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1967 CERT PROGRESS REPORT

CONTROLLED ENVIRONMENTAL RADIOIODINE TESTS AT THE NATIONAL REACTOR TESTING STATION

PROGRESS REPORT NUMBER FOUR

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ABSTRACT

The experimental and theoretical research undertaken during 1967 as part of the Controlled Environmental Radioiodine Test (CERT) program is described. A brief description of the historical development of the program and a summary of the principal results prior to 1967 are included. A mathematical model of bovine metabolism of radioiodine, based on the model proposed by Garner, is developed. Comparison of the predictions of the model with CERT data indicate that the model is adequate for the purpose of predicting the quantity of radioiodine found in milk. CERT experimental data on deposition are compared with the predictions of Sheppard's flux gradient model and with Chamberlain's resistance analogue of deposition. The Chamberlain model appears adequate for carbon plate deposition. Both models are inadequate for describing deposition on grass. The measured median deposition velocities for two simultaneous releases over two separate but adjacent grids were found to be within 20% of one another. Deposition velocity was found to be linearly related to both areal grass density and mean wind speed. The results of calculations of the ratio of the dose to the thyroid resulting from ingestion of milk from cows eating contaminated grass to the dose to the thyroid resulting from the inhalation of the contaminated air above the grass at the time of deposition are included.

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SUMMARY

The objective of the Controlled Environmental Radioiodine Test (CERT) program is to obtain quantitative information on the kinetics of radioiodine transport from the point of release to the atmosphere through the entire air-vegetation-cow-milk sequence in the human food chain. A brief description of the historical development of the CERT program and the principal results of the program prior to 1967 are included in this report. The purpose of this report is to describe the experimental and theoretical research undertaken during 1967.

Modifications of the experimental facilities and of feeding techniques together with a more complete biological sampling program permitted an intensive study of the grass-milk link of the food chain. The data obtained were used in the development of a mathematical model of bovine metabolism of radioiodine derived from the model proposed by Garner[8]. The resultant model:

(1) Allows for a realistic time-dependent radioiodine input

(2) Includes a compartment for radioiodine in body fluid not available to milk

(3) Relates the variable rate of transfer of radioiodine to milk to the cow's milk output.

Two sets of rate constants for the model were determined. The two model predictions were compared to the data for a third cow and the results indicate that the model is adequate for the purpose of predicting the quantity of radioiodine found in milk.

Experimental data from CERT were compared with the predictions of Sheppard's[24] flux gradient model of deposition and with Chamberlain's[5] resistance analogue of deposition. Chamberlain's resistance analogy model appears adequate for carbon plate deposition. However, neither Chamberlain's nor Sheppard's model is adequate for deposition on grass because neither takes into account the imperfect sink characteristics of grass for iodine or the microturbulence structure within the grass canopy.

The parameter deposition velocity is useful in expressing the rate of transfer of radioiodine from air to vegetation provided it is related to variables such as boundary layer transfer velocity, average wind speed, and areal grass density. The measured median deposition velocities for two simultaneous releases over two separate but adjacent grids were found to be within 20% of one another.

The ratio of the dose to the thyroid resulting from ingestion of milk from cows eating contaminated grass to the dose to the thyroid resulting from inhalation of the contaminated air over the grass at the time of deposition was evaluated using data from CERT 20 and standard metabolic parameters. The calculated ratio is 47 for a standard man and 910 for a child in the (0-1)-year age group. The calculated ratio of the ingestion dose to the thyroid of a child in the (0-1)-year age group to the inhalation dose to the thyroid of a standard man is 400. A continuous air concentration of 2.6×10^{-13} μCi/cc of ^{131}I over the

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pasture in dairy farm areas to which CERT data are applicable will produce a dose to the thyroid of a child in the (0-1)-year age group, who drinks 0.5 liter/day of the contaminated milk throughout the year, equal to the ICRP [38] limit of 1.5 rem/year for children under 16 years of age.

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I. INTRODUCTION

1. LITERATURE REVIEW AND GENERAL OBJECTIVES OF THE CERT PROGRAM

The transport of environmental radioiodine through the milk-food chain is governed by a number of variables. The variables which presently are known to be involved are shown in Figure 1. It is obvious that we are dealing with an exceedingly complicated problem, and one involving many disciplines. Consequently, a common approach used to study this problem has been to focus attention on one or two steps in the chain with the choice of step(s) depending on the particular interest and skill of the research group involved. For example, Chamberlain[1 through 5] has done extensive theoretical and experimental studies on the deposition of radioiodine on foliage (the air-vegetation link of the milk-food chain). He introduced the concept of deposition velocity as a means of expressing the rate of transfer of radioiodine from air to vegetation. He also developed a mathematical model which treats deposition as an electrical resistance analogue.

AIR-VEGETATION	VEGETATION-MILK	MILK-HUMAN THYROID
1. Wind Velocity	1. Effective Half-Life of ^{131}I on Grass	1. Milk Consumption
2. Friction Velocity	2. Growth Rate of Grass	2. Stable Iodine Intake
3. Temperature	3. Type of Grass	3. NaCl Intake
4. Relative Humidity	4. Stable Iodine Intake	4. Metabolic Rate
5. Atmospheric Stability	5. NaCl Intake	5. Age and Physical Condition
6. ^{131}I Chemical & Physical Form	6. Metabolic Rate of Cow	
7. Areal Density of Grass	7. Milk Production	
8. Physiological Characteristics of Grass Such as Stomatal Density and Opening	8. Grass Consumption	

Fig. 1 Variables which affect the transport of radioiodine through the milk-food chain.

The vegetation-milk link of the food chain has been studied by Soldat[6], Hull[7], Garner[8], Lengemann[9], and others[10]. These studies have had two main goals: (a) obtaining ratios of milk radioactivity to grass radioactivity and (b) developing mathematical models of radioiodine transfer kinetics in the cow.

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Considerable research has been done on the human thyroid uptake of radioiodine ingested via contaminated milk (the milk-thyroid link of the food chain). A good review of the findings of this work has been presented by Van Middlesworth[11].

To get quantitative information about the radioiodine food chain taken as a whole, it is necessary to piece together the results of the work referenced above. When this is done, several serious problems arise. For example, the individual research projects have been carried out under widely different experimental conditions and the results frequently vary considerably. Thus, there is an element of doubt in applying the results of published research to a particular environmental situation. Furthermore, results are frequently published with incomplete descriptions of methods and conditions under which the experiments were performed. An example of this is the reporting of grass radioiodine activity without indicating whether the grass activity is on a wet weight or dry weight basis. Because of these problems we are conducting a program known as CERT (Controlled Environmental Radioiodine Test). The overall goal of the program is to obtain quantitative information on the kinetics of radioiodine transport from the point of release to the atmosphere through the entire air-vegetation-cow-milk-human food chain. The experiments are carried out on an experimental dairy farm which has been designed to simulate as closely as possible the actual dairy farm environment adjacent to the NRTS site. During a typical experiment we measure as many of the variables shown in Figure 1 as possible.

2. HISTORICAL DEVELOPMENT OF THE CERT PROGRAM

The CERT project began informally with a preliminary elemental ^{131}I release in the spring of 1963. The procedures used and results obtained from this test have been summarized by Hawley et al.[12]. During the summer of 1963, construction began on the Experimental Dairy Farm (EDF). This facility, including suitable pasture, was ready for experimental work by September 1964. Four tests with gaseous ^{131}I were carried out on the EDF by the end of June 1965. These involved studies of all three links (air-vegetation, vegetation-milk, and milk-human thyroid) of the food chain. The results are presented in a 1965 progress report edited by Hawley[13]. Between June and December of 1965, two additional tests were performed. The first of these two was designed to study the behavior of methyl iodide-131 in the milk-food chain; the second was to obtain information on radioiodine kinetics under late fall conditions. Also during this period the first results were obtained from a laboratory experimental reasearch program (designated CERTLE) which was initiated in late 1964 to support the CERT field studies and is still in progress. Specifically, the objectives of the CERTLE program are: (a) to isolate and study the quantitative effects of the variables shown in Figure 1 on radioiodine transport through the food chain and (b) to develop and define field and laboratory techniques. The late fall CERT results and those of the first CERTLE tests are described in the second CERT progress report edited by Bunch[14].

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Twelve CERT tests were carried out during the summer of 1966. The major objective of this test series was to study the meteorological variables, such as turbulence and wind speed which control radioiodine kinetics in the air-vegetation link of the food chain. Three of the tests also involved the use of dairy cattle to obtain data on the vegetation-milk link of the food chain. The data gathered from these tests have been summarized in the third CERT progress report edited by Bunch[15].

3. PRINCIPAL RESULTS AND CONCLUSIONS OBTAINED PRIOR TO 1967

The data obtained in CERT field and laboratory studies prior to 1967 support the following major results and conclusions.

(1) There is no significant difference in the behavior of molecular radioiodine (I_2) at a distance of a few hundred meters from the release point as compared with two miles from this point.

(2) There is a change in the fraction ^{131}I secreted in cow milk from early spring to late fall. (This conclusion is supported only if no metabolic changes occurred in the cattle during the period, and if the estimates of feed consumption were not in error.)

(3) Deposition velocity (V_d) is linearly correlated ($\alpha = 0.01$) with areal grass density (D, grams/unit area, dry weight).

(4) There is a strong linear relationship between normalized deposition velocity ($V_D = V_d/D$) and friction velocity (u_*) during moderate wind speeds in an unstable atmosphere. The relationship is much weaker in a stable atmosphere with light winds.

(5) The deposition velocity (V_d) for methyl iodide is no greater than 0.05% that of molecular iodine.

(6) The average human thyroid uptake fraction for radioiodine ingested via contaminated milk was found to be 0.19 for six volunteers.

(7) The average human thyroid uptake fraction for radioiodine inhaled by three volunteers on the EDF pasture during the CERT 2 release was found to be 0.30.

4. OBJECTIVES OF THE 1967 CERT PROGRAM

The field and laboratory research carried out during CY 1967 and described in this report had the following major objectives:

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(1) To measure deposition of radioiodine on vegetation under high wind speed conditions which occur frequently in this area.

(2) To test the linear relationship between u_* and V_d at high wind speeds.

(3) To do an intensive study on the grass-to-milk link of the environmental food chain by (a) measuring accurately the daily activity input to dairy cows through the use of green chop equipment purchased during CY 1967, (b) measuring total activity output from the cows, and (c) developing a realistic mathematical model for radioiodine kinetics in the cow.

(4) To determine the precision of field measurements of V_d by carrying out simultaneous releases of molecular iodine over two grids of which experimental conditions are matched as closely as possible.

(5) To study the vertical distribution of radioiodine deposited on grass.

To accomplish these objectives two field experiments involving the release of radioiodine were carried out (CERTs 20 and 22). An additional field experiment without an iodine release was performed during which the cows were fed a nearly constant daily amount of radioiodine activity in capsules spiked with sodium iodide-131. The objective of this experiment was to study the metabolism of radioiodine in the cow under constant input conditions.

5. PLAN OF PRESENTATION

In Section II the experimental methods, materials, and facilities are summarized with emphasis on modifications made for the CY 1967 research. Experimental results and discussion are presented in Section III, and the major conclusions drawn from this work are given in Section IV. The plans for research to be undertaken during the summer of 1968 are outlined in Section V.

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II. EXPERIMENTAL METHODS, MATERIALS, AND FACILITIES

1. GENERAL DESCRIPTION OF EDF WITH MODIFICATIONS MADE DURING CY 1967

The location of the EDF on the National Reactor Testing Station (NRTS) site and portions of EDF facilities have been described in previous CERT progress reports[13,15].

The EDF consists of a 27-acre pasture, pump house, irrigation facilities, dairy barn, and supporting equipment. Figure 2 is a schematic drawing of the EDF, and a detailed drawing of the dairy barn area is shown in Figure 3. Note that the pasture is oriented such that the prevailing southwesterly winds carry the radioiodine from the release points directly across it. During CY 1967 individual stalls were built for the dairy cows so that each cow could be fed measured amounts of green chop and could be provided with a metered drinking water supply. These stalls are shown schematically in Figure 3; a photograph of them with the dairy barn in the background is shown in Figure 4.

The pasture grass is a mixed variety consisting predominantly of orchard and brome grasses.

As in past years the dairy herd consisted of six registered Holstein cows obtained for the summer from Montana State University.

2. GREEN CHOP EQUIPMENT AND PROCEDURES

In the spring of 1967 we purchased a used Gehl Green Chopper and subsequently obtained a new International 2656 tractor and wagon for use with the chopper. The green chopper, tractor, and wagon are shown in Figure 5.

The green chop feeding method allowed a much more accurate determination of the daily feed and radioiodine intake for individual cows than was possible with the grazing method used prior to CY 1967. An accurate knowledge of the daily radioiodine intake of each cow is necessary to develop and test realistic mathematical models of radioiodine kinetics in the cow.

The green chop procedures used during the 1967 CERT program were as follows:

(1) The cows were fed freshly cut and weighed green chop twice a day, once at approximately 7 a.m. and again at approximately 4 p.m.

(2) Before the pasture was contaminated with radioiodine, each cow was fed green chop ad libitum for several days to determine the quantity by weight she could eat at each feeding. Then during an experiment she was given about 95% of the ad libitum weight. This method was successful in obviating the

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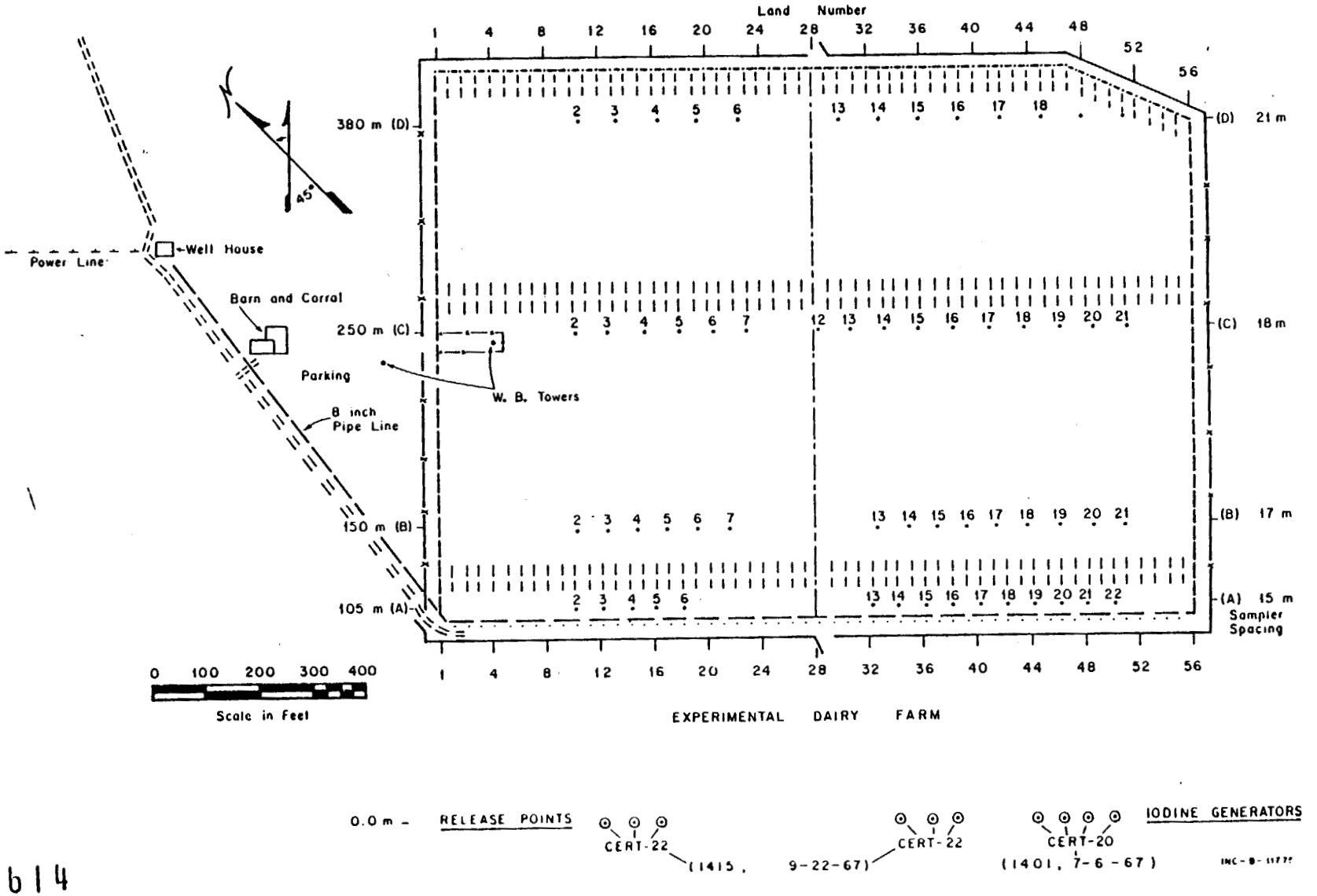

Fig. 2 Experimental Dairy Farm (EDF).

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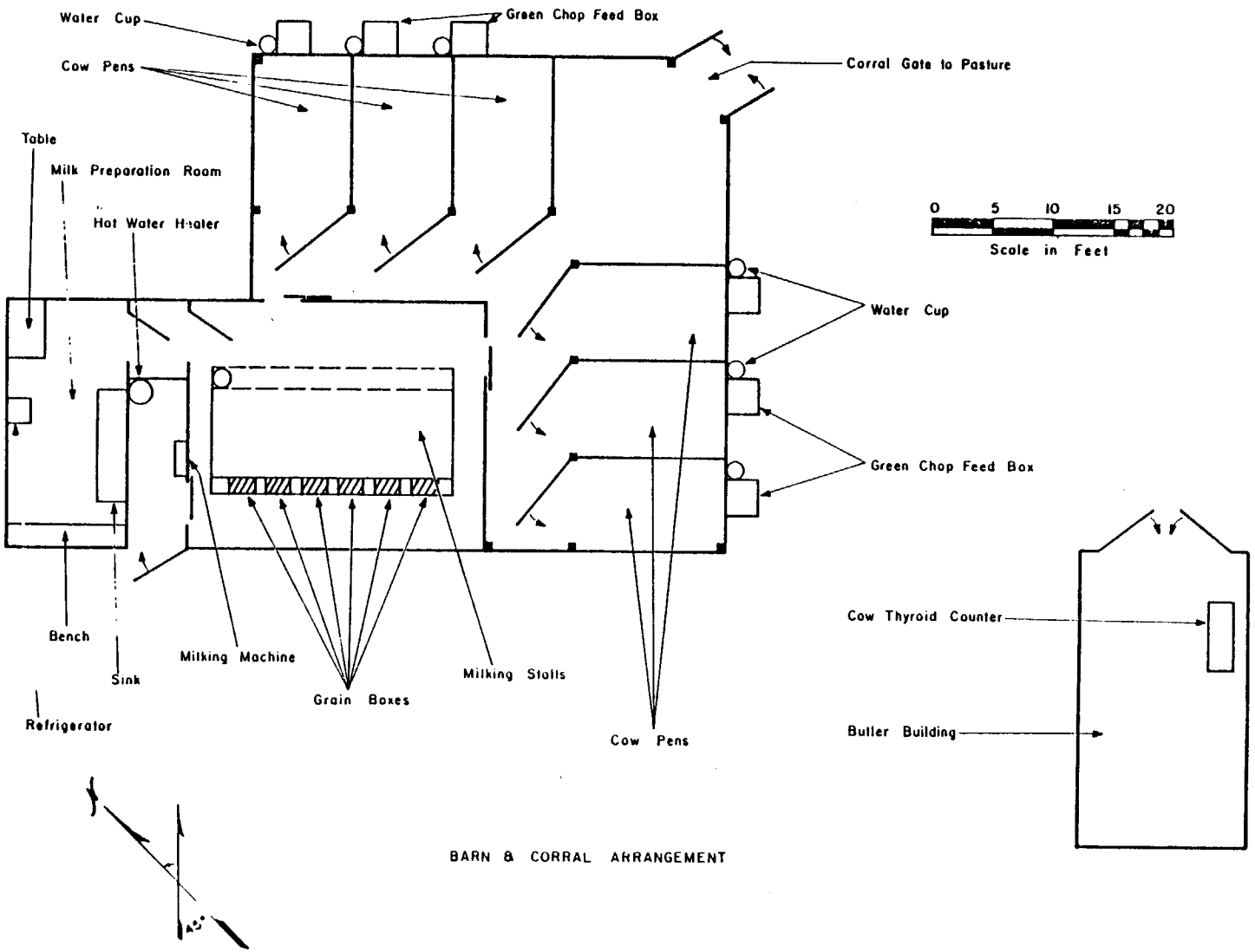

Fig. 3. Barn and corral arrangement at the Experimental Dairy Farm.

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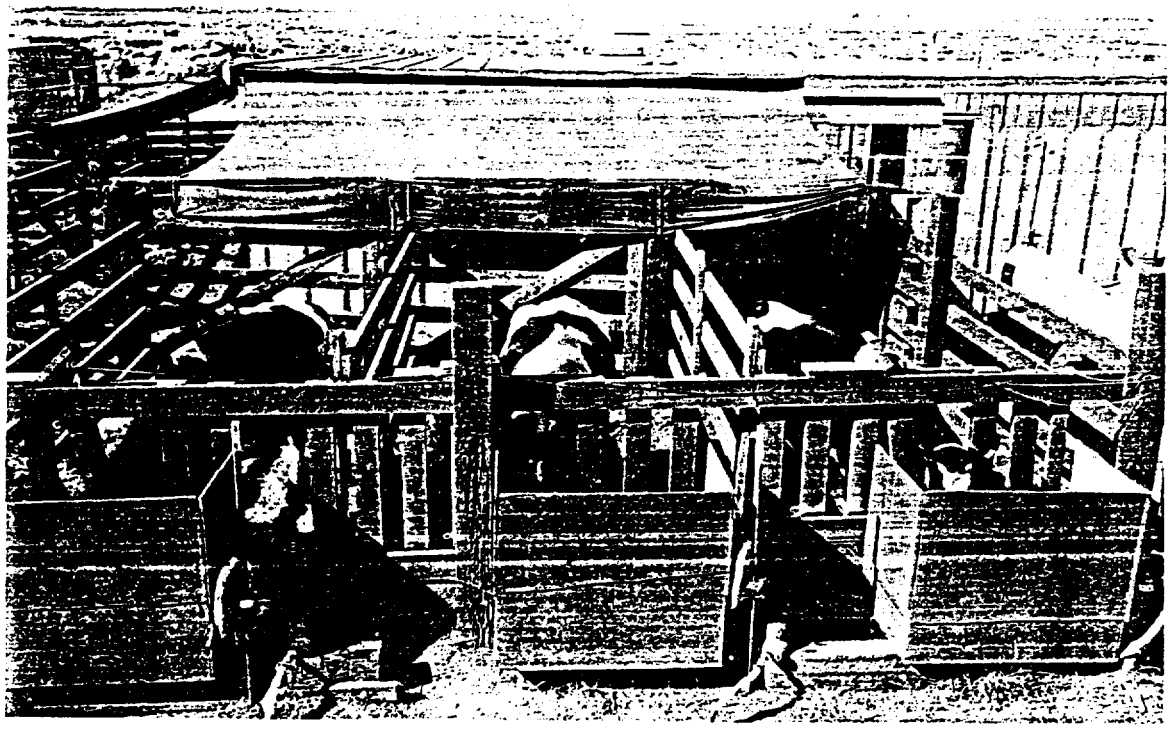

Fig. 4 Stalls for metabolic studies of dairy cattle.

need for correcting the daily feed record for unconsumed green chop.

(3) Grass samples were taken from the pasture just prior to the time the green chop was cut (these samples came from the area over which the chopper passed). Additional samples were taken from the chop after it had been placed in feed boxes. These were assayed for radioiodine activity content. There was never any significant difference in radioactivity content between the two sets of samples which indicates that the feed did not lose a significant quantity of radioiodine during the green chop process. Thus, the data obtained from these green chop experiments are valid for grazing conditions.

(4) At the beginning of an experiment green chopping was done on the sections of pasture having the lowest levels of radioiodine activity. As the experiment proceeded, the chopping was moved to progressively more contaminated sections to compensate for radioiodine concentration losses due to radioactive decay, weathering, and growth.

