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Environmental Physiology and Shelter Engineering

With Special Reference to Domestic Animals

XXXIV. The Influence of Diurnally Variable Temperatures on the Thyroid Activity and Iodide Metabolism of Jersey and Holstein Cows

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INTRODUCTION

This is a continuation of Missouri Research Bulletin 576 which was concerned with the effect of *constant* environmental conditions—air temperature, air velocity, and radiation level and of starvation—on the thyroid activity and iodide metabolism of cows. This preceding bulletin reported that low temperatures (17° F. or -8° C.) increased the thyroid activity of Jersey and Brahman cows 60 to 100 percent but not that of Holstein and Brown Swiss cows. It also reported that high temperatures (95° F. or 35° C.) decreased the thyroid activity of all breeds studied by 30 to 65 percent.

These data on thyroid activity roughly paralleled the heat production (resting metabolism) data on the same animals.[1 2] The conversion ratio (the ratio of blood plasma thyroxine-like I^{131} to blood plasma total I^{131}) was the primary measure of thyroid activity, with the thyroid uptake rate constant and the maximum uptake of I^{131} by the thyroid gland as supporting measurements. The literature on the relation of thyroid activity and temperature was reviewed.

This report is concerned with the effect of diurnally *variable* air temperatures on the thyroid activity and iodide metabolism of Jersey and Holstein cows. These measurements will, it is hoped, help to explain the mechanism of the influence of ambient temperature on metabolic rate.

The definitions of terms peculiar to this work are given in Missouri Research Bulletin 576.

METHODS

Experimental Animals and Schedules: This study was conducted in the Psychroenergetic Laboratory.[3] The environmental temperature, measured by the temperature of the air leaving the chamber, was varied in an approximately sinisoidal manner with a period of 24 hours. The temperature cycles studied are given in Table 1. During this experiment the air velocity in the chambers was about 0.5 m.p.h. (0.8 meters/sec.). The radiant (light) energy level was 5 Btu/ft.^{2}/hr.) in the high-temperature half of the cycle.

TABLE 1 -- TEST SCHEDULE

Diurnal† Temp. Range °F.	Average Temp. °F.	Average Relative Humidity %	Date (1953-1954) From 3 p.m.	Date (1953-1954) To 3 p.m.	Date of I^{131} Injection
*	60	57	Jan. 28	Feb. 4	
12.5-40.4	24	59	Feb. 5	Mar. 11	Feb. 15
**	37	57	Mar. 11	Mar. 18	
40.2-70.7	55	56	Mar. 18	Apr. 22	Apr. 5
62.1-108.0	83	51	Apr. 22	May 7	
*	63	57	May 7	May 13	
69.3-100.7	84	52	May 13	June 3	May 17

†Average daily minimum and maximum.
*Constant temperature.
**Gradual increase from preceding to succeeding temperature range.

The experimental cows are described in Table 2. Their thyroid activities were assayed once during three of the temperature cycles. As the thyroid secretion rate constant determination required measurements over a period of three weeks after injection of I^{131}, it was not possible to obtain more than one assay in the three and five-week test periods. The animals were allowed to equilibrate at a new temperature cycle for three days during the 70 to 100° F. cycle or for 10 days during the other cycles before starting the assay. The dates of injection of I^{131} are given in Table 1.

Radioiodine Methods: For a given assay, 0.5 mc. of carrier-free NaI^{131} was injected into one jugular vein. Blood samples were taken through an indwelling polyethylene venous catheter in the other jugular vein.[4] Four samples were taken in the first 10 minutes after injection and five or six samples between 2 and 24 hours after injection. Milk samples were taken from each milking for 3 to 4 days after injection. The total I^{131} per unit volume of fluid was determined on all samples mentioned above and the thyroxine-like I^{131} per unit volume on the blood samples taken 17 hours after injection. The thyroid I^{131} content was determined twice daily (three times on the day of injection) for three weeks after injection.[5] The methods for these assays are given in a previous bulletin.[6]

