5. This work was supported by grants from the National Science Foundation and the National Heart Institute and the National Institute of Arthritis and Metabolic Diseases of the National Institutes of Health, U.S. Public Health Service.
6. C. S. Hanes, F. J. R. Hird, F. A. Isherwood, *Nature* 166, 288 (1950).
7. M. Gutcho and L. Laufer, *Glutathione* (Academic, New York, 1954), p. 79.
8. J. R. Weisiger, W. Hausmann, L. C. Craig, *J. Am. Chem. Soc.* 77, 3123 (1955).
* Special Public Health Service research fellow of the National Heart Institute.

7 December 1955

Radioactivity in Thyroid Glands Following Nuclear Weapons Tests

Radioactivity has been reported (*1*) and confirmed (*2*) in the thyroid glands of cattle, presumably from I^{131} fallout. The present report (*3*) is a continuous study of the radioactivity in thyroids from the United States, Canada, England, Germany, and Japan during the past year. There was a series of 14 nuclear tests in Nevada from 18 February to 15 May 1955 and a test in the eastern Pacific Ocean in mid-May 1955 (*4*). Additional sources of fission products were presumably released by other countries in the winters of 1954 and 1955.

Dunning (*5*) has estimated biological ingestion of iodine fission products beginning 50 hours after fission results in more than 80 percent of the total radiation dose to the thyroid being due to I^{131}. When ingestion begins later, I^{131} rapidly becomes a more dominant iodine isotope. In the present investigation (*6*) all the radioactivity reported in thyroid glands will be considered as I^{131}.

The simple counting methods described previously (*1*) were used, except that after June 1955 all samples that contained less than 0.002 mμc/g were tested in a 1¾ by 2-in. NaI(Tl) well crystal in conjunction with a pulse height analyzer to increase accuracy in the determination. All samples were counted with a coefficient of variability (*7*) ±5 to 12 percent, except those between October 1954 and June 1955 that contained less than 0.01 mμc/g; in these the coefficient of variability was ±30 to 50 percent. The instruments were calibrated daily against an I^{131} standard. The well crystal with pulse height analyzer had a background of 0.12 count/sec and 1μc I^{131} counted 6600 count/sec.

Human thyroids from all available autopsies in Memphis were tested, and the results from all 175 glands have been shown in Fig. 1. Thyroids from 15 unselected slaughterhouse cattle raised within 200 miles of Memphis were tested each week for 70 weeks. During the period of greatest radioactivity five to ten thyroids were received by airmail every 1 or 2 weeks from England, Germany, Canada, Washington State and every 2 or 3 weeks from Japan. The radioactivity of these glands showed standard deviations similar to those from Memphis; therefore, for simplicity, only the average values for the foreign glands have been presented. The radioactivity was corrected for decay during the 4 to 10 days spent in transportation. The millimicrocuries per gram were plotted against the date of slaughter and bar graphs (Fig. 2) were constructed from these curves. Only the data for the first and 15th of each month are included in Fig. 2, and no bar is shown for an area unless there was a sample within 1 week of the date.

On 17–19 April 1955 the gamma radioactivity in the thyroid area was determined *in vivo* in 20 persons (USPH monitors and their families in Utah and Nevada). Most of these subjects were men stationed around the nuclear weapons tests site. Their work was to determine fallout patterns. A scintillation crystal was placed against the thyroid areas of their necks, and the results were compared with determinations over the thigh. Precautions were taken to prevent errors owing to surface contamination. The limit of sensitivity of these *in vivo* determinations was 2 mμc I^{131}. The results showed that only two individuals (men) had detectable amounts of radioactivity in their thyroid areas, and each of these has a total gamma-emitting equivalent of approximately 5 mμc I^{131}.

The relationship between total chemical iodine and radioactive iodine in cattle thyroids was investigated by analyses of 20 glands with greatest extremes in I^{131} content. These showed no correlation between I^{127} and I^{131} content.

Figure 1 summarizes the most complete data. The ordinate is plotted on a 5-cy log scale in order to show early increases from the base line and also include the maxima, 10,000 times greater. The maximum value in any sample group was frequently 10 times greater than the minimum collected at the same time. Yet, every time the average value increased above 0.002 mμc/g, the minimum was observed to increase. This suggested that the minimum intakes were possibly due to some mechanism, such as respiration, common to all the animals. The maximum values may be dependent on additional variable factors, such as ingestion of fallout material.

The increases shown in October 1954 to 15 February 1955 and November 1955 to March 1956 were believed to be due to nuclear tests, which, so far as I am aware, were not conducted by the USAEC.

