000.1333-1

3 cyp

RECEIVED BY DTIE JAN 21 1969

THE UNIVERSITY OF MICHIGAN

MASTER

SCHOOL OF PUBLIC HEALTH
Department of Environmental Health

Final Report
December 15, 1963 to December 14, 1966

INVESTIGATIONS INTO THE CYCLING AND RECYCLING
OF CERTAIN RADIONUCLIDES THROUGH THE MILK FOOD CHAIN

Charles A. Pelletier
G. Hoyt Whipple

ORA Project 06160

under contract with:

U. S. Atomic Energy Commission
Chicago Operations Office
Contract No. AT(11-1)-133
Argonne, Illinois

Administered through:

OFFICE OF RESEARCH ADMINISTRATION - ANN ARBOR

December 1968

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

ABSTRACT

This study of radionuclide behavior in the milk-food chain was conducted at a commercial dairy farm near Tecumseh, Michigan during 1964 and 1965. The main purpose of the study was to develop mathematical models to describe the movement of radionuclides from air to milk. Three models are presented: the first predicts total deposition on the ground from air concentration and rainfall rate; the second predicts concentration in forage from air concentration, rainfall rate, and the rates at which the forage grows and is consumed by the dairy herd; the third predicts the concentration of cesium-137 in milk from the concentration of cesium-137 in each type of feed and the rate at which each type of feed is consumed by the dairy herd.

The models predict a single week's deposition to within a factor of 3, a single week's forage concentration to within a factor of 2.2, and a single week's cesium-137 concentration in milk to within a factor of 1.7. The error associated with each model becomes smaller as one increases the number of weeks over which the prediction is averaged.

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

ACKNOWLEDGEMENTS

We wish to acknowledge the faithful work of James R. Burns, who collected the many samples involved in the study. Acknowledgement is due to Harold L. Wedlick for his work in all phases of the study, but particularly in developing analytical methods. We wish especially to acknowledge the conscientious and efficient sample analyses of Robert Quattro. Recognition is due to Mrs. Lyla F. Nasr for the strontium-90 analyses, and to Maxine Kruse for the mathematical interpretation of the data. Paul G. Voillequé has given time unselfishly in the final analysis of the data.

The several consultants who have made notable contributions to this work are Dr. William S. Benninghof, Dr. A. Nelson Dingle, and Dr. Mary Ellen Patno, all of the University of Michigan, and Dr. Lynn Robertson and Dr. Carl Huffman, both of Michigan State University.

Finally, we acknowledge with pleasure the most important person of all: Arthur Eaton, the farmer, whose cooperation made the study possible.

TABLE OF CONTENTS

	<u>Page</u>
Abstract	i
Acknowledgements	ii
Table of Contents	iii
List of Tables	vi
List of Figures	ix
 CHAPTER I. INTRODUCTION	 1
CHAPTER II. RELATION BETWEEN DEPOSITION AND CONCENTRATION IN AIR	4
A. Theory	4
1. Wet deposition	4
2. Dry deposition	5
3. Relations from previous measurements	6
B. Experiment	9
1. Concentration of radioactivity in air	9
a. Method	9
b. Results	10
2. Deposition	11
a. Method	11
b. Results	13
3. Rainfall	13
C. Comparison of theory and experiment	14
CHAPTER III. DESCRIPTION OF STUDY FARM	21
A. General description	21
B. Soil mapping and analysis	21
C. Radionuclide survey	28

TABLE OF CONTENTS (cont'd.)

	Page
CHAPTER IV. RELATION BETWEEN FORAGE CONCENTRATION AND DEPOSITION	34
A. Theory	34
1. Aerial deposition	34
a. Wet deposition	35
b. Dry deposition	40
c. Solution of Mathematical models	41
2. Uptake from soil	43
B. Experiment	50
1. Methods	50
a. Grass sample collection	50
b. Soil sample collection	51
c. Grass sample analysis	51
d. Soil sample analysis	54
C. Uptake from soil	54
1. Method	54
2. Results	55
a. Radionuclide concentrations of pasture and sudan grass	55
b. Growth rate and consumption	55
c. Soil uptake calculation	55
d. Radionuclides in soil	58
D. Comparison of theory and experiment	60
CHAPTER V. RELATION BETWEEN FEED AND MILK RADIONUCLIDE CONCENTRATIONS	74
A. Theory	74
B. Experiment	76

TABLE OF CONTENTS (cont'd.)

	Page
1. 1. Methods	76
a. Sample collection	76
b. Radioactivity analysis	77
c. Stable element analysis	77
d. Measurement of intake by the dairy herd	78
e. Measurement of output of the herd	79
C. Results	
C. Comparison between theory and experiment	81
CHAPTER VI. CONCLUSIONS	87
CHAPTER VII. APPENDICES	
A. Strontium-90 procedure	89
B. Tabulated data	94
C. Recording emission spectrograph for the analysis of plant materials and soil extracts	130
CHAPTER VIII. REFERENCES	132

LIST OF TABLES

<u>Table No.</u>		<u>Page</u>
1	Comparison of rainfall measurements with different collectors	15
2	Comparison of 1-week and 4-week collections of rainfall	15
3	Areas and planting history of the fields of the study farm	23
4	Fertilization history of each field of the study farm	24
5	Crop fields for the various fields during the study period	25
6	Results of chemical analysis of soils in the various fields of the study farm	29
7.	Cesium-137 soil concentrations for different soil conditions and planting histories, study farm, October 1964	31
8	Comparison of cesium-137 soil radioactivity levels for different soil conditions and planting histories, study farm, October 1964	33
9	Expected content of strontium-90 in Swedish crops at a total deposition in the plow-layer of 1 Ci Sr-90 per km ²	44
10	Expected Sr-90 content in Swedish milk originating from 1 Ci Sr-90 per km ² deposited either in the plow layer or in the root mat horizon, and in the surface 2 cm of grassland soil	45
11.	Expected content of Cs-137 in Swedish crops at a total deposition in the plow-layer of 1 Ci Cs-137 per km ²	47
12	Expected content in Swedish milk of Cs-137 originating from 1 Ci Cs-137 per km ² deposited either in the plow-layer or in the root mat horizon and in the surface 2 cm of the grassland soil	48
13	Values of growth rate (K) and consumption rate (R) for permanent pasture during the 1964 grazing season	56
14	Average concentration of radionuclides in air and pasture grass from 5-12-64 to 10-6-64	57

LIST OF TABLES (cont'd.)

<u>Table No.</u>		<u>Page</u>
15	Quantities of ammonium acetate extractable radionuclides in pasture soil, study farm, 1964-1965	59
16	Values of k_a , k_r and the corresponding values of σ_A for the study farm pasture grass from April 21 to October 6, 1964	63
17	Values of Δ and σ_A for comparison between theory and experiment	67
18	Relative contributions of dry and wet deposition to the total radioactivity on pasture grass, study farm, April 21 to October 6, 1964	71
19	Values of K_a and K_r calculated from Eq. (15) for various values of t_r removal half life for cerium-praseodymium-144	73
20	Dry matter digestibility factor	80
21	Summary of calcium and strontium-90 measurements during the period October 1964 to October 1965	85

1 B.	Average air concentrations in Tecumseh, Michigan, 1964-65	95
2 B.	Deposition rate measurements in Tecumseh, Michigan, 1964-65	99
3 B.	Results of soil density measurements during soil survey of study farm, October 26-29, 1964	103
4 B.	Radionuclide concentrations in three depths of soil on study farm, October 26-29, 1964	104
5 B.	Ammonium acetate extractable strontium-90 concentrations for selected samples in soil survey, study farm, October 1964.	107
6 B.	Yields and radionuclide concentrations of pasture grass and sudan grass during the grazing season, 1964.	108
7 B.	Concentrations of cesium-137 in each feed	110
8 B.	Concentrations of strontium-90 in each feed	113

LIST OF TABLES (cont'd.)

<u>Table No.</u>		<u>Page</u>
9 B.	Cesium-137 concentrations in, and average daily outputs of milk, urine and feces	115
10 B.	Concentrations of strontium-90 in milk, urine and feces	118
11 B.	Average daily quantities of feed	120
12 B.	Concentrations of potassium in each feed	122
13 B.	Concentrations of potassium in milk, urine and feces	124
14 B.	Concentrations of calcium in each feed	126
15 B.	Concentrations of calcium in milk, urine and feces.	128

LIST OF FIGURES

	Page
1. Important steps in the transmission of radioactive material through the food chain to man.	3
2. Average weekly air concentrations of selected radio-nuclides at Tecumseh, Michigan in 1964 and 1965.	12
3. Measured and theoretical reduction in σ_{Δ} for deposition predictions.	19
4. Layout of the study farm.	22
5. Soil map of the study farm.	26
6. Comparison of Ru-103, and Ru-Rh-106 as measured in rain (cumulative), to that measured on the ground, 1961-1962.	36
7. Comparison of Ce-141 and Ce-Pr-144 as measured in rain (cumulative), to that measured on the ground, 1961-1962.	37
8. Comparison of Zr-Nb-95 as measured in rain (cumulative), to that measured on the ground, 1961-1962	38
9. Comparison between theory and experiment for Ce-Pr-144 and Cs-137 concentrations in grass.	64
10. Comparison between theory and experiment for Sr-90 concentrations in grass.	65
11. Comparison between theory and experiment for Mn-54 concentrations in grass.	66
12. Comparison between theory and experiment for Cs-137 concentrations in milk, urine and feces.	82
13. Comparison between measured outputs of Cs-137 and Sr-90 in feces and in milk.	86

CHAPTER I. INTRODUCTION

This report presents the results of a four-year study of the movement of fallout radionuclides in the milk-food chain. The study was made on a commercial dairy farm near Tecumseh, Michigan. Three progress reports (1-3) concerning the study have been issued, but since these progress reports are not readily available, this present report includes all the important data, methods and results generated in the study.

Fig. 1 is a generalized flow diagram (4) of the pathways which radioactive materials may take through the biosphere. The pathway considered in this study is indicated by the shaded areas and heavy, solid lines in Fig. 1.

The purpose of this study was to develop mathematical models capable of describing the behavior of fallout radionuclides in the milk-food chain. As far as possible, the development of the models was kept separate from the experimental program at the dairy farm, in order that the experimental data might be used to test and verify the models. Since it was not possible to make this separation complete in every case, some of the models given here still require independent verification.

Chapters II, IV and V consider individual links in the food chain. Each chapter contains sections on theory, experimental design, results, and a comparison between theory and experiment.

An almost overpowering mass of data has been generated in this study. As these data have been manipulated, analyzed and fitted, they have suggested relations and extensions which even the delays in completing this report did not permit to be explored. The strikingly large dry deposition of fresh fallout as compared to older fallout, and the differences between the deposition on alfalfa and that on sudan grass are but two examples. It is hoped that in time, addenda to this report will consider such ramifications.

Fig. 1. Important steps in the transmission of radioactive material through the food chain to man (4). The shaded areas show the portion of the chain considered in this study.

CHAPTER II. RELATION BETWEEN DEPOSITION AND CONCENTRATION IN AIR

A. Theory

The large particles produced in a nuclear detonation fall to the ground near the point of detonation; only those particles in the micron and submicron range can stay aloft long enough to contribute to global fallout. It is reported (11) that the major part of the nuclear debris (assumed to have a density of 2 g/cc) in the stratosphere is associated with particles between 0.04 and 0.3 μ in diameter. However, in air close to the earth's surface, nuclear debris has been variously reported to reside on particles of density 2.13 g/cc with diameters greater than 0.7 μ (12), on particles of density 1.8 g/cc with diameters between 0.3 and 1.1 μ (13), and 88 per cent on particles with diameters less than 1.75 μ (14). In all these cases the stratosphere was the source of the observed radioactivity. Thus, it appears that the major portion of nuclear debris in the troposphere eventually attains a size distribution essentially the same as that of the aerosol normally present in the troposphere, and that this debris resides on particles with a density of about 2 g/cc and with diameters less than 2 μ .

1. Wet deposition

Rain and snow bring particles and gases from the troposphere to the surface of the earth by several processes which are not thoroughly understood. It is convenient to consider these wet

deposition processes in two categories: washout and rainout.

Raindrops falling from the base of a cloud, where they are formed, to the earth may capture particles by impaction. This process is referred to as washout. The efficiency of washout for removing particulate matter from the atmosphere is a function of the size, density, and wettability of the particles (15), and of raindrop size (5). Since the sizes of raindrops tend to increase as the rate of rainfall increases, washout efficiency is also a function of rainfall rate (6,7). The calculations and experiments of Chamberlain (8), Engelman (9) and Greenfield (10) lead to the conclusion that washout is ineffective in scavenging particles with diameters less than 2μ from the troposphere. Since, as was shown above, nuclear debris in the troposphere is generally less than 2μ , washout is not an important process in the wet deposition of fallout.

Raindrops, as they are being formed in a cloud, may capture particles and subsequently carry them to earth. Five such processes, referred to as rainout, have been considered: impaction (see above), diffusiophoresis (16), Brownian diffusive capture (10), turbulent diffusive capture (10), and direct condensation of water vapor on particles (16, 17). Of these, the last appears to be the principal scavenging process.

2. Dry deposition

The deposition of airborne radioactivity on the earth's surfaces by processes other than rain scavenging is referred to as

dry deposition. Chamberlain (8) has invoked the term deposition velocity to describe the dry deposition of radioactive materials. This empirical term is defined by the following expression.

$$v_d = \frac{D_a}{C_a} \quad (1)$$

where v_d = deposition velocity, m/day
 D_a = dry deposition rate, pCi/m²-day
 C_a = concentration in air, pCi/m³, or μ Ci/cc

The units given above are the ones used in the measurements of this report. Deposition velocity is commonly expressed in cm/sec. Multiplying v_d in m/day by 1.16×10^{-3} converts it to cm/sec.

The concentration of airborne particles changes with elevation for two reasons: the wind speed decreases as one moves closer to the ground, and the surface of the ground acts as a sink for the airborne material. For this reason it is necessary to specify the elevations of both the point at which air concentration was measured, and of the surface on which deposition was measured. In the work reported here, air concentrations and surface depositions were measured 0.5 m above ground surface, unless otherwise stated.

Expressions for the deposition of airborne material on vegetation are discussed in Chapter IV.

3. Relations from previous measurements

In a previous report (19) we have given the expression below to relate deposition to air concentration.

$$D = C_a H (a - e^{-br}) \quad (2)$$

where D = total wet and dry deposition rate, pCi/m²-day

C_a = air concentration, pCi/m³

H = empirical constant, m/day

a = " " , no units

b = " " , day/inches of rain

r = rainfall rate, inches of rain/day

Data obtained from the environmental survey for the Enrico Fermi Atomic Power Plant on Lake Erie near Monroe, Michigan were used to obtain the average values for the constants given below (19). Deposition and air concentration were measured for successive 4-week periods from December 1962 to June 1964 within an area of about 500 square miles.

$$a = 1.05$$

$$b = 3.1 \text{ day/inches of rain}$$

$$H = 3.8 \times 10^3 \text{ m/day}$$

The data referred to above (19) and similar unpublished data obtained at Tecumseh, Michigan during 1962 and 1963 can also be fitted by the following expression.

$$D = C_a j (f + gr) \quad (3)$$

where j = empirical constant, m/day

f = " " , no units

g = " " , day/inches of rain

D , C_a , and r as in Eq. (2).

The constants in Eq.(3) took on different values, depending on whether the fallout was old, or fresh. For the purpose of this distinction, fallout was considered fresh if barium-140 was present in either air or in deposited radioactivity. The values for the constants in Eq.(3) were as follows.

	<u>old fallout</u>	<u>fresh fallout</u>
j	10^4	10^4
f	0.02	0.1
g	1.15	3.4

Note that the deposition rate, $\underline{D}$, in both Eq. (2) and Eq.(3) is the total of both wet and dry deposition, i.e.

$$D = D_r + D_a$$

where D_r = wet deposition rate, pCi/m²-day

D_a = dry deposition rate, pCi/m²-day

The dry deposition rate may be obtained from either equation by substituting $r = 0$. In the case of Eq.(3) this gives $D_a = C_a j f$, and the deposition velocity, from Eq.(1) is simply $v = j f$.

Substitution of the observed constants in this expression gives for old fallout, $v_d = 0.23$ cm/sec, and for fresh fallout, $v_d = 1.2$ cm/sec. It appears that during periods of fresh fallout relatively more dry deposition occurs for a given air concentration than occurs during periods when only old fallout is present.

B. Experiment

1. Concentration of radioactivity in air

a. Method

Air was drawn continuously at the rate of about 1.5 cfm (700 cc/sec) first through a membrane filter (average pore size, 0.8μ), and then through a glass fiber filter impregnated with activated charcoal. The sampling head was 0.5 m above the ground. The unit was operated for 7 days (4.3×10^8 cc) both filters were removed from the sampling head and replaced with fresh filters; the filters which had been removed were taken to the laboratory for analysis. Seven days after the filters had been removed from the sampling head, they were both counted for beta activity and for gamma activity.

The beta counter was a low background, thin window, gas flow Geiger counter (Instrument and Development Product Co. Planchet-master). The efficiency of this counter for strontium-yttrium-90 beta particles was 37%. All samples were counted for a period long enough so that the standard deviation due to counting was less than 5% of the net count.

The count of gamma activity was performed on a 400 channel gamma ray spectrometer (Radiation Instrument Development Laboratory Model 34-12) with a 3x3 inch sodium iodide crystal. The activities of individual radionuclides were obtained from a matrix analysis of the mixed spectrum.

Fresh fallout was not present after mid-1964, and the gamma spectrometer was not sufficiently sensitive to assay individual isotopes in single samples. During this period, samples representing a combined air volume ten times that of normal samples (i.e. about 4.3×10^9 cc of air) were collected in the Fermi environmental survey, about 40 miles from the study farm. These combined samples were counted for beta and gamma activity by the same methods described above. Regression equations of the ratios of the activity of each gamma-emitting radionuclide to the total beta activity were derived as a function of time. The total beta concentrations measured at the study farm were then multiplied by the ratio given by the appropriate regression equation to obtain an estimate of the concentration of each gamma-emitting radionuclide in the air at the study farm. The validity of the regression equation method was verified in 1965, when a high-volume air sampler was installed at the study farm.

The sensitivity of the strontium-90 analysis (see Appendix A) was inadequate for the normal weekly air samples. Consequently, four successive weekly samples were pooled and analyzed as a composite sample.

b. Results

Table 1B, Appendix B, gives the air concentration data obtained in the work reported here. Weekly air concentrations are given for the following forms of radioactivity: total beta, cerium-praseodymium-144, cerium-141, antimony-125, cesium-137,

zirconium-niobium-95, manganese-54, barium-lanthanum-140, and iodine-131. Four-week air concentrations are given for strontium-90.

Fig. 2 shows the average weekly concentrations of cerium-praseodymium-144, cesium-137, zirconium-niobium-95, and barium-lanthanum-140 in 1964 and 1965. By virtue of their different half-lives, the concentrations of the radionuclides selected for Fig. 2, indicate strikingly the age of the nuclear debris in the study farm environment.

2. Deposition

a. Method

The deposition collector was a polyethylene funnel set in an 8-liter polyethylene jug. Until June 29, 1964 funnels with a diameter of 19.4 cm were used; thereafter, funnels with a diameter of 26.7 cm were used. After 7 days of collection, the funnel was rinsed with a known volume of concentrated nitric acid. The jug, containing the 7-day precipitation and the nitric acid rinse, was sealed and taken to the laboratory for analysis. The same funnel was placed in fresh jug for the following week's collection. Each fresh jug contained 25 mg of zirconium carrier to minimize the adherence of radioactive material to the inner surface of the jug.