From these data the *thyroid activity* was measured by: (1) the rate constant for hormone release, k_4; (2) the rate constant for thyroid uptake, k_1; (3) the maximum level of I^{131} in the thyroid gland, U; and (4) the conversion ratio (portion of the total plasma I^{131} that is thyroxine-like I^{131}). The measurements of *iodide metabolism* include: (1) the rate constant for clearance of blood iodide, $(k_1 + k_2)$; (2) the rate constant for iodide excretion, k_2; (3) the rate constant for thyroid uptake, k_1, previously mentioned; and (4) the rate constant for diffusion of iodide from the blood to the extra-blood fluids, k_3. These rate constants are the instantaneous relative rates of the various processes. The methods used for the determination of these rate constants and the conversion ratio and their interpretation were given in a previous bulletin[6] and in the references cited there.[5 7 8 9]

TABLE 2 -- EXPERIMENTAL ANIMALS (SPRING 1954)*

Cow No.	Birth Date	Date of Last Calving	Number of Previous Lactations	Date of Last Breeding	At Beginning of Expt. Approx. Age Years	Approx. Body Weight Lbs.	Average During February 1954 Milk Lbs/day	Butterfat %
Jersey								
274	Oct. 25, 1948	Aug. 19, 1953	2	Apr. 19, 1954	5	846	16.7	6.0
564	Jan. 16, 1950	Sept. 20, 1953	1	Nov. 30, 1953	4	860	14.6	5.9
295	Apr. 11, 1950	Oct. 4, 1953	1	Apr. 18, 1954	3	704	25.7	6.0
Holstein								
184	Feb. 13, 1947	Sept. 27, 1953	4	-----	7	1200	43.2	3.0
144	June 11, 1945	Sept. 3, 1953	5	June 14, 1954	8 1/2	1288	36.3	3.5
178	Dec. 12, 1946	Apr. 1, 1953	3	-----	8	1297	29.1	3.7

*Data taken from Univ. Mo. Agr. Expt. Sta. Res. Bul. 578.

Additional Remarks:

J-295 -- Removed from experiment March 9, 1954; taken to veterinary clinic. Hardware was removed from rumen. Although cow recovered she was not returned to laboratory.

H-184 -- Had heat stroke May 1 during the 60° to 110°F. diurnal range and was removed from laboratory. Her left hind leg became paralyzed and she was euthanized May 11. The postmortem report by the veterinary department was: The left hind leg was swollen due to an occluding blood clot in the femoral artery. About three-fourths of the muscle in the hind leg had undergone necrosis. She also had acute, diffuse mastitis caused by a Streptococcus. Microscopic sections of the brain and spinal cord showed no morphological changes except for microscopic hemorrhages. The cow would probably have recovered from the heat prostration had she not developed the femoral clot.

J-564 -- Aborted five month fetus May 7. To avoid possible loss she was removed from the laboratory on May 24; her pulse very weak; rectal temperature 108°F. She was slaughtered June 5. The postmortem veterinary report was as follows: A septic thrombus almost filled the right ventricle. The right ventricle, considerably dilated, was lined with 2 cm. of connective tissue in some areas. This would indicate that the lesion had been present possibly two weeks or longer. The lesion was caused by a Streptococcus. No lesions were observed that are commonly associated with heat stroke.