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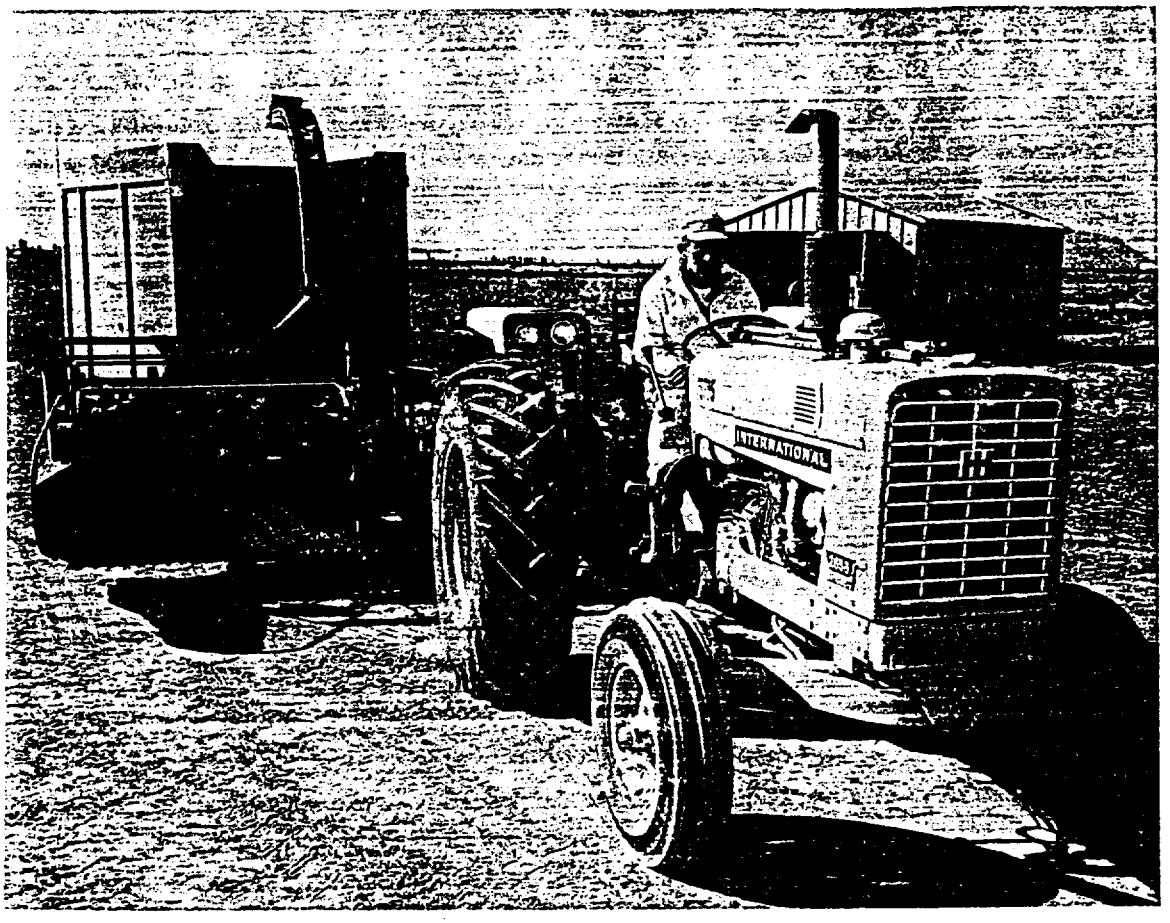

Fig. 5 Green chop equipment at the Experimental Dairy Farm.

(5) The wet weight of the chopped feed given to each cow was measured by placing it in 30-gallon plastic cans and weighing on a vertical spring balance (the tare weight of each can was subtracted from the total weight). As mentioned in (3) above grass samples were taken from each feed box and brought back to the laboratory for activity and moisture assay. Moisture loss during consumption was measured by determining the moisture content of samples taken at the beginning and end of the feed period. The daily feed intake on a dry weight basis was calculated by multiplying wet weight of the feed by the fractional moisture content which was corrected for moisture loss during consumption.

The details of collecting and analyzing grass samples are described later in Section II-6.

3. METHODS FOR RELEASING GASEOUS RADIOIODINE

Radioiodine was released to the atmosphere as $^{131}I_2$ by a sparging technique, the apparatus for which is shown schematically in a previous report by

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Bunch[15]. Sodium iodide-131 in a 0.1 N sodium hydroxide solution was obtained commercially and diluted with 2 N sulfuric acid to a volume of about 200 ml. One hundred lamdba of a 0.1 N sodium iodide solution were added as a carrier. The activity was maintained as I^- by adding 0.1% (W/W) concentration hypophosphorous acid. Immediately prior to the time of release, the I^- was converted to I_2 by oxidation with several drops of 10% (W/W) solution of sodium nitrite. The $^{131}I_2$ was sparged into the atmosphere with nitrogen carrier gas.

It was necessary to determine whether any other chemical species of radioiodine besides $^{131}I_2$ contributed significantly to the activity generated by the sparging technique. This was done by sampling the sparged gas with a Maypack sampler[16 through 19]. Molecular iodine and organic iodides are differentially collected in the Maypack; silver metal fibers collect molecular iodine and pass organic species which then are collected in a carbon or charcoal filter impregnated with stable iodine. In a series of five tests an average material balance of 100.5% was obtained between the total generated radioiodine and that found on the silver filters. It was concluded that molecular iodine was the only species present in significant quantity in the radioiodine gas generated by our sparging technique.

4. AIR SAMPLING METHODS

4.1 Grid Systems

For depostion studies the pasture was divided into a grid which consisted of four sampling lines extending downwind perpendicular to the iodine release points. These lines, designated A through D in Figure 2, are spaced at 105, 150, 250, and 380 meters, respectively, from the release points. Sampling stations were placed at measured intervals along each of the four lines. The station spacings are indicated on the right side of the pasture in Figure 2. Also shown in Figure 2 are the station locations and numbers which were used during CERTs 20 and 22. During CERT 20, stations A 18 through 22, B 17 through 21, C 16 through 19, and D 13 through 16 were used. For CERT 22, which consisted of two simultaneous releases of radioiodine, stations A 2 through 6, A 13 through 17, B 3 through 7, B 13 through 17, C 3 through 7, C 12 through 16, D 2 through 6, and D 13 through 16 were utilized.

4.2 Air Sampling Equipment and Analytical Procedures

The air sampling equipment used at each station consisted of a Staplex high volume sampler positioned one meter above ground level and fitted with a Gelman E particulate prefilter followed by a 1.1-inch-thick coconut-shell charcoal filter impregnated with stable iodine (type MSA-85851). In addition, certain stations were instrumented to measure vertical concentration profiles with low volume samplers (approximate flow: 3.7×10^{-4} m^3/sec) attached to towers at heights of 0.06, 0.12, 0.25, 0.5, 1, 2, and 4, meters above ground level. For CERT 20 these stations were A 20, B 19, C 18, and D 15. For CERT 22 the positions were B 5, B 15, C 5, and C 14. Each low volume sampler was equipped with a Gelman E particulate prefilter and an AC-1 charcoal filter in series. Electricity was furnished to the air samplers by means of gasoline powered generators. The air flow of each sampler was measured prior to the experiment with the filters in place and the electrical generators at operating

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temperature and voltage. The flow measurements were made with a Dwyer air flow meter which gave a direct readout of flow in cubic feet per minute. Immediately after each field experiment the filters were removed from the samplers, placed in polyethylene bags with identification cards, and brought to the laboratory for analysis. In most cases analysis was completed by the end of the day of the field release.

The radioiodine activity on the filters was measured by gamma counting in calibrated well crystal scintillation systems.

4.3 Air Filter Efficiency Measurements

In order to obtain the actual air concentration of radioiodine from filter activity and air volume data, it is necessary to know accurately the collection efficiencies of both the particulate and gaseous filters. Because reliable measurements of radioiodine collection efficiencies for the types of filters used in CERT are not available in the literature, we have made such measurements in our laboratory. Collection efficiencies for $^{131}I_2$ were determined for filters designed to collect gases and for filters designed to collect particulates. We also studied the effect of volume of air sampled on residual collection efficiency of activated charcoal and filter papers and cartridges. It was not necessary to measure collection efficiencies for particles since they have been studied extensively and are available from the filter manufacturers.

The efficiency experiments were made in a cylindrical filter test chamber (dubbed CERTLETTE) (2.5 inches in diameter by 6.5 inches long) constructed of Lucite. This chamber is fitted with filter holders at the inlet and outlet and has a test gas injection line near the inlet. The outlet filter holder contains the test filter, after which there is a carbon-impregnated scrub filter to collect the activity that passed through the test filter. In the experiments described here the inlet filter was Gelman Type E glass fiber which removes atmospheric particles with greater than 99% efficiency; thus the test filters were exposed to air which was essentially free of particles.

The gaseous radioiodine used in the filter tests was generated using the technique described in Section II-3. The activity entered the test chamber at the inlet end about 2 cm from the downstream side of the inlet glass fiber filter. Approximately 0.75 μCi ^{131}I was placed in the generator for each test. Aliquots of generator solution were removed and assayed before and after generation to determine the quantity of ^{131}I released to the filters. The quantity of ^{131}I which deposited on the walls of the chamber was measured (this was typically about 1% of the activity generated). As a final check for material balance, the amount of activity collected by all the filters and the chamber walls was added and compared with the amount generated. The results, averaged over a number of tests, indicated that balance was achieved to within counting statistics which lends a high degree of confidence to the efficiency results.

The efficiency test series for each unused filter consisted of three replicates at face velocities of 71, 35, and 18 cm/sec. The face velocity used here is defined as the volume of air passing through the filter divided by the cross-sectional area of the filter holder. The efficiency is the ratio of the activity found on the filter to the difference between the initial activity in the generator and the sum of the activities found on the chamber and in the generator after the test. The efficiencies are presented in Table I. Type AC-1 and ACGB gas

collection filters and charcoal cartridge filters through which various measured volumes of air had been passed were tested for their residual radioiodine collection efficiencies. These were measured at a single face velocity of 18 cm/sec. The results are shown graphically in Figure 6, where residual radioiodine collection efficiency is plotted against total volume of air sampled.

The data presented in Table I indicate a very wide range of efficiencies for the various types of filters. Nearly all the filters showed a significant inverse relationship between efficiency and face velocity. The glass fiber matrix type Gelman E collected a considerable amount of iodine at low face velocities. Millipore AA and Whatman 41 collected less than 1% at all face velocities. Gas filters of the AC-1, ACGB, and charcoal cartridge type collected molecular iodine readily.

TABLE I

COLLECTION EFFICIENCIES OF VARIOUS FILTERS FOR MOLECULAR IODINE

Filter	Percentage Retention at Specified Face Velocity (cm/sec)			Filter Pore Size (microns)
	71	35	18	
VM-1	1.2	2.5	3.1	5.0
VM-4	1.7	2.4	2.6	0.8
VM-6	18.7	19.7	22.6	0.45
GA-1	0.5	0.7	0.9	5.0
GA-4	3.0	4.8	6.0	0.8
GA-6	1.7	2.2	13.5	0.45
GM-1	1.5	2.0	2.7	5.0
GM-3	0.1	0.1	0.1	1.2
GM-6	3.6	7.0	12.4	0.45
Millapore AA	0.1	0.2	0.3	0.8
Whatman 41	0.04	---	0.08	Fiber
Gelman E	5.7	7.5	7.5	Fiber
AC-1	90.0	89.0	95.0	Fiber
ACGB	92.0	---	91.0	Fiber
Cartridge	---	95.0	---	Charcoal

The AC-1 and ACGB type filters appear to have a limited number of collection sites available. During long periods of sampling, other molecules in the air stream occupy these sites and reduce the filter's efficiency for iodine. The efficiency of the two-inch AC-1 filter drops below 90% after about 18,000 cubic

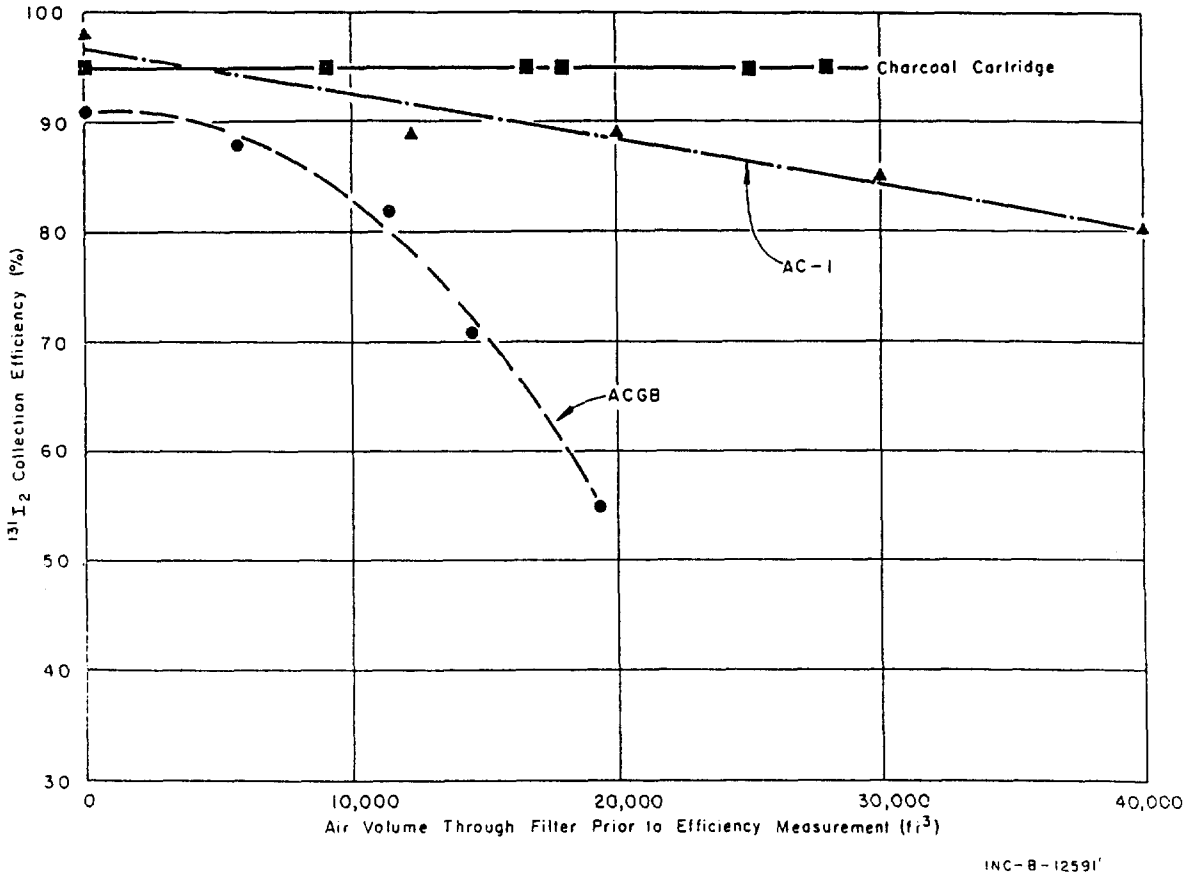

Fig. 6 Radioiodine collection efficiency as a function of filtration history.

feet of air have been filtered. The two-inch ACGB filter begins to lose efficiency rapidly after filtering about 5,000 cubic feet of air. In contrast, the charcoal cartridge filter which contains about four grams of charcoal did not show any reduction of efficiency over the longest sampling periods studied. Presumably the much greater number of deposition sites available in the charcoal cartridge makes it more suitable for long-term sampling.

5. METEOROLOGICAL INSTRUMENTATION

Meteorological data were taken from two locations during the CERT releases. One location provided measurements near the ground from a portable mast in the area of deposition, and the other provided measurements at greater elevations from a fixed tower.

The portable mast instrumentation consisted of sensitive cup anemometers; shielded, unaspirated thermocouples; and shielded aspirated resistance bulbs which were mounted at various positions between four meters and the top of the pasture grass. The fixed tower at the Air Resources Laboratory Field Research Office (ARLFRO) permanent research location (Test Grid 3) was instrumented to a height of 61 meters with shielded aspirated thermocouples, sensitive cup anemometers, and bivanes. Turbulence (wind velocity profile) measurements were not made below the four-meter level at the ARLFRO location because

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low level data from this point would not necessarily have been representative of conditions on the pasture where deposition was measured.

The outputs from the portable mast instrumentation were recorded on charts (temperature) and counters (wind speed). The ARLFRO tower sensor outputs were digitized and recorded via high- and low-speed digital data acquisition systems.

The wind direction and speed at the six-meter level were measured by a propeller vane on a separate mast near the area on which deposition was measured.

6. COLLECTION AND ANALYSIS OF PASTURE GRASS SAMPLES

Two types of grass samples were collected during CERT field experiments:

(1) Those cut from a defined area for use in determining areal deposition of radioiodine

(2) Those taken during green chop feeding as described in Section II-2.

For weight and radioiodine activity measurement, all grass samples were treated identically. Grass was compressed vigorously by hand and placed in a polyethylene bag until enough had been accumulated to fill a quart-ice-cream-type cylindrical container. The bags were wired shut, tagged, and stuffed into the containers. Each sample was gamma counted in a well crystal scintillation counter which had been calibrated for these measurements with grass samples containing known amounts of ^{131}I. Errors due to counting are estimated to be no greater than $\pm$ 10%.

Samples of type (1) described above for deposition measurements were collected at the base of each air sampling station with the help of a small electric grass clipper which has a cutting blade 11 inches long. By moving this blade through the proper horizontal length, the desired area of grass was cut. A stick of the appropriate length was used in conjunction with the clipper to facilitate the collection of these samples. Each sample was cut at 5 cm above ground level (approximate grazing height). The choice of either 1/2 m^2 or 1/4 m^2 area depended on the grass density, since the sample was required to fit into a quart container for counting.

After the grass samples were counted they were removed from the paper cartons and polyethelene bags and placed in paper sacks for drying. Drying was accomplished in an oven at 80°C for at least 16 hours. Finally, the samples were weighed to obtain their dry weights.

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7. COW THYROID COUNTER DESCRIPTION, CALIBRATION, AND OPERATING PROCEDURES

The radioiodine activity in the thyroid of each dairy cow was measured daily with an external thyroid counting system which consisted of a scintillation detector and a Baird Atomic Single Channel Spectrometer (Model 530). The detector, a 3- by 3-inch NaI (Tl) Harshaw integral line crystal, was housed in a 1/2-inch-thick bell-shaped lead shield. A photograph of the system while in use is shown in Figure 7. The test cow was held in position by the metal "squeeze chute". Each thyroid lobe was located prior to counting by use of a portable scintillation probe collimated to a one-inch diameter. This detector was moved back and forth over the lobe area until the count was maximized, which indicated the center of activity of the lobe. The shielded detector was placed directly over this point for counting. The counts under the 0.36 MeV photopeak of ^{131}I were summed for each lobe, corrected for background, and converted to total ^{131}I activity by use of calibration data obtained as described in the following paragraph.

The thyroid counter was calibrated using the amputated head and neck of a cow as a phantom. Point sources of ^{131}I ranging in activity from 0.02 to 17 μCi were implanted in the two lobes of the phantom's thyroid. These implants were counted with the same source-detector geometry as used in the experiments. A calibration curve showing total count rate versus ^{131}I activity was obtained. This was then used directly to convert the experimental count data to thyroid activity. The precision of these data is estimated to be within ±10%.

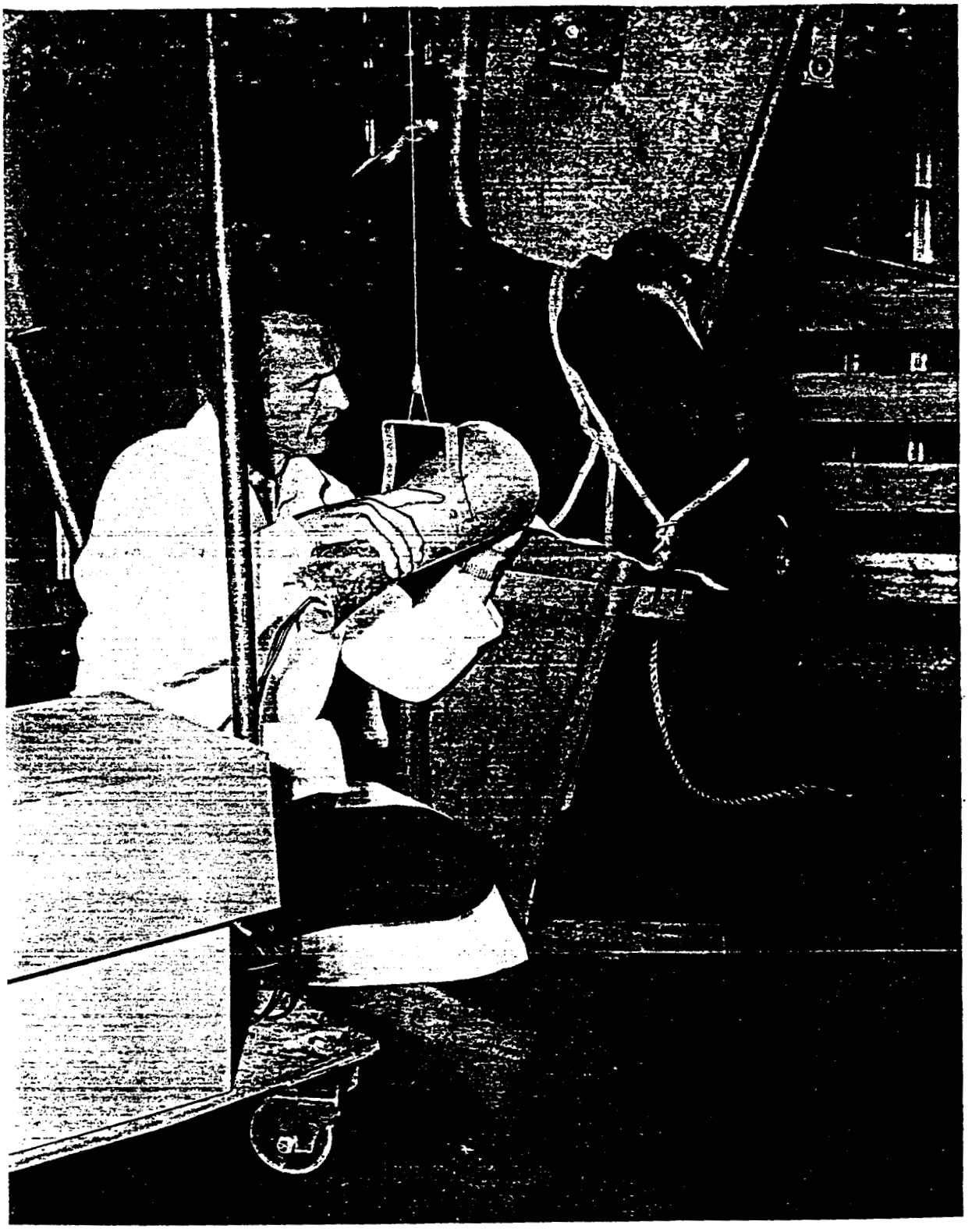

Fig. 7 Cow thyroid counter.

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8. COLLECTION AND ANALYSIS OF BIOLOGICAL SAMPLES FROM THE EXPERIMENTAL DAIRY COWS

8.1 Milk Samples

The cows were milked using a standard electric milker at 7 a.m. and 5 p.m. daily. After each milking, 900-ml samples from each cow were placed in plastic-lined, cylindrical, quart ice cream containers for radioiodine assay. The samples were assayed by gamma counting in a 3- by 4-inch NaI(Tl) well scintillation counter which had been calibrated with milk samples containing known quantities of ^{131}I. The counting rate of each sample was corrected for the natural ^{40}K contribution.

8.2 Urine Samples and Measurements of Total Daily Urine Outputs

8.21 Urine Samples. Daily urine samples were collected from each cow. Urination was stimulated by stroking the perineal area and the urine was collected in a 12-quart bucket. Cylindrical plastic jars (3-1/4 inches in diameter by 3-3/4 inches; 400-ml) were filled with urine from the buckets and gamma counted for ^{131}I activity in a 3- by 4-inch NaI (Tl) well scintillation counter which had been calibrated for this type of sample.

8.22 Measurement of Total Daily Urine Outputs. In our development of a model of radioiodine kinetics in the cow we required measurements of the total quantity of activity excreted daily via the urine. Rather than attempt to collect and assay the total daily urine output from the cows, which might have affected their metabolism, we developed a method whereby the total daily urine output could be measured indirectly and the results used in conjunction with the urine concentration data described above to calculate the total daily radioiodine outputs. The method is based on earlier studies in which the herbicide 2, 4-Dichlorophenoxyacetic acid (2,4-D) was fed to dairy cattle and was shown to be excreted entirely in the urine[20,21]. Provided that a known quantity of 2,4-D is fed daily and all or a known portion of this quantity is eliminated in the urine, the daily urine output can be calculated.

Three experiments were performed. The first was performed to determine clearance rates of 2,4-D and the daily urine output assuming all 2,4-D was excreted in the urine; the second was to test the assumption that all 2,4-D was excreted in the urine; and the third was to compare the urine output calculated from 2,4-D concentrations with the actual urine output.

Carbon-14-labeled 2,4-Dichlorophenoxyacetic acid, which had a stated purity of greater than 99%, was obtained commercially. The first carbon position of the acetic acid group was labeled with ^{14}C.

The concentrations of 2,4-D in the urine, feces, and milk were determined using a liquid scintillation counter. The collection procedures for urine, feces, and milk samples are detailed elsewhere in this report. Aliquots of these samples (1 ml of milk or urine or 1 gram of feces) were prepared for scintillation counting by adding a thixotropic gel powder and 22 ml of scintillation solution. Each sample was counted for twenty minutes.

The first experiment was conducted for nine days and utilized six cows. During the first seven days of the experiment, 2,4-D mixed with alfalfa meal

was fed to the cows in 1/4-ounce capsules. Each cow was given a capsule containing 2.55 μCi of ^{14}C twice daily at 0830 and 1530. During the first four days of the experiment, urine samples were collected twice daily at 0800 and 1500. For the next three days, samples were taken at two-hour intervals beginning at 0700 and ending at 1700. Urine was sampled twice daily at 0830 and 1530 on the eighth and ninth days. With such frequent sampling it was possible to determine the maximum and minimum excretion concentrations of 2,4-D excreted for each 24-hour period. Using the maximum and minimum concentrations of 2,4-D for a 24-hour period, we determined a mean daily urine concentration. The urine volume was calculated by dividing the total daily quantity administered by the mean concentration of 2,4-D in the urine.

The biological half-life (time required for the concentration of radioactivity to decrease by a factor of two) was determined by applying regression analysis to the curve of ^{14}C concentration versus time from the point of highest ^{14}C to the point where the activity was no greater than background. The period from the time the last capsule was given to the time the ^{14}C activity was no greater than background is called the clearance time.

The second experiment lasted six days and utilized three cows. During the first five days 2,4-D mixed with alfalfa meal was fed to the cows in 1/4-ounce capsules. Each cow was given a capsule containing one μCi of ^{14}C three times daily at 0830, 1230, 1630. Urine samples were collected five times daily beginning at 0630 and ending at 1800. Sampling continued until 1800 on the sixth day at which time the ^{14}C activity was no greater than background. All other sampling and measurement procedures involving the urine were the same as those used in the first experiment.