In the laboratory, the volume of liquid in the jug was measured. The volume of nitric acid rinse was subtracted to obtain the volume

Fig. 2. Average weekly air concentrations of selected radionuclides at Tecumseh, Michigan in 1964 and 1965.

of rain which had fallen into the funnel. The contents of the jug were transferred to a 5,000 cc beaker; the jug was rinsed several times with concentrated nitric and hydrochloric acids, and these rinses were added to the beaker. The contents of the beaker were then evaporated almost to dryness. The residue in the 5,000 cc beaker was transferred quantitatively to a 150 cc beaker and once again evaporated to near dryness. Finally, this residue was transferred to a 5-cm diameter planchet and dried.

The planchet was counted for beta and gamma activity in the same manner used for airborne dust filters. For those samples with concentrations below the detection limit of the gamma spectrometer, the individual radionuclides were estimated by the same ratio method used for airborne concentrations.

b. Results

Table 2B, Appendix B, gives the weekly deposition data obtained in the work reported here.

3. Rainfall

The quantity of rain which fell during each 7-day sampling period was determined from the deposition collector. A standard, meteorological rain gage is 8 inches (20 cm) in diameter and has a short cylindrical section atop the conical portion which funnels the rain into the collection vessel. Since both deposition collectors used in the work reported here differed in size and shape from the standard rain gage, the possibility of error

existed. Table 1 shows the results obtained by collecting rain simultaneously in a standard rain gage and the two sizes of funnels placed side by side. For the purposes of this study, the differences in Table 1 are insignificant.

Evaporation of the collected rain during the 1-week collection period is another possible source of error. Table 2 shows the results obtained by collecting rain in two 26.7 cm funnels, side by side, one at 1-week intervals, the other at 4-week intervals. The data in Table 2 indicate that the error introduced by evaporation is insignificant.

C. Comparison of Theory and Experiment

Throughout this study, theory and experiment are compared by the method described below. The use of the method is illustrated for calculated and measured depositions.

A statistic, Δ , is used to compare the weekly values of deposition computed from Eq. (3), in which the constants for old fallout have been substituted. This is the deposition predicted by theory.

$$D_t = C_a \times 10^4 (0.02 + 1.15 r) \quad (3a)$$

The statistic Δ is computed as follows

$$\left. \begin{aligned} \Delta &= (D_e/D_t - 1) \text{ when } D_e \geq D_t \\ \Delta &= (D_t/D_e - 1) \text{ when } D_e < D_t \end{aligned} \right\} \quad (4)$$

TABLE 1. Comparison of Rainfall Measurements with
Different Collectors

<u>Collection Period</u>	<u>Inches of rain indicated by the collector</u>		
	<u>standard 8-inch gage</u>	<u>19.4 cm funnel</u>	<u>26.7 cm funnel</u>
7/6/64 to 11/3/64 (22 weeks)	11.00	-	12.14
5/21/65 to 10/7/65 (19 weeks)	15.66	16.28	-
5/21/65 to 11/27/65 (26 weeks)	18.08	-	18.11

TABLE 2. Comparison of 1-week and 4-week Collections
of Rainfall

<u>Four-week Period, Ending</u>	<u>Inches of Rain</u>	
	<u>Sum of 4 1-week collections</u>	<u>4-week collec- tion</u>
6/10/65	2.57	2.96
7/8/65	3.45	2.89
8/5/65	2.39	2.33
9/30/65	3.26	3.36
10/28/65	2.90	2.89
11/25/65	1.56	1.77
Total	16.13	16.20

where D_t is given by Eq. (3a)

D_e is the experimentally measured deposition.

This statistic was found to be normally distributed about a mean of 0.027 with a standard deviation of 0.94 for the 90 comparisons between computed and measured depositions of old fallout. The hypothesis that the distribution of Δ is normal is accepted at a significance level of 0.05. Two values of Δ , -8.9 and + 9.3, were discarded on the assumption that these large values resulted from errors in sample analysis.

The first criterion for goodness of fit between theory and experiment is that the mean value of Δ be approximately zero, i.e.

$$\bar{\Delta} = \frac{1}{N} \sum_{i=1}^N \Delta_i \approx 0 \quad (5)$$

where N = number of comparisons

In the case of the deposition comparison, the mean value of Δ is 0.027, which is not significantly different from zero.

Another criterion for goodness of fit between theory and experiment is that the standard deviation of the values for Δ , σ_{Δ} , be a minimum for $\bar{\Delta} = 0$. This criterion is unnecessary for the deposition comparison because the constants in Eq. (3a) have been established without reference to the present experimental data. However, this is not the case for comparing the theoretical and experimental results of concentrations in grass. In this study it has been assumed that the sample standard deviation is the true population standard deviation.

The standard deviation of Δ is used to estimate the error associated with a single theoretical value of deposition as follows. It is assumed that the measured values of deposition are the real values. Despite measurement errors, these are the best estimates of the true values of deposition we have. Provided the values of Δ are distributed normally, the following statement of probability is valid.

$$P [- z \sigma_{\Delta} \leq \Delta \leq z \sigma_{\Delta}] = C \quad (6)$$

where C = probability that the true value of Δ lies between $\pm z \sigma_{\Delta}$, i.e. the confidence level
 z = number of standard deviations corresponding to the confidence level, C .

For example, if $z = 1.96$, then the probability that the real value of Δ falls between $\pm 1.96 \sigma_{\Delta}$ is 0.95.

Eq. (6) may also be written in the following form

$$P \left\{ [(-z \sigma_{\Delta} \leq \Delta) \text{ and } (\Delta \leq z \sigma_{\Delta})] \right\} = C$$

Substitution of Eq. (4) for Δ gives

$$P \left\{ \left[-z \sigma_{\Delta} \leq - \left(\frac{D_t}{D_e} - 1 \right) \right] \text{ and } \left[\left(\frac{D_e}{D_t} - 1 \right) \leq z \sigma_{\Delta} \right] \right\} = C$$

which may be rearranged to give

$$P \left\{ \left[-D_e \leq - \frac{D_t}{(1+z\sigma_{\Delta})} \right] \text{ and } [D_e \leq D_t (1+z\sigma_{\Delta})] \right\} = C$$

changing the signs on both sides of the first bracketted inequality,

reverses the inequality and gives the following expression for the range of the computed values within which the real value, D_e , is expected to fall.

$$P \left\{ \frac{D_t}{(1+z\sigma_\Delta)} \leq D_e \leq D_t (1+z\sigma_\Delta) \right\} = C$$

Therefore, one can say that the true value of deposition will fall within the following range 95% of the time

$$\frac{D_t}{2.84} \leq D \leq 2.84 D_t$$

where D_t = theoretical value from Eq. (3a)

D = true value

$$2.84 = 1 + z\sigma_\Delta = 1 + 1.96 \times 0.94$$

If differences between theory and experiment are random, the difference between the average of many computed values and the average of many measured values should be less than the difference between individual computed and measured values. Theoretically, the standard deviation should decrease as $(1/n)^{\frac{1}{2}}$, where n is the number of values averaged. Fig. 3 shows that the standard deviation for deposition comparisons does decrease in this way, and thus supports the contention that differences between theory and experiment are randomly distributed.

Thus, the general expression for estimating the error associated with predictions from the theoretical model for deposition, i.e. Eq. (3a), is

Fig. 3. Measured and theoretical reduction in σ_{Δ} for deposition predictions.

$$\frac{D_t}{(z\sigma_{\Delta}/n^{\frac{1}{2}} + 1)} \leq D \leq D_t (z\sigma_{\Delta}/n^{\frac{1}{2}} + 1) \quad (7)$$

and, 95% of the time, the predicted sum of four consecutive weekly deposition values will lie within the interval

$$D_t/1.92 \leq D \leq 1.92 D_t$$

CHAPTER III. DESCRIPTION OF STUDY FARM

A. General Description

The farm chosen for the study is the dairy farm owned by Arthur Eaton. The farm is located about 2 miles east of downtown Tecumseh, Michigan. Tecumseh is a community of about 10,000 people in which a large medical study is being carried out by the University of Michigan for the National Institutes of Health. It was thought that the study of fallout movement on the Eaton farm could be extended to its movement through the population of Tecumseh. Such an extension is probably unnecessary because many studies of this kind have been and are being carried out.

Fig. 4 shows the layout of the Eaton farm. The farm is composed of 21 fields with a total of about 230 acres. The areas and planting histories of each field are listed in Table 3. Table 4 shows the histories of fertilization of each field, and Table 5 shows the crop yields during the study period.

B. Soil Mapping and Analysis

Mr. Glenn Bedel of the United States Department of Agriculture, Soil Conservation Service, characterized the soils on the farm in May 1964. Samples of top soil, subsoil and underlying soil were visually investigated and analyzed to determine soil type. Fig. 5 shows the resulting soil map. After the soil map was prepared, Dr. Lynn Robertson, Michigan State University, soil consultant for the study, collected samples from each major soil classification

Fig. 4. Layout of the study farm.

TABLE 3. Areas and Planting History of the Fields of the Study Farm

Field	Area	Planting History				
		1961	1962	1963	1964	1965
A	10(40000)	Wheat	Corn	Corn	Oats	Wheat
B	5(20000)	Soybeans	Oats	Wheat	Wheat	Alfalfa (G.C.) **
C	10(40000)	Wheat	Alfalfa	Alfalfa	Alfalfa	Alfalfa (G.C.)
D	11(45000)	Oats	Wheat	Corn	Corn	Soybeans
E	6.3(26000)	Pasture	Pasture	Pasture	Pasture	Sudan Grass (G.C.)
F	9(36000)	Corn	Corn	Wheat	Sudan	Corn
G	8(32000)	Oats	Wheat	Corn	Corn	Wheat
H	7(28000)	Oats	Wheat	Corn	Corn	Soybeans
L	14(57000)	Alfalfa	Alfalfa	Alfalfa	Corn	Corn
M	5(20000)	Wheat	Oats	Oats	Wheat	Wheat
N	9(36000)	Oats	Alfalfa	Alfalfa	Alfalfa	Alfalfa
O	20(81000)	Wheat	Wheat	Wheat	Corn	Corn
P	16(65000)	Alfalfa	Alfalfa	Alfalfa	Corn	Corn
R	15(61000)	Oats	Corn	Wheat	Alfalfa	Alfalfa
S	6(24000)	Corn	Oats	Wheat	Wheat	No Crop
T	6(24000)	Oats	Wheat	Alfalfa	Alfalfa	Alfalfa
U	11(45000)	Corn	Oats	Wheat	Wheat	Corn
V	19(77000)	Alfalfa	Corn	Corn	Corn	Corn
W	11(45000)	Corn	Corn	Soybeans	Wheat	Corn
X	11(45000)	Wheat	Corn	Corn	Oats	Wheat
Y	17(69000)	Soybeans	Soybeans	Corn	Corn	Soybeans

* Acres (square meters)

** G.C.: Green chop

TABLE 4. Fertilization History of Each Field of the Study Farm

FIELD	1964			1965		
	DATE	KIND	QUANTITY*	DATE	KIND	QUANTITY*
A	9-24	5-20-20	250	9-24	5-20-20	300
B	8-10	5-20-20	200	---	-----	---
C	---	-----	---	9-25	5-20-20	300
D	5-8	12-12-12	300	6-10	5-20-20	200
E	2-18	Manure**	18000	6-10	5-20-20	300
F	6-15	12-12-12	300	6-20	5-20-20	300
G	5-15	12-12-12	250	7-12	Nitrogen	100
	9-64	5-20-20	300	----	-----	---
H	5-6	12-12-12	300	6-10	5-20-20	200
L	5-5	5-20-20	300	5-10	5-20-20	300
M	9-27	5-20-20	300	7-12	Nitrogen	100
N	----	-----	---	9-1	5-20-20	300
O	5-1	5-20-20	300	1-20	Manure	18000
				5-6	5-20-20	300
				7-13	Nitrogen	100
P	4-15	Manure	18000	5-6	5-20-20	300
	5-7	5-20-20	200	7-12	Nitrogen	100
R	1-10	Manure	18000	1-25	Manure	18000
S	9-1	5-20-20	300	8-2	5-20-20	300
				9-4	Lime	5000
T	12-20	Manure	18000	---	-----	---
U	8-10	Manure	18000	5-6	5-20-20	300
				6-20	Nitrogen	100
V	5-15	5-20-20	300	5-15	5-20-20	300
	12-24	Manure	18000			
W	---	-----	---	5-1	Manure	18000
				6-1	5-20-20	300
X	4-10	5-20-20	300	9-1	Lime	5000
	9-26	6-24-12	250			
Y	5-8	5-20-20	300	6-2	5-20-20	200

* Pounds per Acre

** Manure expressed in Natural Weight

TABLE 5. Crop Yields for the Various Fields During the Study Period.

Field	Crop	1964			Crop	1965		
		Date Planted	Date Harvested	Yield*		Date Planted	Date Harvested	Yield*
A	Oats**	4-10-64	7-23-64	0.27	Wheat***	9-24-64	7-15-65	0.27
B	Wheat	9- -63	7-18-64	0.34	Alfalfa	8-10-64	5-15-65	G.C., 4 cuts
C	Alfalfa	1962	6-16-64	0.48	Alfalfa	1962	---	G.C., 4 cuts
			7-20-64	0.18				
			9-2-64	0.45				
D	Corn****	5- -64	11-10-64	0.50	Soybeans	6-10-65	12-8-65	----
E	Pasture	1961	--	--	Sudan Grass	6-10-65	---	G.C., 4 cuts
			Grazed					
F	Sudan Grass	6-15-64	7-6 to 9-20	--	Corn	6-20-65	10-10-65	0.30
G	Corn	5-15-64	9-15-64	0.37	Wheat	9-30-64	7-14-65	0.14
H	Corn	5-15-64	10-5-64	0.43	Soybeans	6-10-65	11-4-65	----
L	Corn	5-5-64	10-10-64	0.50	Corn	5-10-65	12-10-65	0.53
M	Wheat	9-26-63	8-1-64	0.34	Wheat	9-27-64	7-28-65	0.31
N	Alfalfa	1962	6-27-64	0.54	Alfalfa	1962	6-10-65	0.52
			7-27-64	0.18			7-19-65	0.36
			9-20-64	0.20			9-16-65	0.23
O	Corn	5-1-64	10-1-64	0.56	Corn	5-6-65	11-25-65	0.70
P	Corn	5-7-64	10-8-64	0.50	Corn	5-6-65	12-10-65	0.70
R	Alfalfa	9-25-63	6-22-64	0.58	Alfalfa	9-25-63	6-10-65	0.53
			7-29-64	0.18			7-20-65	0.28
			(2 cuttings only)				9-20-65	0.31
S	Wheat	9-26-63	8-2-64	0.24	Alfalfa	9-1-64	6-12-65	0.22
							(1 cutting only)	
T	Alfalfa	8-2-62	6-19-64	0.77	Alfalfa	8-2-62	6-4-65	0.55
			7-20-64	0.67			7-12-65	0.67
			(2 cuttings only)				9-2-65	0.55
							(4th cutting G.C.)	
U	Wheat	9-27-63	8-2-64	0.24	Corn	5-6-65	11-25-65	0.50
V	Corn	5-15-64	10-11-64	0.34	Corn	5-15-65	11-20-65	0.28
W	Wheat	9-28-63	8-2-64	0.34	Corn	6-1-65	12-10-65	0.28
X	Oats	4-8-64	7-21-64	0.26	Wheat	9-26-64	7-18-65	0.34
Y	Corn	5-8-64	10-11-64	0.34	Soybeans	6-2-65	11-12-65	----

* Yield in Kg/m² Multiply by 7.9x10⁴ to obtain lbs/acre

*** Weight based on 60 lbs/bushel

** Weight based on 32 lbs/bushel

**** Weight based on 50 lbs/bushel

FIG. 5. SOIL MAP OF STUDY FARM. ARTHUR EATON
FARM, LENAWEE COUNTY, MICHIGAN. SOIL
MAPPED BY U.S. DEPT. OF AGRICULTURE,
SOIL CONSERVATION SERVICE, MAY 1964.
(Legend on next page)

Legend for Fig. 5

250B1	Metea loamy sand, 2 to 6% slope, slight erosion
350C2	Owosso sandy loam, 6 to 12% slope, moderate erosion
511A0	Blount silt loam, 0 to 2% slope, no apparent erosion
540B1	Morley silt loam, 2 to 6% slope, slight erosion
540B2	Morley silt loam, 2 to 6% slope, moderate erosion
540C2	Morley silt loam, 6 to 12% slope, moderate erosion
540C3	Morley silty clay loam, 6 to 12% slope, severe erosion
630A0	Kibbie silt loam, 0 to 2% slope, no apparent erosion
631A0	Kibbie silt loam, 0 to 2% slope, no apparent erosion
677A0	Matherton loam, 0 to 2% slope, no apparent erosion
891A0	Colwood fine sandy loam, 0 to 2% slope, no apparent erosion
8702A0	Sebewa loam, 0 to 2% slope, no apparent erosion
8811A0	Pewamo silt loam, 0 to 2% slope no apparent erosion
8812A0	Pewamo loam, 0 to 2% slope, no apparent erosion
761A0	Metamora sandy loam 0 to 2% slope, no apparent erosion
761B1	Metamora sandy loam 2 to 6% slope, slight erosion

area and performed on them a standard agricultural chemical analysis for the available elements, calcium, phosphorus and magnesium. Table 6 shows the results of these analyses. The sample designation corresponds to the field from which the sample was taken. The remaining numbers in the sample designation correspond to the soil type in the map and legend of Fig. 5. The predominant soil on the farm is a silty loam.

C. Radionuclide Survey

In October, 1964 a soil sampling program was carried out to determine the distribution of fallout materials on the farm. Borings, 7.5 cm in diameter, were made to three depths at 1,170 locations. Samples were collected at depths of 0 to 10 cm, 10 to 20 cm and 20 to 30 cm. The borings were composited to make 117 samples representing each depth and soil type on each field. Duplicates of each sample were analyzed by gamma spectrometry. The details of the method of analysis are given in the next section.

Table 3-B in Appendix B shows the results of density measurements in each of the three depths. The average density for all samples was 1.6, 1.8, and 2.0 gm/cm³ in the depths 0-10, 10-20, and 20-30 cm, respectively.

Table 4-B in Appendix B shows the soil concentration of the radionuclides cerium - praseodymium-144, cesium-137 and manganese-54, as well as potassium. The concentrations of these radionuclides were less than the detection limits at the depth of 20 to 30 cm.

