, the corresponding average had declined to 122 $\mu\mu$c per liter. In order to have an estimate for this 16-month period that takes into account the higher population density in the eastern U.S. and that avoids giving too much weight to extreme fluctuations from less densely populated areas (namely, from a low of 41 $\mu\mu$c per liter for a milkshed in the far West to a high of 219 $\mu\mu$c per liter for one in the Middle West), the U.S. average for this period is taken as that of a milkshed in the East (New York City). The latter average was 64 $\mu\mu$c per liter, or roughly one-half the average for the five milksheds combined.

Continued ingestion of milk contaminated at an average iodine-131 level, L (in $\mu\mu$c per liter), is expected to give at equilibrium a thyroid dose rate R (in rads per year), which can be expressed as follows:

$$R = \frac{0.039 \cdot L \cdot C \cdot U}{M}$$

where C is the average daily consumption of fresh milk in liters; U is the fraction of ingested radioiodine taken up by the thyroid; and M is the thyroid mass in grams.[9] Rough estimates of the values of these parameters for average infants and children in the U.S. are shown in Table 1.

Values of L are expected to be lower than the aforementioned observed iodine-131 levels in milk by a decay factor of about 0.9; that is, the elapsed time between collection of the milk sample at the sampling station (the arbitrary reference point for calculating radioiodine activities[7]) and human ingestion is presumably one to two days. This gives a value of L of 60 $\mu\mu c$ per liter for the average U.S. value and a

TABLE 1

EVALUATION OF AVERAGE THYROID DOSE RATES (R) BY AGE OF INDIVIDUAL FOR A 16-MONTH PERIOD COMMENCING JUNE, 1957. THE ESTIMATED RANGE OF THE AVERAGE VALUES IS SHOWN IN PARENTHESES

Age of Individual	L = Average Milk Iodine-131 Levels, $\mu\mu c$ per liter	C = Average Rate of Fresh Milk Consumption, liters per day	U = Fraction of Radioiodine Taken Up by Thyroid	M = Average Thyroid Mass, gm	R = Thyroidal Dose Rate, rads per year, $= \frac{0.039 \cdot L \cdot C \cdot U}{M}$
0–1	60	0.3	0.3	1.9†	0.11
	(35 to 200)*	(0.2 to 0.6)	(0.2 to 0.5)		(0.03 to 1.2)‡
1–2	60	0.7	0.3	2.5	0.20
	(35 to 200)	(0.5 to 0.9)	(0.2 to 0.5)		(0.05 to 1.4)
2–3	60	0.7	0.3	3.4	0.14
	(35 to 200)	(0.5 to 0.9)	(0.2 to 0.5)		(0.04 to 1.0)
3–5	60	0.7	0.3	5.1	0.10
	(35 to 200)	(0.5 to 0.9)	(0.2 to 0.5)		(0.03 to 0.7)
5–10	60	0.7	0.3	8.6	0.06
	(35 to 200)	(0.5 to 0.9)	(0.2 to 0.5)		(0.02 to 0.4)

* Range of average values for five milksheds, corrected to time of milk ingestion.
† Range of values not known.
‡ Range calculated by compounding ranges shown in preceding columns.

range of 35 to 200 $\mu\mu c$ per liter for the five milksheds. Estimates of the values of C are taken as 0.3 liter per day for the first year of life, and 0.7 liter per day thereafter up to age ten.[10] These values are subject to considerable uncertainty and are based on the consideration that the range of values of C is expected to be between one pint and one quart per day, except during the first year of life when fresh milk consumption may well be lower owing to the widespread use of evaporated milk in infant feeding programs.[11] On the basis of measurements on normal infants and children by Oliner *et al.*,[5] U is taken to be 0.3 (however, Halnan and Pochin[3] estimate a value of 0.45 and some earlier studies summarized by Oliner *et al.*[5] gave values below 0.3). Estimates of the values of M are based on measurements compiled by Boyd.[12]