During the second experiment ^{14}C concentrations in milk and feces were measured. Carbon-14 activity was detected in the milk. The total amount of ^{14}C activity discharged in the milk for the six days of the experiment was calculated by multiplying ^{14}C concentration by the daily milk volume. No ^{14}C was detected in the feces. The difference between the total daily intake of ^{14}C and the ^{14}C found in the milk was used for the computation of urine volume. The biological half-life and clearance time were determined as in the first experiment.

Three cows were used in the third experiment. Each cow was given two doses of 2,4-D, four hours apart. Each dose contained 4.66 μCi of ^{14}C. Urination was stimulated and urine collected every hour and accumulated so that urine was collected for a 48-hour period.

The results of the first experiment showed clearance time in the six cows ranging from 24 to 30 hours. Biological half-lives ranged from 4.5 to 5.5 hours. In the second experiment, which utilized smaller quantities of 2,4-D, the clearance time for the three cows ranged from 22 to 24 hours and biological half-lives ranged from 4.0 to 4.5 hours.

Tables II and III show the daily urine outputs for each cow determined during the first and second experiments below the correction for the ^{14}C secreted in the milk. The average urine output for each cow both before and after this correction is also shown. The uncorrected daily output for six cows during the first experiment ranged from 10 to 22 liters with a mean of 15 liters. For the three cows in the second experiment it ranged from 9 to 20 liters with a mean of 13 liters.

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TABLE II

INDIVIDUAL AND AVERAGE DAILY URINE VOLUMES (LITERS) DETERMINED BY THE ^{14}C-LABELED 2,4-D TECHNIQUE -- EXPERIMENT I

	Uncorrected for ^{14}C loss in milk (July)								
Cow No.	18	19	20	21	22	23	24	Average	Corrected Average
84	12	14	11	11	10	14	14	12	12
88	16	15	15	12	12	14	10	13	12
94	13	10	12	13	14	16	16	14	12
98	20	14	17	16	13	13	12	15	13
142	22	14	16	15	20	19	20	17	17
175	17	16	16	17	14	17	15	16	13
				Mean For All Cows				15	13

TABLE III

INDIVIDUAL AND AVERAGE DAILY URINE VOLUMES (LITERS) DETERMINED BY THE ^{14}C-LABELED 2,4-D TECHNIQUE -- EXPERIMENT II

	Uncorrected for ^{14}C Loss in Milk (August)					
Cow No.	10	11	12	13	Average	Corrected Average
94	10	12	14	15	13	12
142	9	10	11	11	10	10
175	13	17	15	20	16	14
			Mean For All Cows		13	12

Carbon-14 was first detected in the milk from 24 to 36 hours after the first oral dose was administered. It was determined that ^{14}C was discharged at a rate ranging from 0.65 to 0.85% of the daily dose per liter of milk with an average rate of 0.75% per liter for the last five days of the second experiment. This correction, when applied to the results of the first experiment, gives a range of average urine volumes from 12 to 17 liters with a mean of 13 liters, and a range from 10 to 14 liters with a mean of 12 liters for the second experiment (see Tables II and III).

A comparison of the daily urine outputs of the three cows used in the first and second experiments is favorable for cows 94 and 175. Cow 142 became ill

shortly after the second experiment began. This could account for her low urine output during the experiment (see Tables II and III).

Table IV shows the results of the third experiment. It can be seen that the urine outputs determined by the 2,4-D technique, corrected for elimination in milk, compare very well with the actual urine outputs. The percentage of ^{14}C recovered from the urine averaged 84.3% and that in the milk 11.3% giving an average recovery of 95.6%. Within the limits of experimental error, this recovery indicates that virtually all 2,4-D is eliminated from the cow via these two routes.

TABLE IV

COMPARISON OF ACTUAL URINE OUTPUTS IN LITERS WITH THOSE DETERMINED BY THE 2,4-D TRACER TECHNIQUE

Cow No.	Output in Liters by 2,4-D Tracer Technique	Output in Liters by Actual Measurement
94	19	17
142	21	22
175	20	18
Mean For All Cows	20	19

8.3 Fecal Samples and Measurements of Daily Fecal Outputs

8.31 Fecal Sampling. Fecal samples were collected twice daily (a.m. and p.m.) from each cow. Defacation was stimulated by ventilating the perineal area; the feces were collected in twelve quart buckets from which 400-cc samples were taken in cylindrical, plastic (3-1/4 inches in diameter by 3-3/4 inches) jars. The wet weight of each sample was measured. Because the samples contained ^{131}I and ^{141}Ce activity (^{141}Ce was used to measure fecal output; see below) they were assayed by gamma scintillation spectrometry using a multichannel analyzer. This technique allowed simultaneous measurements of the concentrations of both isotopes. After the samples were counted they were removed from the plastic jars, placed on plates (8 by 8 inches), dried in an oven at 80°C for 16 hours, and weighed.

8.32 Measurement of Daily Fecal Outputs. Values of the total daily fecal outputs of the cows were necessary in order to permit calculation of the quantity of radioiodine excreted via the feces for each cow. Previous research on the metabolism of ^{141}Ce ingested by dairy cows showed that this isotope is uniformily mixed and excreted entirely in the feces[22]. Therefore we used ^{141}Ce to measure fecal outputs by a procedure analagous to that described in Section 8.12 for measuring urine outputs using ^{14}C-2,4-D.

Gelatin capsules which contained approximately 0.75 μCi ^{141}Ce absorbed in alfalfa were administered orally to each cow twice daily (a.m. and p.m.) using a veterinary balling gun. Two to three days after starting the experiment the ^{141}Ce concentration in the fecal samples had reached equilibrium. The daily fecal outputs for each cow were calculated by dividing the quantity of ^{141}Ce administered daily (in μCi) by the equilibrium concentration in the fecal samples (in μCi/dry gram). The results shown in Table V are estimated to be accurate to within ± 20%.

8.4 Blood Samples, Blood Volume Measurements, and Total Body Fluid Measurements

8.41 Blood Samples. Daily (a.m.) blood samples were taken from the dairy cattle. Fifty milliliters of blood were withdrawn in a syringe from the

TABLE V

INDIVIDUAL DAILY FECAL OUTPUTS DETERMINED BY THE ^{141}Ce METHOD (Kg Dry Weight)

Date	Cow Identification Number					
July	84	88	94	98	142	175
5	4.5	4.8	5.8	4.6	4.9	5.5
6	4.5	4.8	5.8	4.6	4.9	5.5
7	4.5	4.8	5.8	4.6	4.9	5.5
8	4.5	4.8	5.8	4.6	4.9	5.5
9	4.5	4.8	5.8	4.6	4.9	5.5
10	4.5	5.2	6.0	5.3	6.3	7.4
11	4.5	5.2	6.0	5.3	6.3	7.4
12	4.5	5.2	6.0	5.3	6.3	7.4
13	4.5	5.2	6.0	5.3	6.3	7.4
14	5.4	5.6	6.2	4.7	5.3	7.6
15	5.4	5.6	6.2	4.7	5.3	7.6
16	5.4	5.6	6.2	4.7	5.3	7.6
17	5.9	6.0	6.8	6.4	7.9	9.5
18	5.9	6.0	6.8	6.4	7.9	9.5
19	5.9	6.0	6.8	6.4	7.9	9.5
20	6.7	5.4	9.0	7.7	9.0	9.8
21	7.1	7.6	4.8	7.6	8.8	9.6
22	5.9	6.3	8.0	7.1	[a]	9.5
23	5.9	6.3	8.0	7.1	7.0	9.5
24	5.9	6.3	8.0	7.1	7.0	9.5
25	5.9	6.3	8.0	7.1	7.0	9.5
26	5.9	6.3	8.0	7.1	7.0	9.5
27	6.4	5.9	7.4	7.4	8.1	7.4
28	6.4	5.9	7.4	7.4	8.1	7.4
29	6.4	5.9	7.4	7.4	8.1	7.4
30	7.0	7.0	9.3	9.8	8.4	9.5
31	7.0	7.0	9.3	9.8	8.4	9.5
August						
1	7.0	7.0	9.3	9.8	8.4	9.5
2	4.0	4.0	5.0	5.0	4.4	5.0
3	4.0	4.0	5.0	5.0	4.4	5.0

[a] Data missing

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jugular vein of each cow and were mixed with approximately two milliliters of an anticoagulant in a 75-ml test tube. These samples were transferred to a cylindrical 75-ml vial and gamma counted for ^{131}I activity in a calibrated well crystal scintillation counter.

8.42 Blood Volume and Total Body Fluid Volume Measurements. The blood volume of each cow was measured by use of the standard Evan's blue technique[23]. This technique, which is widely used in hospitals, consists of injecting a known quantity of Evan's blue reagent into the blood stream, waiting a few minutes for complete dilution to take place, and withdrawing a blood sample that is analyzed spectrophotometrically for concentration of the reagent. The results of the blood volume measurements are presented in Table VI.

TABLE VI

INDIVIDUAL BLOOD VOLUMES DETERMINED BY THE EVAN'S BLUE TECHNIQUE

Cow No.	Blood Volume (liters)
84	30.4
88	25.3
94	30.3
98	32.8
142	37.7
175	24.2

The volume of total body fluid in each cow was measured under normal, nonfasting conditions by the antipyrene method discussed by Hix et al.[23]. This technique is analogous to the Evan's blue method described above and is based on the dilution of a known quantity of antipyrene injected intravenously. The results are shown in Table VII.

TABLE VII

INDIVIDUAL TOTAL BODY FLUID VOLUMES DETERMINED BY THE ANTIPYRENE METHOD

Cow No.	Total Body Fluid Volume (liters)
84	415
88	407
94	405
98	371
142	439
175	417

9. DATA REDUCTION AND DEPOSITION VELOCITY CALCULATIONS

Measurements of radioiodine activity in the grass, urine, feces, milk, and blood samples were reduced to units of activity per unit mass or volume and corrected for radioactive decay using CEDAR, a FORTRAN-63 computer program written for the CERT project. This program greatly reduces the burden of routine calculations and provides a simplified, convenient means of storing data. Deposition velocities were calculated using the following relationship:

$$V_d(\text{m/sec}) = \frac{\text{total deposition } (\text{Ci/m}^2)}{\text{time-integrated air concentration } (\frac{\text{Ci-sec}}{\text{m}^3})} \qquad (1)$$

in which the total deposition was measured on grass cut at 5 cm above ground level and the time-integrated air concentration was measured at one meter above ground level.

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III. RESULTS AND DISCUSSION

1. GENERAL INFORMATION

A summary of data obtained from the 1967 CERT field studies appears in Table VIII.

2. METEOROLOGICAL STUDIES ON DEPOSITION

The deposition velocities for CERTs 20 and 22 are given in Table VIII. Median rather than mean values of deposition velocity are shown because the distribution of V_d measurements was found to be log-normal [at the $\alpha = 0.05$ level by chi-squared tests on the (log V_d) distribution].

The two median values of V_d measured in CERT 22 agree to within 20%, which indicates good precision in their measurement. The wind velocity, temperature, and turbulence data gathered during CERTs 20 and 22 are shown in Table IX.

2.1 Existing Models of Deposition

The major variables involved in the transfer of suspended material from air to vegetation are (a) turbulent transfer through the lowest layer of the atmosphere above the vegetation canopy, (b) surface sublayer transfer within and slightly above the vegetation canopy, and (c) the biological, chemical, and physical receptiveness of the vegetation itself. With these factors as a basis, two models have been developed for predicting deposition.

The first model to be developed was the flux-gradient model suggested by Sheppard[24] and based on Equation (2).

$$K \frac{\partial \chi}{\partial z} = V_{d_o} \chi_o \text{ (= deposition rate)} \tag{2}$$

in which

K is the eddy diffusivity (L^2/T)

$\frac{\partial \chi}{\partial z}$ is the vertical air concentration gradient (units/L^4)

V_{d_o} is the deposition velocity at the interface (L/T)

χ_o is the air concentration at the interface (units/L^3).

Two additional relationships are

$$V_{d_o}\chi_o = V_d(z)\,\chi(z) \tag{3}$$

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TABLE VIII

SUMMARY OF 1967 CERT FIELD DATA

CERT Test No.	Objectives	Date	Release Time Interval	Quantity $^{131}I_2$ Released (Ci)	General Meteorological Conditions	Median V_d (cm/sec)	Average Grass Density (dry g/m^2)	$^{131}I_2$ Effective Half-Life on Grass (days)	Ratio Milk Concentration ^{131}I to daily ^{131}I Intake (%/l)
20	(1) To test linear relationship between u_* and V_d at high wind speeds (2) To study grass-to-milk link of food chain (3) To study vertical distribution of radioiodine deposited on grass	7/6/67	1401 - 1431	0.90	unstable (Pasquill Class C)	2.1	149 ± 58[a]	5.0	0.8
21	(1) To study the transport kinetics of radioiodine in the cow under constant input conditions	8/9/67	N/A	N/A	N/A	N/A	N/A	N/A	0.3
22	(1) To test linear relationship between u_* and V_d at high wind speeds (2) To determine the precision of field measurements of V_d by carrying out simultaneous releases of molecular iodine over two grids on which experimental conditions are matched as closely as possible	9/22/67	1415 - 1445	0.52 on each of two grids	unstable (Pasquill Class B)	2.4 2.0	270 ± 49[a] 304 ± 43[a]	5.0	dairy cows not used

[a] The uncertainty given is one sample standard deviation.

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TABLE IX

METEOROLOGICAL DATA FOR CERTs 20 and 22

CERT No.	Deposition Area Speeds on Mast (m/sec) 0.17 m	0.5 m	1 m	2 m	3 m	4 m	Direction	ARLFRO Tower Test Grid 3 Speeds (m/sec) 4 m	16 m	61 m
20	4.1[b]	5.3	6.6	7.7	-	8.5	230[a]	6.8	9.2	10.4
22	3.7	4.7	6.3	7.4	-	8.3	215[c]	7.6	9.7	11.3

CERT No.	$\left[\overline{\theta'^2}\right]^{1/2}$ (degrees) 4 m	16 m	61 m	$\left[\overline{\phi'^2}\right]^{1/2}$ (degrees) 4 m	16 m	61 m	$\left[\overline{u'^2}\right]^{1/2}$ (m/sec) 4 m	16 m	61 m
22	14.4	-	-	5.0	-	-	3.6	-	-

CERT No.	Temperatures (°C) on Mast at Deposition Area 0.5 m	1 m	2 m	Relative Humidity (%) at CFA 2 meters
20	25.7	25.4	25.3	23
22	26.8	26.4	26.2	13

Temperatures (°C) on ARLFRO Tower Test Grid 3

CERT No.	1 m	2 m	4 m	8 m	32 m	61 m
20	26.1	26.0	25.9	-	26.6	26.8
22	28.6	28.4	27.9	26.7	26.4	25.9

CERT No.	U_* (m/sec)[d]	Pasquill Stability Class
20	0.82	C
22	0.76	B

[a] Measurement made at 4-meter level.

[b] Measurement made at grass top 0.3 meters.

[c] Measured at 61 meters.

[d] Friction Velocity derived from the logarithmic velocity profile obtained in the deposition area.

and

$$K = k\, u_* z + D \tag{4}$$

in which

D is the molecular diffusivity of the effluent material (L^2/T)

k is von Karman's constant (dimensionless)

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u_* is the friction velocity (L/T)

z is the height above the interface (L).

Substituting Equations (3) and (4) into Equation (2), integrating, and solving for V_d at $z > 0$ and $D << ku_*z$, we obtain Equation (5).

$$V_d(z) = \frac{ku_*}{\ln(ku_*z/D)} \left[1 - \frac{\chi_o}{\chi(z)} \right] \tag{5}$$

The portion of Equation (5) in brackets equals one for a perfect sink material because theoretically $\chi_o = 0$ for this case.

The assumptions made in this formulation are:

(1) Momentum flux equals mass flux in the atmospheric boundary layer

(2) Molecular diffusion becomes the controlling factor for transfer close to the surface, i.e., in the surface sublayer

(3) The deposition velocity is proportional to the relative sink capacity of the surface.

The second approach as presented by Chamberlain[5] utilizes the three stages of transfer from air to natural surfaces in an electrical resistance analogy. This analogy is depicted in Figure 8 and is represented mathematically by Equation (6),

$$\frac{1}{V_d(z)} = R_T(z) = R_{BL}(z) + R_{SS} + R_S \tag{6}$$

in which

$R_T(z)$ is the total resistance at the reference height z

$R_{BL}(z)$ is the atmospheric boundary layer resistance at the reference height z

R_{SS} is the surface sublayer resistance

R_S is the biological, chemical, and physical resistance at the surface of deposition.

The atmospheric boundary layer resistance, $R_{BL}(z)$ is taken to be the momentum transfer resistance, or

$$R_{BL}(z) = \frac{\rho\bar{u}(z)}{\tau} = \frac{\bar{u}(z)}{u_*^2} \tag{7}$$

where ρ is the density of air, τ is the stress, and $\bar{u}(z)$ is the mean wind speed at height z.

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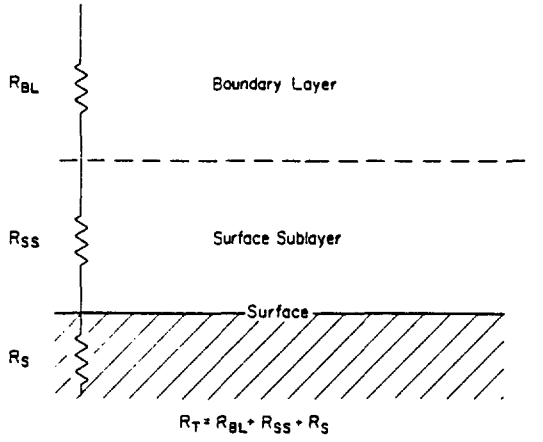

Fig. 8 Electrical resistance analogue to deposition.

The surface sublayer resistance formula, Equation (8), was derived by Owen and Thomson [25] from wind tunnel work on heat transfer to bluff-type roughness surfaces.

$$R_{SS} = (u_* B)^{-1} = \frac{\alpha \, Re^m Pr^n}{u_*} = \frac{\alpha}{u_*} \left(\frac{u_* z_o}{\nu} \right)^m \left(\frac{\nu}{D} \right)^n \tag{8}$$

in which

Re is the Reynolds number $\left(= \frac{u_* z_o}{\nu} \right)$

Pr is the Prandlt number $\left(= \frac{\nu}{D} \right)$

ν is the kinematic viscosity of air

z_o is the roughness length which characterizes the surface

D is the molecular diffusivity of the substance

α is a function of the surface roughness

m,n are constants.

Owen and Thomson determined m and n empirically and found values of 0.45 and 0.8, respectively. The parameter α was determined by Chamberlain[4] from experimental data and was found to be about 0.08 for short grass.

The interface resistance, R_S, has not been evaluated for partial sink grass (fibrous type) surfaces.

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2.2 Experimental Data Compared to Model Predictions

The models described in the previous section can be tested for applicability to the environment by comparing their predicted deposition velocities with those measured in CERT field studies. These comparisons are not completely straightforward; the models were developed for gaseous elemental iodine whereas the CERT field data indicate that a significant fraction of the radioiodine may be attached to particles. (For example, in CERT 20 the average ratio of the activity of the charcoal filter to that on the particulate prefilter was 2.2 with a range of 1.9 to 2.6; for CERT 22 the average ratio was 2.0 with a range of 1.6 to 2.8.) The experimentally measured deposition velocities of radioiodine onto carbon plates (a biologically inert bluff-type surface) were compared with those predicted by Sheppard's flux-gradient model equation [see Equation (5)] without the bracketed portion. The molecular diffusivity of gaseous $^{131}I_2$ was assumed to be 0.08 cm^2/sec. The results are shown in Figure 9. The line of best fit is V_d(carbon) = 0.278 V_d (Sheppard), and there is significant correlation (at the 0.01 level) between these two parameters.

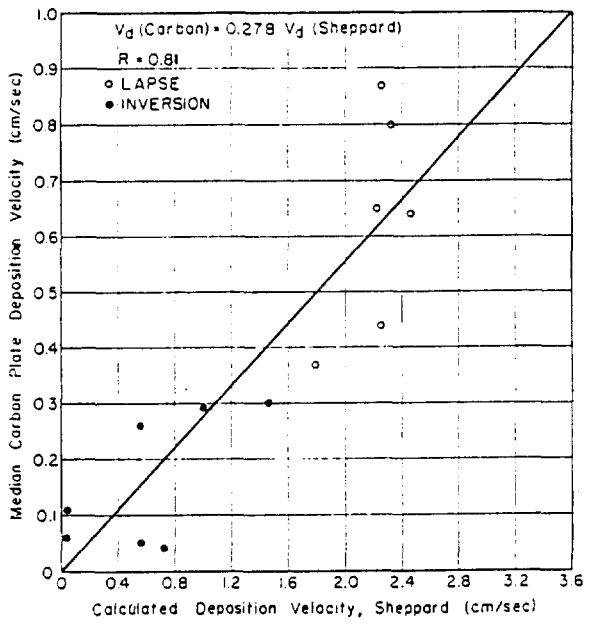

Fig. 9 Relationship between median carbon plate deposition velocities and Sheppard model calculations.

The resistance analogy model was also tested using the measured carbon plate deposition velocities. The boundary layer resistance, $\bar{u}/u_*^2$, was subtracted from the reciprocal of the measured deposition velocity for each test, and the difference was plotted against the surface sublayer resistance as defined by Owen and Thomson without the correction for surface roughness (Figure 10). The line of best fit by the statistical logarithmic least squares method (significant at the 0.01 level) had a slope of near one. The value of $\alpha = 3$ obtained from the curve is in good agreement with the values found by Owen and Thomson for surfaces of similar character. The Reynold's numbers during inversion conditions were usually below those required for fully rough flow, but this did not seem to affect the results. A significant correlation (at the 0.01 level) between calculated and observed V_d was found and the comparison is shown graphically in Figure 11.

For grass deposition, the testing of models is not as straightforward as for carbon plate deposition because grass is semirigid fibrous-type surface, which is quite different from the bluff-type surface for which the models were developed. Also, grass depositions velocities were found to be significantly correlated with grass density (see Section III-2). Because of this relationship each measurement of V_d in each of the CERT tests through CY 1967 was normalized by dividing by grass density, and the medians of these normalized values were used to represent the tests. The normalized V_d values were plotted against the boundary layer transfer velocity, $u_*^2/\bar{u}$, (Figure 12) and against average wind velocity, $\bar{u}$, (Figure 13) and were found to be correlated with both velocities (at the 0.01 level). It is interesting to note that the two cases

with the highest normalized deposition velocities occurred during inversion conditions. The wind speed profiles during these two cases indicated a stagnant layer to a depth of 0.4 meters, and gradients of wind velocity above this layer were indicative of typical inversion profiles. For this reason, these two normalized deposition velocities were not included in the correlation analysis shown in Figure 13.

Since a significant linear relationship was found between normalized V_d and boundary layer transfer velocity, conformance to the boundary layer resistance model was tested. First, to achieve dimensional consistency, reciprocals of the normalized grass V_d values for each test were divided by the average grass density for all field tests and the boundary layer resistance values were subtracted from the reciprocals of the normalized V_d values. These differences were then compared with the surface sublayer resistances (Figure 14). With the two anomalous inversion values eliminated from the graph, the line of best fit (significant correlation at the 0.01 level) yielded a value of $\alpha = 1.8$, which is an order of magnitude higher than the findings of other investigators. It was also found that there was no significant improvement in the prediction when the surface sublayer resistance was added to the boundary layer resistance.

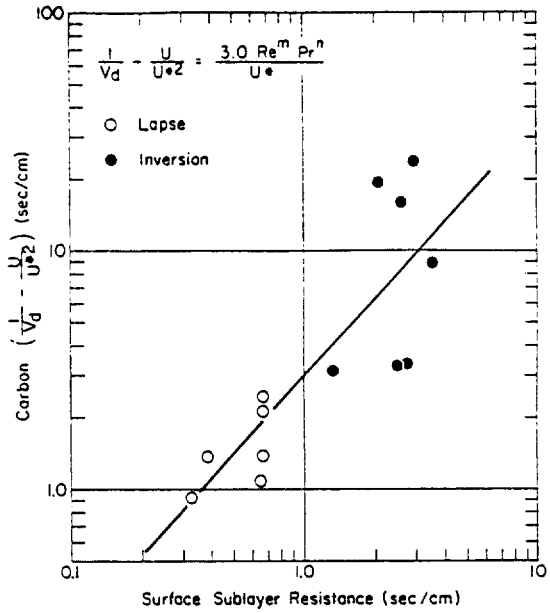

Fig. 10 Relationship between measured and calculated surface sublayer resistance for carbon plates.

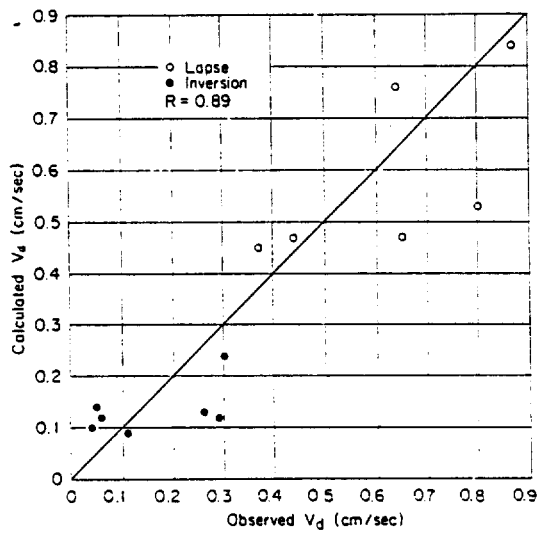

Fig. 11 Comparison between observed carbon plate V_d and V_d calculated from resistance analogy model.

The average ratios of momentum transfer derived from the wind profile to mass transfer determined from the concentration profile were found to be 0.9 in stable and 1.4 in unstable conditions. These averages are significantly different ($\alpha = 0.05$).