TABLE 6. Results of Chemical Analysis of Soils in the Various Fields of the Study Farm (Analyses Performed at Michigan State University)

FIELD AND SOIL TYPE	pH	Exchangeable Elements**		(Pounds per Acre)***		Lime Requirement (Tons per Acre)
		P	K	Ca	Mg	
A761	5.9	057	136	1331	240	1.5
B511	6.1	078	196	2496	424	2.5
B540	6.1	115	208	2496	384	2.5
C511	6.2	016	176	2288	280	2.0
C540	6.2	022	184	2496	344	2.0
D540	6.2	036	184	2600	296	2.0
D511	5.9	046	168	2080	272	2.0
E511	6.6	053	488	3598	408	0.0
E8811	6.8	038	368	4992	512	0.0
F511	6.6	028	240	3390	368	0.0
F8811	6.1	030	436	4784	608	2.5
G630	6.6	080	280	4368	448	0.0
G8811	6.8	064	480	7280	640	0.0
H630	5.9	046	244	2704	296	3.5
H8811	6.7	076	360	7280	720	0.0
L511	6.6	016	160	3016	296	0.0
L540	5.8	022	224	3016	312	1.5
M540	6.0	036	184	2392	344	2.5
N511	6.0	043	184	2288	312	2.5
N540	6.1	066	196	2392	256	2.5
O631	5.8	070	120	1560	128	1.5
O677	6.7	044	184	4160	272	0.0
O891	5.9	051	216	2288	312	3.5
P511	5.6	018	196	2704	448	3.5
P540	5.8	021	160	2392	328	3.0
R8812	6.6	059	348	4680	584	0.0
S250	5.8	051	196	1664	160	3.0
S350	6.7	029	208	4472	136	0.0
S511	5.5	056	160	1560	128	3.5
S540	7.0	033	168	3952	128	0.0
S8812	6.6	070	348	5408	448	0.0
T511	5.6	059	120	2080	224	2.0
T870	6.3	042	208	2808	272	2.0
T8812	6.0	046	184	2808	328	2.5
U677	6.0	089	168	1331	144	2.0
V1540	5.3	046	168	1560	192	3.0
V2540	5.1	038	196	1872	224	4.0
W511	5.2	042	168	1456	160	3.5
X511	5.5	035	168	1664	224	3.0
X540	5.2	045	192	1331	208	3.0
Y511	5.2	038	152	1664	184	4.0
Y540	5.4	045	200	2080	240	1.5
Y8812	5.6	040	192	2496	272	2.0

* Letter is field designation (Fig. 4): number is soil type (Fig. 5)

** Ammonium acetate extractable

*** Based on the assumption of two million pounds of soil per acre.

The concentration of strontium-90 extractable by ammonium acetate was determined in selected samples. Table 5-B in Appendix B shows the results. The samples were selected to be representative of the entire farm.

Cesium-137 was chosen for a detailed analysis of the distribution of fallout materials on the farm. The overall distribution on the farm was quite uniform. The average concentration in the 0 to 20 cm depth was 0.335 pCi/gm with a sample standard deviation of 0.0585 pCi/gm or 17.5%. The cesium-137 deposition was even more uniform when calculated on an area basis. The average deposition in the 0 to 20 cm layer was 11.0 pCi/cm² with a sample standard deviation of 1.7 pCi/cm² or 15.5%.

Table 7 shows a comparison between the concentrations of cesium-137 for a different soil types, slopes, severity of erosion and planting histories. The average concentrations decrease as one goes from soils with no erosion to soils with moderate erosion, which is to be expected. However, an analysis of variance shows no significant difference between the three means at a significance level of $\alpha = 0.05$. The cesium-137 concentration in the soil of the pasture and corn fields are higher than that in the soil of the wheat and alfalfa fields, but again an analysis of variance failed to show a significant difference in the means of the four fields. There was also no significant difference between the average concentrations for the different slopes and soil types. No statistical tests were made on the concentrations

TABLE 7. CESIUM-137 SOIL CONCENTRATIONS
FOR DIFFERENT SOIL CONDITIONS AND PLANTING
HISTORIES, STUDY FARM, OCTOBER 1964.

Depth (cm)	Soils With No Apparent Erosion	Soils With Slight Erosion	Soils With Moderate Erosion	
0-10	0.445 pCi/gm	0.406 pCi/gm	0.374 pCi/gm	
10-20	<u>0.254</u>	<u>0.230</u>	<u>0.182</u>	
Average	0.350 $\pm$.064* (26)**	0.318 $\pm$.042 (9)	0.278 $\pm$.059 (4)	
	<u>Soils With 0-2% Slope</u>	<u>Soils With 2-6% Slope</u>	<u>Soils With 6-12% Slope</u>	
0-10	0.445	0.384	0.465	
10-20	<u>0.254</u>	<u>0.224</u>	<u>0.170</u>	
Average	0.350 $\pm$.064 (26)	0.304 $\pm$.056 (11)	0.318 $\pm$.0036 (2)	
	<u>Soils of Sandy Loam***</u>	<u>Soils of Loam</u>	<u>Soils of Silty Loam</u>	
0-10	0.418	0.427	0.436	
10-20	<u>0.222</u>	<u>0.238</u>	<u>0.274</u>	
Average	0.320 $\pm$.027 (5)	0.333 $\pm$.074 (6)	0.355 $\pm$.066 (27)	
	<u>Soils Planted in Wheat****</u>	<u>Soils Planted in Corn</u>	<u>Soils Planted in Alfalfa</u>	<u>Pasture Soil</u>
0-10	0.475	0.411	0.430	0.66
10-20	<u>0.197</u>	<u>0.315</u>	<u>0.150</u>	<u>0.07</u>
Average	0.336 $\pm$.019 (6)	0.363 $\pm$.082 (8)	0.290 $\pm$.053 (6)	0.37 $\pm$.06 (2)

* Sample Standard Deviation

** Number of Samples

*** Sandy Loam: soil types 761, 250, 350 and 891; Loam: soil types 870, 8812 and 677; Silty loam: soil types 8811, 631, 630, 511, 540. See Figure 5.

**** Wheat in fields B, S and U; Corn in fields D, G, H, V and Y; Alfalfa in fields C, N and T; Pasture in Field E. See Figure 4.

in the individual layers. However, it seems likely that the differences in concentration in the 10-20 cm layer for the eroded and sloping soils would be significant. The concentrations in the 10-20 cm layer of the relatively undisturbed soils of the alfalfa and pasture yields are most likely significantly lower than the concentrations in the same layer of the wheat and especially the corn fields.

Table 8 shows a similar comparison between the cesium-137 activities on an area basis. The differences in total cesium activities are not as pronounced on an area basis as those expressed on a concentration basis.

The average concentrations of ammonium acetate extractable strontium-90 were 0.0536, 0.0306 and 0.012 pCi/g in the 0-10, 10-20, and 20-30 cm depth intervals, respectively. Expressed on an area basis the ammonium acetate extractable strontium-90 was 0.856, 0.520 and 0.226 pCi/cm² for the same intervals. The quantity of extractable strontium-90 in the 0-10 cm layer was 53.4% of the total measured while the average quantity of cesium-137 in the same layer was 60.2% of the total measured. The quantity of extractable strontium-90 in the 20-30 cm layer was 14.1% of the total while that of cesium-137 was less than 10.8%. Therefore, it appears that, at least the ammonium acetate extractable strontium-90 is moving down into the soil faster than the cesium-137.

TABLE 8. Comparison of Cesium-137 Soil Radioactivity Levels for Different Soil Conditions and Planting Histories, Study Farm, October 1964.

DEPTH (CM)	SOILS WITH NO APPARENT EROSION	SOILS WITH SLIGHT EROSION	SOILS WITH MODERATE EROSION	
0-10	7.1 pCi/cm ²	6.5 pCi/cm ²	6.27 pCi/cm ²	
10-20	4.4	4.1	3.27	
0-20	11.5 [±] 1.7 [*] (26) **	10.6 [±] 1.2(9)	9.54 [±] 1.8(4)	
0-10 0-20	61.7%	61.4%	65.9%	
	SOILS WITH 0-2 % SLOPE	SOILS WITH 2-6 % SLOPE	SOILS WITH 6-12 % SLOPE	
0-10	7.1	6.1	8.06	
10-20	4.4	4.0	2.84	
0-20	11.5 [±] 1.7(26)	10.1 [±] 1.5(11)	10.9 [±] .26 (2)	
0-10 0-20	61.7%	60.5%	74%	
	SOILS OF SANDY LOAM ***	SOILS OF LOAM	SOILS OF SILTY LOAM	
0-10	7.0	7.4	6.65	
10-20	3.8	4.7	4.15	
0-20	10.8 [±] .70 (5)	11.1 [±] 1.6(6)	10.8 [±] 1.8(27)	
0-10 0-20	65%	66.7%	61.6%	
	SOILS PLANTED IN WHEAT ****	SOILS PLANTED IN CORN	SOILS PLANTED IN ALFALFA	PASTURE SOIL
0-10	7.8	5.8	7.5	11.7
10-20	3.4	5.3	2.7	1.1
0-20	11.2 [±] .96(6)	11.1 [±] 2.4(8)	10.2 [±] 1.2(6)	12.8 [±] 1.1(2)
0-10 0-20	69.6%	52.2%	73.5%	91.5%

* Sample Standard Deviation

** Number of Samples

*** Sandy Loam: Soil Types 761,250,350,and 891; Loam: Soil Types 870,8812, and 677; Silty Loam: Soil Types 8811, 631, 630,511,540. SEE FIG.5.

**** Wheat in Fields B,S andU; Corn in D,G,H,V, and Y; Alfalfa in Fields C,N, and T; Pasture in Field E. SEE FIG. 4.

CHAPTER IV. RELATION BETWEEN FORAGE CONCENTRATION AND DEPOSITION

A. Theory

1. Aerial Deposition

The next link in the chain involves the transport of contamination from air and rain to forage. The rate of change of radioactivity on forage covering a unit horizontal area is given by the following equation

$$\frac{d(A_v)_d}{dt} = a D_r + b D_a - (\lambda_r + \lambda_{ph}) (A_v)_d - R(C_v)_d \quad (8)$$

where $(A_v)_d$ = forage radioactivity per unit ground area due to direct deposition, pCi/m²

D_r and D_a = deposition rate from wet and dry processes respectively, pCi/m²-day

t = time, days

λ_r = removal constant, days⁻¹

λ_{ph} = physical decay constant, days⁻¹

R = consumption rate of vegetation by the herd, kg/m²-day

$(C_v)_d$ = forage radioactivity concentration due to direct deposition, pCi/kg

a and b = fraction of the wet and dry deposition, respectively, intercepted by forage.

For Eq. 8 to be useful in predicting forage concentration, the deposition rates D_r and D_a must be related to the deposition

rate measured by the rain collector. Figures 6-8 show a comparison between the deposition of several radionuclides measured as described in Chapter II, and the deposition found on the ground at the Tecumseh farm from November 1961 through June 1962 (unpublished data). Some fallout had occurred before measurements were begun. With the possible exception of zirconium-niobium-95, the funnel measurements of deposition appear to be a good measure of the deposition on the ground. Valchok (20) has also reported good agreement between accumulated monthly strontium-90 measurements made with steep-walled, stainless steel pots and plastic-funnel, ion-exchange column collectors as compared to strontium-90 levels in soil in New York City. Both Southern Michigan and New York City are areas of moderate precipitation so that most of the radioactivity is deposited by precipitation. However, the previous section shows that dry deposition onto the collection funnel also takes place. Mathematical expressions for wet and dry deposition are considered separately below.

a. Wet Deposition

Eq. (3a) shows that the deposition rate due only to precipitation, (i.e. when $D_a = 0$) may be expressed as follows:

$$D_r = 1.15 \times 10^4 C_a P \quad (9)$$

Only a fraction of D_r is intercepted and retained by forage.

It seems reasonable to assume that the fraction should be related to the rainfall intercepted by the vegetation. The quantity of

Fig. 6. Comparison of Ru-103, and Ru-Rh-106 as measured in rain (cumulative), to that measured on the ground, 1961-1962.

Fig. 7. Comparison of Ce-141, and Ce-Pr-144 as measured in rain (cumulative) to that measured on the ground, 1961-1962.

Fig. 8. Comparison of Zr-Nb-95 as measured in rain (cumulative) to that measured on the ground, 1961-1962.

rain intercepted and retained by vegetation is a function of the rainfall quantity and the diversity of vegetation (21). The smaller the rainfall, the larger the fraction retained; also, the greater the density of vegetation, the larger the fraction retained.

Horton (21) has estimated that the fraction of rainfall retained by pasture grass is given by the following expression

$$\text{Fraction Retained} = \left(\frac{A}{P_s} + B \right) h \quad (10)$$

where: A = a constant equal to the rainfall storage capacity of vegetation per unit height of vegetation

P_s = the quantity of rainfall per shower

B = a constant representing the fraction of rain which evaporates from the vegetation during a shower per unit height of vegetation

h = the height of vegetation

Eq. (10) implies that all rainfall below the storage capacity is intercepted (fraction retained = 1). However, Burgy and Pomeroy (25) have shown that for a grass canopy about 25 cm high the storage capacity was not satisfied by a rainfall equal to the storage capacity. "Rather, storage is satisfied in increments as the rainfall progresses, so that a large portion of the rain reaches the ground even at the beginning of small storms" (25). Eq. (10) is based on the assumption that the vegetation covers 100% of the ground area. It is not known whether the grass plots used by Burgy and Pomeroy met this condition. At any rate, even in their experiments the fraction retained was higher for smaller rainfalls.

For the purposes of this study the term A/P_s in Eq. (10) has been neglected because: 1) it tends to be small in relation to B for weekly rainfalls, 2) we did not sample the deposition during each shower; and 3) it complicates the mathematical expression unduly. Further, we have related the interceptive fraction to grass density rather than to grass height. This is preferable from two standpoints: 1) the leaf area is directly proportional to density, and 2) grass density can be related to the quantity of grass added by growth (K) and that consumed by the dairy herd (R). In terms of Eq. (8) then, the quantity of a radionuclide retained by pasture grass is

$$aD_r = k_r Y \times 1.15 \times 10^4 C_a P \quad (11)$$

where: k_r = fraction retained per unit grass density, m^2/kg

Y = stand of grass at time t , kg/m^2

The value of Y is inferred from measurements and the value of k_r is determined by comparing Eq.(8) to the experimental data.

b) Dry Deposition

Eq. (3a) shows that the dry deposition right on the rain collector can be estimated as $200 C_a \text{ pCi}/m^2$ a day. To use this expression we have to know the relation between dry deposition on the rain collector and on grass. Unfortunately, information on this relation is not available. However, it has been shown (22) that deposition of radio-iodine on pasture grass is directly proportional to grass density (Y).

The constant 200 is the deposition velocity in m/day of the nuclide on the rain collector. One would expect the deposition velocity to be greater on grass because of its much greater surface area per unit horizontal area (23,24).

Lacking quantitative information about the deposition velocity of fallout materials on the study from pasture grass, we are forced again to use the experimental data in terms of Eq. (8). Dry deposition on pasture grass is assumed to follow the expression:

$$bD_a = k_a YC_a \quad (12)$$

where k_a = the deposition velocity per unit grass density,
 $m^3/kg\text{-day}$

C_a = average air concentration, pCi/m^3

The value of k_a is determined by comparing Eq. (8) to the experimental data.

It has been shown (22) that deposition velocity is proportional to friction velocity (u^*) which in turn is proportional to average wind speed ($\bar{u}$). However, this variable is not included and the constant k_a is applicable under conditions of average wind speed which was probably from 5 to 10 miles per hour.

c) Solution of Mathematical Models

To solve Eq. (8) for the gross concentration at any time t , the following relations are used.

$$(A_v)_d = Y(C_v)_d \quad (13)$$

$$\text{and } \frac{dY}{dt} = K - R \quad (14)$$

where K = growth rate of vegetation, $\text{kg/m}^2\text{-day}$

By substituting Eq. (11-14) in Eq. (8), one obtains the following equation for the rate of change of a radionuclide concentration in grass due to direct deposition.

$$\frac{d(C_v)_d}{dt} = (1.15 \times 10^4 k_r P - k_a) C_a - (\lambda_e + K/Y)(C_v)_d \quad (15)$$

where $\lambda_e = \lambda_r + \lambda_{ph}$

and all other symbols are defined above.

Eq. (15) can be solved for the case where the grass is being consumed as fast as it is growing (i.e. for $K=R$) with the following result.

$$(C_v)_d = \frac{(1.15 \times 10^4 k_r P + k_a) C_a}{(\lambda_e + K/Y_o)} \left[1 - e^{-(\lambda_e + K/Y_o)t} \right] + (C_v)_{do} e^{-(\lambda_e + K/Y_o)t} \quad (16)$$

where Y_o = stand of grass when $t=0$

$(C_v)_{do}$ = radionuclide concentration at $t = 0$, pCi/kg

Eq. (15) can also be solved for the case where there is no consumption (i.e. for $R = 0$), as in the case where a stand of alfalfa is used for winter hay. The solution is the following.

$$(C_v)_d = \frac{(1.15 \times 10^4 k_r P + k_a) C_a}{\lambda_e (Y_o + Kt)} \left[(Y_o - K/\lambda_e)(1 - e^{-\lambda_e t}) + Kt \right] + \frac{(C_v)_{do} Y_o e^{-\lambda_e t}}{(Y_o + Kt)} \quad (17)$$

For all other cases, Eq. (15) must be solved numerically.

2. Uptake from Soil

There is no theory describing the uptake of radionuclides from soil sufficiently well developed for this study. However, there is evidence that strontium-90 (32-36) and cesium-137 (34,36) from weapons testing may be taken up from the soil by forage, and several empirical relations have been presented. Fredriksson and Eriksson (36) have estimated the concentrations of strontium-90 in hay and pasture grass as a result of soil uptake for four different soil types. Table 9 is taken from their report. Soil type 1 has "a high degree of calcium saturation" while class 4 has a "calcium deficiency". Table 10 shows the expected concentration of strontium-90 in the milk of cows foraging on the four types of lands (36).

The following equation has been given to predict the concentration (Sr-90/Ca) in milk (32-34). The symbols have been changed to be compatible with this report.

$$C_{ms} = a_{ms} s_s + b_{ms} D_s \quad (18)$$

where: C_{ms} = Ci of Sr-90 per gram of calcium in milk.

s_s = accrued Sr-90 on soil

D_s = current Sr-90 deposition per month (during the pasture season)

TABLE 9. Expected content of Strontium-90 in Swedish Crops at a Total Deposition in the Plow-Layer of 1 Ci Sr-90 per km² (36).

Hay from cultivated land and pasture vegetation*

Land Class	Type of Feed	Expected Content of Sr-90	
		μCi per Kg dry matter	μCi per g Ca
1	Hay of grasses	≤ 8.0	≤ 0.9
	Hay of Clover	≤ 18.0	≤ 0.9
	Pasture grass	≤ 15.0	≤ 1.5
2	Hay of grasses	8.1-10	1.0-1.2
	Hay of clover	19-24	1.0-1.2
	Pasture grass	16-25	1.6-3.0
3	Hay of grasses	11-14	1.3-1.8
	Hay of clover	25-36	1.3-1.8
	Pasture grass	26-50	3.1-7.5
4	Hay of grasses	15-28	1.9-4.5
	Hay of clover	37-65	1.9-4.5
	Pasture grass	51-100	7.6-17.0

* Sr-90 mainly deposited in the root mat horizon and in the surface 2 cm of the grassland soil

TABLE 10. Expected Sr-90 content in Swedish Milk originating from 1 Ci Sr-90* per km² deposited either in the plow layer or in the root mat horizon, and in the surface 2 cm of grassland soil (36).

Land Class	Type of Fed	Expected content of Sr-90	
		μCi per kg milk	μCi per g of Ca
1	Pasture vegetation	≤ 0.17	≤ 0.15
	Hay and roots**	≤ 0.12	≤ 0.11
	Tops (in autumn)	≤ 0.07	≤ 0.06
2	Pasture vegetation	0.18-0.33	0.16-0.30
	Hay and roots**	0.13-0.18	0.12-0.16
	Tops	0.08-0.10	0.07-0.09
3	Pasture vegetation	0.34-0.75	0.31-0.75
	Hay and roots**	0.19-0.27	0.17-0.27
	Tops	0.11-0.16	0.10-0.16
4	Pasture vegetation	0.76-1.50	0.76-1.70
	Hay and roots**	0.28-0.54	0.28-0.60
	Tops	0.17-0.27	0.17-0.30

*The observed value of 0.10 was applied for the ratio (OR) μCi/g of Ca in milk to μCi/g of Ca in feed.