Five days after the first test of the Nevada series, there was a detectable increase in the I^{131} content of cattle thyroids in Memphis. The minimum was above minimum detectable level and did not return to that level for 8 months. The observed rate of increase of thyroid I^{131} may be sensitive to the frequency of sampling and the freedom permitted the animal 2 or 3 days preceding slaughter. Two weeks elapsed between the beginning of the Nevada series and the first maximum of that period. The last maximum, 6 June, was observed 3 weeks after

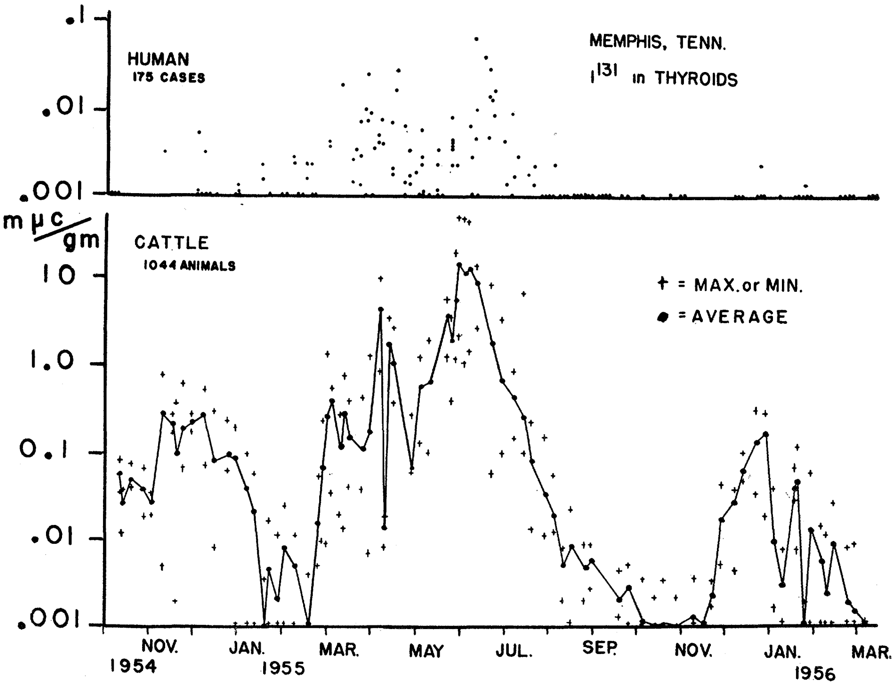

Fig. 1. Iodine-131 in human and cattlethyroid glands.

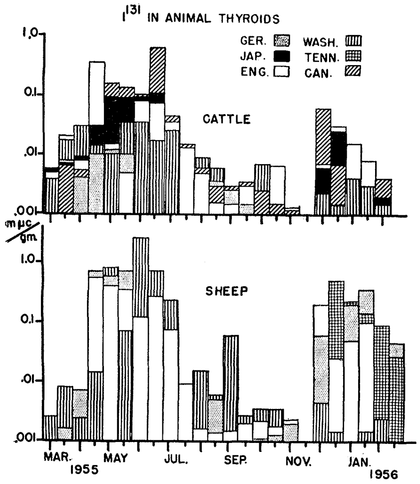

Fig. 2. Iodine-131 in cattle and sheep thyroid glands.

the last test of 15 May. The delay of 5 days to first detect radioactivity and 14–20 days to reach a maximum could suggest that a major fraction of the I^{131} fell out slowly (2). An additional explanation is the possibility that the environment was maximally "labeled" with I^{131} when the increase of thyroid I^{131} began. The thyroid gradually accumulated the isotope, but the I^{131} continually decayed. The result would be a rapid increase, since accumulation rate exceeded decay rate, then finally, decay rate would surpass accumulation, since the environmental intake and accumulated material both decayed.

At least the following 12 factors of unknown relative importance determined the maximum accumulation of I^{131} in thyroids distant from the test site: (i) total mass of I^{131} released, (ii) altitude of release and dust present, (iii) proportion of I^{131} or parent isotope released in gas and solid state, (iv) repeated nuclear tests, (v) distance the I^{131} traveled before detection in the thyroid gland, (vi) a flattening of the distribution curve of the radioactive concentration as the radioactive mass was diluted, (vii) weather conditions, (viii) possibility of radioactive mass returning to sample area after once passing, (ix) radioactive decay, (x) inadequacy of samples, (xi) continued intake of the isotope, (xii) rate of thyroid accumulation and release of the iodine.

The upper portion of Fig. 1 shows that I^{131} increased in human thyroid glands in Memphis when an increase was demonstrated in cattle. The maximum I^{131} per gram of human thyroid was less than 0.5 percent of the maximum for cattle from the same general area. This difference may be related to the fact that the human thyroid is more than 10 times larger than that of cattle (compared on body weight basis), but the total volume of air inhaled per day is less in the human beings. In addition, human beings do not ingest large amounts of dust in their diet.