The total amount of radioiodine deposited on the pasture was calculated for six of the CERT releases for which there was sufficient field data. The results are shown in Table X as a percentage of the total amount released. The ranges of distances downwind between which these total deposition values were measured, the stability, the measured deposition velocity, and friction velocity are also shown for each test.

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The data demonstrate two important aspects of the turbulent transfer of gaseous radioiodine effluents from air to a natural surface (i.e., grass).

(1) Because good results were obtained via the Chamberlain resistance analogy model for carbon plate deposition velocities, and because the boundary layer transfer velocity, $u_*^2/\bar{u}$, showed a good empirical relationship to normalized grass deposition velocities, the boundary layer transfer term in Equation (6) appears to be adequate. However, this term would be more theoretically correct if it included changes in the concentration profile due to the nonperfect sink characteristics of the grass. Therefore, a need exists for the determination of fractional retention factors for radioiodine on grass.

(2) The two models tested were found to be inadequate for the region very close to a grass surface. The necessity of normalizing grass deposition velocities for grass density demonstrated the need for some measure of total effective surface area instead of plane area available for deposition on fibrous surfaces. Also, the scavenging of material by the grass blades is volumetric rather than planar and therefore may depend on the residence time of the material in the grass. This indicates the need for more research on the microturbulence structure within a grass canopy before a fundamentally sound model of the surface sublayer can be formulated.

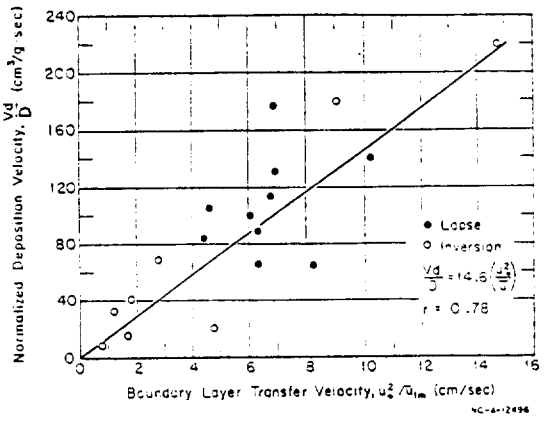

Fig. 12 Relationship between normalized depositions velocity and boundary layer transfer velocity.

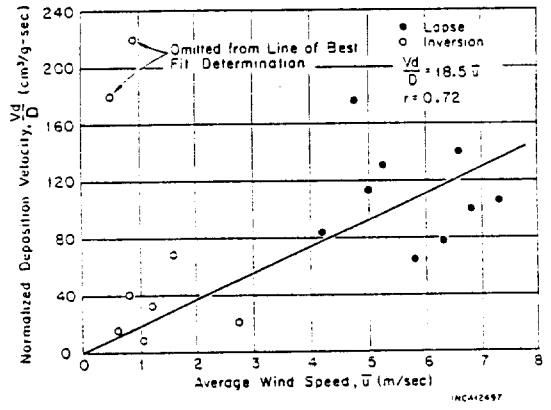

Fig. 13 Normalized deposition velocity as a function of average wind speed.

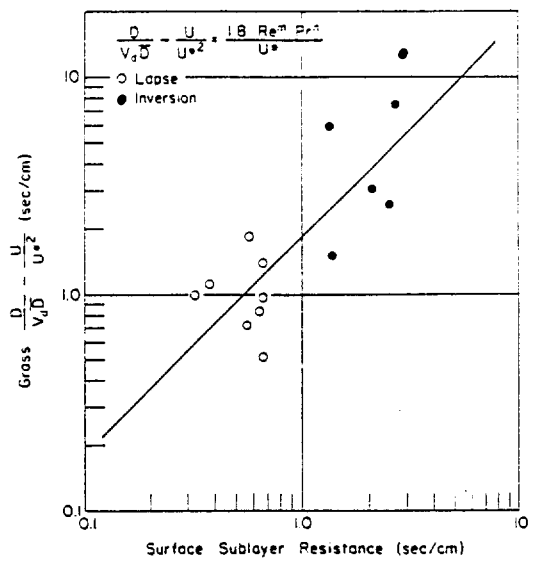

Fig. 14 Relationship between measured and calculated surface sublayer resistance for grass.

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TABLE X

SUMMARY OF CERT PASTURE DEPOSITION DATA

CERT Test No.	% of Total ^{131}I Released Deposited on Pasture	Distance Range (m)	V_d (cm/sec)	u_*(m/sec)	Stability
1	1.1	100-300	0.7	0.6	Unstable
2	1.1	100-300	0.6	0.6	Unstable
4	0.7	50-100	0.2	0.1	Stable
5	1.3	50-300	0.1	0.4	Stable
7	3.0	100-380	1.0	0.4	Unstable
19	1.0	100-380	1.2	0.6	Unstable

3. GRASS STUDIES

3.1 Deposition

The processes affecting the deposition of radioiodine on vegetation are not well understood. Until they are well understood, CERT results cannot be extrapolated safely to other locations or to other times.

There have been 21 field experiments in which deposition was measured. With few exceptions the median values of V_D and values of $\bar{u}$ have fallen near the curve in Figure 13. One begins to have confidence in a relation which appears to be valid over a wide range of meteorological conditions and over a period of five years. However, without understanding the mechanisms of deposition, one still feels uneasy about extrapolating the relation to other locations and times. The relation between V_d and D was found indirectly from these data when it was noticed that little correlation existed between V_d and $\bar{u}$, but fairly good correlation existed between V_D and $\bar{u}$.

A linear relationship between V_d and D was also found with the individual measurements (from which the median value for the test is derived) from CERT 2[13]. However, values of V_d and D from other CERT tests show little or no correlation.

Even if the data from every CERT test showed a relation between V_d and D, it is only empirical, and it and apparent relation between V_D and u_* are only clues to the processes which go on during deposition.

Another way to observe deposition phenomena is to measure the radioactivity profile of single samples immediately after deposition. The radioactivity and density profiles were measured from samples collected during CERTs 20 and 22. Figure 15 shows the density profiles. Each point represents the average density per inch of grass length of three samples. The average density

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of the samples taken during CERT 22 was less than that for samples collected during CERT 20. Figure 16 shows the profiles of relative deposition for the same two experiments. Each point represents the average deposition per inch of grass divided by the total deposition on the grass. Note that the deposition is more evenly distributed with height for the higher density grass. In both cases however, the grass in the first few inches near the ground showed relatively little radioiodine deposition. Figure 17 shows the relative radioiodine concentration as a function of height for both CERTs 20 and 22. Each point represents the quotient of the point in Figure 16 and the corresponding point in Figure 15. Note that relatively more radioiodine was deposited per gram of grass toward the top than near the ground. This is true for both high and low density grass.

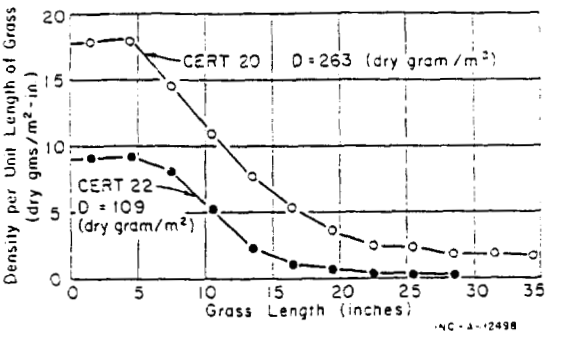

Fig. 15 Average grass density profiles measured during CERTs 20 and 22.

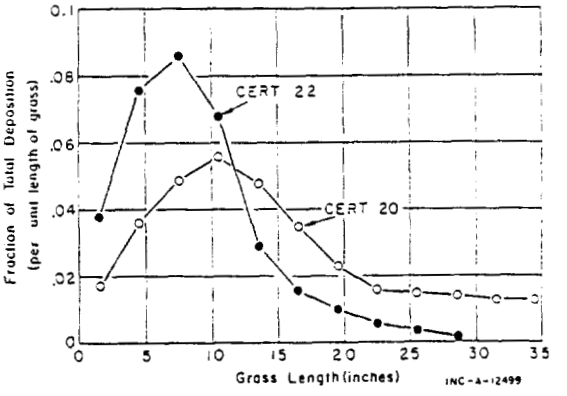

Fig. 16 Average radioiodine deposition profiles measured during CERTs 20 and 22.

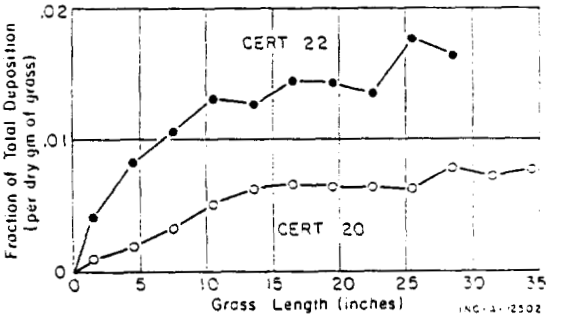

Fig. 17 Radioiodine concentration profiles in grass for CERTs 20 and 22.

There are several possible explanations for the profiles observed in Figures 16 and 17.

(1) The overlying grass filters the radioiodine on its way to the ground, and the radioiodine is not available to deposit on the grass nearer the ground.

(2) The overlying grass offers resistance to the flow of air, thus reducing momentum (and mass) transfer down into the grass.

(3) As the density of grass becomes greater more air space is taken up by the grass, and less radioiodine gets near the grass surface for possible absorption.

(4) The density of stomata on the blades of the pasture grass is known to decrease near the ground. If the stomata are the sites of deposition, this would explain the decrease in deposition near the ground.

A combination of two or more of these processes may be responsible for the observed profiles. At any rate, the the fundamental processes underlying the relationships between V_d and D, and V_D and $\bar{u}$ are linked with those

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causing the observed profiles; and by analyzing fewer samples in more detail than has been our practice, we may at least be nearer to asking the right questions.

3.2 Retention

The effective half-life of radioiodine on grass is defined to be the product of the radioactive and removal half-lives divided by their sum. Effective half-lives of iodine-131 on grass ranging from 3.5 to 6.5 days have been measured in the CERT program. A value of five days was measured during CERT 20. This is equivalent to a removal half-life of 13 days. An effective half-life of five days has been observed so often that there is a tendency to take if for granted. The underlying 13-day removal half-life is almost never questioned. This practice has not led to serious error because of the relatively short half-life of the iodine-131 itself. However, for radionuclides with longer half-lives, the practice is unacceptable. Very little is known about the processes by which a radionuclide is removed from vegetation. The range of removal half-lives associated with the above range of effective half-lives is 6.2 to 34 days -- a range which nicely sums up our unenlightened state regarding removal mechanisms.

In the hazard evaluations known to the authors, the tacit assumption is made that cattle consume a negligible quantity of radionuclide compared with that removed by decay and the type removal referred to above. Theoretically this can lead to a state where the cattle consume (mathematically) more radioactivity than was deposited; i.e., continuity is lost. It can be shown (see Appendix B) that to preserve continuity the following equation must be satisfied:

$$\frac{N}{S} \leq \frac{D_o \lambda_{eff}}{I} \tag{9}$$

in which

N is the number of cattle in the herd

S is the area of the pasture (m^2)

D_o is the grass density during depostion (kg/m^2)

I is the consumption rate of a single cow (kg/day)

λ_{eff} is the effective decay constant ($days^{-1}$).

For iodine-131 λ_{eff} is generally taken as 0.139 $days^{-1}$. Typical values of D_o and I are 0.15 kg/m^2 and 10 kg/day, respectively. These quantities give a value of (N/S) equal to 0.0021 m^{-2} which is equivalent to about 10 cows per acre. One-half to one cow per acre is realistic for most dairy farms, which is much lower than 10 cows per acre, and continuity is not violated. A longer removal and radiological half-life would very likely lead to a substantial overestimate of consumption by the dairy herd.

The depostion experiment of CERT 20 was continued to observe retention phenomena. Three more samples were collected six days after deposition to compare with the three collected immediately after deposition. The samples

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were chosen so that they represented as closely as possible the same grass that was sampled six days earlier. The samples were analyzed in the same manner as the earlier samples.

Figure 18 shows the average distribution of radioactivity with height for the samples collected during CERT 20 under the following conditions: (a) immediately after deposition (observed), (b) six days after deposition (observed and decay corrected to deposition date), and (c) six days after deposition (calculated assuming only translocation due to growth).

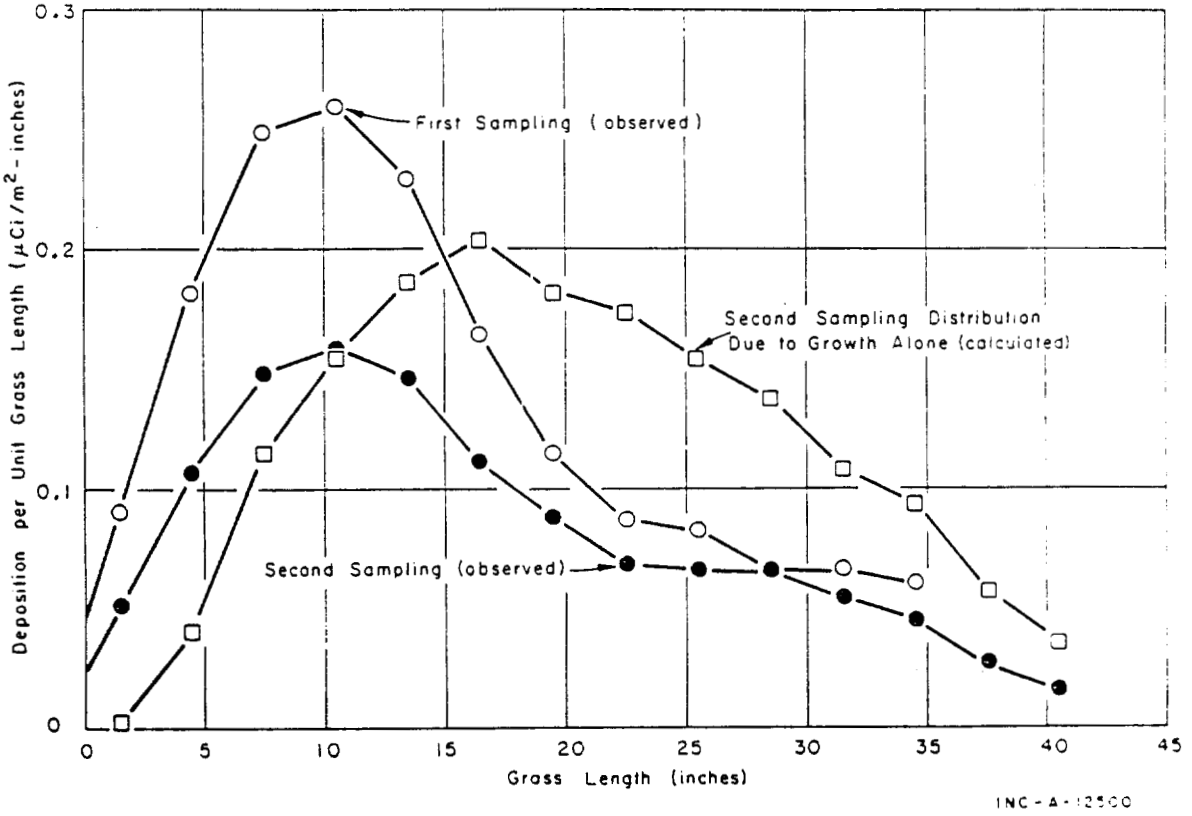

Fig. 18 Comparison of measured and calculated distributions of radioiodine with height.

The distribution due to translocation resulting from growth was calculated by assuming that the grass grew from follicles at ground level. Actually the follicles were located at a height of three to six inches. It was further assumed that the cross-sectional area of the grass blades did not increase with their length. The upward movement of radioactivity was estimated by starting at the grass top and assuming the density in each three-inch increment to be composed, in whole or in part, of the grass (and its associated radioactivity) that was measured previously in the increment immediately below. The area under the distribution curve measured during the first sampling is equal to that under the distribution curve calculated as being from translocation due to growth.

Figure 18 shows that radioiodine was removed from the top two-thirds of the grass. The measured activity in the lowest 10 inches is higher than the calculated activity. This may be due to the assumptions used in the calculations, or it could be real and due to stem-base absorption or adherence of activity

sloughed from greater heights. More observations of this kind in the field and in the laboratory are needed to provide understanding of the fundamental removal processes.

4. DAIRY HERD STUDIES

4.1 Data Obtained During CERTs 20 and 21

The measured quantities of radioiodine ingested and in the thyroid, blood, total body fluid, urine, feces, and milk of each cow as functions of time as well as milk production data are given in Appendix A. Tables A-I to A-VIII contain the data from CERT 20; Tables A-IX to A-XVI contain the data from CERT 21. These data are shown graphically for one of the cows (No. 175) in Figure 19 for CERT 20 and in Figure 20 for CERT 21.

4.2 Milk-to-Grass Ratio

An empirical expression frequently used to quantify the transport of radioiodine from grass to milk is the ratio of ^{131}I concentration in milk to that on grass. Published values range from 0.018 to 0.100[7, 26, 27] and average 0.050. These values are expressed as μCi/l milk to μCi/dry kg grass. From CERT 20 data, we calculate a value of 0.052 which is in good agreement with the published values. Another common expression is the ratio of milk concentration to the total daily radioiodine intake. Values reported in the literature have ranged from 0.5%/l to 1.0%/l[28,29]. In CERT 20 we measured an average value of 0.8% for six cows, and in CERT 21 the average value was 0.3% for three cows. This latter ratio is the more meaningful expression of the two since it relates milk concentration to total ^{131}I intake rather than just intake concentration.

4.3 Mathematical Model of the Kinetics of Radioiodine Transport From Grass to Milk

The data from CERT 20 were used to develop a mathematical model of bovine metabolism of ingested radioiodine. To develop a model which adequately represents the situation in which a pasture is contaminated with radioiodine, we have modified the model proposed by Garner[8] to describe the transfer of fission products to cow's milk. The improved model can be used to predict the quantity of radioiodine which will appear in cow's milk during and subsequent to the period of ingestion of grass from a comtaminated pasture.

The model is shown in Figure 21. The ingested radioiodine enters the rumen compartment, Q_1, from which a portion is taken into the body fluid compartment, Q_3. The portion not taken up is carried out in the feces, Q_2. Portions of the radioiodine activity which enter the body fluid compartment, Q_3, are transferred to: (a) the milk, Q_4, (b) the thyroid, Q_6, (c) the urine, Q_5, and the feces. Radioiodine leaving the thyroid compartment enters one of the two body fluid compartments (Q_3 or Q_7) (the distinction between the two body fluid compartments is discussed below). The activity in compartment Q_7 is excreted in either the feces or the urine. The subscripts of the transfer rate constants indicate the transfer process referred to and the direction of transfer. For example, r_{36} is the rate constant which describes the transfer of radoiodine from Q_3 to Q_6. The differential equations which are the mathematical representation of the model are as follows.

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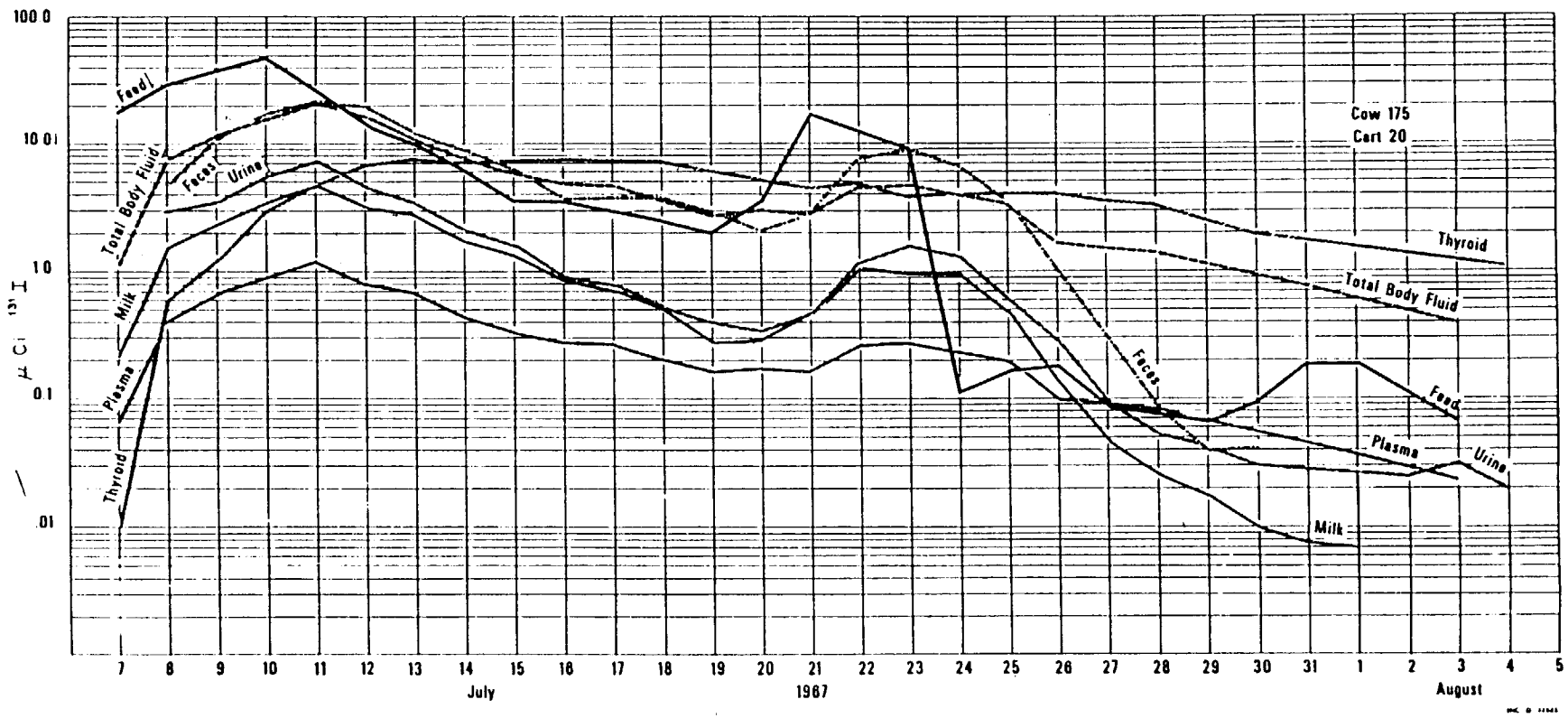

Fig. 19 Measured radioiodine activity -- Cow 175, CERT 20.