**Equal amounts of hay and roots in the feed on a dry matter basis.

a_{ms} and b_{ms} = constants determined from data for New York State during 1954-1963

$$a_{ms} = 4 \times 10^{-13} \text{ Ci/g Ca per mCi deposited per mi}^2$$

$$b_{ms} = 4.7 \times 10^{-12} \text{ Ci/g Ca per mCi deposited per mi}^2 \text{ per month.}$$

For an accrued quantity of strontium-90 equal to 1 Ci/km^2 , Eq.(18) gives a milk concentration of $0.25 \text{ } \mu\text{Ci/gm of Ca}$, using the New York State values of a_{ms} and b_{ms} . Table 10 shows that this concentration is in the range of values given for pasture grass grown in class 2 soils in Sweden.

Table 11 shows the estimates Frederiksson and Ericksson have given for the expected cesium-137 concentration in hay and pasture grass for four classes of land in Sweden (36). The main characteristic of soil class 1 which results in low cesium-137 uptake is "a high content of clay rich in potassium". We infer from this that classes 2, 3 and 4 contain progressively less clay rich in potassium.

Table 12 shows the expected milk concentrations from cows consuming the forage grown in these four classes of soil.

An equation of the same form as Eq. (18) for strontium-90 has been found to fit observed measurements in the United Kingdom and Sweden (34). The equation, in the terminology of this report, is

$$C_{mc} = a_{mc} s_c + b_{mc} D_c \quad (19)$$

TABLE 11. Expected Content of Cs-137 in Swedish Crops
at a Total Deposition in the Plow-Layer of
1 Ci Cs-137 per km² (36)

Hay and grass from cultivated land and pasture vegetation

Land Class	Type of Feed	Expected content of Cs-137
		$\mu\text{Ci per kg dry matter}$
1	Hay and grass from cultivated land Pasture vegetation	≤ 0.10 ≤ 0.60
2	Hay and grass from cultivated land Pasture vegetation	0.11-0.20 0.61-1.2
3	Hay and grass from cultivated land Pasture vegetation	0.2-0.40 1.3-3.0
4	Hay and grass from cultivated land Pasture vegetation	0.41-1.0 3.1-6.0

* Cs-137 mainly deposited in the root mat horizon and in the surface 2 cm of the grassland soil

TABLE 12. Expected content in Swedish milk of Cs-137 originating from 1 CiCs-137 per km² deposited either in the plow-layer or in the root mat horizon and in the surface 2 cm of the grass-land soil. (36)

LAND CLASS	TYPE OF FEED	EXPECTED CONTENT OF Cs-137 μ Ci per kg MILK
1	Pasture vegetation	≤ 0.05
	Hay and roots *	≤ 0.01
	Tops	≤ 0.10
2	Pasture vegetation	0.06 - 0.10
	Hay and roots *	0.02 - 0.04
	Tops	0.11 - 0.30
3	Pasture vegetation	0.11 - 0.25
	Hay and roots *	0.05 - 0.08
	Tops	0.31 - 0.60
4	Pasture vegetation	0.26 - 0.60
	Hay and roots *	0.09 - 0.25
	Tops	0.61 - 2.0
	Grass from unfertilized old pastures in forests and in mountain districts	0.61 -10.0

* Equal amounts of hay and roots in the feed on dry matter basis.

where C_{mc} = average country-wide concentration of Cs-137 in milk (pCi/l) for the given year.

S_c = total Cs-137 accumulated over the previous two years (mCi/km^2)

D_c = fallout rate of Cs-137 for the given year (mCi/km^2)

$a_{mc} + b_{mc}$ = proportionality constants for Cs-137 fallout for total deposition over the previous two years and over the current year in $(\text{pCi}/\text{l})/(\text{mCi}/\text{km}^2)$.

For the United Kingdom values of a_{mc} and b_{mc} are estimated to be 0.65 and 3.6 respectively.

From a study of powdered milk in the United States, Anderson, et.al (37) found a correlation between the average monthly cesium-137 concentration in milk and the deposition in the previous four months during the grazing season. In terms of Eq.(19), the findings of Anderson, et.al (37) in the United States mean a correlation with recently deposited cesium-137. They also found a correlation between the cesium-137 milk concentration during the barn feeding season and the deposition at the time the forage was grown.

Because the correlation in Eq. (19) was found with cesium-137 deposited only over the previous 2 years and not with the total accrued deposit, as was the case for strontium-90, the implication is that cesium-137 may ultimately become fixed in the soil. The lysimeter experiments of Fredriksson et.al (38) support this implication. However, these lysimeter experiments show that the addition of fertilizer to the soil tends to free the ions of cesium-137 for uptake by plants.

The estimates in Tables 9 and 11 show that the concentration of cesium-137 in vegetation due to uptake from the soil is about 1/10 that of strontium-90.

The empirical relations derived from the above studies are applicable to large geographical areas over relatively long time periods. For week-to-week comparisons of theory and experiment an experimental procedure is used to estimate soil uptake. The procedure is based on a comparison of radionuclide concentration in air to that in vegetation, and is described below.

Ammonium acetate-extractable concentrations of cesium-137, strontium-90 and manganese-54 were also determined to show their availability to plants. However, no direct comparisons between soil and plant concentrations were made from these data.

B. Experiment

During 1964, the herd grazed on a permanent grass pasture and also on a temporary pasture of sudan grass. In 1965, green chop feeding was initiated, and most of the pasture was plowed under and planted in sudan grass. Therefore, Eq. (15) was tested with pasture grass activity only during the 1964 grazing season. Most of the time the yield of the pasture was insufficient to feed the herd so that a hay supplement was used.

1. Methods

a. Grass sample collection

While the cows were on pasture, three 1 m^2 plots were chosen at random and isolated from the herd by electrified fencing each

week. At the end of the week the grass was cut to a height which approximated the height above which the herd usually grazed (about 7 cm). The quantity of grass cut was taken as the growth for the week. When the cows were not on pasture the three 1 m^2 plots were clipped at about grazing level at the beginning of each week and the amount collected at the end of the week was taken as the week's growth.

The grass density measurements made before the herd went on pasture (weeks 16 to 19) represent all the grass, not just that above grazing level. From time to time the density of grass below the grazing level was measured.

Sudan grass was also collected from an area of 1 m^2 . The temporary pasture was divided into three parts. When the herd had consumed all the grass in one part, another part was opened to grazing. The density measurements from week 26 through 30 represent cumulative growth. Subsequent measurements represent the stand of grass that was present at the time of measurement.

b. Soil sample collection

Each week a soil sample from the pasture was collected from an area of 72 cm^2 and 100 cm deep. A cylindrical metal punch was used to collect the sample. The grass and litter were analyzed with the sample.

c. Grass sample analysis

Grass samples were dried at 100°C for 24 hours and weighed. After weighing, the grass was dry-ashed in a muffle furnace at

550°C until the ash was white. The ash was then placed in a glass vial and counted in the 15/16" diameter well of a 3"x3" sodium iodide crystal. The activities of individual radionuclides were determined by a matrix solution of the mixed spectrum. The efficiency for counting each radionuclide was determined as a function of the height of the sample in the well. The coefficients in the matrix were also determined as a function of the height of the sample in the well and also as a function of the sample density. Correction of efficiency for density was found unnecessary.

As in the case of air and deposition samples, each spectrum was corrected for zero intercept and gain. This was accomplished by the following interaction technique. The matrix was solved for all the radionuclides known to be in the sample as though the year's intercept and gain settings were the same as they were when the spectrum of each standard was measured. A composite spectrum was then constructed from the library of standard spectra. The composite and the sample spectra were then superimposed and the differences in the counts in each channel of peaks were determined. Peaks toward the upper and lower end of the spectra were used. For grass, the peaks normally used were those from potassium-40 (1.48 Mev) and cesium-137 (0.66 Mev). If the composite and sample spectra were not in alignment, the differences in channel counts ranged from positive through zero to negative or from negative through zero to positive. The sum of the absolute differences is directly proportional to the degree of misalignment and the direction of misalignment is determined by whether the differences in channel counts goes from positive to negative or negative to positive. If the cause of misalignment is

the zero intercept, the ratio of the positive to negative counts in each peak examined will be equal. If the cause of misalignment is an improper gain setting, the ratio of the positive to negative, or negative to positive counts will be greater for the higher energy peak than the corresponding ratio for the lower energy peak. If both the gain and zero intercept are causes of misalignment there is a unique combination of adjustments to make the composite and sample spectra line up exactly (within the counting error associated with each peak). If the composite and sample spectra were misaligned, the counting rate in each channel of the sample spectrum was divided into 10 equal parts. The spectrum was then adjusted starting at the uppermost channel to move the spectrum to the right (up) and the lower most channel to move the spectrum to the left (down). The spectrum was adjusted by shifting the counts in each channel equally for a zero intercept correction and in proportion to the energy for the gain correction. After a shift was made the matrix was resolved and the comparison between the composite and sample spectrum was again made. The sample spectrum was considered aligned when the absolute difference between the counts in the test peaks of the composite and sample spectra were a minimum. The absolute difference passes through minimum and then increases as the optimum correction is passed.

The correction for gain and zero intercept alignment was not made unless the counts in the test peaks had an error of less than 10% of the net count.

After gamma counting, the vials were stored for subsequent strontium-90 analysis of their contents. The procedure for strontium-90 analysis is given in Appendix A.

d. Soil Sample Analysis

Soil samples were oven dried at 100°C for about 24 hours. Samples were then homogenized with a mortar and pestle and an aliquot of about 1300 g was placed in a 1 liter Marinelli beaker and counted on the gamma spectrometer. The standard spectrum for natural soil radioactivity was taken from deep soil (25 cm or deeper).

An aliquot of about 500 grams was placed in a large funnel and 1,000 ml of ammonium acetate solution was allowed to percolate through the sample under gravity. The ammonium acetate was then evaporated and the residue was placed in a glass vial for gamma counting in the well crystal.

C. Uptake from Soil

1. Method

To estimate the contribution to the vegetation concentration from soil uptake the following procedure was used. It was assumed that the concentration of cerium-praseodymium-144 on vegetation was the result of aerial deposition only, i.e. that none of this radionuclide was taken up from the soil by vegetation. It was assumed further that the total deposition and removal half life on vegetation were the same for all radionuclides. Provided that these assumptions are correct, the ratio of the radionuclide of interest to cerium-praseodymium-144 in air will equal the same ratio on vegetation. If this ratio is higher for vegetation than for air, the increased concentration of the radionuclide of

interest in vegetation is assumed to result from soil uptake.

2. Results

a. Radionuclide Concentrations of Pasture and Sudan Grass

Table 6-B in Appendix B shows the results of the measurements of radionuclide concentration and grass yield for both pasture grass and sudan grass. Each entry is the average of three measurements.

b. Growth Rate and Consumption

Table 13 shows the values of growth rate inferred from the weekly yield measurements and the consumption rate by the dairy herd. The consumption rate was assumed to be equal to growth rate after the first week of grazing in the spring and one week after returning from the temporary sudan grass pasture on week 32. This is a good assumption because the pasture was insufficient for the herd's needs and they ate all the edible grass that was available.

c. Soil Uptake Calculation

Four radionuclides were measurable in grass throughout the 24-week period of grazing (4/21/64 to 10/6/64): cesium-137, strontium-90, manganese-54 and cerium-praseodymium-144. Table 14 shows the average air and vegetation concentrations for the period. Also shown are the ratios of the radionuclide concentrations

TABLE 13. Values of Growth Rate (K) and Consumption Rate (R) for the Permanent Pasture during the 1964 Grazing Season.

Week Number	Growth Rate (Kg/m ² -day)	Consumption Rate (Kg/m ² -day)
17	2.75×10^{-3}	0
18	4.42	0
19	5.37	0
20	3.41	8.63×10^{-3}
21	3.04	3.04
22	1.92	1.92
23	0.98	0.98
24	2.85	2.85
25	3.62	3.62
26	1.32	1.32
27	0.93	0.93
28	0.92	0
29	1.00	0
30	0.76	0
31	0.76	0
32	1.73	5.18
33	2.79	2.79
34	2.69	2.69
35	1.20	0
36	1.70	1.70
37	1.23	1.23
38	1.19	1.19
39	0.77	0.77
40	0.76	0.76

TABLE 14. Average Concentration of Radionuclides in
Air and Pasture Grass from 5-12-64 to 10-6-64

<u>Radionuclide</u>	<u>Concentration</u>		<u>Ratio</u> [*]	
	<u>Air</u> (pCi/m ³)	<u>Grass</u> (pCi/kg)	<u>Air</u>	<u>Grass</u>
Ce-Pr-144	1.11	3.18X10 ^J	1.00	1.00
Cs-137	0.0594	1.70X10 ³	0.0535	0.0535
Sr-90	0.0357	1.20X10 ³	0.0322	0.0378
Mn-54	0.0382	1.16X10 ³	0.0344	0.0365

* Ratio = Radionuclide Concentration/Concentration of Ce-Pr-144

to the concentration of cerium-praseodymium-144. The cesium-137 ratios are identical while the grass ratios from strontium-90 and manganese-54 are larger than the corresponding ratios for air. To make the corresponding grass and air ratios for these two radionuclides equal it is necessary to subtract 1.8×10^2 $\mu\text{Ci/kg}$ and 0.7×10^2 pCi/kg from the strontium-90 and manganese-54 grass concentrations respectively.

Therefore, the contributions to the measured concentrations of strontium-90 and manganese-54 from soil uptake are assumed to have been 15% and 6% respectively. The estimated contributions from soil uptake are subtracted from the measured concentrations before comparing theory, Eq. (15), to the experimental data.

d. Radionuclides in Soil

Table 15 shows the results of the soil sampling of the pasture in 1964 and 1965. A small section of the pasture near the barn was not planted in sudan grass, as was the rest of the pasture. This small section was used as a corral. The soil samples were taken in this area in 1965. Most of the ammonium acetate extractable cesium-137 and manganese-54 concentrations were below their minimum detectable levels, 0.025 and 0.01 pCi/g respectively. On the other hand all the strontium-90 concentrations were well above the minimum detectable concentration for this isotope.

Total strontium-90 was not determined in the soil. To estimate the total concentration the cesium-137 concentration was divided by 1.45 (34). The strontium-90 values thus derived may be high because some of the strontium-90 may have leached

TABLE 15. Quantities of Ammonium Acetate Extractable Radionuclides In Pasture Soil, Study Farm, 1964-1965. Sampling depth, 10 cm.

<u>Sampling period</u>	<u>Type</u>	<u>Concentration (pCi/g)</u>			
		<u>Cs-137</u>	<u>Sr-90</u>	<u>Mn-54</u>	<u>Potassium (g/g)</u>
1964	Total	0.57(31)**	0.39***	0.21(31)	0.0205 (31)
	Extractable*	<0.025(22)	0.17(28)	<0.02(22)	0.00027(22)
	% Extractable	<5.4	43.5	<9.5	1.3
1965	Total	0.61(24)	0.42***	0.095(23)	0.0203(24)
	Extractable*	<0.025(22)	0.224(24)	<0.01(22)	0.00041(22)
	% Extractable	<4.1	53	<10.5	2.0

* Leachable in Ammonium Acetate

** Number in parenthesis is number of analyses.

*** Estimated by dividing Cs-137 concentration by 1.45

down into the soil below 10 cm. Indeed, the results of the soil survey described in Chapter III show that half again as much strontium-90 may have leached below 10 cm.

Although we did not attempt to infer the uptake of strontium-90 from the soil by pasture grass using the ammonium acetate extractable strontium-90 concentrations, the very high fraction of extractable strontium-90 does indicate that it is available for plant uptake, and adds further evidence for the uptake inferred in the previous section.

D. Comparison Between Theory and Experiment

The initial values of grass density (Y_0) and radionuclide concentration (C_v)_{do} are those measured on week 16. The comparison begins on week 17. A value of 0.0495 days^{-1} is used for the removal constant. This is equivalent to a removal half life of 14 days (26-29).

While it has been argued that rainfall washes previously deposited fallout radionuclides from vegetation (27,24,30,31), this has never been demonstrated satisfactorily. The evidence presented by Pierson and Keane (37) for washoff of radionuclides by rain is circumstantial. The mathematical expression used to evaluate the data in their study assumed that rainfall was the removal mechanism. The fact that the average value of the wash-off factor inferred from the data had a standard deviation of equal to the value itself leaves the original assumption open to question.

In repeating the results of their own experiment, Kirchmann et.al (30), assume that wash-off by rain caused the observed decrease in strontium-85 and cesium-134 when contaminated grass plots were exposed to weather. The fact that no decrease was noted in similar experiments carried out in the laboratory (away from rain) does not necessarily demonstrate that rain was the cause for the decrease when exposed to weather. Mechanical agitation of the leaves by wind might equally well have been the cause.

The fact that radioactivity can be removed from leaves by washing them in water (29,30) does not prove that this activity can be removed in significant quantities by rain.

At the beginning of this study it was assumed that the only mechanism for removal was wash-off by rain. However, the fit of the model to the data was much poorer than by assuming a constant 14 day half-life for removal regardless of the amount of rainfall. Experiments are needed in which realistically contaminated plants can be subjected to falling water drops having about the same drop size distribution and fall velocities as rain.

The following procedure was used to fit the model to the experimental data.

- 1) Determine the range of k_a values

$$k_a \text{ (minimum)} = 0$$

k_a (maximum) is the value at which $\bar{\Delta} = 0$ (See Chapter II), when $k_r = 0$.

- 2) Determine the range of k_r values

$$k_r \text{ (minimum)} = 0$$

k_r (maximum) is the value at which $\bar{\Delta} = 0$, when $k_a = 0$.

- 3) Divide the range of k_a values into increments of 0.2×10^3 $\text{m}^3/\text{kg day}$, and for each value of k_a (i.e. 0, 0.2×10^3 , 0.4×10^3 , 0.6×10^3 etc) find the value of k_r for which $\bar{\Delta} = 0$.
- 4) Determine the value of σ_{Δ} for each pair of k_a and k_r values for which $\bar{\Delta} = 0$.
- 5) Extrapolate graphically the values determined in 4 above to find the values of k_a and k_r which give the minimum value of σ_{Δ} .

Table 16 shows the values of k_a and k_r that were determined in this way. The minimum values of σ_{Δ} are also listed. We believe that the differences in the values of k_a and k_r for the different radionuclides are not necessarily real. The experimental data to which the model was compared were too variable to permit a reliable estimate of k_a and k_r for any individual radionuclide. The average values of k_a and k_r are considered the best estimate of the true values for each radionuclide.

Figures 9-11 show the comparisons between concentration values computed by Eq. (15) and those measured experimentally. The average value of k_a and k_r , 1.31×10^3 and 0.94 respectively, are used. Table 17 shows the values of Δ and σ for each comparison. Also shown in Table 17 are the results of statistical testing of the distributions of Δ for normality. The hypothesis that the distribution for all radionuclides except cerium-

TABLE 16. Values of k_a , k_r and the Corresponding
Values of σ_Δ for the Study Farm Pasture
Grass from April 21 to October 6, 1964

Radionuclide	k_a ($m^3/kg\text{-day}$)	k_r (m^2/kg)	σ_Δ	$k_a(\text{max})^*$ ($m^3/kg\text{-day}$)	$k_r(\text{max})^{**}$ (m^2/kg)
Ce-Pr-144	1.45×10^3	0.8	0.56	2.4×10^3	2.1
Cs-137	0.95×10^3	1.2	0.58	2.3×10^3	2.1
Sr-90	0.75×10^3	1.35	0.71	2.4×10^3	2.1
Mn-54	2.10×10^3	0.40	0.69	2.5×10^3	2.3
<u>Average</u>	1.31×10^3	0.94			

* Value of k_a for $\Delta = 0$ and $k_r = 0$

** Value of k_r for $\Delta = 0$ and $k_a = 0$

Fig. 10. Comparison between theory and experiment for Sr-90 concentrations in grass.