Figure 2 shows that increases in I^{131} content of thyroids from sheep in England and Germany occurred 2 to 4 weeks after the 1 March maximum in Memphis. These delays may have been due in part to factors ii, v, vi, vii, and x. The April maximum radioactivity in the samples from England and Germany was quantitatively similar to the March maximum in the Memphis cattle.

In areas from which both sheep and cattle specimens were obtained, if the I^{131} of one species exceeded the other, the sheep were consistently the greater. This may be related to ingestion of more dust by the close-grazing sheep.

The greatest concentration of I^{131} in Memphis specimens, 1 June, did not appear to be the season's greatest concentration outside of North America. The differences between the world-wide distribution of the March and June maximum may have been related to factors i, ii, vii, and x. In the spring of 1955 the distribution of I^{131} may have been relatively uniform throughout the entire Northern Hemisphere.

Dunning (5) has shown theoretical methods to estimate radiation dose from radioiodine fallout. Assuming that the 1044 cattle in Fig. 1 are representative, these data make it possible to determine experimentally the radiation dose in cattle of the Memphis area. The maximum and average data of Fig. 1 were plotted on square coordinates and the curves were integrated. The result was millimicrocuries per day per gram and this was multiplied by 12.3 (mrep per day per millimicrocurie of I^{131} per gram). The data for the Memphis cattle were studied by these analyses. The November 1954 fallout delivered a maximum of 0.30 rep and an average of 0.11 rep to the cattle thyroids; the Nevada series resulted in a maximum of 13 rep and an average of 4.3 rep in cattle thyroids; the fallout in the winter of 1955–56 produced a maximum of 0.10 rep and an average of 0.04 rep in the bovine glands.

Dunning's analysis applied to the Memphis cattle data on the last test of the Nevada series (15 May) showed an average of 4 to 6 rep delivered to the cattle thyroids. This equals the 4.3 rep, average calculated here for the entire Nevada test period.

The data from England (253 glands) were the most complete of those from outside the United States, so the average radiation was calculated for cattle and sheep in England during the period April–November 1955. This estimate showed 0.15 rep and 0.40 rep per thyroid for cattle and sheep, respectively, among the specimens from England. This radiation dosage can be compared with the 5000 to 10,000 rep from I^{131} necessary to treat hyperthyroidism in human beings.

Even though I^{131} fallout was easily detected in cattle and sheep thyroids the total radiation dose to the gland was small during the period studied.

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References and Notes

1. L. Van Middlesworth, *Nucleonics* 12, No. 9, 56 (1954).
2. R. L. Gunther and H. B. Jones, *U.S. Atomic Energy Commission Document, UCRL-2689 and Addendum* (1954).
3. This investigation was supported by grants from the U.S. Atomic Energy Commission, the U.S. Public Health Service, and the University of Tennessee Reserve for Research. I am indebted to C. L. Dunham, director of the division of biology and medicine, U.S. Atomic Energy Commission, for encouragement and help in extending my previous study (1) into this investigation. The technical assistance of Nancy Heckle is gratefully acknowledged.
4. *Major Activities in the Atomic Energy Program.* January–June 1955, U.S. Government Priority Office, Washington 25, D.C.
5. G. M. Dunning, *Nucleonics* 14, No. 2, 38 (1956).
6. I wish to acknowledge the assistance of the following collaborators who sent specimens of thyroid glands from their areas: Ray B. Watkins, chief veterinarian, Seattle and King County Public Health Department, Seattle, Wash., F. D. Sowby, Department of National Health and Welfare, Ottawa, Ont., Canada; H. Miller, Sheffield National Center for Radiotherapy, Sheffield, England; Corporation of London, Metropolitan Cattle Market, London, England; Max Muhlpointner and Company K. G., München, Germany; Ryoichi Tanaka, Ibaragi University, Ibaragi Ken, Japan; Memphis Packing Company (Div. of Armour & Co.), Memphis, Tenn., and the Neuhoff Packing Company (Div. of Swift & Co.), Nashville, Tenn. Human thyroids were obtained through the courtesy of M. L. Trumbull, pathology department, Baptist Memorial Hospital, Memphis, Tenn. The survey of USPH monitors was made possible through the help of R. A. Dudley of the division of biology and medicine, U.S. Atomic Energy Commission, and the cooperation of O. Placak and C. Powell of the USPHS.
7. A. Thomas, *Nucleonics* 6, No. 2, 50 (1950).

5 April 1956

Gum Replica Technique for Electron or Light Microscopy

In a study of the effects of organic solvents on the surface structures of plant-rust spores, the need arose for use of replica techniques in order that surface changes on the spore could be observed with the electron microscope. Replica techniques involving the use of heat, pressure, or organic solvents could not be utilized because of the sensitivity of spores to these treatments. Attempts to make replica patterns of rust spores by evaporation of silicon monoxide, carbon [D. E. Bradley, *Brit. J. Appl. Phys.* 5, 65 (1954)], and similar substances were unsuccessful, because the relatively large