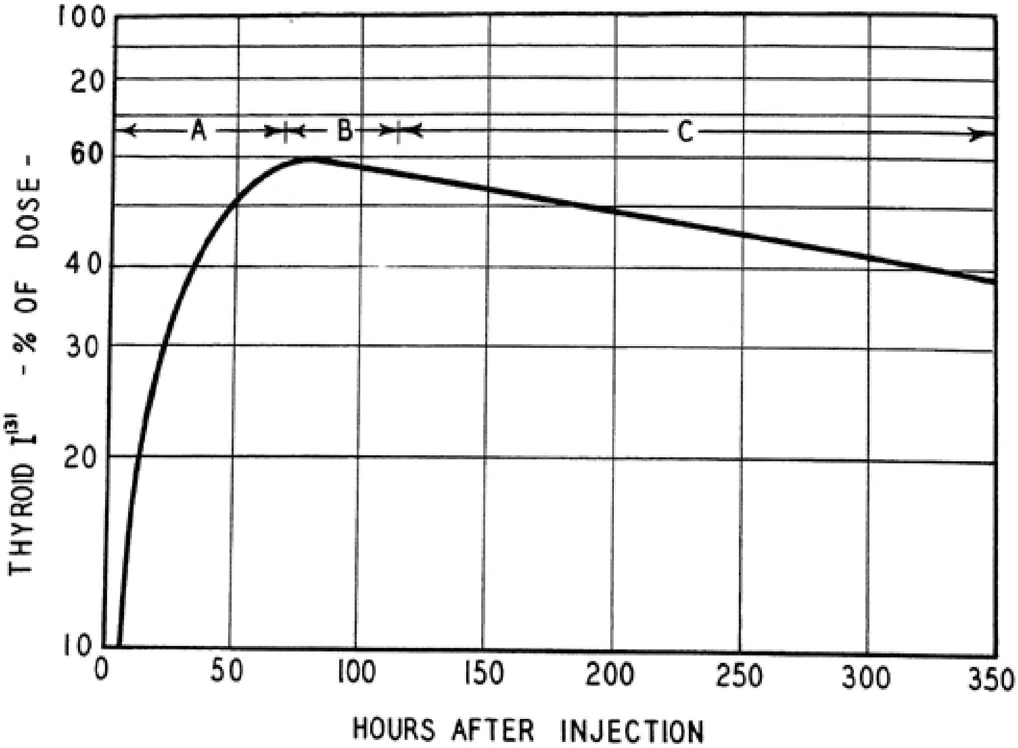

Fig. 1—Thyroid content of I^{131}. An idealized semi-logarithmic plot of the I^{131} in the thyroid gland as a function of time after injection with NaI^{131}. Portion A of the curve shows the predominantly uptake phase of I^{131} by thyroid (k_1); B the maximum concentration of I^{131} (U); and C the release of the thyroid hormone or hormone-like containing I^{131} (k_4).

Fig. 2—Method of *in vivo* determination of the I^{131} in the thyroid gland of a Jersey cow.

In this study all data collected after 70 hours post-injection were used in computing the rate constant for thyroid secretion, k_4. The maximum uptake of I^{131} by the thyroid gland, U, was determined by averaging the values of the thyroid radioiodine content for 70 to 115 hours after injection. Although these points are on the declining segment of the curve near the maximum (Phase B, Fig. 1), it was felt that their average would give a better representation of the maximum thyroid content of I^{131} than a single point, because of the possible variation in placing the counter on the cows neck in the determination of the thyroid I^{131} content[5] (Fig. 2).

DATA AND DISCUSSION

Thyroid Activity: The thyroid activity as expressed by the rate constants for hormone release, k_4; thyroid uptake, k_1; and the maximum thyroid I^{131} level, U, are given in Fig. 3. The conversion ratio data are presented in Table 3. The conversion ratio shows no conclusive trend with temperature. The rate constants, k_1 and k_4, and the thyroid uptake, U, indicate decreasing thyroid activity with increasing ambient temperature. Table 4 gives the numerical values for Fig. 3 as percentages of their values at 40-70° F. or 4-21° C., taken to be the comfort zone for cattle.[10] In the cold cycle these parameters of thyroid activity increased by about 20 percent of their comfort-zone values and in the hot cycle they decreased by about 30 percent. The heat production (resting metabolism) of these animals *increased* during the cold cycle by 10 to 20 percent above that of the comfort-zone tempera-