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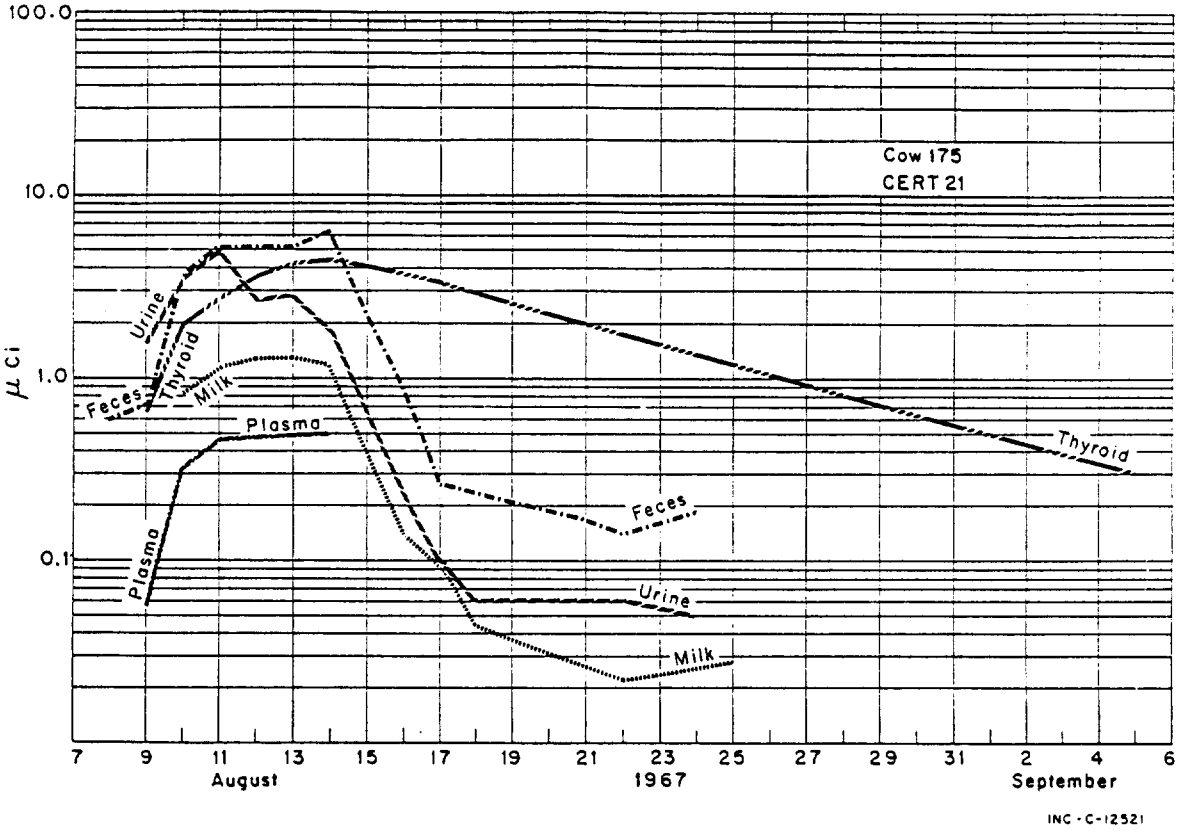

Fig. 20 Measured radioiodine activity -- Cow 175, CERT 21.

$$\frac{dQ_1}{dt} = QIN - (r_{12} + r_{13} + \lambda)Q_1 \tag{10}$$

$$\frac{dQ_2}{dt} = r_{12}\, Q_1 + r_{32}\, Q_3 + r_{72}\, Q_7 \tag{11}$$

$$\frac{dQ_3}{dt} = r_{13}\, Q_1 + r_{63}\, Q_6 - (r_{32} + r_{34} + r_{35} + r_{36} + \lambda)\, Q_3 \tag{12}$$

$$\frac{dQ_4}{dt} = r_{34}\, Q_3 \tag{13}$$

$$\frac{dQ_5}{dt} = r_{35}\, Q_3 + r_{75} Q_7 \tag{14}$$

$$\frac{dQ_6}{dt} = r_{36} Q_3 - (r_{63} + r_{67} + \lambda)Q_6 \tag{15}$$

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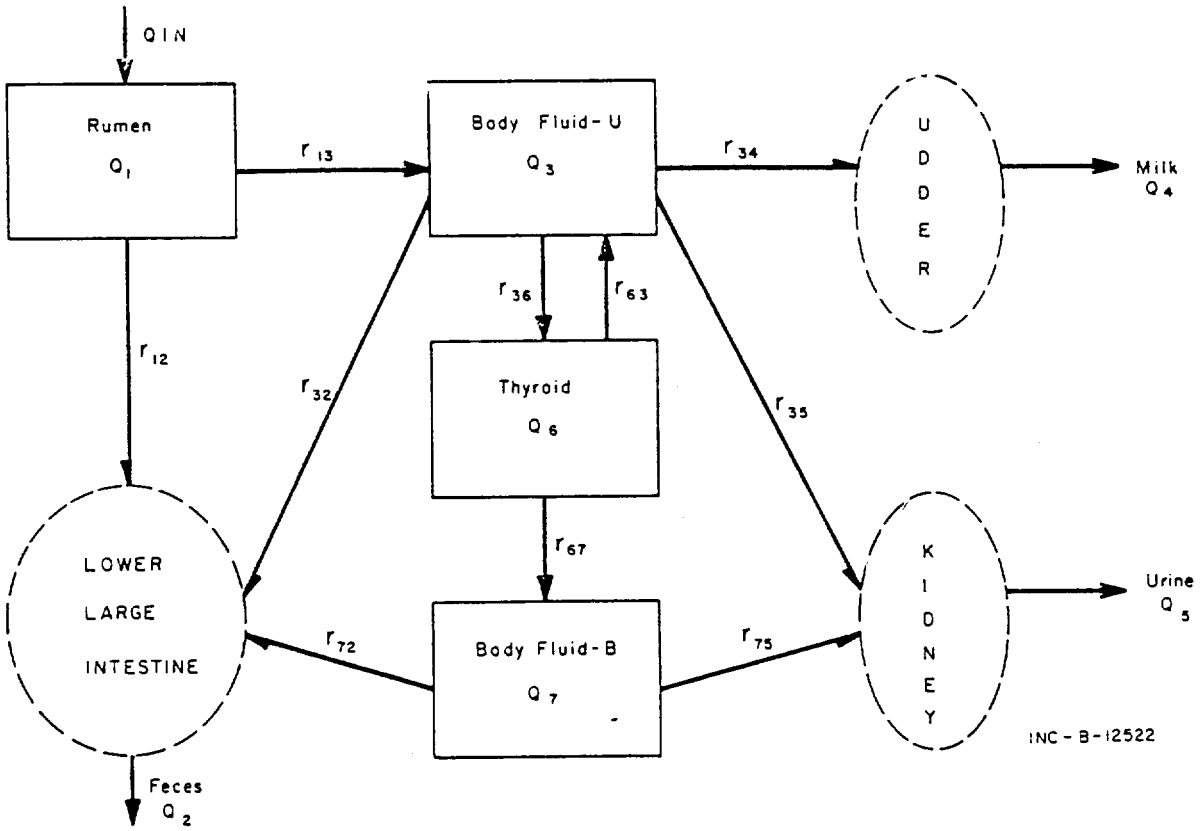

Fig. 21 Model of bovine metabolism of radioiodine.

$$\frac{dQ_7}{dt} = r_{67}Q_6 - (r_{72} + r_{75} + \lambda)\, Q_7 \tag{16}$$

Lambda (λ) represents the radioactive decay constant from iodine-131. The quantities measured directly or calculable from experimental data taken during CERTs 20 and 21 were Q_2, Q_4, Q_5, Q_6, and the sum ($Q_3 + Q_7$).

Two of the important modifications of Garner's model can be seen in Figure 21. The first is the addition of a variable input term QIN. QIN is the product of the concentration of radioiodine in the ingested feed in microcuries per gram (dry weight) and the dry weight of the feed (grams/unit time). The addition of this term significantly broadens the range of applicability of the model since few situations correspond to a single instantaneous ingestion. The second alteration to be noted is the addition of the body fluid compartment, Q_7. This compartment represents the radioiodine in the body fluids which, because of radioiodine's chemical form, is not tranferrable to the milk. It is believed that compartment Q_7 represents the iodine which is bound to protein molecules which are not transferrable from the blood to the milk [30]. The CERT 20 data provide evidence that an adequate model of bovine radioiodine metabolism must include such a compartment. Figure 19 shows that the quantity of radioiodine secreted in milk is not proportional to the quantity of radioiodine in the total body fluid.

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The third major modification of the model involves the transfer rate described by r_{34}. If r_{34} were actually constant, the morning milk would contain nearly twice as much iodine as the evening milk (since Q_3 does not change drastically over a 24-hour period). The CERT 20 data on radioiodine in milk (Table A-III) shows that this is not the case. Further, the milk output data (Table A-II) show that the cows produced, on the average, only 21% more milk in the morning than in the evening. The milk production rate and the transfer rate r_{34} must decrease with time after feeding. The time dependence of r_{34} may be expressed by Equation (17).

$$r_{34}(t) = R \cdot f(t) \tag{17}$$

in which

R is a constant ($days^{-1}$) which represents the maximum value of the transfer rate r_{34}, i.e., the value of r_{34} at $t = 0$

f(t) is a function of time since feeding, t, which has its maximum value at $t = 0$.

The function f(t) which best describes the real situation is not known. A single parameter function which may be adequate is $f(t) = \bar{e}^{\lambda * t}$, in which $\lambda*$ is a constant ($days^{-1}$) which describes the rate of decrease of the transfer rate with time after feeding.

The value of the single parameter in the function f(t) can be determined by applying the condition that the quantity of radioiodine in the milk for a given milking be proportional to the average milk output for that milking. This condition can be expressed mathematically by Equation (18).

$$\frac{(Q_4)_{am}}{(Q_4)_{pm}} = \frac{\dot{\bar{O}}_{am}}{\bar{O}_{pm}} \tag{18}$$

in which $(Q_4)_{am}$ and $(Q_4)_{pm}$ are the radioiodine outputs in the morning and evening milk, respectively, and $\bar{O}_{am}$ and $\bar{O}_{pm}$ are the average milk outputs for the morning and evening milkings, respectively. The radioiodine output quantities are given by Equations (19) and (20).

$$(Q_4)_{am} = \int_0^{2/3} R \cdot f(t) \cdot Q_3(t)dt \tag{19}$$

$$(Q_4)_{pm} = \int_0^{1/3} R \cdot f(t) \cdot Q_3(t)dt \quad . \tag{20}$$

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By assuming that $Q_3(t)$ may be approximated by a constant over the period of one day, one can determine the value of one parameter in an expression for f(t) using Equation (21).

$$\frac{\int_0^{2/3} f(t)dt}{\int_0^{1/3} f(t)dt} = \frac{\bar{O}_{am}}{\bar{O}_{pm}} \tag{21}$$

If $f(t) = e^{-\lambda^* t}$ is assumed, Equation (21) becomes

$$\frac{\int_0^{2/3} e^{-\lambda^* t} dt}{\int_0^{1/3} e^{-\lambda^* t} dt} = \frac{\bar{O}_{am}}{\bar{O}_{pm}} \tag{22}$$

and the parameter λ^* is determined from the relation

$$\frac{\bar{O}_{am}}{\bar{O}_{pm}} = \frac{(1 - e^{-\frac{2\lambda^*}{3}})}{(1 - e^{-\frac{\lambda^*}{3}})} = (1 + e^{-\frac{\lambda^*}{3}}) \tag{23}$$

which results from the integration of Equation (22).

An analog computer was used to simulate the metabolic model. Several simplifications were made for efficient operation of the computer.

(1) The model cow was fed and sampled at two set times -- 8 a.m. and 4 p.m. These times are approximations of the actual times of feedings and sampling of the cows.

(2) The rate of intake of radioiodine was assumed to be constant (> 0) during the two-hour periods 8 to 10 a.m. and 4 to 6 p.m. and to be zero at all other times. It was observed during the experiment that the consumption of green chop by the cows was usually complete in about two hours.

(3) To facilitate comparison with the experimental data, the urine, feces, and milk compartments were emptied daily (twice daily for milk) at the time of experimental sampling.

(4) The transfer rate r_{34} was approximated by two effective transfer rates. The transfer rates used were adjusted for the two different length time periods and for milk output.

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$$r_{34}(t) = \begin{cases} \bar{r}_{34} f_1(t) \text{ for the 8 a.m. to 4 p.m. period} \\ \bar{r}_{34} f_2(t) \text{ for the 4 p.m. to 8 a.m. period} \end{cases}$$

where $\bar{r}_{34}$ is the average value of the transfer rate and $f_1(t)$ and $f_2(t)$ are constant functions given by $f_1(t) = 1$ and, from Equation (21)

$$f_2(t) = 0.5 \left[\frac{\bar{0}_{am}}{\bar{0}_{pm}} \right] .$$

The input to the computer consisted of a set of first approximations to the rate constants and the radioiodine input to the cow during the experiment. The computer-predicted quantities of radioiodine in the various compartments were plotted as functions of time and compared with the experimental data. The rate constants were then adjusted in a manner which would reduce the discrepancies between the predictions and the experimental data. The revised rate constants were fed to the computer. This procedure was repeated until a set of best-fit rate constants was found. The fitting procedure used was to obtain a good fit for the body fluid and thyroid compartments first and then to proceed with the final adjustments for all the compartments.

The analogue computer was used to obtain, by the method just described, sets of best-fit rate constants for two cows: Cow 84, the lowest average milk producer, and Cow 175, the cow with the highest average milk production. Figures 22 through 31 show the best-fit comparisons between the experimental data and the predictions of the model for the two cows. Table XI contains the two sets of best-fit transfer rate constants obtained from the computer runs.

The time-averaged value of the transfer rate r_{34} was obtained and is given in Table XI. The time dependence of r_{34} is expressed in Equation (17). The time-average of this transfer rate is

$$\overline{r_{34}} = \overline{R\ f(t)} \quad . \tag{24}$$

Assuming $f(t) = e^{\lambda * t}$, we have that

$$\overline{r_{34}} = \overline{R\ e^{-\lambda^* t}} = R\ \overline{e^{-\lambda^* t}} = R/e \quad . \tag{25}$$

The maximum rate of transfer per liter of milk produced, $R/\bar{0}$, where $\bar{0}$ is the average daily milk output, was calculated for the two cows. Table XII, which summarizes the data related to transfer rate r_{34}, contains these calculated values. It was anticipated that the per-liter transfer rate might be a constant for all cows [29,30,31], but, as can be seen from Table XII, the values differ by almost a factor of two.

The analogue computer was subsequently used to predict the compartmental burdens for a third cow (Cow 94) utilizing the experimental radioiodine input for Cow 94 with (a) the rate constants for the model based on the best-fit comparisons for Cow 84 and (b) the rate constants for the model based on the best-fit comparisons for Cow 175. Figures 32 through 36 show the plots of the

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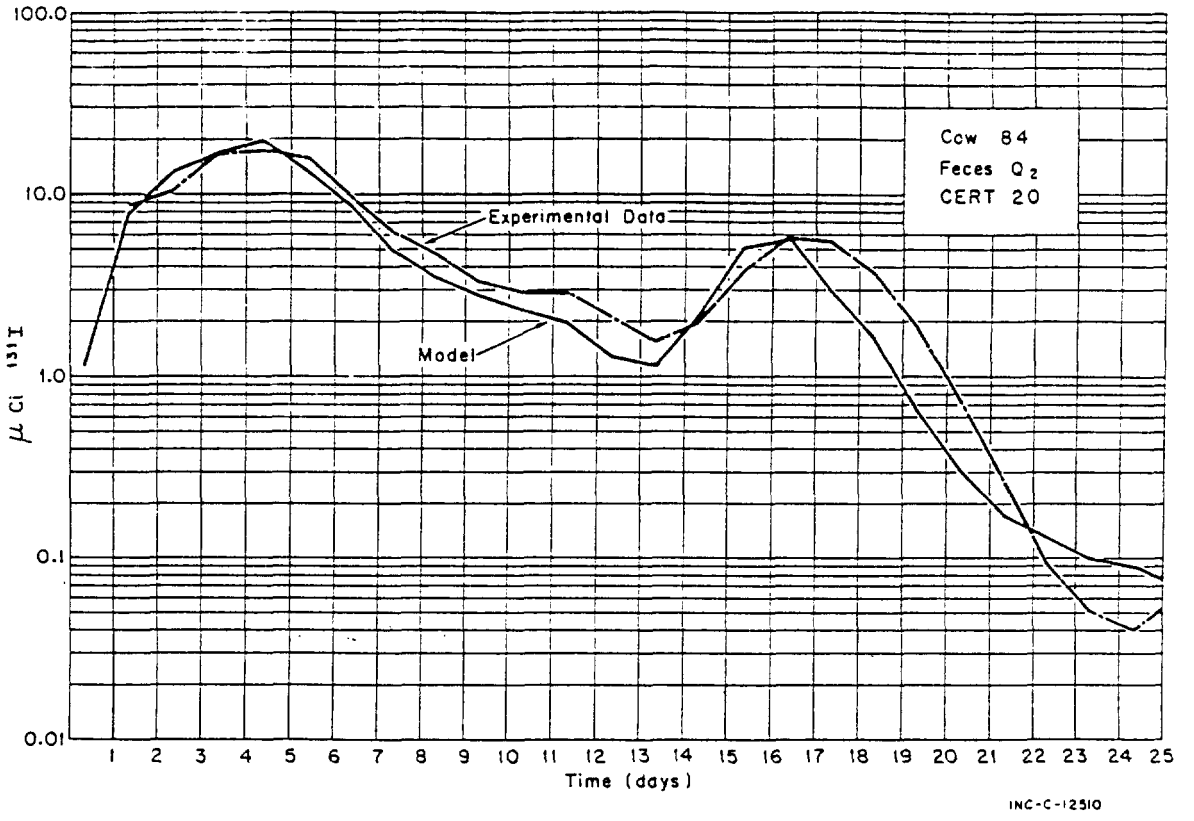

Fig. 22 Best fit of model to fecal radioiodine excretion data -- Cow 84, CERT 20.

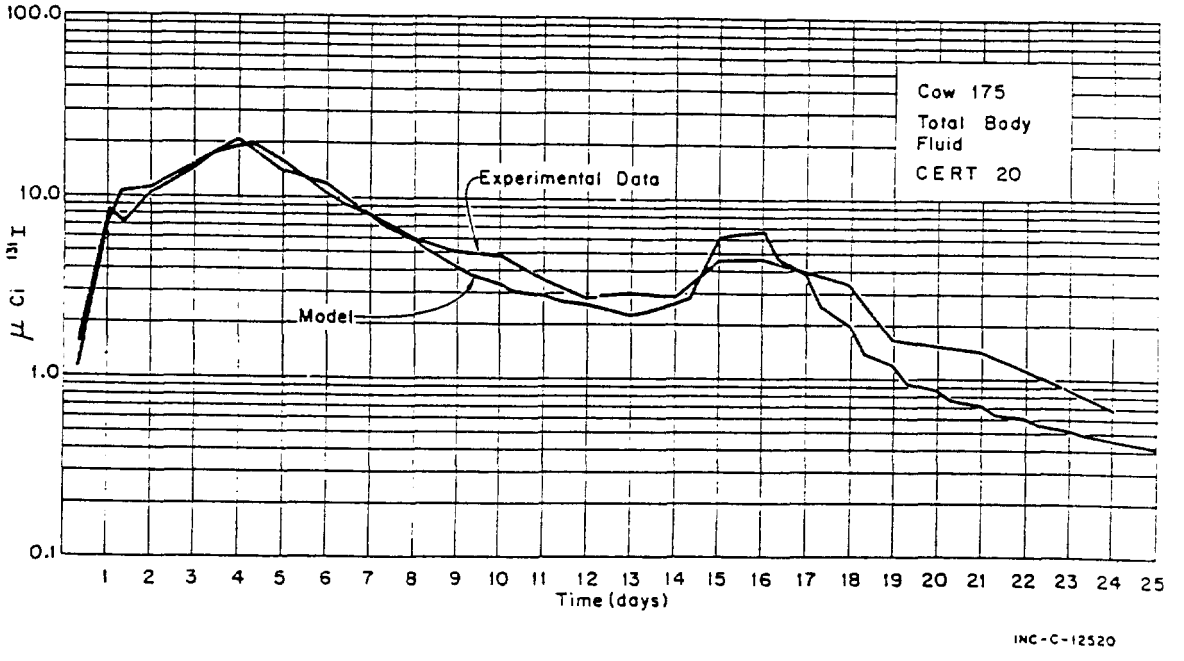

Fig. 23 Best fit of model to data on radioiodine in total body fluid -- Cow 84, CERT 20.

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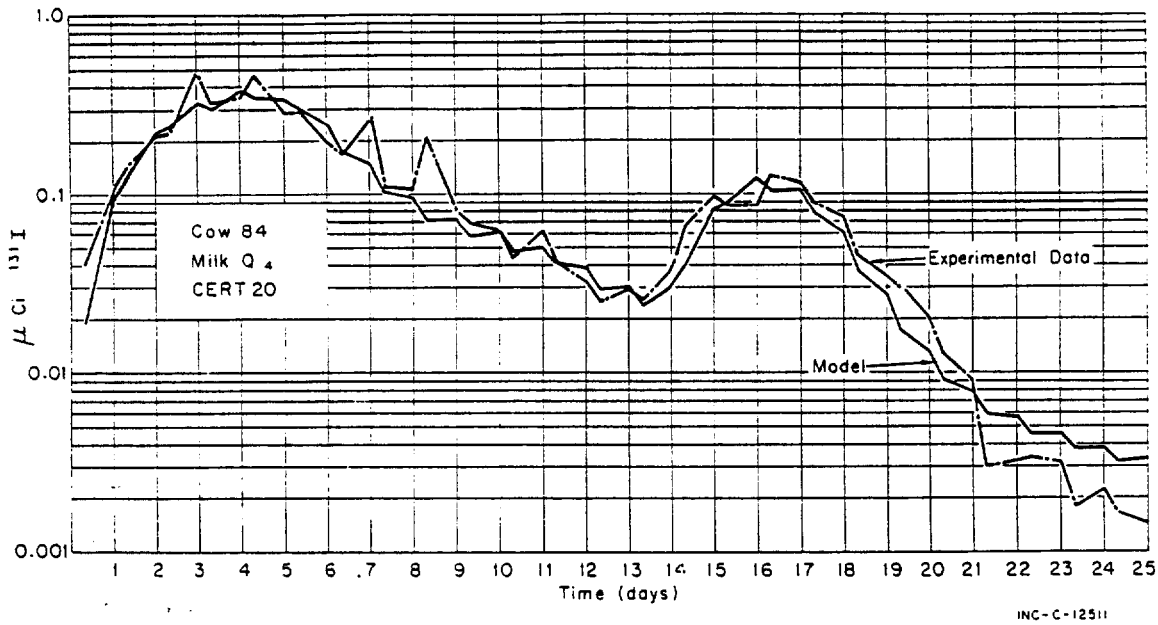

Fig. 24 Best fit of model to data on radioiodine in milk -- Cow 84, CERT 20.

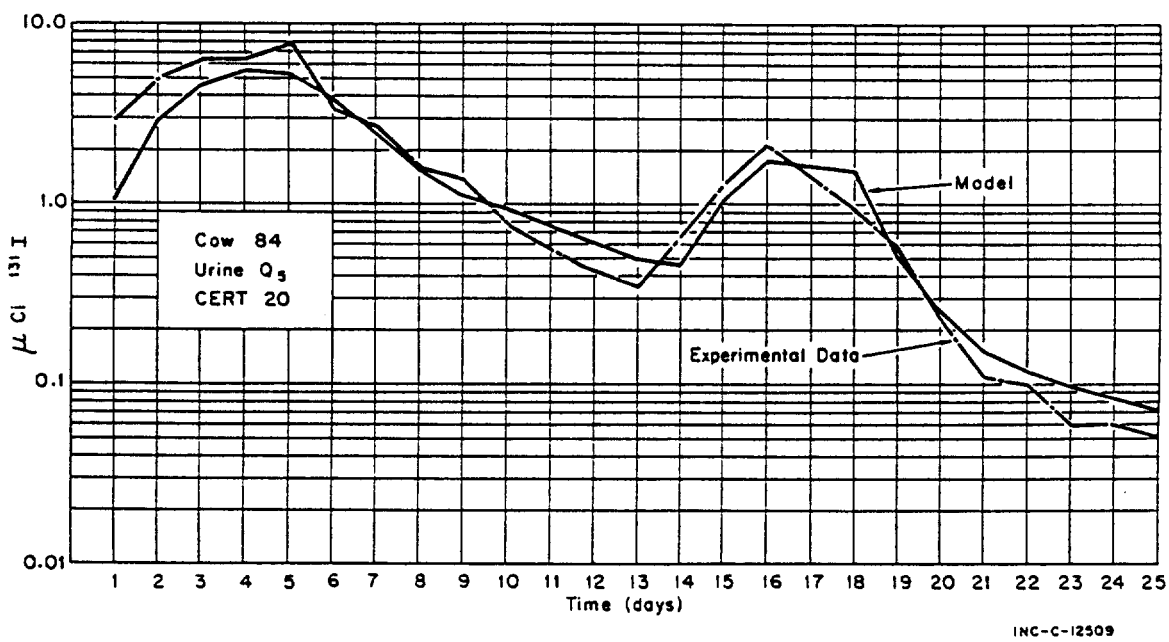

Fig. 25 Best fit of model to data on radioiodine excreted in urine -- Cow 84, CERT 20.

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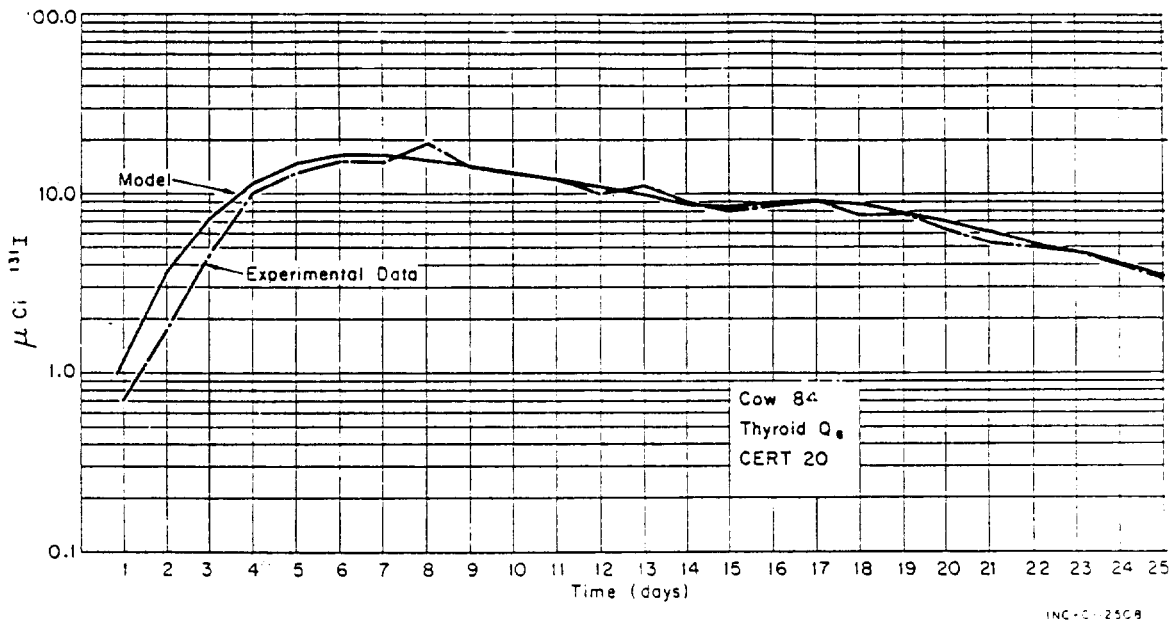

Fig. 26 Best fit of model to data on radioiodine in the thyroid -- Cow 84, CERT 20.