From Table 1, it can be seen that the calculated values of R for average infants and children in the U.S. during the 16-month period commencing June, 1957, depend upon age and vary from 0.06 to 0.2 rad per year. It should be noted that actual thyroid dose rates during this period may have been slightly higher than the calculated values of R, since there must also have been a dose contribution from the shorter-lived radioiodines in fallout[13] and from inhaled radioiodine.[14] For each age group the estimated range in values of R (shown in parentheses in Table 1) is considerable, depending chiefly upon observed geographical variation in milk radioiodine levels and upon uncertainties as to the true average values for rate of milk consumption and radioiodine uptake. On an individual basis the range in values of R would be somewhat greater than that shown in Table 1, since there are expected to be greater individual variations in the values of L, C, U, and M. Since the monthly variation in milk radioiodine levels was observed[7] to range from lows of 0 to highs (in two of the milksheds) of over 900 $\mu\mu$c per liter, thyroidal dose rates to infants and children consuming such milk probably fluctuated widely on a short-term basis. For example, on a weekly basis, such dose rates would be expected to have ranged from 0 to about 0.1 rad per week during the 16-month period under consideration. Moreover, dose rates to different parts of the thyroid gland may fluctuate considerably on a short-term basis, owing to the possibility of non-uniform distribution of the radioiodine, as discussed by Oddie.[15]

Prior to June, 1957, data on milk levels of radioiodine activity are not available. However, cattle and human (largely adult) thyroid radioactivity measurements have been related to nuclear testing patterns for part of the year 1954 and for the years 1955 and 1956.[2, 16] In addition, the number and timing of such tests during 1957–1958 have been reported in relation to observed iodine-131 levels in milk.[7] On the basis of such information, it appears that for several years prior to 1957 annual thyroid doses to the average infant and child in the U.S. may have been similar to those calculated above for the 16-month period commencing June, 1957.

Natural background radiations are believed to contribute an absorbed dose to soft tissues of about 0.1 rad per year.[17] From the above account it appears that for the last few years the radioiodines in fallout have contributed an annual dose to the thyroids of average infants and children in the U.S. that is similar to, or in some circumstances greater than, the annual dose to such organs from natural background radiations.[18]

Summary.—On the basis of published data on iodine-131 levels in cow's milk during a 16-month period ending September, 1958, the thyroid glands of average infants and children in the U.S. are estimated to have experienced over the last few years annual doses of about 0.1 rad to 0.2 rad from the radioiodine in fallout. These doses are roughly one to two times the annual dose to such organs from natural background radiation. For a number of reasons, individual thyroid dose rates from fallout are expected to show wide deviations from the average rate.

[1] See review of cattle radioiodine studies by C. L. Comar, and R. H. Wasserman, in *Progress in Nuclear Energy, Ser. VI* (London: Pergamon Press, 1956), 184–196.

[2] Wolff, A. H., *Public Health Reports*, **72**, 1121(1957).

[3] Halnan, K. E., and E. F. Pochin, *Brit. J. Radiol.*, **31**, 581 (1958). These investigators assume the following values for infant vs. adult thyroids, respectively: a mass of 2 vs. 25 gm; a radioiodine uptake of 45 per cent vs. 30 per cent; 0 per cent vs. 10 per cent absorption of the gamma radiation; and complete absorption of the beta radiation in each case.

[4] It is this fact which seems to have been overlooked in evaluating fallout doses of radioiodine. However, the importance of this fact was recognized in the case of the Windscale reactor accident in England; see, for example, Burch, P. R. J., *Nature*, **183**, 515 (1959).

[5] Oliner, L., R. M. Kohlenbrener, T. Fields, and R. H. Kunstadter, *J. Clin. Endocrinol. and Metab.*, **17**, 61 (1957).