TABLE 3 -- CONVERSION RATIO

Cow No.	Conversion Ratio Cold 10-40°F	Normal 40-70°F	Hot 70-100°F
Holstein			
184	.062	.046	--
144	.015	.027	.027
178	.047	.118	.027
Jersey			
274	.030	.073	.032
564	.023	.151	.044
295	.117	--	--

TABLE 4 -- THYROID ACTIVITY AS PERCENT OF THE ACTIVITY DURING THE 40° TO 70°F (COMFORT ZONE) TEMPERATURE CYCLE

Cow	k_1		k_4		U		Average	
No.	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot
Holstein								
184	111	--	332	--	122	--	116.5	--
144	133	70.3	117	64.3	106	72.9	118.6	69.2
178	148	75.3	130	62.7	123	75.1	133.6	71.0
Jersey								
274	56.2	66.5	341	38.7	94.8	69.2	75.5	58.1
564	87.9	55.7	118	34.4	102	63.3	103.9	51.1

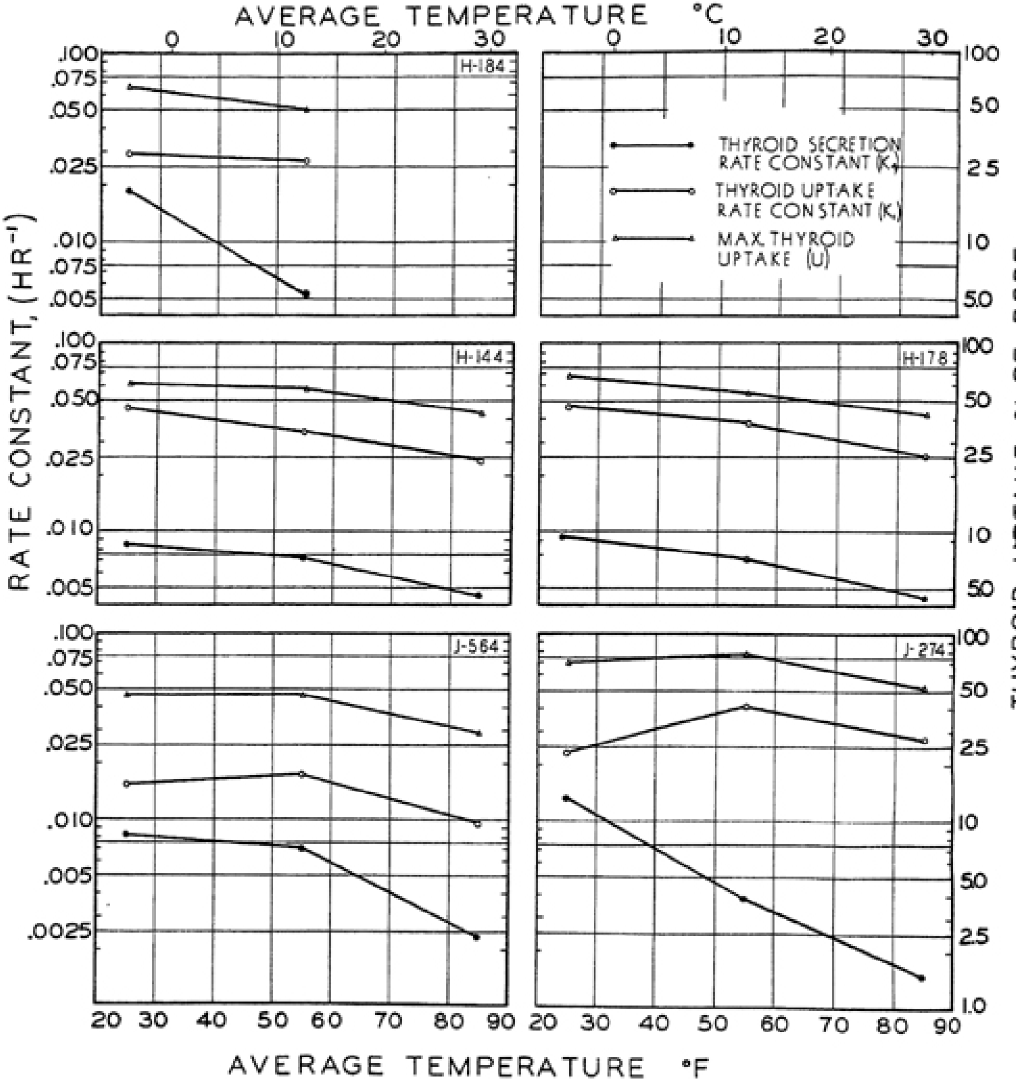

Fig. 3.—Thyroid activity of Jersey and Holstein cows. Semi-logarithmic plots of the rate constants for thyroid uptake, k_1, and hormone release, k_4, and the maximum uptake of I^{131} by the thyroid gland, U, as a function of the average temperature. Note decreasing trend of parameters with increasing average temperature.

ture cycle and in the hot cycle they *decreased* by 10 to 20 percent.[11] Thus, as was shown in the preceding report,[6] thyroid activity and heat production curves were roughly parallel, the thyroid activity showing a larger change than the heat production with changing ambient temperature.

It is of interest to note that the rate constants for thyroid uptake and secretion, and the maximum thyroid uptake, all parallel each other. This is due in part to the mathematical interrelation of k_1 and U,

$$k_1 = U\,(k_1 + k_2).$$

The rate constant for the clearance of blood iodide ($k_1 + k_2$), on the average, did not change with changing temperature in the cows and hence the maximum thyroid uptake, U, and the rate constant for thyroid clearance, k_1, should be directly proportional to each other. In the cattle, either of these measurements appears sufficient to characterize the uptake phase of thyroid activity. The parallelism between these two measures of the uptake phase of thyroid activity (k_1 and U), and the hormone release rate constant, indicate that the thyroid is neither storing nor releasing stored iodine.