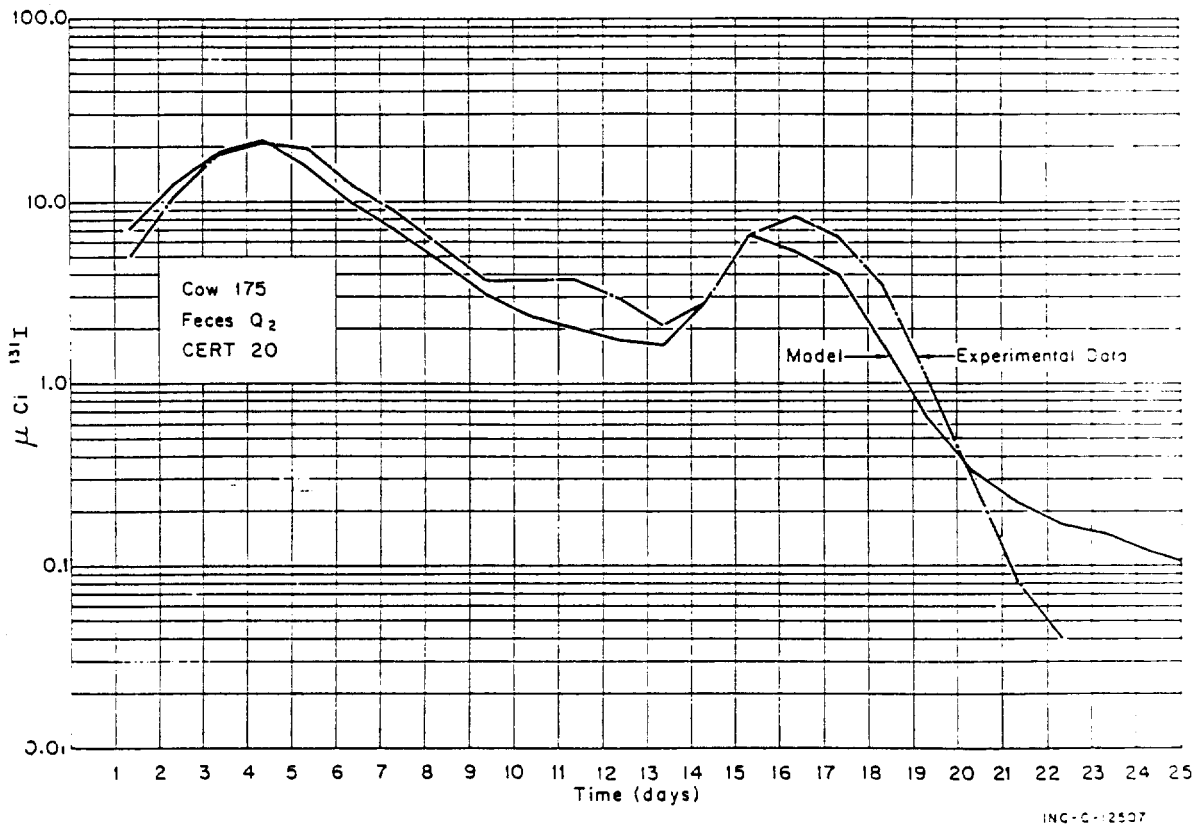

Fig. 27 Best fit of model to fecal radioiodine excretion data -- Cow 175, CERT 20.

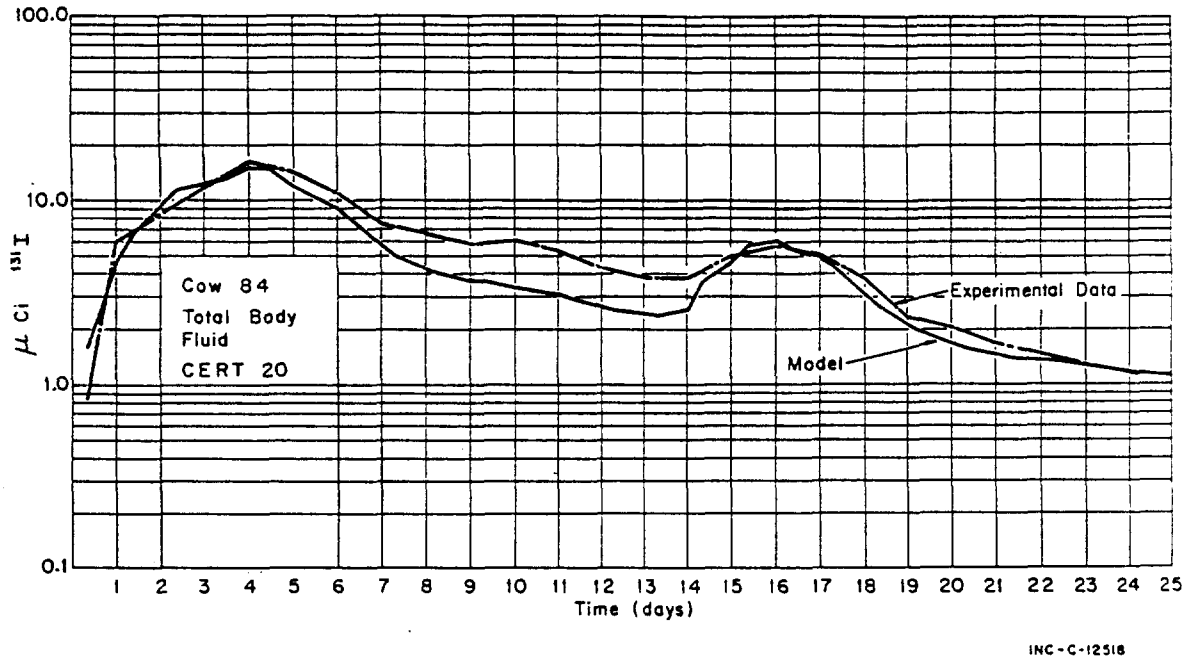

Fig. 28 Best fit of model to data on radioiodine in total body fluid -- Cow 175, CERT 20.

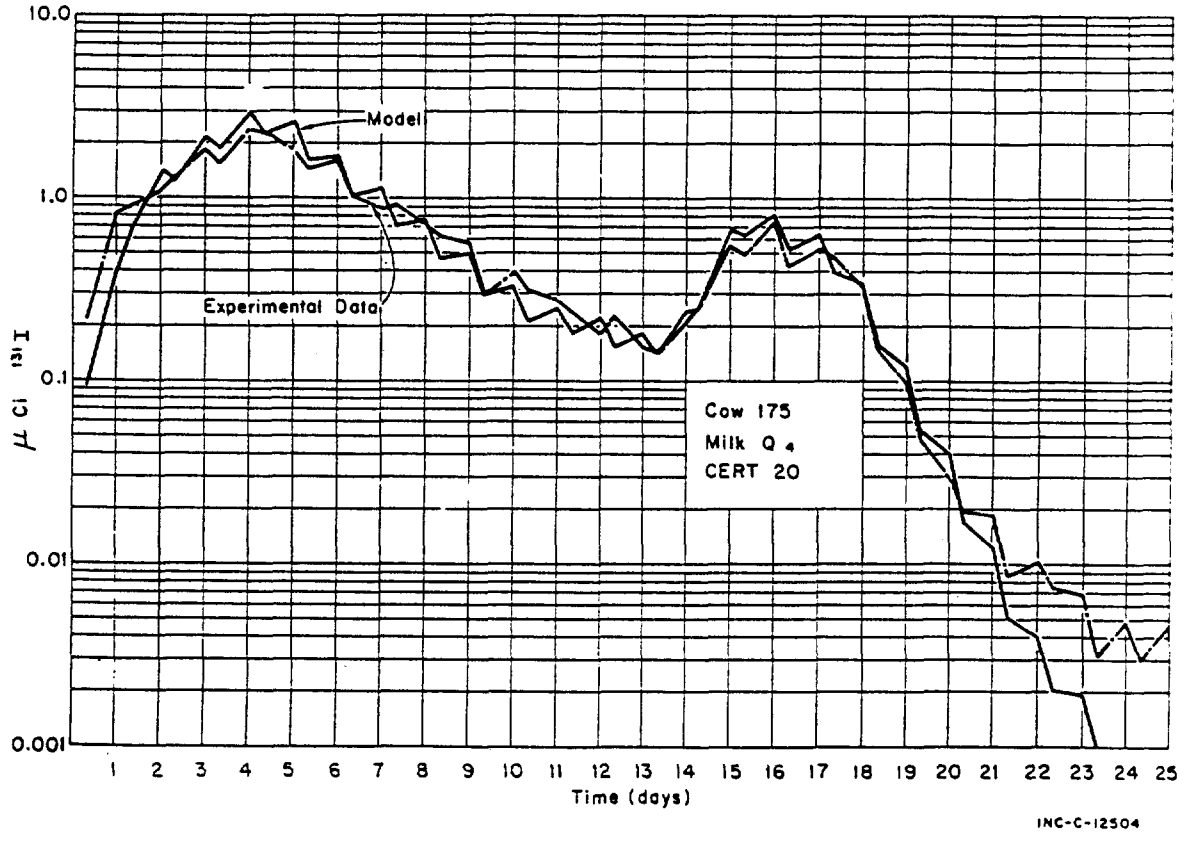

Fig. 29 Best fit of model to data on radioiodine in milk -- Cow 175, CERT 20.

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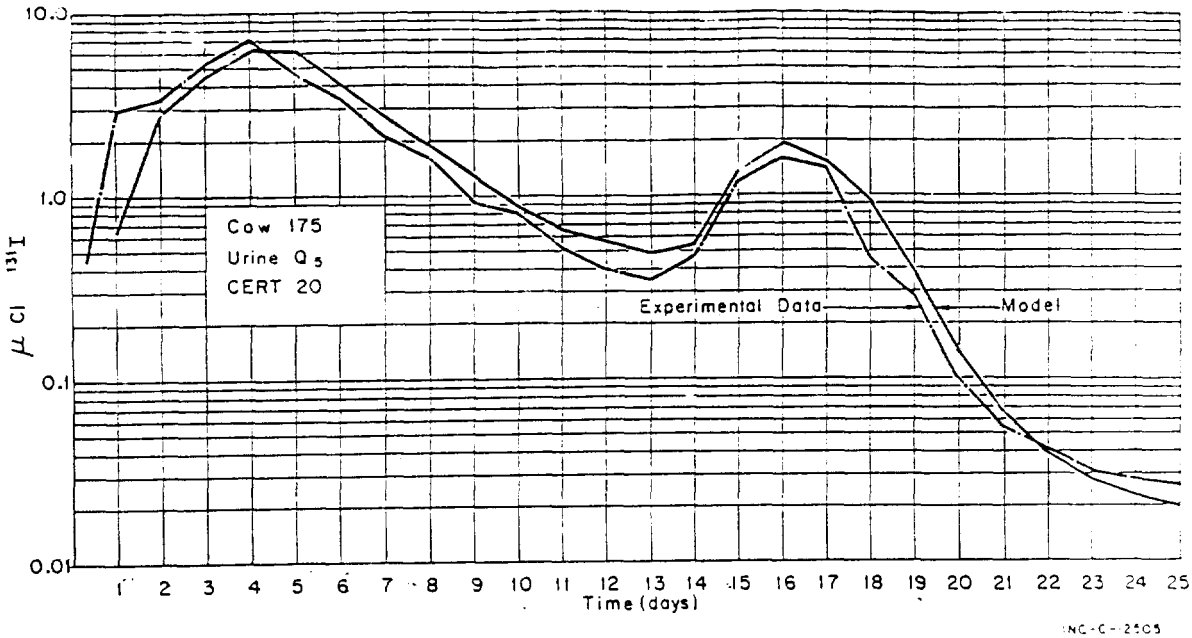

Fig. 30 Best fit of model to data on radioiodine excreted in urine -- Cow 175, CERT 20.

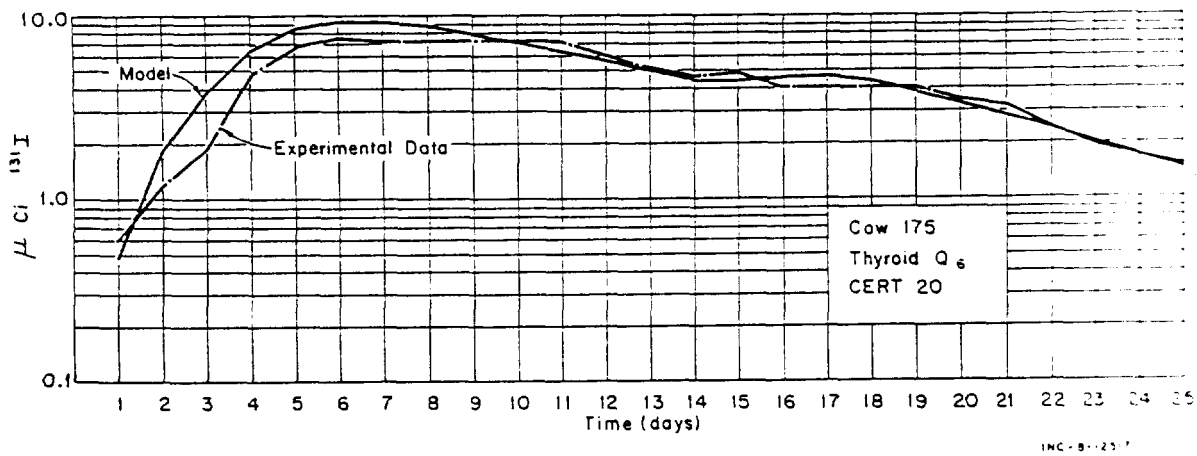

Fig. 31 Best fit of model to data on radioiodine in the thyroid -- Cow 175, CERT 20.

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TABLE XI

EMPIRICALLY DETERMINED RATE CONSTANTS FOR METABOLIC MODEL

Symbolic Representation	Constants for Cow 84 ($days^{-1}$)	Constants for Cow 175 ($days^{-1}$)
r_{12}	0.432	0.432
r_{13}	0.821	1.037
r_{32}	0.518	0.518
r_{34}[a]	0.069	0.346
r_{35}	0.389	0.346
r_{36}	0.380	0.181
r_{63}	0.047	0.086
r_{67}	0.017	0.069
r_{72}	0.015	0.295
r_{75}	0.022	0.043

[a]The tabled value is the time average, $\overline{r_{34}}$ (see Text).

TABLE XII

BODY FLUID-TO-MILK TRANSFER RATE DATA

Cow	$\overline{O}_{am}$ (liters)	$\overline{O}_{pm}$ (liters)	$\frac{\overline{O}_{am}}{\overline{O}_{pm}}$	$f_2(t)$	λ^* ($days^{-1}$)	$\overline{r}_{34}$ ($days^{-1}$)	R ($days^{-1}$)	$R/\overline{O}$ ($liters^{-1}$)
84	3.47	3.17	1.09	0.55	7.20	0.069	0.188	0.0283
175	12.27	9.63	1.27	0.64	3.75	0.346	0.944	0.0429

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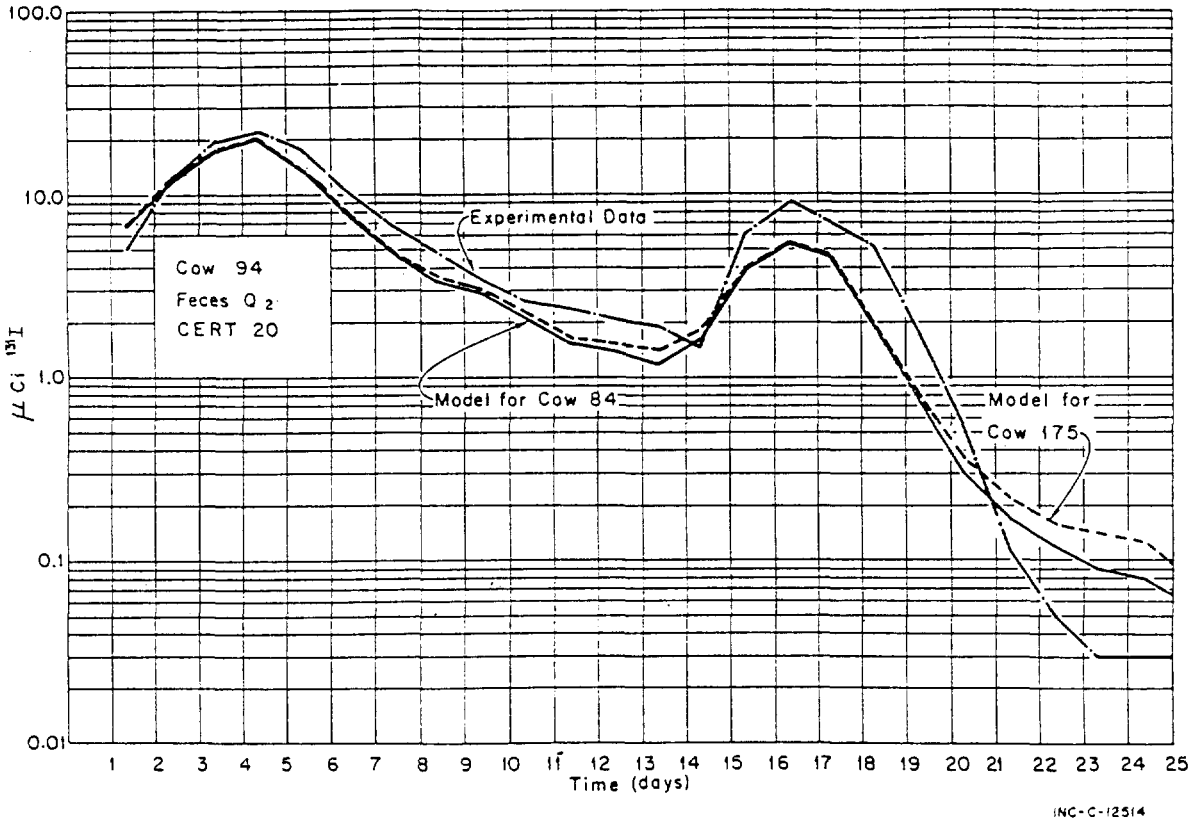

Fig. 32 Comparison of model predictions with fecal radioiodine excretion data for Cow 94, CERT 20.

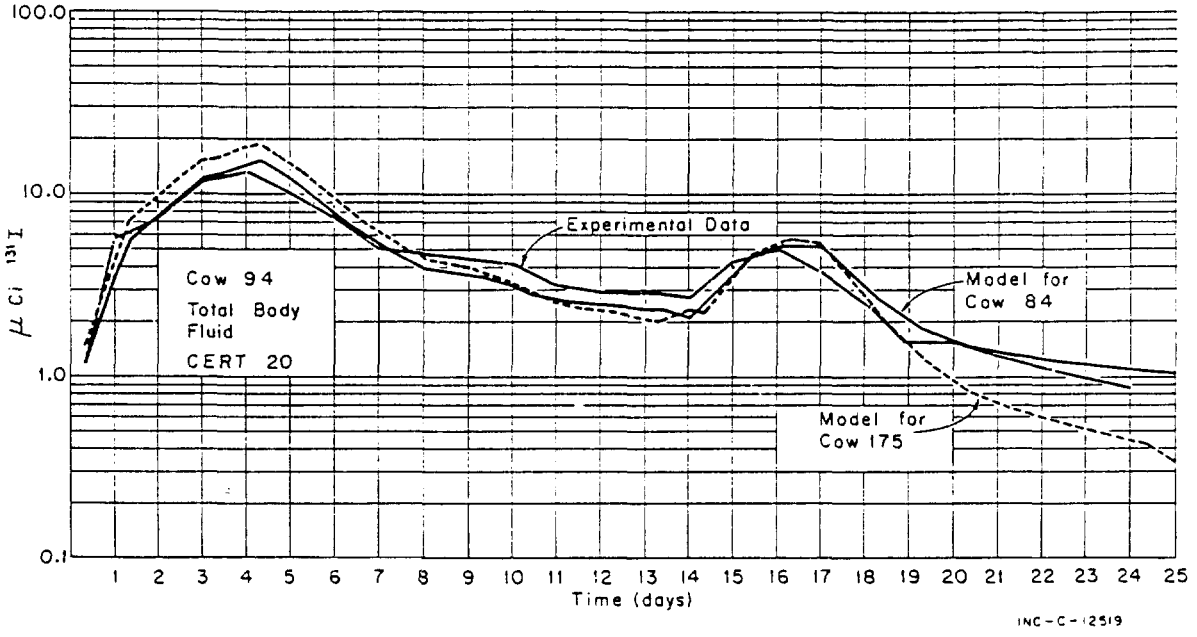

Fig. 33 Comparison of model predictions with data on radioiodine in total body fluid for Cow 94, CERT 20.

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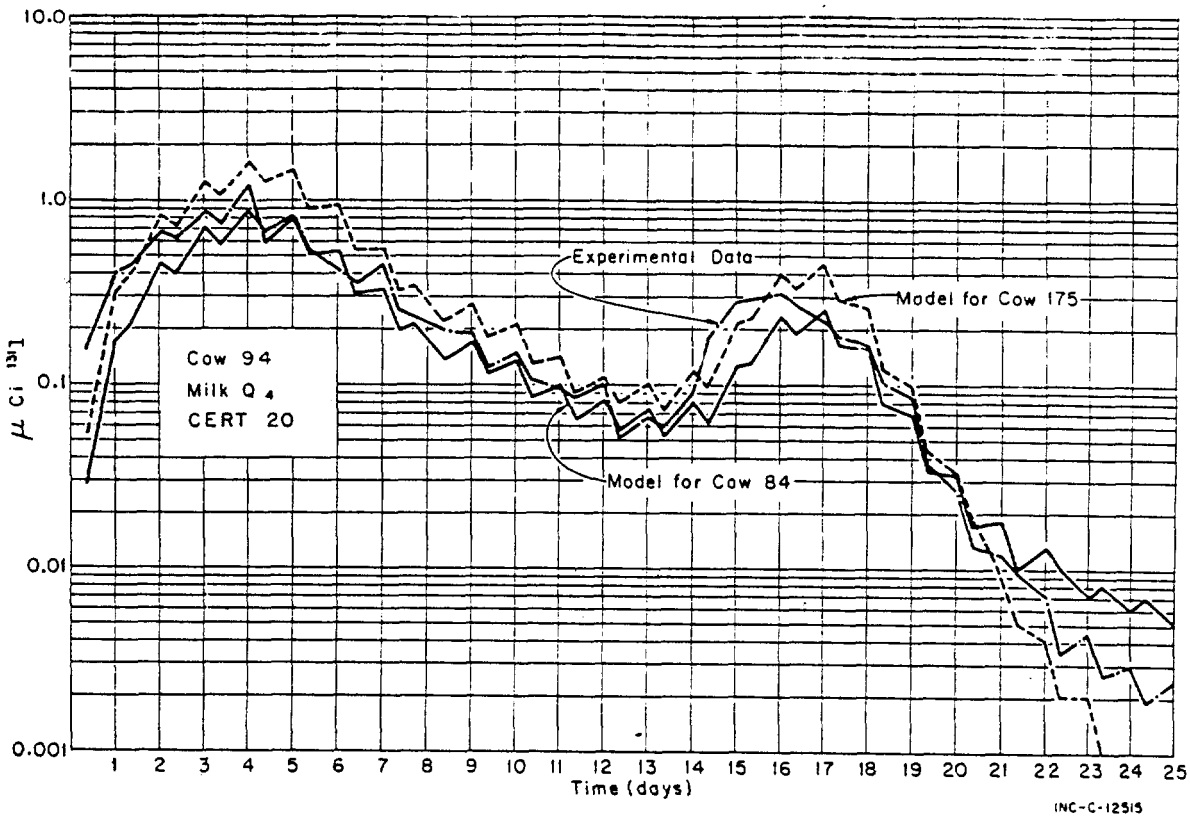

Fig. 34 Comparison of model predictions with data on radioiodine in milk for Cow 94, CERT 20.

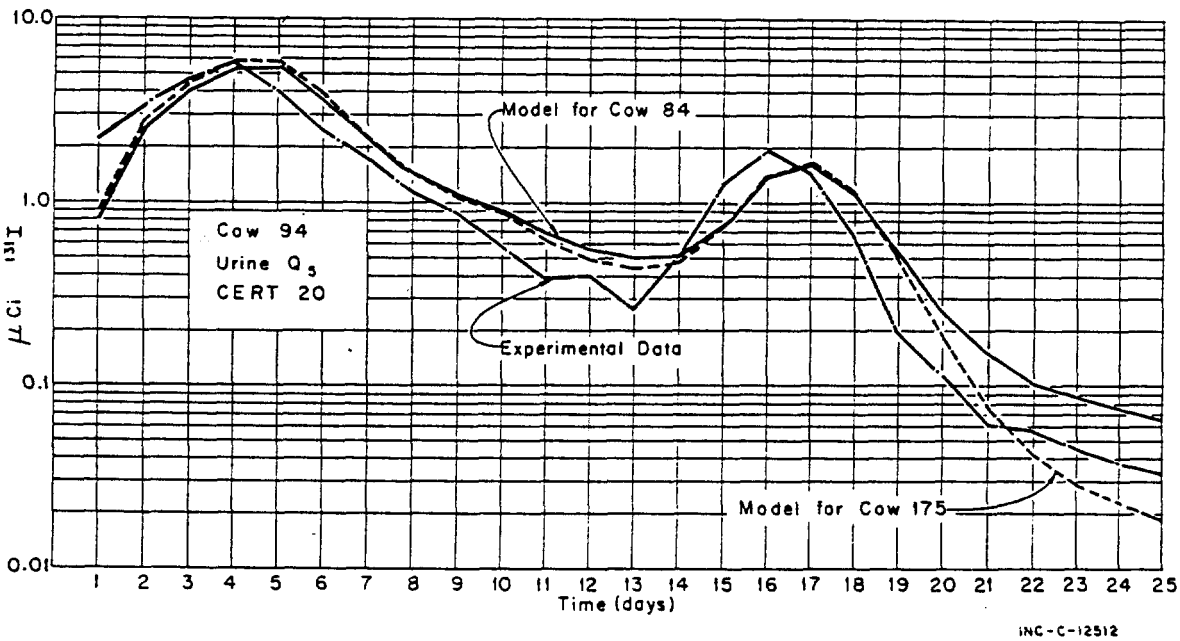

Fig. 35 Comparison of model predictions with data on radioiodine excreted in urine for Cow 94, CERT 20.