Fig. 11. Comparison between theory and experiment for Mn-54 concentrations in grass.

TABLE 17. Values of Δ and σ_{Δ} for comparison between theory and experiment using $k_a = 1.31 \times 10^3 \text{ m}^3/\text{kg} \cdot \text{day}$ and $k_r = 0.94 \text{ m}^2/\text{kg}$.

RADIONUCLIDE	Δ	σ_{Δ}	NORMALITY OF Δ 'S*
Ce-Pr-144	-0.016	0.56	No
Cs-137	-0.051	0.60	Yes
Sr-90	-0.045	0.73	Yes
Mn-54	+0.196	0.70	Yes

* Chi-square test at $\alpha=0.05$

praseodymium-144 is normal is accepted ($\alpha = .05$). The distribution of Δ for the cerium and praseodymium-144 comparison was too peaked in the area of the mean to be normal. The area under the measured distribution curve from approximately $\Delta = 0.1$ to 0 is about 0.19 compared with 0.08 for the normal distribution. The difference is compensated for in the area from $\Delta = 0$ to $\Delta = 0.55$, where the approximate area under the measured Δ distribution curve is approximately 0.23 compared with 0.34 for the normal distribution. Therefore, the assumption that the distribution of Δ for cerium-praseodymium-144 is normal will tend to overestimate the chance that the real grass concentration is greater than the calculated concentration. The values of σ_{Δ} are applicable only to the pair of values of k_a and k_r listed in Table 16. If the sum of k_a and $1.15 \times 10^4 k_r P$ is changed appreciably, the value of $\bar{\Delta}$ will change significantly from zero.

There are certain salient features of the comparisons. The best comparison between theory and experiment is that for cerium-praseodymium-144. At least part of the reason for this is due to the higher level of activity for cerium than the other nuclides and the lower counting errors. The fact that the experimental concentrations were lower than the theoretical values during the first weeks of comparison may be the result of the very low initial value of grass yield ($Y_0 = 0.0066 \text{ kg/m}^2$). In retrospect this value appears to be too low and may be in error. As Eq. (17) shows, a low value of Y_0 and a high growth rate (K) will cause the concentration to decrease rapidly. Another feature worth noting is that in general the measured grass concentration

decreases more rapidly after a noticeable contaminating event than do the theoretical values. We believe that this may be caused by the assumption implicit in Eq. (15), that the radioactivity is uniform. Because grass grows from folicles near the ground, the contaminated parts are probably pushed upward where they are consumed by the herd, thus grass which was not contaminated by the event is left in the pasture.

The last salient feature is that the comparison for all radionuclides is better for the weeks up to week 34 than for subsequent weeks. Week 34, et seq. are characterized by a high rainfall but a low total deposition because of the lower air concentrations. The two peaks in the measured concentrations occurring on weeks 34 and 38 are associated with rainfalls of 2.2 and 1.13 inches respectively. To cause the theoretical concentrations to peak during these two in weeks would require a value of k_r from 2 to 3 times that which fits the data fairly well during weeks 17-33. We have no explanation for the much poorer fit of the theory and the experiment during these last few weeks.

It is interesting to compare the contributions from dry and wet processes determined in this study. The following expression, derived from Eq. (15), describes the deposition per unit area on grass as a result of dry and wet deposition.

$$D_v = (k_a + k_r \times 1.15 \times 10^4 \times R) Y C_a \quad (20)$$

where, D_v = total deposition rate on vegetation, pCi/m²-day.

The average rainfall for the 24 week period of measurement was 0.1 inches/day. Table 18 shows the relative contributions of dry and wet deposition to the total deposition on the pasture grass using the values of k_a and k_r determined for each radionuclide and for the average values of k_a and k_r . Although the relative contributions vary considerably among the radionuclides there is little doubt that dry deposition was a major contribution to the total deposition. If the contribution from rain had predominated it should have been evident in this type of analysis.

The average yield (Y) during the period of measurement was 0.062 kg/m^2 . Therefore, the average dry deposition velocity ($k_a Y$) was 80.5 m/dry.

This is surprisingly low in relation to the dry deposition velocity on the rain collector which was 200 m/day. Although the dry deposition velocity for individual radionuclides was quite variable, its value could not have exceeded 154 m/day, which corresponds to the maximum value of k_a for manganese-54. The fact that the deposition velocity on grass was less than that on the rain collector could be the result of two things: 1) air concentrations were measured at the same height as the rain collector surface, which was 30 to 40 cm higher than grass surface. The air concentration decreases to zero as it approaches the ground; 2) it has been shown (22) that the uppermost areas of the grass contain the great majority of the total iodine-131 contamination as a result of dry deposition. It was shown (22)

TABLE 18. Relative Contributions of Dry and Wet Deposition to the Total Radioactivity on Pasture Grass, Study Farm, April 21 to October 6, 1964.*

<u>Radionuclide</u>	<u>Percent of Total Concentration</u>	
	<u>Dry</u>	<u>Wet</u>
Ce-Pr-144	63	37
Cs-137	41	59
Sr-90	33	67
Mn-54	82	18
Average	45	55
Average**	43	57

* Average rainfall rate 0.25 cm/day

** Average values of k_a and k_r from Table 12.

that 20% (by density) of the grass contained 90% of the deposited radioiodine. Therefore, even though grass has an area from 5 to 10 times the horizontal area it covers, only a fraction of it actually intercepts radioactivity.

For the average grass density of 0.062 kg/m^2 the pasture intercepted an average of 40% of the dry deposition on the rain collector and 5.6% of the wet deposition on the rain collector.

The assumption was made that all the radionuclides were removed from the grass with a half life of 14 days.

To test the consequences of this assumption on the calculated values of k_a and k_r , comparisons between Eq. 15 and the experimental data were made for cerium-praseodymium-144 using removal half lifes of 10, 12, 14, 16 and 18 days. Table 19 shows the resulting values of k_a and k_d which give the minimum value of σ_Δ . As the assumed value of the half life increases the calculated values of both k_a and k_r decrease. However, when the grass is being consumed as fast as it grows, Eq. (16), the dependence of the deposition coefficients on half life diminishes as λ_e becomes small with respect to the ratio of growth rate to the stand of grass (K/Y_0). The minimum values of σ_Δ get larger as the removal half life is increased indicating a poorer fit between the concentrations calculated from Eq. (15) and the experimental concentrations.

TABLE 19. Values of K_a and K_r Calculated from Eq. (15) for
Various Values of Removal Half Life for
Cerium-Prasedymium - 144.

Assumed Removal Half Life (days)	K_a (m^3/kg day)	K_r (m^2/kg)
10	2.0×10^3	0.89
12	1.6×10^3	0.84
14	1.45×10^3	0.80
16	1.3×10^3	0.75
18	1.2×10^3	0.70

CHAPTER V. RELATION BETWEEN FEED AND MILK RADIONUCLIDE CONCENTRATIONS

A. Theory

There is an abundance of information in the literature on the transfer of radionuclides from the bovine diet to milk. Of particular note is the work of Comar (39), Wasserman and Lengemann on the transfer of iodine-131 (40,41) and strontium-90 (42,43,44) to milk, the work at the National Reactor Testing Station on iodine-131 (22,45), Garner's work (46,50) and the work of others (47) in the United Kingdom on fission product transfer to milk, and the work of Ward and Johnson on the transfer of cesium-137 to milk (48,49,51). All of these studies have led to empirical relations between the intake and output of radionuclides in milk.

It is generally agreed that the output of a radionuclide in milk is directly proportional to the quantity of milk produced. That is, the milk concentration is directly proportional to intake. The relation is usually expressed as the percent of the daily intake per liter of milk. It also seems to be generally agreed that the concentration of strontium in milk is directly related to the concentration of calcium in the feed. Comar (39) has introduced the term Observed Ratio, OR, to predict strontium concentrations in milk. In terms of strontium-90 the OR is defined as follows:

$$OR_{\text{milk/diet}} = \frac{\text{pCi Sr-90 g Ca in milk}}{\text{pCi Sr-90 g Ca in diet}} \quad (21)$$

Values of the Observed Ratio have been reported in the range 0.09 to 0.16; the value 0.1 is most common (43).

At the beginning of the study we had hoped to derive mathematical models which would predict the concentration of a radionuclide as a function of time. The OR and the values of percent of daily intake per liter of milk are applicable to intakes either for short periods of time or for equilibrium conditions between intake and milk output. However, the only radionuclide whose metabolism has been documented well enough to warrant the derivation and use of a dynamic model is cesium-137. Dynamic mathematical models are also available for iodine-131 (22,50) but their use is not warranted in this study because radioiodine was present in the diet only for a brief period in 1965.

Although a two-compartment model based on the work of Johnson (51) has been derived, it has only been partially tested at the time of this writing. A simplified one-compartment model which has been tested is used here. The rate of change of cesium-137 activity in the compartment (which may be thought of as blood) is given by the following expression.

$$\frac{dX_b}{dt} = \sum_{i=1}^k I_i C_i F_i + JR C_v F_v - (mO_m + u + \lambda) X_b \quad (22)$$

where X_b = quantity of the radionuclide in the average
cow at any time t , pCi.

t = time, days

I_i = intake of the i th kind of feed, kg/day

C_i = cesium-137 concentration in the i th type of feed, pCi/kg

F_i = digestibility of cesium-137 in the i th type of feed,
a fraction

k = number of feeds. When the herd is on dry feed, $k = 3$
because grain, hay and silage make up diet

J = area of pasture grazed by one cow, m^2/cow

R = consumption rate of pasture by dairy herd, kg/m^2 -day

F_v = digestibility of cesium-137 in pasture grass, a fraction

C_v = cesium-137 concentration in pasture grass, pCi/kg

m = transfer coefficient from blood to milk, $liters^{-1}$

O_m = daily output of milk, liters/day

u = transfer coefficient from blood to urine, $days^{-1}$

λ = radiological half life of cesium-137, $days^{-1}$

It is assumed in Eq. (22) that there is no endogenous cesium-137 in the feces, i.e., that all the cesium-137 in the feces is undigested. The values of m , u , and F_i are determined by fitting Eq.(15) to the measured concentrations in milk, urine, and feces.

B. Experiment

1. Methods

a. Sample Collection

The sampling of pasture grass and sudan grass has already been described.

During the dry feeding season samples of grain, hay, silage, feces, urine and milk were composited daily, and the composites

were collected each week. The farmer composited the samples of feed and excreta at the time of feeding or milking.

During the green chopping season in 1965, daily samples were collected from the trailer used to haul the green chop.

b. Radioactivity Analysis

Samples of grain, hay silage and feces were analyzed in the manner described previously for pasture grass. During the green chopping season samples of alfalfa and sudan grass were dried at 100°C and about 200 g were counted in a 1 liter Marinelli beaker. Calibration and reference spectra were determined using roughly the same density material. To accomplish this, known quantities of standard solutions were evaporated on rags, which were stuffed into the Marinelli beakers for counting. An aliquot of each green chop sample was analyzed in this manner, in addition to the normal gamma analysis of dry ash. The contents of the glass vials from gamma counting the grain, hay, silage feces and green chop were analyzed for strontium-90.

Milk and urine samples were evaporated to dryness, dry ashed and gamma counted in glass vials in the same manner used for grass samples. During part of the green chop season samples were counted in 1 liter Marinelli beakers before drying and ashing.

c. Stable Element Analysis

Beginning in the pasture season of 1964 selected samples of each media were sent to the Ohio Agricultural Experiment Station

for analysis of sixteen stable elements by emission spectroscopy. The analytical procedure is given in Appendix C.

d. Measurement of Intake by the Dairy Herd

During the grazing season of 1964, the quantity of pasture grass consumed by the herd was estimated by measuring the yield of the pasture grass at the beginning and at the end of each week. Three 1 m^2 plots chosen at random were isolated from the cows and the yield was compared to the grazed portion. The isolated areas were clipped down to the level of the grazed area. The weight of the clipping divided by the area clipped represents the intake of the herd for that week. During the barn feeding season the farmer weighed the quantities of stored feed given to the herd.

During the green chopping season the contents of the wagon used to haul the green chop and also to feed the herd were weighed before and after feeding. It was found that wagon loads of alfalfa usually weighed about the same and that from 5 to 10% of the green chop was not eaten. Thereafter, the weight of feed consumed was estimated on a volume basis.

During the green chopping season and the grazing season the farmer weighed the quantity of grain fed to the herd.

The intake of drinking water is estimated to have been 50 liters/day (53). A more precise estimate of water intake is unnecessary because the water contained only negligible concentrations of radioactivity. Even the calcium taken in by way of drinking water is a small part of the total.

e. Measurement of Output of the Herd

The average milk output is determined from the farmer's sales records and the number of cows being milked.

Fecal output was determined by multiplying each type of feed by its respective dry matter digestibility. Table 20 lists the dry matter digestibility factors. The quantity of a feed in kg/day is multiplied by (1-digestibility factor) to obtain the feces output in kg/day from that feed. The total fecal output is found by adding the contribution from each feed.

Urine output is computed from the potassium concentration in urine on the assumption that the potassium pool remained constant. The total potassium input, minus the potassium excreted in the feces and milk, is divided by the potassium concentration in urine. Occasionally a urine output was calculated which was obviously too high. In these cases the average of the urine outputs calculated on the preceding and following week was used in place of the suspect output. This happened in eight instances. During the 1964 grazing season when the estimated grass intakes were highly variable, the average urine output for the entire grazing season was used each week. Urine samples were not collected during the first four weeks of the study. Therefore, urine output estimates were not made.

C. Results

All the results are in Appendix B. Tables 7-B and 8-B list the concentrations of cesium-137 and strontium-90 in feed materials.

TABLE 20. Dry Matter Digestibility Factor (52)

<u>Feed</u>	<u>Digestibility Factor</u>
Alfalfa Hay	0.60
Prebloom Fresh	0.56
Ensilage	0.66
Sudan Grass Grazing	0.71
Hand Fed	0.67
Mixed Grain	0.75 (computed from each component)

Note: The digestibility factor for grazing sudan grass
is also used for pasture grass.

Tables 9-B and 10-B list the concentrations of cesium-137 and strontium-90 in milk, urine and feces. Table 9B also lists the outputs in liters/day or kg/day of milk, urine and feces. Table 11-B lists the average daily quantities of each feed. These were calculated by dividing the total quantity of feed by the number of cows. Tables 12-B and 13-B list the concentration of potassium in feed materials, milk, urine and feces. Potassium concentrations were determined by gamma spectrometer analysis and the conversion factor of 860 pCi of potassium-40 per gram of potassium.

Most of the stable element concentrations were extremely variable with time. For those elements whose concentrations were near the detection limits of the emission spectrometer, this variability is understandable, but for elements whose concentrations were well above the detection limits, the reasons for the observed variability are still in doubt, despite concerted effort. Tables 14-B and 15-B list the concentrations of calcium in feed materials, milk, urine and feces. These concentrations appear to be sufficiently accurate for the purposes of this study.

D. Comparison between theory and Experiment

Fig. 12 shows the comparison between the cesium-137 concentrations in milk and urine, computed from Eq. (22), and those measured on the study farm. The measured outputs of cesium-137 in feces compared to those calculated from Eq. (22) are also shown in Fig. 12. The value of σ_A for milk is 0.35. In general the fit

$$\frac{dX}{dt} = \sum I_i C_i F_i + JRC_v F_v - (m \cdot O_m + u + \lambda)X$$

$$X = \frac{(\sum I_i C_i F_i + JRC_v F_v)}{m \cdot O_m + u + \lambda} \left(1 - e^{-(m \cdot O_m + u + \lambda)t}\right) + X_0 e^{-(m \cdot O_m + u + \lambda)t}$$

	F
Grain	0.60
Hay	0.20
Ensilage	0.50
Alfalfa (green)	0.10
Sudan Grass	0.05
Pasture Grass	0.10

Milk Concentration = $X m$ pCi/liter
 Urine Concentration = $X u$ pCi/liter
 Urine Output

$$\text{Feces Output} = \sum I_i C_i (1 - F_i) + JRC_v (1 - F_v) \text{ pCi/day}$$

$$m = 2.18 \times 10^{-3} \text{ liters}^{-1}$$

$$u = 0.092 \text{ days}^{-1}$$

$$X_0 = \frac{(\text{Milk Concentration})_0}{m}$$

Fig.12. Comparison between theory and experiment for Cs-137 concentrations in milk, urine and feces.

between theory and experiment is very good. The only serious discrepancy occurred between weeks 30 and 40, when the measured values are consistently lower than the theoretical values. There are two possible explanations for this disparity:

- 1) During this period the cows grazed both on the pasture and on what was left of the sudan grass. As can be seen from Fig. 12, the digestibility (F) of cesium-137 in sudan grass is smaller than that in other feeds. Although the cows probably got very little cesium-137 from sudan grass, the low digestibility in this grass may have depressed the digestibility of cesium-137 in the other feeds.
- 2) Another explanation is that the one-compartment model is inadequate to describe the behavior of cesium-137 in the dairy herd when, as in the 1964 grazing season, large sustained decreases in the assimilated cesium-137 occur. A portion of the cesium-137 intake may have gone to replenish the muscle pool and was thus not secreted in the milk.

During the two-year study period the cesium-137 content of each liter of milk represented, on the average, 0.48% of the daily intake. This value falls between those reported by Johnson and Ward (49) for a high hay diet (0.24%) and for a high grain diet (0.58%). During the grazing season in 1964 and also during the green chop feeding season in 1965, the average value was 0.38% of the daily intake per liter of milk. When the cows were on sudan grass in 1964 and 1965, the value was 0.32%. The low values during

periods of grazing and green chop feeding are also indicated in Fig. 12 by the lower cesium-137 digestibilities in pasture and sudan grass than in grain and ensilage. The reason for the low digestibilities is not known.

Table 21 shows the average intake and output of calcium and strontium-90 during the dry feeding seasons in 1964 and 1965, and the green chop feeding season in 1965. The Observed Ratio value is in the range 0.09 to 0.16, reported by others. Fig. 13 shows the quantities of cesium-137 and strontium-90 in feces and in milk during the study. During certain weeks of the green chopping season, the strontium-90 in feces was very high. These high feces levels are due to unusually high strontium-90 concentrations in alfalfa green chop (see Table 8-B, Appendix B). Although milk concentrations also increased during the same weeks, the increases were not as pronounced as those in feces. The best explanation for the high alfalfa levels is that a substantial fraction of the strontium-90 in alfalfa was taken up from the soil. If one assumes that the cesium-137/strontium-90 ratio should be the same for alfalfa as for air, then 81% of the strontium-90 in alfalfa must have been taken up from the soil. Sudan grass did not demonstrate a preferential strontium-90 uptake, since the cesium-137/strontium-90 ratio was the same (1.85) in air and sudan grass. It is not clear whether the apparent high strontium-90 uptake by alfalfa is a characteristic of the crop, or is the result of a moderate calcium deficiency in the alfalfa field.

TABLE 21. SUMMARY OF CALCIUM AND STRONTIUM-90 MEASUREMENTS DURING THE PERIOD OCTOBER 1964 TO OCTOBER 1965.