Iodide Metabolism: Immediately after intravenous injection of a tracer dose of NaI^{131} it is rapidly mixed through the blood. The I^{131} diffuses through the capillary barrier into the non-blood iodide space with a rate constant k_3. This rate constant was determined during the hot and cold temperature cycles. These data, presented in Table 5, show no change of this rate constant between these ambient conditions. It would be instructive to repeat this measurement on severely heat-stressed animals with a rectal temperature elevation greater than 5° F.

TABLE 5 -- RATE CONSTANT FOR CAPILLARY DIFFUSION OF RADIOIODIDE (k_3)

Cow No.	k_3 (hr^{-1}) 7-42°F	64-102°F
Holstein		
184	11	--
144	17	7
178	9	11
Jersey		
274	13	10
564	10	10
295	10	--

As was observed previously,[6] there was no temperature change in the rate constant for clearance of blood I^{131} ($k_1 + k_2$). (See Fig. 4.) The total removal of radioiodine from blood is thus independent of environmental temperature. When the two principal processes controlling the radioiodide level in blood—thyroid uptake and excretion of I^{131}—are examined separately it is apparent that this invariance of the rate constant for total clearance is due to compensating changes of these two processes. These three rate constants are plotted in Fig. 4. The rate constant for thyroid uptake of I^{131}, k_1, decreased with increasing temperature, reflecting the decreased secretion rate of the gland (Fig. 3), and the rate constant for excretion by all avenues increased by the same amount. This indicates that if the animal was in a steady state with respect to iodide metabolism, the supply of iodide in the blood available to the thyroid is constant. This would permit the thyroid gland to operate with a constant source of raw materials and prevent malfunction due to excess or deficiency source of iodide.