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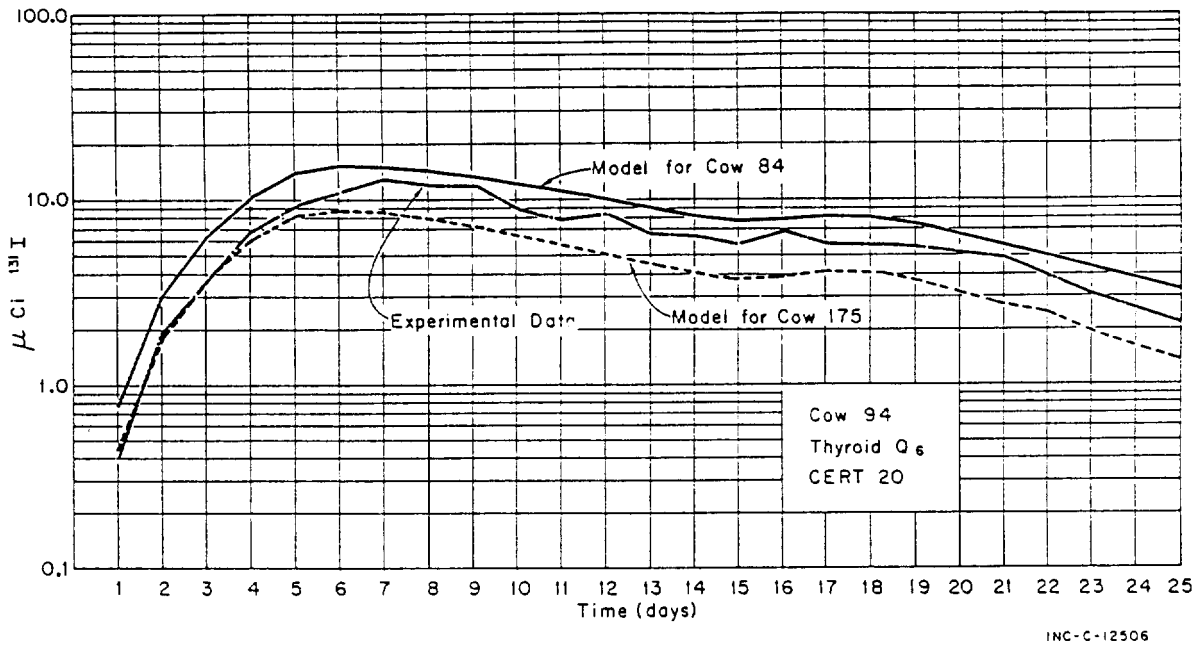

Fig. 36 Comparison of model predictions with data on radioiodine in the thyroid for Cow 94, CERT 20.

two sets of predicted quantities together with the experimentally measured amount of radioiodine for each compartment for Cow 94.

In general, the model appears to be adequate for the purpose of predicting the radioiodine in milk produced subsequent to the cow's ingestion of contaminated pasture grass. The obvious fact that the model, though reasonable, is too simple to account for all the observable manifestations of the cow's metabolic processes is not a severe handicap in this regard. It is apparent, when one examines Equations (10) through (16), that the two sets of rate constants given in Tabe XI are not unique sets for the two cows. However, the best-fit transfer rate r_{34} will be representative of reality if good fits are obtained for the body fluid compartments and for radioiodine in milk. Transfer rate r_{34} is the most critical for our purpose, and the fitting procedure is designed to ensure that the value of r_{34} determined is characteristic of the process and not merely contrived.

5. RATIO OF INGESTION DOSE TO INHALATION DOSE

By assuming physiological parameters for a "standard man" and for a child in the (0-1)-year age group, one can use the CERT data to calculate the ratio of the dose to the thyroid resulting from the consumption of milk produced by cows ingesting contaminated pasture grass to the dose to the thyroid resulting from the inhalation of the air above the pasture grass for a radioiodine release of short duration. The assumed physiological parameters for the "standard man" are:

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(1) Breathing rate (moderate exercise) = 20 liters/minute[32]

(2) Thyroid uptake fraction for inhaled radioiodine = 0.23[33]

(3) Thyroid uptake fraction for ingested radioiodine = 0.30[33]

(4) Average milk consumption rate = 0.35 liters/day[34]

(5) Dose conversion factor; infinity dose to thyroid = 6.9 rem/μCi ^{131}I (from data in Reference 35).

The assumed physiological parameters for a child in the (0-1)-year age group are:

(1) Breathing rate (resting) = 1.45 liters/minute[36]

(2) Thyroid uptake fraction for inhaled radioiodine = 0.23[33]

(3) Thyroid uptake fraction for ingested radioiodine = 0.30[33]

(4) Average milk consumption rate = 0.5 liters/day[34]

(5) Dose conversion factor; infinity dose to thyroid = 42.0 rem/μCi ^{131}I (from data in Reference 35).

The peak time-integrated air concentration above the grass which was subsequently chopped for feed was measured to be 42.4 μCi sec/m^3 for CERT 20. The median value of the deposition velocity measured for CERT 20 was 2.1 cm/sec. The average peak milk concentration for the six cows was 0.15 μCi/liter. The observed half-life of ^{131}I in the milk was five days for CERT 20. The "standard man" would inhale 0.014 μCi of ^{131}I of which 0.0032 μCi would be taken up by the thyroid. The total resulting dose, termed the inhalation dose, would be 0.022 rem. The total ^{131}I activity ingested was calculated by integrating the daily intake from the time of maximum concentration to infinity using the five-day half-life in the milk and adding the ingestion prior to the time of maximum concentration which was estimated using the method of the Federal Radiation Council[37]. The total ^{131}I activity ingested by the man would be 0.49 μCi; the resulting thyroid activity would be 0.15 μCi. The total dose resulting from milk consumption, termed the ingestion dose, would be 1.04 rem. Thus the ratio of the ingestion dose to the inhalation dose for the standard man was calculated to be 47. This is in good agreement with Soldat's[26] value of 40 for this ratio.

The (0-1)-year old child, exposed to the same air concentration as the man, would inhale 1.0×10^{-3} μCi. Of this amount 2.3×10^{-4} μCi would be taken up by the thyroid and would produce a total inhalation dose of 9.7×10^{-3} rem. The child would ingest 0.70 μCi of which 0.21 μCi would be taken up by the thyroid. The resulting ingestion dose would be 8.8 rem, and the ratio of the ingestion dose to the inhalation dose for the child would be 910, which is significantly higher than the value of 400 obtained by Soldat[26].

The ratio of the child's ingestion dose to the inhalation dose to the "standard man" is 400. This ratio can be used to calculate the air concentration of ^{131}I which would produce a dose of 1.5 rem/year to the thyroid of a child in the

(0-1)-year age group, who, it is assumed, consumes milk contaminated at this level throughout the year. The yearly dose of 1.5 rem is the nonoccupational dose limit recommended by the International Commission on Radiological Protection (ICRP) [38] for children up to 16 years of age. Exposure to the maximum permissible air concentration given by the ICRP[31] or in Title 10, Code of Federal Regulations, Part 20 (10 CFR 20) (Appendix B, Table I) for 40 hours/week will result in an inhalation dose to the thyroid of 30 rem/year. The continuous air concentration which will produce a yearly dose of 1.5 rem to the thyroid of the (0-1)-year old child is thus calculated to be 2.6×10^{-13} $\mu Ci/cm^3$. The current requirement for power reactor operators is to use a nonoccupational ^{131}I air concentration obtained by dividing the 10 CFR 20, Appendix B, Table II value by 700. The resulting air concentration would produce an ingestion dose of 810 mrem/year to the thyroid of a child in the (0-1)-year age group.

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IV. CONCLUSIONS

The results of one 1967 CERT study lead us to the following conclusions:

(1) The quantitative results from CERT studies are in agreement with those obtained in other studies. However, because of a lack of understanding of some of the fundamental physical and chemical processes which produce the measured effects, one should apply the results to other locations with due caution.

(2) The parameter deposition velocity is useful in expressing the rate of transfer of radioiodine from air to vegetation provided it is related to variables such as boundary layer transfer velocity, average wind speed, and areal grass density. The measured median deposition velocities for two simultaneous releases over two separate but adjacent grids were found to be within 20% of one another.

(3) The comparisons of CERT deposition data with the predictions of Sheppard's[24] flux gradient model of deposition and with Chamberlain's[5] resistance analogy of deposition indicate that neither model is adequate for deposition on grass because neither takes into account (a) the imperfect sink characteristics of grass for iodine or (b) the microturbulence structure within the grass canopy.

(4) A mathematical model of bovine metabolism of radioiodine derived from the model proposed by Garner[8] appears to be adequate for the purpose of predicting the quantity of radioiodine found in milk subsequent to the cow's ingestion of contaminated feed. The final form of the model:

(a) Allows for a realistic time-dependent radioiodine input

(b) Includes a compartment for radioiodine in body fluid not available to milk

(c) Relates the variable rate of transfer of radioiodine to milk to the cow's milk output.

Properties (b) and (c) of the model are the direct result of experimental findings.

(5) The ratio of the dose to the thyroid resulting from ingestion of milk from cows eating contaminated grass to the dose to the thyroid resulting from inhalation of the contaminated air over the grass at the time of deposition to be 47 for a "standard man" and 910 for a child in the (0-1)-year age group. The calculated ratio of the ingestion dose to the thyroid of a child in this group to the inhalation dose to the thyroid of a man is 400. A continuous air concentration of 2.6×10^{-13} μCi/cc of ^{131}I over the pasture in dairy farm areas to which CERT data are applicable will produce a dose to the thyroid of a child in the (0-1)-year age group, who drinks the contaminated milk throughout the year, equal to the ICRP[38] limit of 1.5 rem/year for children under 16 years of age.

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V. FUTURE WORK

During 1968 several field experiments will be conducted at the EDF.

Two separate experiments to study the metabolism of radioiodine will be conducted. The first release of $^{131}I_2$ will be over an area of the normal mixed pasture grass. The second release will be over an area in which Sudan grass has been planted. The dairy cows will be fed contaminated green chop after both releases, and complete studies of the metabolism of the radioiodine will be made. The primary objective of these tests is to determine whether the type of grass on which the radioiodine is deposited affects the fraction of the deposited radioiodine transferred to milk. If the fraction of the deposited radioiodine transferred from Sudan grass to milk is smaller than the transfer fraction for mixed pasture grass (as we have reason to suspect), then the use of Sudan grass as a feed for dairy cows would reduce the ingestion dose to the thyroid of a person consuming the contaminated milk. The phenomena of deposition and retention of radioiodine on vegetation will be studied concurrently.

The remaining data from the CERT 20 metabolic study and from the CERT 21 capsule feeding study will be used to obtain additional sets of best-fit rate constants for the metabolic model. A program for digital computer simulation of the model is currently being written and tested. (The digital computer is available for these determinations on a continuous basis.) The data from the two tests described above will also be used in this manner. A significant reduction in the fraction transferred to milk should be reflected by significant change in one or more of the model's rate constants.

Another experiment will consist of the release of $^{35}SO_2$ over a stand of alfalfa at the EDF. This test will be carried out in cooperation with Dr. A. Clyde Hill of the University of Utah who is engaged in air pollution research. The primary objective of the test will be to measure the deposition velocity of $^{35}SO_2$. Because it is generally believed that SO_2 deposits only in the stomata of plants, the results of this experiment will provide a basis for comparison with a subsequent experiment with radioiodine, and the comparison may yield information about mechanisms of deposition and retention of radioiodine. (The simultaneous release of $^{35}SO_2$ and $^{131}I_2$ is not feasible because of the chemical interactions which may occur between the two gases.)

Also during 1968, field studies on the behavior of airborne particulates in the environment will be started. To prepare for the field studies, we will devote a portion of our laboratory research effort to the development of techniques for tagging, sizing, and releasing mono- and poly-disperse particulate aerosols.

Our new environmental chamber now has a construction completion date late in 1968. When it becomes operational we will have the capability to control the temperatures, relative humidity, wind velocity, artificial rainfall, turbulence, and contaminant concentration. This chamber will allow more detailed study of the processes which underlie the observed deposition and retention characteristics of radioactive gases and particulates.

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VI. REFERENCES

1. A. C. Chamberlain, Aspects of Travel and Deposition of Aerosol and Vapour Clouds, AERE-HP/R-1261 (September 1953).

2. A. C. Chamberlain, "Aspects of the Deposition of Radioactive and Other Gases and Particulates", Int. J. of Air Pollution, 3 (October 1960) pp 63-88.

3. P. J. Barry and A. C. Chamberlain, "Deposition of Iodine onto Plant Leaves from Air", Health Phys., 9 (December 1963) pp 1149-1157.

4. A. C. Chamberlain, "Deposition", in I. A. Singer, M. E. Smith and E. W. Bierly (eds.), Conference on AEC Meteorological Activities May 19-22, 1964, BNL-914 (June 1965) pp 125-132.

5. A. C. Chamberlain, "Transport of Gases to and from Grass and Grass-Like Surfaces", Proc. Roy Soc. (London) Ser. A, 290 (February 1966) pp 236-265.

6. J. K. Soldat, "The Relationship Between I^{131} Concentrations in Various Environmental Samples", Health Phys., 9 (December 1963) pp 1167-1171.

7. A. P. Hull, "Vegetation Retention and Vegetation-Milk Ratios of Fallout I^{131}", Health Phys., 9 (December 1963) pp 1173-1177.

8. R. J. Garner, "A Mathematical Analysis of the Transfer of Fission Products to Cows' Milk", Health Phys., 13 (February 1967) pp 205-212.

9. F. W. Lengemann, "Predicting the Total Projected Intake of Radioiodine from Milk by Man", Health Phys., 12 (June 1966) pp 825-835.

10. M. Eisenbud and M. E. Wrenn, "Biological Disposition of Radioiodine -- A Review", Health Phys., 9 (December 1963) pp 1133-1139.

11. L. Van Middlesworth, "Factors Influencing the Thyroid Uptake of Iodine Isotopes from Nuclear Fission -- A Review", Health Phys., 9 (December 1963) pp 1197-1121.

12. C. A. Hawley, Jr., C. W. Sill, G. L. Voelz, N. F. Islitzer, Controlled Environmental Radioiodine Tests at the National Reactor Testing Station, IDO-12035 (June 1964).

13. C. A. Hawley, Jr. (ed.), Controlled Environmental Radioiodine Tests at the National Reactor Testing Station -- 1965 Progress Report, IDO-12047 (February 1966).

14. D. F. Bunch (ed.), Controlled Environmental Radioiodine Tests -- Progress Report Number Two, IDO-12053 (August 1966).

15. D. F. Bunch (ed.), Controlled Environmental Radioiodine Tests -- Progress Report Number Three, IDO-12063 (January 1968).

16. W. J. Megaw and F. G. May, "The Behaviour of Iodine Released in Reactor Containers", Reactor Sci. & Tech., 16 No. 9 (September 1962) pp 427-436.

17. A. C. Chamberlain et al., "Physical Chemistry of Iodine and Removal of Iodine from Gas Streams", Reactor Sci. & Tech., 17 No. 11/12 (December 1963) pp 519-550.

18. W. E. Browning, Jr. and R. D. Ackley, "Investigation of Iodine Behavior in May Packs by Means of Composite Diffusion Tubes", in Wm. B. Cottrell (prog. coord.), Nuclear Safety Program Semiannual Progress Report for Period Ending June 30, 1964, ORNL-3691 (November 1964) pp 52-58.

19. J. E. Howes, Jr., et al., Investigation of Techniques for Sampling and Analysis of Iodine Under Simulated Reactor Accident Conditions, BMI-1814 (September 1967).

20. C. A. Bache et al., "Elimination of 2 Methyl-4-Chlorophenoxy-acetic Acid and 4-(2-Methyl-4-Chlorophenoxybutyric) Acid in the Urine from Cows", J. Dairy Sci, 47 (1964) pp 93-94.

21. W. H. Gutenmann et al., "Disappearance of 4-(2,4-Dichlorophenoxybutyric) Acid Herbicide in the Dairy Cow", J. Dairy Sci., 46 (1963) pp 991-992.

22. R. G. Cragle, J. K. Miller, P. T. Chandler, "Gastrointestinal Sites of Absorption and Secretion of Ca, P, Zn, and I in Dairy Cattle", in Radioisotopes in Animal Nutrition and Physiology, Vienna: International Atomic Energy Agency, 1965, pp 499-515.

23. E. L. Hix, G. K. L. Underbjerg, and J. S. Hughes, "The Body Fluids of Ruminants and their Simultaneous Determination", Am. J. Vet. Res., (January 1969) pp 184-191.

24. P. A. Sheppard, "Turbuent Transfer Through the Earth's Surface and Through the Air Above", Quarterly Journal of the Royal Meteorological Society, 84 (1958) pp 205-216.

25 P. R. Owen and W. R. Thomson, "Heat Transfer Across Rough Surfaces", J. of Fluid Mech., 15 (Jan-Apr 1963) pp 321-334.

26. J. K. Soldat, "Environmental Evaluation of an Acute Release of ^{131}I to the Atmosphere", Health Phys., 11 (October 1965) pp 1009-1015.

27. D. V. Booker, Physical Measurements of Activity in Samples from Windscale, AERE-HP/R-2607 (October 1958).

28. C. A. Pelletier, The Sensitivity of Environmental Surveys to Atmospheric Releases from Nuclear Facilities, Thesis, Michigan, University of Michigan, 1966.

29. F. W. Lengemann and C. L. Comar, "Metabolism of I^{131} by Dairy Cows During Long Term Daily Administration of the Radioisotope", Health Phys., 10 (February 1964) pp 55-59.

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30. J. K. Miller and E. W. Swanson, "Some Factors Affecting Iodine Secretion in Milk," J. Dairy Sci., 46 (1963) pp 927-932.

31. J. K. Miller, E. W. Swanson, and R. G. Cragle, "Effect of Feeding Thyroxine on Secretion of ^{131}I in Milk," J. Dairy Sci., 46 (1963) pp 819-824.

32. Task Group on Lung Dynamics, "Deposition and Retention Models for Internal Dosimetry of the Human Respiratory Tract", Health Phys., 12 (February 1966) pp 173-207.

33. The International Commission on Radiological Protection, Radiation Protection -- Recommendations of the International Commission on Radiological Protection. ICRP Publication 2, Report of Committee II on Permissable Dose for Internal Radiation, New York: Pergamon Press, 1959.

34. Bureau of the Census, Department of Commerce, and Division of Radiological Health, Public Health Service, "Consumption of Selected Food Items in U.S. Households -- July 1962", Radiological Health Data, 4 (March 1963) pp 124-129.

35. K. E. Cowser et al., Dose-Estimation Studies Related to Proposed Construction of an Atlantic-Pacific Interoceanic Canal with Nuclear Explosives: Phase I, ORNL-4101 (March 1967).

36. J. G. Kereiakes et al., "Radionuclide Doses to Infants and Children: A Plea for a Standard Child", Health Phys., 11 (October 1965) pp 999-1004.

37. Federal Radiation Council, Report No. 5 -- Background Material for the Development of Radiation Protection Standards, Washington, D. C.: U.S. Government Printing Office, 1964.

38. The International Commission on Radiological Protection, Radiation Protection -- Recommendations of the International Commission on Radiological Protection. ICRP Publication 9, New York: Pergamon Press, 1966.

APPENDIX A

TABULATED DATA OBTAINED DURING CERTS 20 AND 21

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TABLE A-I

RADIOIODINE INGESTED BY EACH COW DURING CERT 20
(In Microcuries for Each Feeding)

Date July	Cow Identification Number 84	88	94	98	142	175
7	9.72 1.15×10^{1}	8.14 1.03×10^{1}	7.45 8.98	8.47 7.49	9.66 9.20	8.06 1.0×10^{1}
8	1.42×10^{1} 1.70×10^{1}	1.43×10^{1} 1.71×10^{1}	1.57×10^{1} 1.15×10^{1}	8.54 1.21×10^{1}	1.25×10^{1} 1.35×10^{1}	1.60×10^{1} 1.34×10^{1}
9	1.95×10^{1} 1.38×10^{1}	2.04×10^{1} 1.26×10^{1}	1.61×10^{1} 2.19×10^{1}	1.50×10^{1} 2.32×10^{1}	1.66×10^{1} 2.35×10^{1}	1.79×10^{1} 2.05×10^{1}
10	1.92×10^{1} 2.10×10^{1}	1.66×10^{1} 1.56×10^{1}	1.49×10^{1} 2.30×10^{1}	2.07×10^{1} 1.70×10^{1}	2.30×10^{1} 2.54×10^{1}	2.87×10^{1} 1.85×10^{1}
11	1.44×10^{1} 3.11	2.00×10^{1} 1.20	1.94×10^{1} 1.45	1.50×10^{1} 2.83	1.82×10^{1} 1.40	2.17×10^{1} 3.75
12	9.32 4.62	4.95 4.06	6.39 3.84	4.62 3.35	9.29 6.21	9.03 5.10
13	2.15 1.96	3.60 3.31	3.04 2.93	3.65 2.52	3.44 3.66	5.52 5.34
14	2.17 2.42	3.53 2.43	2.02 2.29	2.59 2.41	3.07 1.80	3.14 3.13
15	2.17 1.75	2.90 1.76	2.77 2.30	2.17 1.88	2.36 2.38	2.37 1.45
16	2.59 1.02	3.11 --	1.58 1.44	2.16 3.65×10^{-1}	1.79 1.54	2.00 1.49
17	1.26 1.85	1.11 1.42	7.68×10^{-1} 1.05	1.39 1.74	8.05×10^{-1} 1.69	1.03 1.97
18	7.48×10^{-1} 3.88×10^{-1}	9.62×10^{-1} 4.45×10^{-1}	1.01 1.17	8.50×10^{-1} 4.77×10^{-1}	1.23 1.10	1.16 1.42
19	9.19×10^{-1} 8.03×10^{-1}	6.31×10^{-1} 3.17×10^{-1}	1.12 8.95×10^{-1}	6.12×10^{-1} 6.60×10^{-1}	1.24 8.70×10^{-1}	1.04 1.03
20	6.68×10^{-1} 1.86	1.54 2.32	1.07 2.46	4.96×10^{-1} 2.43	1.07 2.61	2.26 2.36
21	7.56 4.73	5.24 5.44	8.48 6.87	4.58 6.86	4.05 6.55	7.02 1.03×10^{1}
22	8.21 4.68	3.68 3.91	6.04 5.57	4.77 5.15	6.38 1.20×10^{1}	5.45 3.22
23	1.92 3.62	5.33 4.46	4.50 3.85	3.32 4.21	3.65 6.31	2.79 4.12

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TABLE A-II

RADIOIODINE IN MILK PRODUCED BY EACH COW DURING CERT 20
(In Picocuries for Each Milking)

Date	Cow Identification Number					
July	84	88	94	98	142	175
7	[a] 4.10×10^{4}	[a] 9.12×10^{4}	[a] 1.57×10^{5}	[a] 1.04×10^{5}	[a] 5.59×10^{4}	[a] 2.18×10^{5}
8	1.03×10^{5} 1.48×10^{5}	2.41×10^{5} 3.52×10^{5}	3.92×10^{5} 4.49×10^{5}	2.96×10^{5} 3.90×10^{5}	1.65×10^{5} 1.87×10^{5}	8.39×10^{5} 7.32×10^{5}
9	2.14×10^{5} 2.30×10^{5}	5.98×10^{5} 6.13×10^{5}	6.70×10^{5} 6.33×10^{5}	5.63×10^{5} 5.66×10^{5}	2.21×10^{5} 2.61×10^{5}	1.10×10^{6} 1.23×10^{6}
10	4.96×10^{5} 3.22×10^{5}	6.61×10^{5} 7.68×10^{5}	8.62×10^{5} 7.37×10^{5}	8.24×10^{5} 9.14×10^{5}	4.45×10^{5} 4.19×10^{5}	1.86×10^{6} 1.54×10^{6}
11	3.50×10^{5} 4.62×10^{5}	9.64×10^{5} 4.33×10^{5}	1.20×10^{6} 5.86×10^{5}	1.01×10^{6} 8.22×10^{5}	4.96×10^{5} 6.84×10^{5}	2.44×10^{6} 2.23×10^{6}
12	2.88×10^{5} 2.90×10^{5}	8.46×10^{5} 1.02×10^{6}	8.01×10^{5} 5.43×10^{5}	1.06×10^{6} 7.54×10^{5}	5.46×10^{5} 3.65×10^{5}	1.30×10^{6} 1.47×10^{6}
13	1.92×10^{5} 1.79×10^{5}	8.31×10^{5} 5.69×10^{5}	4.15×10^{5} 3.45×10^{5}	7.87×10^{5} 4.75×10^{5}	5.05×10^{5} 2.11×10^{5}	1.73×10^{6} 1.10×10^{6}
14	2.64×10^{5} 1.10×10^{5}	5.96×10^{5} 3.74×10^{5}	4.45×10^{5} 2.51×10^{5}	5.51×10^{5} 3.10×10^{5}	2.40×10^{5} 1.50×10^{5}	8.66×10^{5} 9.25×10^{5}
15	1.06×10^{5} 2.06×10^{5}	3.90×10^{5} 1.14×10^{5}	[b] 1.96×10^{5}	3.43×10^{5} 2.10×10^{5}	1.75×10^{5} 1.05×10^{5}	7.09×10^{5} 6.07×10^{5}
16	8.02×10^{4} 6.81×10^{4}	2.00×10^{5} 1.68×10^{5}	1.88×10^{5} 1.33×10^{5}	2.34×10^{5} 1.81×10^{5}	1.03×10^{5} 9.07×10^{4}	5.62×10^{5} 2.97×10^{5}
17	6.27×10^{4} 4.45×10^{4}	1.07×10^{5} 1.59×10^{5}	1.49×10^{5} 1.07×10^{5}	2.26×10^{5} 1.05×10^{5}	9.78×10^{4} 6.52×10^{4}	3.99×10^{5} 3.12×10^{5}
18	6.15×10^{4} 4.14×10^{4}	1.24×10^{5} 1.05×10^{5}	9.64×10^{4} 8.42×10^{4}	1.37×10^{5} 1.04×10^{5}	6.80×10^{4} 5.43×10^{4}	2.67×10^{5} 2.44×10^{5}
19	3.28×10^{4} 2.49×10^{4}	4.69×10^{4} 5.72×10^{4}	1.00×10^{5} 5.12×10^{4}	6.45×10^{4} 4.97×10^{4}	4.79×10^{4} 3.41×10^{4}	1.70×10^{5} 1.28×10^{5}
20	2.90×10^{4} 2.56×10^{4}	6.46×10^{4} 6.18×10^{4}	6.63×10^{4} 5.96×10^{4}	5.50×10^{4} 5.55×10^{4}	3.81×10^{4} 3.74×10^{4}	1.52×10^{5} 1.40×10^{5}
21	3.72×10^{4} 6.74×10^{4}	1.11×10^{5} 1.81×10^{5}	8.88×10^{4} 1.75×10^{5}	6.92×10^{4} 1.02×10^{5}	5.49×10^{4} 8.19×10^{4}	2.03×10^{5} 2.68×10^{5}
22	9.74×10^{4} 8.51×10^{4}	2.63×10^{5} 2.83×10^{5}	2.87×10^{5} 2.93×10^{5}	2.38×10^{5} 2.07×10^{5}	1.85×10^{5} 1.70×10^{5}	5.52×10^{5} 4.96×10^{5}
23	8.54×10^{4} 1.28×10^{5}	3.20×10^{5} 2.56×10^{5}	3.18×10^{5} 2.72×10^{5}	3.59×10^{5} 2.74×10^{5}	2.58×10^{5} 1.57×10^{5}	7.44×10^{5} 4.26×10^{5}
24	1.17×10^{5} 8.86×10^{4}	2.78×10^{5} 2.76×10^{5}	2.21×10^{5} 1.86×10^{5}	2.83×10^{5} 2.47×10^{5}	1.70×10^{5} 1.54×10^{5}	5.34×10^{5} 4.75×10^{5}
25	7.44×10^{4} 4.46×10^{4}	1.87×10^{4} 2.70×10^{5}	1.63×10^{5} 1.02×10^{5}	1.85×10^{5} 1.42×10^{5}	1.35×10^{5} 8.94×10^{4}	3.35×10^{5} 1.48×10^{5}
26	3.52×10^{4} 3.05×10^{4}	8.41×10^{4} 6.34×10^{4}	8.69×10^{4} 3.69×10^{4}	1.05×10^{5} 5.71×10^{4}	7.08×10^{4} 2.90×10^{4}	9.77×10^{4} 4.66×10^{4}
27	2.00×10^{4} 1.24×10^{4}	4.41×10^{4} 2.57×10^{4}	2.63×10^{4} 1.30×10^{4}	4.47×10^{4} 2.62×10^{4}	2.76×10^{4} 1.52×10^{4}	2.86×10^{4} 1.90×10^{4}
28	8.01×10^{3} 2.99×10^{3}	1.98×10^{4} 1.40×10^{4}	1.17×10^{4} 9.47×10^{3}	1.99×10^{4} 5.41×10^{3}	1.49×10^{4} 8.36×10^{3}	1.82×10^{4} 8.76×10^{3}
29	5.98×10^{3} 3.37×10^{3}	1.03×10^{4} 6.88×10^{3}	7.11×10^{3} 3.44×10^{3}	1.03×10^{4} 5.96×10^{3}	8.27×10^{3} 4.86×10^{3}	1.03×10^{4} 7.44×10^{3}
30	3.13×10^{3} 1.81×10^{3}	6.01×10^{3} 4.23×10^{3}	4.32×10^{3} 2.61×10^{3}	5.93×10^{3} 3.13×10^{3}	5.27×10^{3} 3.28×10^{3}	6.96×10^{3} 3.11×10^{3}
31	2.27×10^{3} 1.62×10^{3}	5.16×10^{3} 3.58×10^{3}	2.97×10^{3} 1.88×10^{3}	5.08×10^{3} 2.38×10^{3}	4.67×10^{3} 2.39×10^{3}	4.75×10^{3} 3.02×10^{3}
August						
1	1.41×10^{3} 1.48×10^{3}	3.49×10^{3} 2.86×10^{3}	2.41×10^{3} 1.40×10^{3}	2.67×10^{3} 2.65×10^{3}	2.41×10^{3} 2.66×10^{3}	4.58×10^{3} 2.23×10^{3}

[a] Milked prior to first ingestion of contaminated feed.