A. CALCIUM

<u>Intake</u>			<u>Output</u>		
Type of Feed	Concentration	Intake(g/day)	Type of output	Concentration	Output (g/day)
Hay or green chop	10 g/kg	102. (66%)	Feces	20 g/kg	130. (87%)
Grain	5.1 g/kg	42. (27%)	Urine	0.13 g/l	1.7 (1%)
Ensilage	1.6 g/kg	4.5 (3%)	Milk	0.96 g/l	17.0 (12%)
Water	0.13 g/l	6.5 (4%)			
	Total	153.		Total	149.

B. STRONTIUM

Hay of green chop	1,000 pCi/kg	9,600 pCi/d(92%)	Feces	1,400 pCi/kg	9,300 (96%)
Grain	63	530 (5%)	Urine	16 pCi/l	230 (2%)
Ensilage	120	330 (3%)	Milk	0 pCi/l	160 (2%)
	Total	10,500			

C. STRONTIUM-90/CALCIUM

<u>Intake</u>	<u>Output in Milk</u>	<u>Observed Ratio</u>
68 pCi/g	9.4 pCi/g	0.14

Fig. 13. Comparison between measured outputs of Cs-137 and Sr-90 in feces and in milk.

CHAPTER VI. CONCLUSIONS

Specific conclusions are given in Chapters II, IV and V in the sections which compare theory and experiment. The following general conclusions have been singled out as being particularly noteworthy.

1) Dry deposition is an important mechanism for contaminating forage. In a region where the rainfall during the growing season averages 0.1 inch per day, dry deposition of such long-lived radionuclides as strontium-90 and cesium-137 can contribute as much as 55% of the contamination on forage. In the same region, the dry deposition of fresh fallout can contribute as much as 90% of forage contamination. The deposition rate for fresh fallout can be as much as 40 times that for old fallout at the same air concentration.

2) The fraction of the cesium-137 in feed which is secreted in milk is markedly dependent on the type of feed material. Cesium-137 on grain is more available to milk than that on alfalfa hay, which in turn is more available than that on sudan grass.

3) The agreement between values computed from the mathematical models presented here and the experimental values becomes progressively better as the radionuclides progress down the chain from air to milk. A single prediction of weekly deposition is

accurate to within a factor of 3; a single prediction of weekly grass concentration of cesium-137 is accurate to within a factor of 2.2; a single prediction of weekly cesium-137 concentration in milk is accurate to within a factor of 1.7. The agreement between theory and experiment improves as the averaging period is increased.

VII. APPENDICES

APPENDIX A. STRONTIUM-90 PROCEDURE

1. Transfer the sample from the planchet or counting vial, after appropriate gamma and/or beta counting, into a 400 ml pyrex beaker with the aid of a few ml of 70% HNO_3 (Note 1)
2. The content of the beaker is thoroughly wetted with 70% HNO_3 ; the beaker is covered with a plain watch glass and placed on³ a hot plate.
3. Evaporate to dryness. (Note 2).
4. Remove the beaker from the hot plate and allow it to cool.
5. Add enough 30% H_2O_2 just to cover the residue in the beaker.
6. Allow the reaction to subside and add 200 ml of concentrated HCl . Add cautiously in small increments to keep the reaction low.
7. Allow the reaction to subside and add 25-30 ml of 30% H_2O_2 . Caution: this reaction is vigorous and the H_2O_2 must be² added in small increments.
8. Stir the solution occasionally until the reaction subsides and cools sufficiently to handle.
9. Filter through a glass fiber filter using an all glass filter funnel assembly and wash residue with hot HCl (20 volume %) and then with hot water. (Note 3).
10. Place the filter pad and residue in a 2-inch stainless steel planchet and reserve for further analysis and counting.
11. Add 1 ml of strontium-85 tracer and 1 ml of strontium carrier to the filtrate.
12. Evaporate the solution to 25 ml.
13. Add 100-150 ml of 90% HNO_3 and heat for 15-30 minutes with stirring.
14. Set solution in ice bath to enhance precipitation of $\text{Sr}(\text{NO}_3)_2$.
15. Filter through a glass fiber filter with vacuum and allow as much of the filtrate to drain off as possible. Do not wash $\text{Sr}(\text{NO}_3)_2$ precipitate.
16. Discard the filtrate.

17. Place a clean 150-ml beaker under the filter assembly and rinse down the sides of the precipitating flask with water and dissolve the $\text{Sr}(\text{NO}_3)_2$ in the flask and on the filter pad.
18. Wash the beaker and filter pad collecting a total of 23 ml of solution in the 150-ml beaker.
19. Add 77 ml of cold 90% HNO_3 and place the solution in the ice bath to enhance the precipitation of $\text{Sr}(\text{NO}_3)_2$.
20. Filter through a glass fiber filter with vacuum and allow as much of the filtrate to drain as possible.
21. Discard filtrate.
22. Place a 50-ml centrifuge tube under the filter assembly.
23. Dissolve the $\text{Sr}(\text{NO}_3)_2$ with distilled water and collect the washings in the 50-ml centrifuge tube. (Note 4).
24. Add 1 ml of iron carrier (10 mg/ml FeCl_3).
25. Bubble through the solution, carbon dioxide free ammonia gas, until the precipitation of $\text{Fe}(\text{OH})_3$ is complete. (Note 5) Using old NH_3 can give low recovery.
26. Centrifuge the precipitate and decant the supernate into a clean 150-ml beaker.
27. Dissolve the precipitate with 6 N HNO_3 .
28. Reprecipitate the $\text{Fe}(\text{OH})_3$ as in Step 25.
29. Centrifuge the precipitate and combine the supernate with that from Step 26.
30. Discard the $\text{Fe}(\text{OH})_3$ precipitate.
31. Evaporate the solution to dryness on the hot plate.
32. Dissolve the residue in the beaker with 0.1 N HCl and transfer to a 60-ml separatory funnel.
33. Rinse the beaker thoroughly adding the washings to the separatory funnel and adjust the volume to 15 ml.
34. Add 15 ml of 5% HDEHP (di(2 ethyl hexyl) orthophosphoric acid in toluene).
35. Shake for 3 minutes, allow the phases to separate and drain the lower aqueous layer into a counting vial.
36. Add 10 of 0.1 N HCl to the organic phase in the separatory funnel.

37. Shake for 3 minutes, allow the phases to separate and drain the lower aqueous layer into the same counting vial.
38. Discard the organic fraction and set the aqueous fraction aside to count the strontium-85 tracer and to allow the yttrium-90 to build in.
39. Gamma count the vial contents on the spectrometer for strontium-85.
40. Gamma count 1 ml of the original strontium-85 tracer.
41. Calculate the recovery of strontium. (Note 6)
42. After 17 days the yttrium-90 is in equilibrium with the strontium-90 and the analysis can be completed by isolating the yttrium-90 for beta counting.
43. Transfer the contents of the counting vial to a 125-ml separatory funnel.
44. Rinse the vial 3 times with 3 ml of 0.1 N HCl.
45. Add 35 ml of 5% HDEHP to the separatory funnel and shake 3 minutes.
46. Note time as t_1 , start of yttrium-90 decay.
47. Allow phases to separate and drain the aqueous layer into a second 125-ml separatory funnel.
48. Add 35 ml of 5% HDEHP to the second separatory funnel, shake for 3 minutes.
49. Allow the phases to separate and drain the lower aqueous phase into a storage bottle. (Note 7)
50. Combine the organic fractions into one separatory funnel and add 4 ml of 0.1 N HCl.
51. Shake for 3 minutes and allow the phases to separate.
52. Drain off the lower aqueous phase and discard.
53. Wash the organic phase once more discarding the aqueous phase of 0.1 N HCl.
54. Add 40 ml of 4 N HNO_3 , shake for 3-5 minutes and allow the phases to separate.
55. Drain off the lower aqueous phase into a clean 150-ml pyrex beaker.

56. Repeat Steps 54 and 55 twice using 30 ml of 4 N HNO_3 .
57. Combine the 4 N HNO_3 extracts and place on a hot plate.
58. Discard the organic fraction.
59. Transfer the nitric acid solution to a 2-inch stainless steel planchet.
60. Evaporate to dryness under an infrared lamp.
61. Count for an appropriate length of time on the low background beta counter. Note time t_2 .
62. After one week from the first count recount the yttrium-90 in the planchet. Note time t_3 .
63. Observe the decay between t_2 and t_3 and compare it to the literature value of 64.4 hours for yttrium-90.
64. Correct for decay of yttrium-90 from t_2 to t_1 .
65. Correct for decay of strontium-90 from t_1 to effective date or collection date.
66. Convert cpm to millicuries per sample size.

Notes on Strontium-90 Procedure

1. After transfer, each of the planchets is counted on the low background beta counter to insure that all the activity has been removed. The gamma counting vials were checked for any remaining gamma activity. No significant amount was detected in checking the first 10 vials of each type of media and the procedure now is to check only a few random vials to insure that all the activity has been removed.

2. In some samples where the initial dry ashing was incomplete (or absent as in the case of rain and air samples), it is necessary to add more 70% HNO_3 and wet ash until no more organic material is present.

3. The all glass filter funnel assembly is obtained from the Millipore Corporation No. XX10047 and the glass fiber filter pads from the Gelman Instrument Company, type A. This assembly is used throughout in all filtration steps.

4. More HNO_3 precipitations may be necessary if the calcium content is still very high.

5. Ammonium hydroxide from a freshly opened bottle can also be used but with time it will absorb carbon dioxide from the atmosphere. The presence of CO_2 will precipitate the strontium at this point.

6. Gamma count the sample and the strontium-85 standard at the same time so that no decay corrections are necessary.

7. This phase contains the strontium fraction and should be saved until the results of the yttrium-90 are completed. Then if necessary, the yttrium can be re-extracted for another analysis.

APPENDIX B. TABULATED DATA

<u>Table</u>	<u>Title</u>	<u>Page</u>
1 B.	Average air concentrations in Tecumseh, Michigan, 1964-65	95
2 B.	Deposition rate measurements in Tecumseh, Michigan, 1964-65	99
3 B.	Results of soil density measurements during soil survey of study farm, October 26-29, 1964	103
4 B.	Radionuclide concentrations in three depths of soil on study farm, October 26-29, 1964	104
5 B.	Ammonium acetate extractable strontium-90 concentrations for selected samples in soil survey, study farm, October 1964.	107
6 B.	Yields and radionuclide concentrations of pasture grass and sudan grass during the grazing season, 1964.	108
7 B.	Concentrations of cesium-137 in each feed	110
8 B.	Concentrations of strontium-90 in each feed	113
9 B.	Cesium-137 concentrations in, and average daily outputs of milk, urine and feces	115
10 B.	Concentrations of strontium-90 in milk, urine and feces	118
11 B.	Average daily quantities of feed	120
12 B.	Concentrations of potassium in each feed	122
13 B.	Concentrations of potassium in milk, urine and feces	124
14 B.	Concentrations of calcium in each feed	126
15 B.	Concentrations of calcium in milk, urine and feces.	128

TABLE 1-B. Average Air Concentrations in
Tecumseh, Michigan. 1964-65 (pCi/m³)

Collection date	Week	Gross β	Ce ¹⁴⁴ + Pr ¹⁴⁴	Ce ¹⁴¹	Sb ¹²⁵	Sr ⁹⁰	Cs ¹³⁷	Zr ⁹⁵ + Nb ⁹⁵	Mn ⁵⁴	Ba ¹⁴⁰ + La ¹⁴⁰	I ¹³¹
<u>1964</u>											
1-2	1	1.0	0.80		0.026		0.039	0.13	0.047		
1-9	2	0.77	0.85		0.02		0.030	0.10	0.039		
1-16	3	0.71	0.83		0.015		0.027	0.094	0.035		
1-23	4	0.82	1.0		0.016		0.031	0.10	0.041		
1-30	5	1.20	0.99		0.036		0.056	0.092	0.072		
2-6	6	1.0	1.3		0.030		0.047	0.10	0.060		
2-13	7	1.2	1.1		0.020		0.057	0.097	0.047		
2-20	8	1.2	1.3		0.019		0.046	0.089	0.049		
2-27	9	1.1	1.1		0.019		0.047	0.12	0.048		
3-6	10	1.3	1.4		0.023		0.055	0.086	0.057		
3-16	11	1.1	1.3		0.023		0.037	0.099	0.039		
3-29	12	1.5	1.4		0.032		0.051	0.085	0.054		
3-30	13	1.4	1.5		0.024		0.051	0.10	0.072		
4-6	14	1.7	1.2		0.029	0.048	0.062	0.079	0.051		
4-19	15	1.7	1.9		0.038		0.078	0.095	0.058		
4-20	16	1.8	1.6		0.040		0.083	0.10	0.061		
4-21	17	0.56	0.59		0.010		0.016	0.02	0.012		
5-4	18	2.0	2.0		0.031	0.049	0.055	0.062	0.042		
5-11	19	2.1	2.2		0.062		0.12	0.120	0.081		
5-18	20	2.0	2.0		0.060		0.11	0.11	0.077		
5-25	21	2.1	1.9		0.064		0.11	0.096	0.072		
6-1	22	1.8	1.9		0.055	0.072	0.096	0.082	0.063		
6-8	23	2.1	2.2		0.083		0.086	0.080	0.067		
6-15	24	1.9	1.7		0.075		0.078	0.072	0.063		
6-22	25	1.7	1.7		0.056		0.10	0.065	0.064		
6-29	26	1.3	0.73		0.024	0.035	0.045	0.022	0.027		
7-6	27	1.2	1.5		0.047		0.089	0.047	0.053		
7-13	28	0.93	1.3		0.042		0.082	0.040	0.049		
7-20	29	-	0.81		0.026		0.057	0.027	0.033		
7-27	30	0.86	0.76		0.025	0.030	0.049	0.021	0.029		

TABLE 1-B. (continued)

Collection date	Week	Gross β	Ce ¹⁴⁴ + Pr ¹⁴⁴	Ce ¹⁴¹	Sb ¹²⁵	Sr ⁹⁰	Cs ¹³⁷	Zr ⁹⁵ + Nb ⁹⁵	Mn ⁵⁴	Ba ¹⁴⁰ + La ¹⁴⁰	U ¹³¹
8-3	31	0.88	0.80		0.027		0.052	0.018	0.029		
8-10	32	0.69	0.54		0.017		0.035	0.010	0.019		
8-17	33	0.47	0.47		0.020		0.030	0.010	0.018		
8-24	34	0.31	0.43		0.019	0.014	0.025	0.009	0.012		
8-31	35	0.32	0.30		0.013		0.020	0.008	0.009		
9-7	36	0.36	0.31		0.009		0.024	<0.005	0.010		
9-14	37	0.38	0.48		0.018		0.036		0.018		
9-21	38	0.36	0.25		0.011	0.014	0.017		0.011		
9-28	39	0.23	0.35		<0.007		0.023		0.011		
10-15	40	0.30	0.27		-	-	0.016		0.010		
10-12	41	0.17	0.24		-		0.014		0.008		
10-19	42	0.29	0.22		-	0.0068	0.020		0.008		
10-26	43	0.28	0.18				0.011		0.005		
11-2	44	0.90	0.22	0.086	0.013	-	0.012	0.047	0.007	0.23	0.066
11-9	45	0.58	0.44	0.086	0.018		<0.011	0.044	0.015	0.25	0.049
11-16	46	0.32	0.29	0.043	0.016	0.0061	0.016	0.022	0.008	0.093	<0.010
11-23	47	0.39	0.18	0.020	0.010		0.012	0.010	0.007	0.050	
11-30	48	0.21	0.14	0.016	<0.007		0.011	0.008	0.009		
12-7	49	0.16	0.14	<0.015	-			<0.005	0.005		
12-14	50	0.11	0.12			0.0055			0.004		
12-21	51	0.16	0.10				0.012		0.004		
12-28	52	0.15	0.19		0.008	-	0.014		0.007		
1965											
1-4	53	0.12	0.13		0.007		0.009		0.005		
1-11	54	0.18	0.11		0.006	0.0064	0.008		0.005		
1-18	55	0.15	0.11		0.006		0.007		0.004		
1-25	56	0.10	0.11		0.07		0.009		0.006		
2-1	57	0.16	0.097		0.005		0.008		0.003		
2-8	58	0.15	0.14		0.008	0.0063	0.012		0.005		
2-15	59	0.12	0.13		0.006		0.009		0.004		
2-22	60	0.15	0.14		0.005		0.015		0.004		
3-1	61	0.11	0.15		0.008		0.012	0.002	0.005		

TABLE 1-B (continued)

Collection date	Week	Gross β	Ce ¹⁴⁴ + Pr ¹⁴⁴	Ce ¹⁴¹	Sb ¹²⁵	Sr ⁹⁰	Cs ¹³⁷	Zr ⁹⁵ + Nb ⁹⁵	Mn ⁵⁴	Ba ¹⁴⁰ + La ¹⁴⁰	I ¹³¹
3-8	62	0.11	0.10		0.005	0.010	0.010		0.003		
3-15	63	0.10	0.11		0.005		0.011		0.004		
3-22	64	0.14	0.21		0.011		0.024		0.006		
3-29	65	0.30	0.24		0.016		0.024		0.007		
4-5	66	0.25	0.27		0.015	0.015	0.030		0.008		
4-12	67	0.26	0.17		0.008		0.018		0.005		
4-19	68	0.24	0.17		0.012		0.016		0.007		
4-26	69	0.16	0.13		0.007		0.019		0.006		
5-6	70	0.34	0.24		0.012	0.015	0.030		0.009		
5-13	71	0.22	0.13		0.006		0.018		0.005		
5-20	72	0.16	0.16		0.009		0.019		0.005		
5-27	73	0.38	0.18	0.039	0.010		0.022	0.026	0.007	0.104	0.036
6-23	74	0.19	0.16	0.018	0.010	0.0078			<0.004		
6-10	75	0.34	0.35	0.052	0.011		0.012		0.004		
6-17	76	0.23	0.10	0.041	0.010		0.014		0.007		
6-24	77	0.51	0.50	0.041	0.008						
7-1	78	0.42	0.42	0.034	0.007	0.0080	0.009		0.005		
7-8	79	0.30	0.37	0.021	0.005		0.008		0.005		
7-15	80	0.13	0.21	0.004	0.004	-	0.007		0.004		
7-22	81	0.17	0.21	0.005	0.008		0.009		0.006		
7-29	82	0.13	0.15	0.011	0.008	0.010	0.008		0.003		
8-5	83	0.17	0.085		0.006		0.012		0.005		
8-12	84	0.14	0.11		0.003	-	0.009		0.004		
8-19	85	0.11	0.068		0.005		0.015		0.004		
8-26	86	0.19	0.089		0.006	0.0050	0.012	0.002	0.005		
9-2	87	0.055	0.086		0.004		0.010		0.003		
9-9	88	0.044	0.053		<0.003		0.011		0.004		
9-16	89	0.037	0.035				0.024		0.006		
9-23	90	0.034				0.0021	0.024		0.007		
9-30	91	0.067	0.030		0.005		0.030		0.008		
10-7	92	0.0055	0.038		0.004	-	0.018		0.005		
10-14	93	0.045	0.024		<0.003		0.016		0.007		
10-21	94	0.049	0.033		0.004	0.0024	0.019		0.006		
10-28	95	0.031	0.024		0.003		0.030		0.009		

TABLE 1-B. (continued)

Collection date	Week	Gross β	Ce ¹⁴⁴ + Pr ¹⁴⁴	Ce ¹⁴¹	Sb ¹²⁵	Sr ⁹⁰	Cs ¹³⁷	Zr ⁹⁵ + Nb ⁹⁵	Mn ⁵⁴	Ba ¹⁴⁰ + La ¹⁴⁰	I ¹³¹
11-4	96	0.042	0.034		0.004		0.018		0.005		
11-11	97	0.037	0.025		<0.003		0.019		0.005		
11-18	98	0.039	0.037			0.0035	0.022	0.026	0.007	0.104	0.036
11-25	99	0.057	0.025				0.003				
12-2	100	0.060									
12-9	101	0.057				0.004					
12-16	102	0.058									
12-23	103		0.028				0.004				
12-30	104		0.025				0.003				

Regression equations used to calculate the concentrations of each radionuclide when gamma spectrometry was not sufficiently sensitive were as follows:

$$\text{Ce}^{144} + \text{Pr}^{144} / \text{Gross } \beta = 1.15 e^{-0.0045t}$$

$$\text{Cs}^{137} / \text{Gross } \beta = 0.040 e^{0.0116t}$$

$$\text{Mn}^{54} / \text{Gross } \beta = 0.044 e^{-0.0079t}$$

$$\text{Sb}^{125} / \text{Gross } \beta = 0.021 e^{0.0121t}$$

$$\text{Zr}^{95} + \text{Nb}^{95} / \text{Gross } \beta = 0.13 e^{-0.05t}$$

t is expressed in weeks, with t = 1 for week ending 1-2-64

All equations are applicable from t = 1 through t = 42 (10-19-64),

All except equation for Zr⁹⁵ + Nb⁹⁵ are valid from week 49-64

through week 71 (5-13-65).