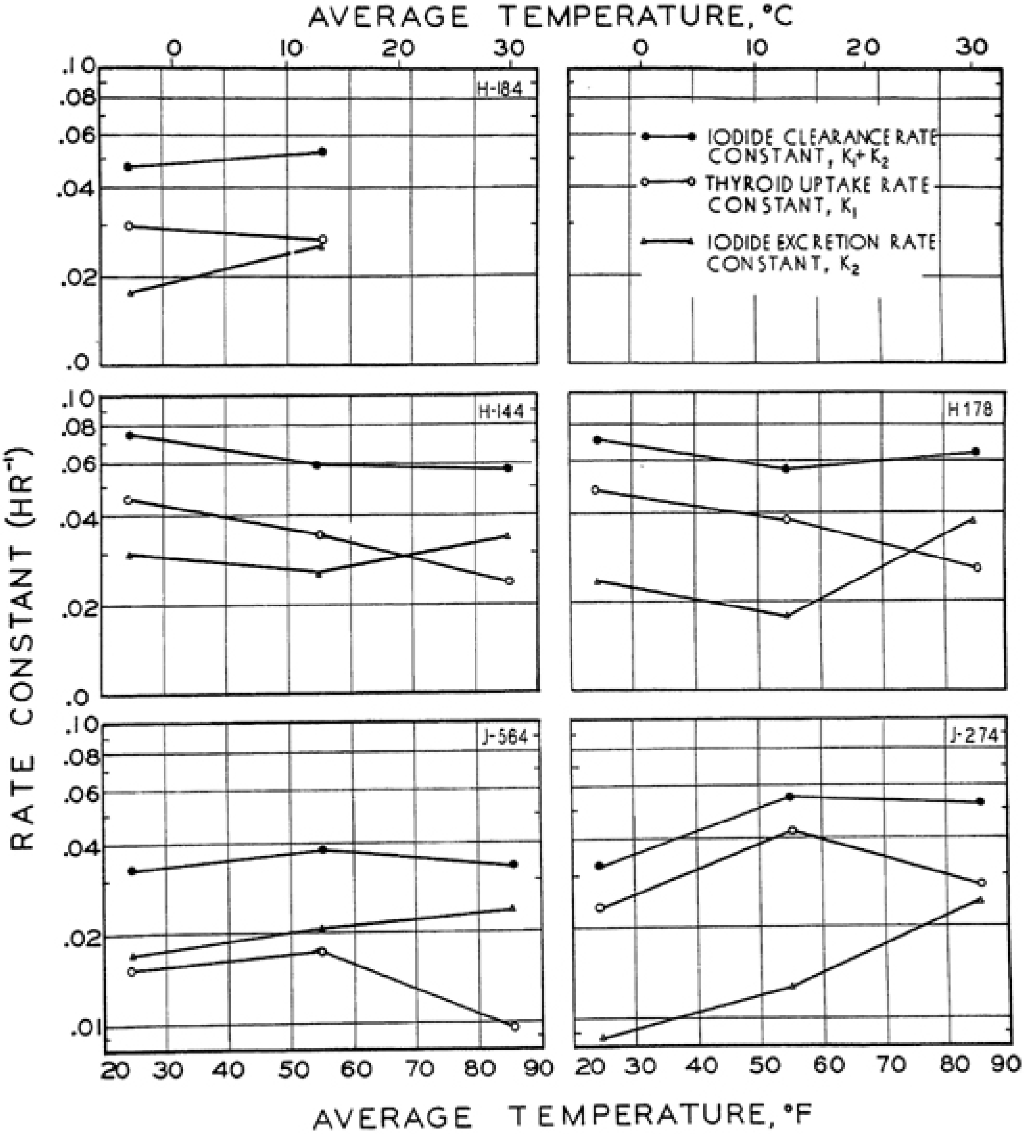

Fig. 4.—Iodide clearance in Jersey and Holstein cows. Semi-logarithmic plots of the rate constants for clearance of blood I^{131}, $k_1 + k_2$, for thyroid uptake, k_1, and for excretion of I^{131}, k_2. Note that thyroid uptake rate constant decreases and the excretion rate constant increases by equal amounts as the average temperature increases.