[6] This evidence is based chiefly on follow-up studies by C. L. Simpson and L. H. Hempelmann, *Cancer*, **10**, 42 (1957) of infants irradiated about the chest with doses of several hundred r of X-rays; and follow-up studies by Sheline, G. E., S. Lindsay, and H. G. Bell, *J. Clin. Endocrin. and Metab.*, **19**, 127 (1959) of children and adults receiving radioiodine therapy for hyperthyroidism. See also reviews by Duffy, B. J., Jr., *J. Clin. Endocrin. and Metab.*, **17**, 1383 (1957) and Rooney, D. R., and R. W. Powell, *J. Am. Med Assoc.*, **169**, (1959). There is some evidence from these

sources that the infant thyroid, in spite of its much smaller size, is more sensitive to radiation-induced carcinogenesis than the adult thyroid.

[7] Campbell, J. E., G. K. Murphy, A. S. Goldin, H. B. Robinson, C. P. Straub, F. J. Weber and K. H. Lewis, *Am. J. Public Health*, 49, 225 (1959).

[8] "Strontium Program—Quarterly Summary Report," *Health and Safety Laboratory Document HASL-55*, U.S. Atomic Energy Commission, New York Operations Office (1959).

[9] The evaluation of the constant in this equation is based on physical and biological data for iodine-131, which have been summarized, for example, in "Recommendations of the International Commission on Radiological Protection," *Brit. J. Radiol.*, Supplement No. 6 (1952). It is assumed that the effective half-life of iodine-131 is 7.7 days and that the effective beta energy is 0.19 Mev.

[10] A recent survey of 312 children under the age of six in suburban Long Island by H. H. Neumann, *Arch. Pediat.*, **74**, 456(1957), gave a mean value of 840 ml of fluid cow's milk consumed per day with the lower third of the group averaging 647 cc per day and the upper third averaging 1,005 cc per day.

[11] Since evaporated milk will tend to be several months old before it is consumed, its iodine-131 activity should be virtually nil.

[12] Boyd, E., in *Handbook of Biological Data*, ed. by W. S. Specter (Philadelphia: W. B. Saunders Co., 1956).

[13] Dunning, G. M., *Nucleonics*, **14**, No. 2, 38 (1956).

[14] See, for example, R. L. Gunther and H. B. Jones, *U.S. Atomic Energy Commission Document UCRL-2689 and addendum* (1954).

[15] Oddie, T. H., *Brit. J. Radiol.*, **24**, 333 (1951).

[16] Middlesworth, L. Van, *Nucleonics*, **12**, No. 9, 56 (1954) and *Science*, **123**, 982 (1956); Comar, C. L., B. F. Trum, U. S. G. Kuhn III, R. H. Wasserman, M. M. Nold, and J. C. Schooley, *Science*, **126**, 16 (1957).

[17] Spiers, F. W., *Brit. J. Radiol.*, **29**, 409 (1956).

[18] It should be noted that with the cessation of nuclear weapons testing in November, 1958, human thyroid levels of radioiodine should decline exponentially and by January, 1959, there should no longer have been any appreciable contamination of milk with radioiodine from past weapons tests. The level of radioiodine in cow's milk may well be the most important index of short-term environmental contamination with fission products whether from weapons tests or other sources [see discussion in *Safety Aspects of Nuclear Reactors*, ed. C. R. McCullough (New York: D. Van Nostrand Co., 1957), 28].

THE ELIMINATION OF DNA FROM SOMA CELLS

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The current widespread interest in the role of DNA in protein synthesis, on the parts of cytologists and biochemists alike, brings into question anew a very old enigma of cytology, which is, the reason for the elimination of parts of or whole chromosomes from somatic cells or nuclei of embryos so that in some animals the chromosome complex of germ cells is markedly different from that of the soma cell of the same individual. In the fungus-feeding fly, *Oligarces paradoxus*, for example, germ cells show 66 chromosomes while soma cells contain only 10 such elements (Reitberger[1]).

The loss of parts of chromosomes from soma cells was first observed by Boveri[2] in the cleaving eggs of *Ascaris megalocephala*, and sporadically through the years other examples of such aberrant behavior have been recorded. The elimination