TABLE 2-B. Deposition Rate Measurements in
Tecumseh, Michigan, 1964-65 (pCi/m²-day)

Collection date	Week	Gross β	Ce ¹⁴⁴ + Pr ¹⁴⁴	Ce ¹⁴¹	Sb ¹²⁵	Sr ⁹⁰	Cs ¹³⁷	Zr ⁹⁵ + Nb ⁹⁵	Mn ⁵⁴	Ba ¹⁴⁰ + La ¹⁴⁰	Rainfall (inches)
1-2	1	357	407		7.5		15	44	16		0.073
1-9	2	830	938		18		34	96	36		0.74
1-16	3	186	208		4.1		7.6	20	7.8		0.01
1-23	4	972	1090		22		41	102	41		0.103
1-30	5	243	281		5.6		10	24	10		0.165
2-5	6	372	413		8.6		16	35	15		0.139
2-13	7	214	238		4.9		9.4	19	8.8		0.105
2-20	8	744	819		18		33	62	30		0.145
2-27	9	114	125		2.7		5.1	9	4.6		0.01
3-6	10	500	550		12		22	38	20		0.24
3-16	11	3000	3300		75		138	220	120		0.81
3-23	12	1260	1390		32		58	84	50		0.48
3-30	13	2720	2970		68		130	170	106		1.46
4-6	14	5000	5450		130		235	300	195		1.44
4-13	15	600	648		14		29	35	23		0.04
4-20	16	1570	1700		41		75	84	61		0.19
4-27	17	1020	1090		28		50	56	39		0.55
5-4	18	3720	3980		100		186	183	141		1.36
5-11	19	1030	1090		28		52	47	39		0.65
5-18	20	2290	2430		64		116	100	89		0.56
5-25	21	986	1040		27		51	41	36		0.32
6-1	22	457	480		13		24	18	17		0.04
6-8	23	4720	4920		137		250	174	170		1.74
6-15	24	1720	1790		50		91	60	62		0.79
6-22	25	1420	1460		41		77	50	51		0.66
6-29	26	272	277		82		15	9	10		0
7-6	27	1120	1140		34		62	34	39		0.46
7-13	28	2430	2450		73		134	68	84		1.20
7-20	29	515	520		16		29	13	18		0.38
7-27	30	1130	1130		35		64	28	40		0.85
8-3	31	443	443		14		25	11	15		0.44

TABLE 2-B (continued)

Collection date	Week	Gross β	Ce ¹⁴⁴ + Pr ¹⁴⁴	Ce ¹⁴¹	Sb ¹²⁵	Sr ⁹⁰	Cs ¹³⁷	Zr ⁹⁵ + Nb ⁹⁵	Mn ⁵⁴	Ba ¹⁴⁰ + La ¹⁴⁰	Rain-fall (in.)
8-10	32	515	510		16		30	12	18		0.36
8-17	33	1160	1150		37		68	26	39		1.45
8-24	34	886	869		29		53	18	29		2.20
8-31	35	386	378		13		23	7	13		1.00
9-7	36	93	90		3		6	2	3		0
9-14	37	92	89		3		6	2	3		0.49
9-21	38	458	440		16		28	7	15		1.13
9-28	39	214	205		8		13	3	7		0.49
10-5	40	84	81		3		5	1	3		0.03
10-12	41	300	285		11		20	4	10		0.17
10-19	42	172	163		6		11	2	5		0.08
10-26	43	429	337	132	20		18	72	11	350	0.02
11-2	44	1000	490	96	20		30	49	10	278	0.15
11-9	45	110	55	8	3		3	4	2	18	0.03
11-16	46	229	129	14	7		9	7	5		0.31
11-23	47	86	57	7	3		6	4	4		0.10
11-30	48	200	186	-	8		14	-	6		0.57
12-7	49	66	61		3		5	-	2		0.20
12-14	50	329	303		13		24		10		0.77
12-21	51	200	184		8		15		6		0.05
12-28	52	200	182		8		15		6		0.33
1965											
1-4	53	172	157		7		13		5		0.99
1-11	54	157	141		7		12		5		0.54
1-18	55	30	27		1		2		1		0.05
1-26	56	300	267		13		23		8		1.17
2-1	57	229	204		10		18		6		0.13
2-8	58	141	124		6		11		4		0.09
2-15	59	180	158		8		14		5		0.80
2-22	60	27	24		1		2		1		0.02
3-1	61	84	73		4		7		2		0.10
3-8	62	400	348		18		33		11		1.40
3-15	63	74	64		3		6		2		0.11
3-22	64	386	332		18		33		10		0.54

TABLE 2-B (continued)

Collection date	Week	Gross β	Ce ¹⁴⁴ + Pr ¹⁴⁴	Ce ¹⁴¹	Sb ¹²⁵	Sr ⁹⁰	Cs ¹³⁷	Zr ⁹⁵ + Nb ⁹⁵	Mn ⁵⁴	Ba ¹⁴⁰ + La ¹⁴⁰	Rain-fall (in)
3-29	65	139	120		7		12		4		0.09
4-5	66										0.12
4-12	67	543	584		26		47		14		1.05
4-19	68										-
4-26	69	243	376		12		22		8		0.42
5-6	70	358	394		18		32		9		0.80
5-13	71	157	132		8		14		4		0.06
5-20	72	329	276		17		30		8		0
5-27	73	1440	676	147	37		83	146	27	800	0.53
6-3	74	1330	1120	126	71		112	130	35	486	1.44
6-10	75	1430	1470	218	46		76	210	33		0.60
6-17	76	214	92	39	9		17	46	6		0.04
6-24	77	844	82	20	13		28	32	12		0.85
7-1	78	229	231	19	4		12	29	4		0.25
7-8	79	630	770	30	10		30	29	10		1.98
7-15	80	157	256	5	5		11	11	2		0.19
	81	73	91	2	3		6	5	2		0.06
7-22	82	141	165	1	9		15	3	4		0.46
7-29	83	172	134		10		17		4		1.90
8-5	84	143	112		9		15		3		0.86
8-12	85										
8-19	86	102	79		6		11		2		0.56
8-26	87	143	110		9		16		3		1.30
9-2	88	113	87		7		12		3		1.00
9-9	89	80	61		5		9		2		1.47
9-16	90	57	43		4		6		1		0.60
9-23	91	50	38		3		6		1		0.68
9-30	92	17	13		1		2		0.4		0.25
10-7	93	13	10		1		2		0.3		0.35
10-14	94	12	9		1		1		0.3		1.36
10-21	95	39	29		3		5		1		1.38
10-28	96	4	3		0.3		0.5		0.1		0.01
11-4	97	37	27		3		4		1		0.62
11-11	98	50	36		4		6		1		0.70
11-18	99	60	43		4		7		0.2	-	0.51
11-25											

TABLE 2-B (continued)

Collection date	Week	Gross β	Ce ¹⁴⁴ + Pr ¹⁴⁴	Ce ¹⁴¹	Sb ¹²⁵	Sr ⁹⁰	Cs ¹³⁷	Zr ⁹⁵ + Nb ⁹⁵	Mn ⁵⁴	Ba ¹⁴⁰ + La ¹⁴⁰	Rain-fall (in.)
12-2	100	27	20		2		3		0.5		0.23
12-9	101	27	19		2		3		0.5		0.17
12-16	102	60	43		5		8		1.		1.50
12-23	103										
12-30	104										

Regression equations used to calculate the concentration of each radionuclide when gamma spectrometry was not sufficiently sensitive were as follows:

$$\text{Ce}^{144} + \text{Pr}^{144} / \text{Gross } \beta = 1.15 e^{-0.0045t}$$

$$\text{Cs}^{137} / \text{Gross } \beta = 0.04 e^{0.0116t}$$

$$\text{Mn}^{54} / \text{Gross } \beta = 0.044 e^{-0.0079t}$$

$$\text{Sb}^{125} / \text{Gross } \beta = 0.021 e^{0.0121t}$$

$$\text{Zr}^{95} + \text{Nb}^{95} / \text{Gross } \beta = 0.13 e^{-0.05t}$$

t is expressed in weeks, with t = 1 for week ending 1-2-64

All equations are applicable from t = 1 through t = 42 (10-19-64), and all except equation for Zr⁹⁵ + Nb⁹⁵ are applicable from week 49 (12-7-64) through week 71 (5-13-65).

TABLE 3B. Results of Soil Density Measurements During
Soil Survey of Study Farm, October 26-29, 1964

Field	Soil Type	Density (dry g/cm ²) Depth (cm)		
		0-10	10-20	20-30
A	761A0	16.2	18.4	20.4
B	511A0	14.9	18.4	21.8
	540B1	13.8	16.6	18.4
C	511A0	17.6	18.2	20.0
	540B1	18.4	20.8	19.8
D	511A0	14.5	18.8	19.6
	540B1	15.1	19.2	19.8
E	511A0	19.3	17.2	17.8
	8811A0	16.5	16.2	18.1
F	511A0	17.8	17.4	21.7
	8811A0	16.2	16.2	19.3
G	630A0	15.5	18.9	21.5
	8811A0	13.5	16.2	14.6
H	8811A0	13.6	15.7	18.8
L	511A0	14.0	18.2	20.9
	540B1	14.1	19.3	18.9
M	540B1	15.9	17.3	19.3
N	511A0	15.2	17.5	19.6
	540B1	16.7	17.2	20.6
O	631A0	14.8	19.5	19.3
	677A0	16.0	19.9	20.4
	891A0	16.3	17.9	21.0
P	511A0	15.3	16.7	20.4
R	250B1	16.0	17.9	19.1
	350C2	17.7	16.0	19.0
	540B2	17.0	20.9	20.8
	8812A0	15.8	15.4	16.4
S	250B1	17.0	19.2	21.7
	511A0	16.5	16.0	20.4
	530C2	16.9	17.2	18.2
T	8702A0	17.2	19.7	22.8
	8812A0	19.8	15.7	19.7
U	677A0	19.5	16.4	20.8
V	540B2	14.7	17.9	20.0
W	511A0	16.7	17.7	20.2
X	511A0	16.2	17.6	21.2
	540B2	17.0	15.7	19.4
Y	8812A0	14.5	16.4	19.6
	511A0	11.3	14.4	19.2
	Average	16.0	17.6	19.8

TABLE 4B. Radionuclide Concentrations in
Three Depths of Soil on Study
Farm, October 26-29, 1964*

CONCENTRATION (pCi/g)						
FIELD	SOIL TYPE	DEPTH(CM)	Ce-Pr-144	Cs-137	Mn-54	K(g/g)
A	761A0	0-10	4.0	0.32	0.093	0.0141
		10-20	3.2	0.24	0.074	0.0137
B	511A0	0-10	3.8	0.45	0.14	0.0199
		10-20	2.0	0.21	< 0.05	0.0205
	540B1	0-10	2.4	0.52	0.15	0.0205
		10-20	<1.0	0.20	< 0.05	0.0214
C	511A0	0-10	4.2	0.40	0.14	0.0181
		10-20	1.4	0.10	< 0.05	0.0188
	540B1	0-10	2.2	0.37	0.09	0.0196
		10-20	<1.0	0.10	< 0.05	0.0198
D	511A0	0-10	<2.1	0.33	0.10	0.0199
		10-20	<1.0	0.28	0.06	0.0206
	540B1	0-10	<1.0	0.38	0.07	0.0199
		10-20	1.3	0.30	0.09	0.0198
E	511A0	0-10	3.0	0.59	0.15	0.0191
		10-20	0.9	0.04	< 0.05	0.0195
	8811A0	1-10	2.9	0.73	0.21	0.0238
		10-20	---	0.09	< 0.05	0.0243
F	511A0	0-10	2.6	0.42	0.11	0.0229
		10-20	1.1	0.30	0.08	0.0217
	8811A0	0-10	3.1	0.48	0.16	0.0230
		10-20	<1.0	0.33	0.06	0.0249
G	630A0	0-10	2.6	0.32	0.13	0.0200
		10-20	3.3	0.25	0.10	0.0202
	8811A0	0-10	5.3	0.62	0.17	0.0221
		10-20	3.0	0.41	0.11	0.0220
H	8811A0	0-10	6.4	0.40	0.16	0.0206
		10-20	3.2	0.28	< 0.05	0.0208
L	511A0	0-10	2.5	0.49	0.15	0.0208
		10-20	<1.0	0.38	0.07	0.0195
	540B1	0-10	2.3	0.31	0.10	0.0201
		10-20	2.1	0.22	0.08	0.0206
M	540B1	0-10	1.0	0.34	0.08	0.0216
		10-20	3.2	0.35	0.11	0.0216
N	511A0	0-10	4.0	0.58	0.20	0.0214
		10-20	<1.0	0.19	< 0.05	0.0214
	540B1	0-10	1.5	0.49	0.10	0.0205
		10-20	---	0.10	---	0.0207

TABLE 4B. Continued

FIELD	SOIL TYPE	DEPTH	Ce-Pf-144	Cs-137	Mn-54	K(g/g)
O	631A0	0-10	3.9	0.39	0.09	0.0166
		10-20	2.7	0.24	<0.05	0.0166
	677A0	0-10	2.9	0.34	0.07	0.0164
		10-20	1.7	0.31	<0.05	0.0163
	891A0	0-10	3.0	0.39	0.09	0.0183
		10-20	3.8	0.31	0.06	0.0184
P	511A0	0-10	2.8	0.35	0.10	0.0196
		10-20	3.5	0.30	0.08	0.0193
R	250B1	0-10	5.4	0.44	0.15	0.0203
		10-20	1.9	0.23	< 0.05	0.0199
	350C2	0-10	2.3	0.49	0.14	0.0209
		10-20	< 1.0	0.15	----	0.0201
	540B2	0-10	2.2	0.25	< 0.05	0.0185
		10-20	2.2	0.14	< 0.05	0.0190
	8812A0	0-10	2.3	0.52	0.16	0.0217
		10-20	---	0.27	< 0.05	0.0211
S	250B1	0-10	4.4	0.45	0.13	0.0174
		10-20	1.5	0.18	< 0.05	0.0164
	511A0	0-10	4.4	0.53	0.18	0.0171
		10-20	4.6	0.15	0.07	0.0198
	530C2	0-10	5.7	0.44	0.15	0.0182
		10-20	1.3	0.19	< 0.05	0.0184
T	8702A0	0-10	4.1	0.34	0.11	0.0166
		10-20	2.3	0.23	< 0.05	0.0177
	8812A0	0-10	3.8	0.40	0.13	0.0169
		10-20	2.0	0.18	< 0.05	0.0184
U	677A0	0-10	4.8	0.46	0.15	0.0150
		10-20	2.4	0.25	< 0.05	0.0152
V	540B2	0-10	3.6	0.32	0.09	0.0194
		10-20	2.5	0.25	0.09	0.0186
W	511A0	0-10	3.1	0.36	0.11	0.0173
		10-20	2.1	0.20	< 0.05	0.0184
X	511A0	0-10	3.8	0.44	0.12	0.0199
		10-20	3.2	0.32	0.08	0.0208
	540B1	0-10	3.9	0.35	0.09	0.0203
		10-20	3.8	0.39	0.11	0.0201
Y	8812A0	0-10	4.3	0.56	0.16	0.0211
		10-20	5.1	0.40	0.14	0.0206

TABLE 4B. Continued

FIELD	SOIL TYPE	DEPTH(CM)	Ce-Pr-144	Cs-137	Mn-54	K(g/g)
Y	511A0	0-10	3.71	0.36	0.12	0.0205
		10-20	2.6	0.35	0.10	0.0214

*

The concentrations of the radionuclides in the 20-30 depth intervals were less than the detection limits. The detection limits are the following: Ce-Pr-144: 1 pCi/gm; Cs-137: 0.06 pCi/gm; Mn-54 : 0.05 pCi/gm. The concentrations of potassium were in general slightly higher in the 20-30 cm depth interval than in the 10-20 cm. interval

TABLE 5B. Ammonium Acetate Extractable Strontium-90
Concentrations for Selected Samples in Soil
Survey, Study Farm, October, 1964.