Choice of Parameters of the Thyroid Activity of Dairy Cattle: The activity of the thyroid gland can be divided into three phases—its uptake of iodide from the blood, synthesis of the hormone, and the release of the thyroid hormone to the blood. The first and last of these phases can be readily studied with radioiodine without injury to the animal, or administration of drugs or hormones which would probably alter the physiology of the animal. Fortunately the rate constants for these two processes are widely different, the rate constant for thyroid uptake being of the order of 3×10^{-2}/hr., and for thyroid secretion being of the order of 3×10^{-3}/hr. (see Figs. 1 and 3).

In this and in the preceding report[6] we have presented data using the rate constants for thyroid uptake of I^{131} and hormone release, the maximum uptake of I^{131}, and the conversion ratio as parameters of thyroid activity. Let us examine these parameters.

The conversion ratio has been used clinically with some degree of success in the diagnosis of thyroid pathologies.[12] It indicated changes in thyroid activity over wide ranges of constant temperature (17 to 95° F. or -8 to 35° C.) but did not indicate changes of thyroid activity over narrow ranges of constant temperature (40 to 80° F. or 4 to 27° C.),[6] or in the present study using variable temperatures (Table 3). The errors implicit in the conversion ratio measurement are necessarily high because it is dependent on two non-identical, but complementary, measurements—blood plasma total I^{131} and blood plasma thyroxine-like I^{131}. The several steps in measuring the blood plasma thyroxine-like I^{131} make it prone to error.

Over a limited range of constant temperature it was found that the rate constant for thyroid uptake or the maximum uptake of I^{131} by the thyroid gland indicated variations of thyroid activity not apparent from the conversion ratio data.[6] Similar results were found in the present experiment (Table 3 and Fig. 3).

The present study indicates about equal sensitivity of the rate constants for thyroid uptake (k_1) and hormone release (k_4) and the maximum uptake of I^{131} (U) by the thyroid gland as parameters of thyroid activity. All of these parameters can be determined from a single measurable —the I^{131} content of the thyroid gland as a function of time.[7] Since these parameters depend on one or more sets of several identical measurements they have a relatively small inherent error. The rate constant for excretion of radioiodide from the animal may also be determined from this set of data.

The rate constant for thyroid uptake, k_1, and the maximum uptake, U, by the thyroid gland are parameters of the uptake phase (iodide phase) of thyroid activity; the rate constant for hormone release, k_4 is a parameter of the secretory phase (organic phase) of thyroid activity. It would appear that the secretory phase of thyroid activity is more significant than the uptake phase from the point of view of the thyroid gland as a regulator of physiological processes.

SUMMARY AND ABSTRACT

Data are presented on the influence of diurnally-variable air temperature levels on the thyroid activity and iodide metabolism of Jersey and Holstein cows. A daily temperature cycle of 10 to 40° F. (-10 to 4° C.) increased

the thyroid activity by 20 percent over the value of a temperature cycle 40 to 70° F. (4 to 21° C.). A temperature cycle of 70 to 100° F. (21 to 38° C.) decreased the thyroid activity by about 30 percent below its value during the 40 to 70° F. cycle. These data roughly paralleled the heat production data for the same animals. The rate constant for uptake, release by the thyroid and maximum level of I^{131} in the thyroid, all indicated the same changes of thyroid activity. The conversion ratio data showed no trend with temperature in this study.

The rate constant for transcapillary diffusion of I^{131} was not altered by the conditions studied here nor was the rate constant for clearance of plasma iodide. The two components of the rate constant for clearance of plasma iodide indicated temperature trends. The rate constant for thyroid uptake decreased, and the rate constant for I^{131} excretion increased so as to keep their sum constant as the temperature increased.

This study suggests that the rate constant for hormone release, k_4, is the best single index of thyroid activity. The rate constant for thyroid uptake of I^{131}, k_1, and the maximum uptake of I^{131} by the thyroid gland, U, are respectively the second and third best single indices of thyroid activity. Although these three indices show approximately equal sensitivity to temperature induced changes of thyroid activity, the rate constant for hormone release is preferred because it is a measure of the secretory phase of thyroid activity.

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