[b] No analysis.

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TABLE A-III

MILK PRODUCTION OF EACH COW DURING CERT 20
(In Liters for Each Milking)

Date	Cow Identification Number											
July	84		88		94		98		142		175	
	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
7	3.2	3.8	4.6	5.6	8.9	6.9	7.8	7.3	7.8	6.2	10.0	10.7
8	3.1	3.6	4.4	5.3	8.6	6.9	6.8	7.4	7.3	6.2	12.4	9.8
9	3.7	3.2	5.8	5.1	8.6	6.4	7.4	6.3	6.1	5.4	12.2	10.0
10	4.0	3.6	4.4	4.4	8.4	6.0	7.1	5.8	7.2	5.7	12.2	9.5
11	3.4	4.2	4.8	4.8	8.9	6.9	7.2	6.0	6.0	6.4	13.1	11.1
12	3.1	3.6	4.9	4.7	8.2	6.4	8.2	6.0	7.2	5.6	11.4	10.4
13	3.1	3.4	5.9	4.7	8.3	5.8	7.5	5.1	7.2	5.3	14.7	10.8
14	3.3	3.0	6.3	4.7	9.1	5.9	8.3	5.1	7.1	5.3	10.0	12.1
15	3.8	3.8	6.3	4.6	8.1	6.2	7.6	5.7	7.8	5.7	11.5	11.4
16	3.9	3.4	4.4	4.4	7.1	6.0	6.7	5.6	6.3	5.6	13.8	8.0
17	3.6	2.7	4.0	5.9	8.3	6.3	9.5	4.9	7.6	5.6	13.1	10.9
18	4.2	3.1	5.8	5.3	7.1	7.2	8.2	6.9	7.2	6.1	12.2	12.1
19	2.9	2.9	4.8	4.0	6.2	5.9	5.8	5.3	6.8	5.3	10.9	9.3
20	3.4	2.9	5.6	4.7	8.3	6.0	6.8	6.2	7.2	6.0	13.9	10.0
21	3.4	3.1	5.6	4.8	6.8	6.0	6.8	5.3	6.7	5.2	12.4	9.5
22	4.1	2.9	5.3	4.4	7.2	6.4	7.7	5.1	7.1	5.9	12.4	10.4
23	2.8	4.0	5.2	4.2	6.7	5.8	8.3	6.2	8.3	5.2	13.3	8.7
24	3.9	3.1	4.9	5.3	5.1	4.9	7.1	6.2	6.0	5.8	12.2	11.9
25	3.2	2.2	0.7	6.8	5.0	4.2	5.2	5.6	6.0	5.1	12.5	8.1
26	2.9	3.2	4.4	4.2	7.6	4.7	7.5	5.4	7.5	4.4	12.2	8.8
27	3.8	2.9	6.0	4.1	6.9	4.7	7.7	5.6	6.4	4.6	10.0	8.8
28	3.2	1.4	5.4	5.0	7.0	4.2	7.0	4.6	7.1	5.1	12.1	7.7
29	4.0	2.9	5.8	4.2	7.8	4.3	7.3	4.9	7.1	4.2	12.4	10.0
30	3.4	3.2	5.2	4.7	6.3	5.2	7.5	5.3	6.4	5.2	11.7	8.7
31	3.4	3.0	5.3	4.2	6.4	4.9	6.8	5.3	6.8	4.6	11.2	7.8
August												
1	3.3	3.3	5.3	4.5	6.4	4.0	7.0	5.1	6.2	5.3	12.4	8.0

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TABLE A-IV

RADIOIODINE EXCRETED IN FECES BY EACH COW DURING CERT 20
(In Microcuries)

Date	Cow Identification Number					
July	84	88	94	98	142	175
8	8.6	4.2	5.1	4.7	5.2	5.1
9	10.4	10.0	12.0	9.6	9.6	10.8
10	16.8	14.6	19.7	17.1	23.2	18.2
11	17.2	20.7	22.1	19.3	26.0	21.9
12	16.0	14.1	17.4	13.5	21.7	19.7
13	9.6	10.3	10.4	11.1	12.0	12.1
14	6.6	7.4	6.8	7.5	6.3	8.8
15	4.6	5.2	4.9	4.0	4.4	5.7
16	3.3	4.1	3.5	3.3	3.1	3.7
17	2.9	3.2	2.6	3.4	4.0	3.7
18	2.9	2.8	2.4	2.9	3.5	3.8
19	2.0	2.0	2.1	2.1	2.7	2.9
20	1.6	1.2	1.9	1.6	2.1	2.1
21	2.0	2.1	1.5	1.8	2.9	2.8
22	3.8	4.4	7.1	4.9	[a]	7.7
23	5.8	5.9	9.9	7.0	8.2	8.9
24	5.5	5.5	7.8	6.7	7.5	6.7
25	3.7	2.0	5.1	5.0	4.3	3.5
26	1.8	1.7	1.7	2.2	1.6	1.1
27	0.7	0.6	0.5	0.9	0.7	0.3
28	0.3	0.2	0.2	0.4	0.3	0.08
29	0.09	0.07	0.07	0.1	0.1	0.03
30	0.05	0.04	0.04	0.07	0.08	0.03
31	0.04	0.04	0.04	0.06	0.08	0.03
August						
1	0.06	0.04	0.05	0.04	0.05	0.03

[a] No analysis.

0023671

TABLE A-V

RADIOIODINE EXCRETED IN URINE BY EACH COW DURING CERT 20
(In Microcuries)

Date	Cow Identification Number					
July	84	88	94	98	142	175
8	3.0	2.8	2.2	1.8	2.7	3.0
9	4.9	3.6	3.4	2.5	4.6	3.5
10	6.3	3.2	4.7	3.8	6.9	5.2
11	6.4	6.1	5.7	4.3	7.8	7.2
12	7.6	5.4	4.0	3.1	6.1	4.6
13	3.3	4.0	2.0	2.2	3.8	3.4
14	2.7	2.3	1.7	1.6	2.5	2.1
15	1.6	1.6	1.1	1.0	1.6	1.6
16	1.3	1.4	0.9	0.6	1.2	0.9
17	0.8	0.7	0.6	0.5	0.8	0.8
18	0.6	0.5	0.4	0.4	0.6	0.5
19	0.5	0.4	0.4	0.3	0.5	0.4
20	0.4	0.2	0.3	0.2	0.4	0.3
21	0.7	0.5	0.5	0.4	0.7	0.5
22	1.3	1.1	1.3	1.4	1.8	1.1
23	2.1	1.6	1.9	0.9	1.6	1.6
24	1.4	1.5	1.4	1.2	1.8	1.3
25	0.9	0.9	0.7	0.7	0.9	[a]
26	0.6	0.4	0.2	0.3	0.4	0.3
27	0.2	0.1	0.1	0.1	0.2	0.1
28	0.1	0.08	0.06	0.06	0.1	0.05
29	0.1	0.06	0.06	0.05	0.07	0.04
30	0.06	0.04	0.04	0.04	0.07	0.03
31	0.06	0.04	0.04	0.04	0.06	0.03
August						
1	0.05	0.03	0.03	0.03	0.05	0.03
2	0.04	0.03	0.03	0.02	0.05	0.02
3	0.03	0.03	0.04	0.03	0.04	0.03
4	0.03	0.02	0.03	0.03	0.03	0.02

[a] No analysis

0023672

TABLE A-VI

RADIOIODINE IN BLOOD OF EACH COW DURING CERT 20
(In Microcuries)

Date	Cow Identification Number					
July	84	88	94	98	142	175
7	0.06	0.03	0.09	0.15	0.23	0.07
8	0.44	0.34	0.43	0.67	0.33	0.43
9	0.63	0.63	0.56	0.45	0.80	0.68
10	0.89	0.72	0.89	0.97	1.50	0.89
11	1.21	0.95	0.99	0.97	1.67	1.20
12	1.04	0.81	0.76	0.82	1.50	0.81
13	0.83	0.68	0.56	0.65	1.30	0.68
14	0.54	0.43	0.39	0.53	0.91	0.46
15	0.45	0.40	0.35	0.34	0.73	0.35
16	0.43	0.31	0.33	0.31	0.66	0.28
17	0.45	0.31	0.32	0.27	0.65	0.27
18	0.39	0.23	0.24	0.26	0.48	0.21
19	0.31	0.20	0.22	0.25	0.49	0.17
20	0.28	0.17	0.22	0.20	0.43	0.13
21	0.28	0.21	0.20	0.19	0.45	0.17
22	0.36	0.28	0.32	0.28	0.59	0.17
23	0.41	0.32	0.38	0.30	0.63	0.23
24	0.37	0.26	0.28	0.22	0.52	0.23
25	0.28	0.24	0.19	0.20	0.44	0.21
26	0.17	0.15	0.12	0.12	0.28	0.11
27	0.15	0.12	0.12	0.09	0.21	0.13
28	0.12	0.08	0.10	0.06	0.16	0.13
31	0.08	0.05	0.07	0.02	0.12	0.05
August						
3	0.08	0.05	0.05	0.04	0.14	0.02
8	0.04	0.03	0.04	0.03	0.06	0.02

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TABLE A-VII

RADIOIODINE IN TOTAL BODY FLUID OF EACH COW DURING CERT 20[a]
(In Microcuries)

Date	Cow Identification Number					
July	84	88	94	98	142	175
7	1.0	0.5	1.2	1.7	2.7	0.7
8	6.9	5.5	5.8	7.5	3.9	4.8
9	10.0	9.7	7.5	5.1	9.4	7.6
10	14.2	11.6	12.0	10.9	17.6	10.0
11	18.9	15.3	13.3	10.9	19.6	13.5
12	16.3	13.0	10.2	9.3	17.6	9.1
13	12.8	10.9	7.5	7.4	15.3	7.6
14	8.6	6.8	5.1	5.9	10.7	5.1
15	7.8	6.4	4.7	3.8	8.5	3.9
16	6.8	5.1	4.5	3.4	6.5	3.1
17	7.1	5.0	4.2	3.0	7.6	3.1
18	6.2	3.6	3.3	2.9	5.6	2.3
19	5.0	3.1	2.9	2.8	5.7	1.8
20	4.4	2.8	2.9	2.3	5.0	2.0
21	4.4	3.4	2.7	2.1	5.2	1.9
22	5.8	4.5	4.3	3.2	6.9	3.0
23	6.5	5.2	5.1	3.4	7.4	2.6
24	5.8	4.2	3.8	2.5	6.1	2.6
25	4.4	3.9	2.6	2.3	5.1	2.2
26	2.7	2.5	1.5	1.3	3.3	1.1
27	2.4	1.8	1.6	1.0	2.5	1.0
28	1.9	1.3	1.3	0.7	1.9	0.9
31	1.3	0.9	0.9	0.3	1.4	0.5
August						
3	1.2	0.8	0.7	0.5	1.6	0.3
8	0.5	0.4	0.6	0.4	0.7	0.3

[a] Calculated values based on the assumption that the ^{131}I activity in blood is in equilibrium with the ^{131}I activity in the other body fluids.

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TABLE A-VIII

RADIOIODINE IN EACH COW'S THYROID DURING CERT 20
(In Microcuries)

Date	Cow Identification Number					
July	84	88	94	98	142	175
7	<0.01	<0.01	0.01	0.01	0.01	0.01
8	0.7	0.7	0.4	0.6	0.6	0.6
9	1.8	1.1	1.9	1.4	2.3	1.3
10	4.7	2.9	3.5	2.3	3.2	2.9
11	10	8.0	6.7	5.5	15	4.8
12	13	9.2	9.2	10	16	6.6
13	15	12	11	12	18	7.5
14	15	16	13	14	20	7.2
15	19	16	12	15	20	7.1
16	14	14	12	12	16	7.5
17	13	15	9.0	12	16	7.1
18	12	14	8.0	11	16	7.1
19	10	13	8.4	9.7	14	[illegible]
20	11	11	6.7	8.5	11	[illegible]
21	8.4	10	6.5	7.8	9.3	[illegible]
22	7.8	9.0	5.8	8.0	10	[illegible]
23	8.5	9.2	6.8	7.8	9.5	[illegible]
24	9.0	10	5.9	7.8	9.5	[illegible]
25	7.5	9.4	5.9	7.2	9.6	[illegible]
26	7.6	9.2	5.6	7.2	8.5	[illegible]
27	6.1	7.8	5.2	5.2	7.1	[illegible]
28	5.3	6.5	4.9	6.2	7.5	[illegible]
30	4.6	4.8	3.1	4.1	4.9	[illegible]
August						
1	3.3	3.9	2.2	2.5	3.7	[illegible]
4	1.8	2.5	1.5	[a]	2.3	[illegible]

[a] No analysis.

TABLE A-IX

RADIOIODINE INTAKE FOR EACH COW DURING CERT 21[a]

Date	Cow Identification Number		
August	94	142	175
9	12.8	12.8	12.8
10	13.4	13.4	13.4
11	12.9	12.9	12.9
12	13.1	13.1	13.1
13	12.8	12.8	12.8

[a]Cows were given the radioiodine in capsules.

TABLE A-X

MILK PRODUCTION OF EACH COW DURING CERT 21
(In Liters for Each Milking)

Date	Cow Identification Number					
August	94		142		175	
	AM	PM	AM	PM	AM	PM
10	5.6	5.8	7.4	5.8	11.5	10.2
11	6.2	5.3	7.2	5.9	13.3	9.7
12	7.0	4.1	6.0	5.0	13.3	8.9
13	6.6	4.6	6.8	5.3	13.0	9.3
14	5.9	4.3	5.3	5.1	12.0	9.0
15	6.2	4.6	6.6	4.2	13.3	9.7
16	6.6	3.6	6.4	4.5	13.9	8.5
17	6.1	4.9	7.2	5.0	14.0	9.3
18	5.0	5.4	6.5	5.2	13.6	8.3
22	5.1	4.4	6.2	4.9	13.3	9.5
25	5.1	3.7	6.7	5.8	12.9	10.9

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Table A-XI

RADIOIODINE IN MILK PRODUCED BY EACH COW DURING CERT 21
(In Picocuries for Each Milking)

Date	Cow Identification Number		
August	94	142	175
10	1.46×10^5	9.34×10^4	3.67×10^5
	2.04×10^5	1.15×10^5	4.57×10^5
11	2.05×10^5	1.10×10^5	6.15×10^5
	2.11×10^5	1.48×10^5	5.44×10^5
12	2.29×10^5	1.21×10^5	7.22×10^5
	1.77×10^5	1.37×10^5	5.61×10^5
13	2.45×10^5	1.48×10^5	6.60×10^5
	2.27×10^5	1.65×10^5	6.24×10^5
14	2.61×10^5	1.46×10^5	7.33×10^5
	1.33×10^5	1.22×10^5	4.25×10^5
15	7.81×10^4	7.85×10^4	2.64×10^5
	4.18×10^4	2.98×10^4	1.21×10^5
16	3.13×10^4	2.32×10^4	8.78×10^4
	1.94×10^4	2.93×10^4	5.41×10^4
17	2.27×10^4	3.05×10^4	6.48×10^4
	1.70×10^4	1.96×10^4	3.16×10^4
18	1.53×10^4	2.18×10^4	4.39×10^4
	[a]	[a]	[a]
22	[a]	[a]	[a]
	1.10×10^4	1.27×10^4	2.29×10^4

[a] No analysis.

TABLE A-XII

RADIOIODINE EXCRETED IN FECES
BY EACH COW DURING CERT 21
(In Microcuries)

Date	Cow Identification Number		
August	94	142	175
9	0.1	0.7	0.7
10	3.9	3.1	3.6
11	4.6	6.9	5.2
12	4.9	5.4	5.2
13	5.8	5.1	5.2
14	7.2	8.1	6.4
15	2.6	2.7	2.1
16	0.9	0.8	0.8
17	0.5	0.4	0.3

TABLE A-XIII

RADIOIODINE EXCRETED IN URINE
OF EACH COW DURING CERT 21
(In Microcuries)

Date	Cow Identification Number		
August	94	142	175
9	2.6	1.3	2.2
10	3.5	3.7	4.9
11	3.6	2.6	4.1
12	3.1	2.7	3.6
13	3.6	2.5	3.8
14	1.8	1.8	2.5
15	0.9	0.6	0.9
16	0.3	0.3	0.3
17	0.1	0.09	0.1
18	0.09	0.08	0.08
21	0.09	0.07	0.08
22	0.09	0.08	0.08
24	0.08	0.07	0.07

TABLE A-XIV

RADIOIODINE IN BLOOD OF EACH COW DURING CERT 21
(In Micocuries)

Date	Cow Identification Number		
August	94	142	175
9	9.7×10^{-5}	9.7×10^{-5}	5.8×10^{-5}
10	3.0×10^{-4}	4.4×10^{-4}	3.3×10^{-4}
11	5.4×10^{-4}	5.5×10^{-4}	4.5×10^{-4}
12	5.6×10^{-4}	8.1×10^{-4}	4.7×10^{-4}
14	4.5×10^{-4}	6.8×10^{-4}	4.9×10^{-4}

TABLE A-XV

RADIOIODINE IN TOTAL BODY FLUID
OF EACH COW DURING CERT 21[a]
(In Micocuries)

Date	Cow Identification Number		
August	94	142	175
9	1.3	1.1	1.0
10	4.1	5.1	5.7
11	7.2	6.5	7.8
12	7.5	9.5	8.1
14	6.1	7.9	8.5

[a]Values calculated on the assumption that the ^{131}I activity in blood is in equilibrium with the ^{131}I activity in the other body fluids.

TABLE A-XVI

RADIOIODINE IN EACH COW'S
THYROID DURING CERT 21
(In Micocuries)

Date	Cow Identification Number		
August	94	142	175
8	0.8	1.2	0.6
9	0.6	1.6	0.7
10	1.8	3.1	0.9
11	3.5	5.7	1.9
12	5.6	8.0	2.7
13	5.8	11	2.5
14	7.4	13	4.3
15	8.4	12	4.4
16	6.5	10	4.0
18	6.1	9.0	3.3
25	2.1	3.0	1.1
28	1.6	1.9	0.8
29	1.3	1.5	0.7
September			
1	0.9	1.1	0.5
5	0.6	0.7	0.3

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APPENDIX B

ANALYSIS OF CONTINUITY FOR A CONTAMINANT IN THE AIR-VEGETATION-MILK FOOD CHAIN

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APPENDIX B

ANALYSIS OF CONTINUITY FOR A CONTAMINANT IN THE AIR-VEGETATION-MILK FOOD CHAIN

The time rate of change of activity of material deposited on a pasture is given by Equation (B-1).

$$S \frac{dA_v}{dt} = - \frac{NI}{D_o} A_v e^{-\lambda_{eff} t} - SA_v \lambda_{eff} \qquad \text{(B-1)}$$

in which

S is the area of the pasture (m^2)

A_v is the activity per unit area of the deposited material ($\mu Ci/m^2$)

N is the the number of cows on the pasture

I is the food intake of a single cow (kg/day)

D_o is the grass density at the time of deposition (kg/m^2)

λ_{eff} is the effective removal rate constant ($days^{-1}$).

Equation (B-1) can be solved for A_v with the following result:

$$A_v = A_o \exp \left[- \left\{ \lambda_{eff} t + B \left(1 - e^{-\lambda_{eff} t} \right) \right\} \right] \qquad \text{(B-2)}$$

in which

A_o is the activity initially deposited in $\mu Ci/m^2$

$$B = \left(\frac{N}{S}\right) \frac{I}{D_o \lambda_{eff}} \quad .$$

To preserve continuity, the following equation must be satisfied at all times:

$$A_c + SA_d + SA_v = SV_d C_a \qquad \text{(B-3)}$$

in which

A_c is the activity comsumed by the dairy herd (μCi)

A_d is the activity per unit area lost by decay and removal processes ($\mu Ci/m^2$)

V_d is the deposition velocity (m/sec)

C_a is the time-integrated air concentration during the period of deposition ($\mu Ci\text{-}sec/m^3$).

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The expression for the activity consumption rate by the dairy herd is

$$\frac{dA_c}{dt} = \frac{NI\ A_o\ e^{-\lambda_{eff}t}}{D_o} \quad . \tag{B-4}$$

The solution of Equation (B-4) gives the following expression for A_c:

$$A_c = \frac{NI\ A_o}{D_o \lambda_{eff}} \left(1 - e^{-\lambda_{eff}t}\right) \quad . \tag{B-5}$$

Substituting Equations (B-2) and (B-5) into Equation (B-3) yields the following expression for A_d:

$$A_d = A_o \left[1 - \exp\left\{ -\left[\lambda_{eff}t + B\left(1 - e^{-\lambda_{eff}t}\right)\right] \right\} - B\left(1 - e^{-\lambda_{eff}t}\right) \right]. \tag{B-6}$$

At time t = oo, A_d is given by Equation (B-7).

$$A_d = A_o\ (1 - B) = A_o \left[1 - \frac{NI}{SD_o \lambda_{eff}} \right] \tag{B-7}$$

Thus to preserve continuity the relation

$$\frac{NI}{SD_o \lambda_{eff}} \leq 1 \tag{B-8}$$

must be satisfied.

A commonly used value of λ_{eff} for iodine-131 is 0.139 days^{-1}. Typical values of D_o and I are 0.15 kg/m^2 and 10 kg/day, respectively. Under these conditions, the maximum value (N/S) can take on is 2.1×10^{-3} m^{-2}. In the late spring or early summer the high growth rate of the pasture will increase D_o in which case the number of cows per unit area could be increased without violating continuity. On the other hand, during the hot summer months D_o may be smaller and the limit on (N/S) to avoid loss of continuity would be reduced. A good pasture can support one cow on one to two acres over the entire grazing season. This is equivalent to a range of N/S values of 1.2×10^{-4} to 2.4×10^{-4} m^{-2}. It would seem that, for iodine-131 at least, good farming practices will assure that continuity is not violated. For longer lived contaminants, for which the removal half-life determines the value of λ_{eff}, the situation is not so clear. A removal half-life on the order of thirty days combined with a low initial area of grass density would create a situation where the traditional mathematical treatment would overestimate radiation exposure.

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