Field	Soil Type	Concentration (pCi/g)		
		Depth (cm)		
		0-10	10-20	20-30
B	511A0	.061	.024	.006
C	540B1	.045	.017	.009
E	8811A0	.059	.019	.011
G	8811A0	.086	.059	.024
L	511A0	.051	.034	.016
N	511A0	.039	.018	.014
	540B1	.065	.019	.007
R	350C2	.048	.022	.007
	8812A0	.067	.036	.018
T	8702A0	.039	.029	.011
X	511A0	.037	lost	.010
	540B1	.038	.031	.009
Y	8812A0	.063	.059	.013
	Average	.0536	.0306	.012

TABLE 6-B. YIELDS AND RADIONUCLIDE CONCENTRATIONS OF
PASTURE GRASS AND SUDAN GRASS DURING THE GRAZING SEASON, 1964

Collection date	Week	Radionuclide Concentration (pCi/kg)						Yield** (kg/m ²)
		Ce ¹⁴⁴ Pr ¹⁴⁴	Sb ¹²⁵	Cs ¹³⁷	Zr ⁹⁵ + Nb ⁹⁵	Mn ⁵⁴	Sr-90	
1964								
4-21	16	57.4x10 ³	1.5x10 ³	2.8x10 ³	3.4x10 ³	1.7x10 ³	2.1x10 ³	0.0066
4-28	17	50.5	0.89	1.5	1.0	1.4	1.2	0.0192
5-5	18	29.2	0.74	1.5	.98	1.3	0.96	0.0310
5-12	19	41.0	0.88	2.2	1.7	2.3	0.82	0.0376
5-19	20	47.5	1.5	2.9	1.7	1.9	1.6	0.0239
5-25	21	35.3	1.1	2.5	1.2	1.4	1.5	0.0214
6-1	22	27.3	0.59	1.7	0.69	1.3	1.9	0.0134
6-8	23	88.7	1.1	3.3	1.2	2.3	2.8	0.0069
6-15	24	36.9	0.64	2.2	0.75	1.2	1.0	0.0200
6-22	25	43.9	0.83	2.5	0.93	1.4	0.81	0.0253
6-29	26	17.6	0.62	1.2	0.69	1.3	1.5	0.0092
		2.4*	<0.17*	0.35*	0.21*	0.28*	0.40*	0.0566*
7-6	27	31.8	-	2.1	0.79	0.92	1.2	0.0065
		9.1*	0.27*	0.66*	0.34*	0.44*	0.29*	0.0942*
7-13	28	64.7	0.96	1.9	1.1	0.93	1.7	0.0064
		40.1*	0.61*	2.4*	0.55*	0.84*	0.65*	0.158*
7-20	29	36.5	1.1	1.7	0.73	0.77	1.1	0.014
		20.5*	0.44*	1.3*	0.30*	0.48*	0.35*	0.319*
7-27	30	33.7	0.89	1.8	0.54	1.20	1.0	0.016
		18.7*	0.25*	0.66*	0.13*	0.40*	0.15*	0.352*
8-3	31	29.8	0.70	1.7	0.49	1.3	0.77	0.0214
		9.6	-	0.67	-	0.70*	0.49*	0.0134*
8-10	32	12.8	0.80	0.52	0.20	0.79	0.76	0.0120
8-17	33	18.0	0.80	0.82	0.25	0.49	0.68	0.0196
8-24	34	32.	0.60	2.00	0.45	1.13	2.40	0.0188
		20.*	0.55*	1.7*	0.30*	0.66*	0.53*	0.0495*
8-31	35	10	0.40	0.74	0.22	0.34	1.2	0.0118
		7*	-	0.69*	-	0.58*	0.57*	0.030*
9-8	36	6.8	0.40*	0.70	0.34	0.55	0.70	0.0178
9-15	37	8.0	-	0.89	-	0.60	0.53	0.0087
		6.0*	0.40*	0.80*	-	-	0.33*	0.0210*
9-22	38	22	-	1.8	-	1.0	0.59	0.0083
		12.*	-	1.6*	-	0.63*	0.54*	0.0243*

TABLE 6-B (continued)

		Radionuclide Concentration (pCi/kg)						Yield** (kg/m ²)
Collection Date	Week	Ce ¹⁴⁴ - Pr ¹⁴⁴	Sb ¹²⁵	Cs-137	Zr ⁹⁵ - Nb ⁹⁵	Mn ⁵⁴	Sr-90	
9-29	39	20.	-	1.2	0.5	0.97	1.1	0.0053
		9.*	-	0.69*	-	0.45*	0.93*	0.0160*
10-6	40	20	-	1.1	-	1.0	0.86*	0.0053
		11.*	-	0.64*	-	-	0.83*	0.0069*

*Sudan grass

**Except for weeks 16-19 density was measured above grazing height which was about 7 cm.

TABLE 7B. CONCENTRATIONS OF CESIUM-137
IN EACH FEED

Date Collected 1964	Week Number	Concentration (pCi/kg)					Alfalfa
		Grain	Hay	Ensilage	Pasture Grass	Sudan Grass	
3-16	11	230	1500	410	---	---	---
3-23	12	340	1400	310	---	---	---
3-30	13	320	1400	670	---	---	---
4-6	14	330	1900	470	---	---	---
4-13	15	330	1900	710	---	---	---
4-21	16	350	1900	640	2800	---	---
4-28	17	330	1500	1500	1500	---	---
5-5	18	320	1200	---	1500	---	---
5-12	19	370	---	---	2200	---	---
5-19	20	310	---	---	2900	---	---
5-25	21	320	1800	---	2500	---	---
6-1	22	290	2300	---	1700	---	---
6-8	23	290	860	---	3300	---	---
6-15	24	250	690	---	2200	---	---
6-22	25	290	1300	---	2500	---	---
6-29	26	340	870	---	1200	350	---
7-6	27	320	1100	---	2100	560	---
7-13	28	310	---	---	1900	2400	---
7-20	29	310	---	---	1700	1300	---
7-27	30	220	2800	---	1800	660	---
8-3	31	280	1600	---	1700	670	---
8-10	32	320	1800	---	520	---	---
8-17	33	290	1200	---	820	---	---
8-24	34	310	1100	---	2000	1700	---
8-31	35	310	1700	---	740	690	---
9-8	36	260	1500	---	700	---	---
9-15	37	310	3000	---	890	800	---
9-22	38	330	2200	720	1800	1600	---
9-29	39	270	2200	---	1200	690	---
10-6	40	300	1900	510	1100	640	---
10-12	41	360	1900	630	---	---	---
10-19	42	240	470	730	---	---	---
10-26	43	270	1800	720	---	---	---
11-2	44	250	1600	690	---	---	---
11-9	45	270	1700	610	---	---	---
11-16	46	240	1600	640	---	---	---
11-23	47	260	1500	690	---	---	---
11-30	48	260	1400	650	---	---	---
12-7	49	240	1600	580	---	---	---
12-14	50	260	1300	520	---	---	---
12-21	51	180	1500	550	---	---	---
12-28	52	270	1100	540	---	---	---

TABLE 7-B. Continued

Date Collected 1965	Week Number	Concentration (pCi/kg)					
		Grain	Hay	Ensilage	Pasture Grass	Sudan Grass	Alfalfa
1-4	53	240	670	470	---	---	---
1-11	54	240	800	650	---	---	---
1-18	55	280	760	630	---	---	---
1-25	56	260	720	630	---	---	---
2-1	57	180	550	610	---	---	---
2-8	58	230	1400	620	---	---	---
2-15	59	230	1600	730	---	---	---
2-22	60	220	2000	650	---	---	---
3-1	61	170	1300	560	---	---	---
3-8	62	350	1100	740	---	---	---
3-15	63	330	890	690	---	---	---
3-22	64	---	---	---	---	---	---
3-29	65	340	1100	670	---	---	---
4-5	66	270	640	650	---	---	---
4-12	67	240	1100	640	---	---	---
4-19	68	370	1300	710	---	---	---
4-26	69	240	1000	910	---	---	---
5-3	70	310	1000	410	---	---	---
5-10	71	270	830	600	---	---	---
5-17	72	250	---	---	---	---	---
5-24	73	290	---	---	---	---	660
5-31	74	220	---	---	---	---	580
6-7	75	210	---	---	---	---	470
6-14	76	---	---	---	---	---	550
6-21	77	120	---	---	---	---	660
6-28	78	180	---	---	---	---	830
7-6	79	200	---	---	---	---	720
7-12	80	200	---	---	---	690(4)	1010(3)
7-19	81	180	---	---	---	440	---
7-26	82	200	---	---	---	350	---
8-2	83	220	---	---	---	---	750
8-9	84	160	---	---	---	540	---
8-16	85	160	---	---	---	560	---
8-23	86	250	---	---	---	---	450
8-30	87	200	---	---	---	---	370
9-6	88	290	---	---	---	---	410
9-13	89	220	---	---	---	320(4)	340(3)
9-20	90	210	---	---	---	450	---
9-27	91	180	---	---	---	350	---
10-4	92	180	---	---	---	420(2)	410(5)
10-11	93	220	---	---	---	---	350
10-18	94	160	---	---	---	---	350
10-25	95	180	590	160	---	---	---
11-1	96	160	440	190	---	---	---
11-8	97	160	310	210	---	---	---

TABLE 7-B. Continued

Date	Week	Concentration (pCi/kg)					
<u>Collected</u> <u>1965</u>	<u>Number</u>	<u>Grain</u>	<u>Hay</u>	<u>Ensilage</u>	<u>Pasture</u> <u>Grass</u>	<u>Sudan</u> <u>Grass</u>	<u>Alfalfa</u>
11-15	98	180	530	200	---	---	---
11-22	99	120	430	160	---	---	---
11-29	100	140	710	160	---	---	---
12-6	101	160	380	260	---	---	---
12-13	102	140	490	220	---	---	---

TABLE 8-B. CONCENTRATIONS OF STRONTIUM-90
IN EACH FEED

<u>Week</u> <u>Number</u>	<u>Concentration (pCi/kg)</u>					
	<u>Grain</u>	<u>Hay</u>	<u>Ensilage</u>	<u>Pasture</u> <u>Grass</u>	<u>Sudan</u> <u>Grass</u>	<u>Alfalfa</u>
11	140	1550	410	---	---	---
12	121	1100	330	---	---	---
13	68	870	160	---	---	---
14	160	1250	520	---	---	---
15	21	1700	390	---	---	---
16	25	---	440	2070	---	---
17	17	1060	---	1200	---	---
18	23	1200	---	960	---	---
19	45	1200	---	819	---	---
20	50	1200	---	1560	---	---
21	66	1230	---	1480	---	---
22	106	1000	---	1890	---	---
23	116	---	---	2840	---	---
24	68	1580	---	1000	---	---
25	86	---	---	810	---	---
26	77	1480	---	1500	400	---
27	85	---	---	1200	290	---
28	77	---	---	1700	650	---
29	47	2130	---	1100	350	---
30	51	1000	---	1000	150	---
31	63	1300	---	770	49	---
32	77	1150	---	760	---	---
33	100	1300	---	680	---	---
34	85	850	---	2400	530	---
35	46	1180	---	1200	570	---
36	81	1460	---	700	---	---
37	66	1750	---	530	330	---
38	85	1720	---	590	540	---
39	58	930	310	1100	930	---
40	---	620	260	860	830	---
41	---	---	360	---	---	---
42	---	820	300	---	---	---
43	42	1100	130	---	---	---
44	47	710	220	---	---	---
45	42	1830	220	---	---	---
46	46	---	170	---	---	---
47	57	840	190	---	---	---
48	59	700	80	---	---	---
49	52	1000	120	---	---	---
50	53	800	210	---	---	---
51	149	---	140	---	---	---
52	71	800	180	---	---	---
53	115	700	190	---	---	---
54	130	850	190	---	---	---

TABLE 8-B. Continued

Week Number	Concentration (pCi/kg)					
	<u>Grain</u>	<u>Hay</u>	<u>Ensilage</u>	<u>Pasture Grass</u>	<u>Sudan Grass</u>	<u>Alfalfa</u>
55	83	910	140	---	---	---
56	---	730	100	---	---	---
57	63	870	220	---	---	---
58	67	970	170	---	---	---
59	39	1600	250	---	---	---
60	34	1500	100	---	---	---
61	---	1000	390	---	---	---
62	95	800	---	---	---	---
63	51	1730	---	---	---	---
64	70	1240	---	---	---	---
65	27	630	320	---	---	---
66	35	440	170	---	---	---
67	90	1050	400	---	---	---
68	42	1100	330	---	---	---
69	25	1300	240	---	---	---
70	45	1100	410	---	---	---
71	58	1100	350	---	---	---
72	72	---	---	---	---	1980
73	89	---	---	---	---	---
74	41	---	---	---	---	2400
75	---	---	---	---	---	1200
76	68	---	---	---	---	1510
77	43	---	---	---	---	1480
78	41	---	---	---	---	1700
79	55	---	---	---	---	1420
80	55	---	---	---	280(4)	1850(3)
81	30	---	---	---	190	---
82	68	---	---	---	200	---
83	---	---	---	---	---	1210
84	29	---	---	---	470	---
85	53	---	---	---	300	---
86	63	---	---	---	---	950
87	75	---	---	---	---	1660
88	54	---	---	---	---	1660
89	98	---	---	---	270(4)	1260(3)
90	74	---	---	---	280	---
91	66	---	---	---	120	---
92	83	---	---	---	110(2)	1680
93	132	---	---	---	---	1370
94	93	---	---	---	---	1540
95	108	1450	110	---	---	---
96	80	980	100	---	---	---
97	108	1080	130	---	---	---
98	86	1240	160	---	---	---
99	87	660	100	---	---	---
100	104	660	150	---	---	---
101	122	---	230	---	---	---
102	---	---	---	---	---	---

TABLE 9-B. CESIUM-137 CONCENTRATIONS IN
AND AVERAGE DAILY OUTPUTS OF MILK, URINE
AND FECES

Week Number	Concentration			Output		
	Milk ($\frac{\text{pCi}}{\text{liter}}$)	Urine ($\frac{\text{pCi}}{\text{liter}}$)	Feces ($\frac{\text{pCi}}{\text{kg}}$)	Milk ($\frac{\text{liters}}{\text{day}}$)	Urine ($\frac{\text{liters}}{\text{day}}$)	Feces ($\frac{\text{kg}}{\text{day}}$)
11	98	---	2500	21.8	---	7.0
12	91	---	1700	22.4	---	7.0
13	132	---	2600	22.2	---	7.0
14	116	---	1800	21.9	---	7.0
15	113	341	1900	21.1	10.1	7.0
16	105	366	1700	21.8	12.3	7.0
17	106	353	1800	22.6	14.0	7.0
18	108	453	1900	22.7	9.6	6.8
19	109	253	2300	22.9	11.5	6.8
20	86	169	3800	24.6	16.6	5.3
21	73	231	3800	24.6	16.6	5.4
22	91	221	2900	23.6	16.6	5.1
23	69	192	2500	26.3	16.6	4.8
24	56	138	2900	25.2	16.6	5.1
25	70	117	3200	23.3	16.6	6.5
26	68	190	2500	21.7	16.6	6.4
27	63	220	2200	22.9	16.6	5.5
28	42	105	2100	24.0	16.6	5.5
29	46	87	2200	21.8	16.6	6.8
30	33	75	2500	23.5	16.6	6.0
31	33	50	2100	21.7	16.6	6.9
32	32	99	2100	22.1	16.6	5.3
33	45	140	2200	20.4	16.6	4.7
34	66	214	2500	17.6	16.6	6.2
35	48	186	2100	21.7	16.6	5.3
36	35	121	1200	21.8	16.6	5.1
37	36	88	1400	20.9	16.6	4.9
38	49	81	2300	20.9	16.6	5.2
39	44	172	1700	19.5	16.6	4.4
40	37	168	1600	23.9	16.6	4.7
41	57	126	2000	23.8	16.6	6.2
42	40	132	1000	24.5	16.6	6.2
43	51	125	1300	22.9	15.3	6.6
44	71	230	1500	21.5	13.2	6.6
45	74	173	1600	20.3	13.7	6.8
46	58	239	1800	21.1	12.9	6.5
47	72	184	1800	20.7	13.5	6.3
48	74	133	1700	20.3	13.1	6.4
49	72	227	1400	20.8	12.7	6.2
50	64	241	1600	21.8	11.2	6.3
51	66	303	1500	21.6	12.9	6.1
52	67	209	1500	21.2	9.7	6.0
53	67	223	1100	19.7	11.1	5.9

TABLE 9-B. Continued

Week Number	Concentration			Output		
	Milk ($\frac{\text{pCi}}{\text{liter}}$)	Urine ($\frac{\text{pCi}}{\text{liter}}$)	Feces ($\frac{\text{pCi}}{\text{kg}}$)	Milk ($\frac{\text{liters}}{\text{day}}$)	Urine ($\frac{\text{liters}}{\text{day}}$)	Feces ($\frac{\text{kg}}{\text{day}}$)
54	54	186	1200	19.0	10.0	6.3
55	62	181	980	18.8	10.6	6.5
56	61	225	1100	18.2	11.0	6.1
57	60	301	1100	16.7	11.3	6.3
58	57	155	1500	16.2	12.3	6.2
59	64	155	1700	16.3	15.2	6.1
60	58	228	1700	16.1	10.4	6.3
61	57	216	1500	17.8	10.7	6.1
62	61	195	1400	17.3	13.9	6.1
63	59	160	1500	17.1	16.2	6.1
64	62	150	---	16.6	14.9	6.4
65	60	220	1300	15.2	13.6	6.2
66	63	158	1100	15.8	15.5	6.5
67	61	199	1400	15.8	13.5	6.2
68	63	113	1100	15.7	15.7	6.3
69	67	148	1100	15.3	17.9	6.5
70	64	134	1400	15.4	15.5	6.3
71	64	189	860	14.8	17.6	6.2
72	68	118	1100	---	18.9	6.7
73	43	109	1000	15.5	15.9	6.8
74	46	117	1500	16.7	16.7	6.8
75	47	93	880	16.6	16.0	6.8
76	37	92	770	16.6	16.2	6.8
77	35	92	870	15.8	16.3	6.8
78	37	71	1000	14.9	10.0	6.8
79	36	---	920	13.7	12.5	6.8
80	38	72	960	14.0	15.0	5.2
81	25	35	750	15.2	17.5	5.2
82	21	55	440	15.1	17.5	5.3
83	22	57	710	16.1	21.1	7.3
84	23	65	690	17.0	18.4	6.5
85	24	50	770	17.6	24.2	6.3
86	22	42	720	16.5	18.3	7.3
87	31	56	750	16.5	15.3	7.3
88	25	61	840	15.2	13.8	7.3
89	24	25	650	15.6	19.3	6.0
90	27	45	570	16.3	22.6	5.3
91	15	32	600	15.5	14.6	5.3
92	19	47	630	16.6	15.9	6.5
93	31	62	650	17.4	17.1	7.3
94	19	83	570	17.8	14.0	7.3
95	26	76	570	17.8	22.9	6.7
96	29	91	580	16.7	14.6	4.2
97	35	85	640	16.5	15.4	6.2
98	29	79	580	16.7	20.6	6.5

TABLE 9-B. Continued

Week Number	Concentration			Output		
	Milk	Urine	Feces	Milk	Urine	Feces
	($\frac{\text{pCi}}{\text{liter}}$)	($\frac{\text{pCi}}{\text{liter}}$)	($\frac{\text{pCi}}{\text{kg}}$)	($\frac{\text{liters}}{\text{day}}$)	($\frac{\text{liters}}{\text{day}}$)	($\frac{\text{kg}}{\text{day}}$)
99	31	58	480	16.4	14.9	6.3
100	31	70	530	17.7	17.8	5.9
101	22	73	640	17.4	17.0	6.5
102	25	---	550	17.5	---	5.9

TABLE 10-B. CONCENTRATIONS OF STRONTIUM-90
IN MILK, URINE, AND FECES

Week Number	Concentration		
	Milk (pCi/liter)	Urine pCi/liter	Feces pCi/kg
11	15	--	1100
12	15	--	2150
13	22	--	2070
14	19	--	1690
15	13	--	1760
16	17	--	1950
17	12	6	1830
18	14	48	1700
19	9	28	2100
20	13	8	2370
21	18	35	1900
22	23	10	2260
23	--	--	2390
24	13	47	2080
25	12	20	2114
26	31	24	1880
27	15	21	960
28	15	9	1120
29	--	11	1080
30	50	14	1480
31	24	12	1530
32	16	15	2114
33	--	20	1970
34	44	56	----
35	5	13	----
36	8	--	1150
37	11	20	1440
38	10	20	----
39	16	24	1420
40	23	9	1410
41	27	30	940
42	12	21	1120
43	13	10	1300
44	15	44	1240
45	14	--	1650
46	11	38	1650
47	13	17	1360
48	9	8	1170
49	10	14	1620
50	10	--	1400
51	11	23	1580
52	10	21	1270
53	9	6	1440
54	8	18	1170
55	7	17	1090
56	9	17	1400

TABLE 10-B. Continued

Week Number	Concentration		
	Milk (pCi/liter)	Urine pCi/liter	Feces pCi/kg
57	8	40	1530
58	9	38	1080
59	11	33	1260
60	11	15	1380
61	10	6	1500
62	13	15	1060
63	11	8	1830
64	9	44	840
65	22	15	830
66	9	14	1290
67	7	27	970
68	7	9	990
69	8	18	810
70	8	10	1840
71	12	22	1940
72	10	14	2730
73	10	20	2530
74	9	6	1750
75	9	20	----
76	7	14	2460
77	8	15	1590
78	4	8	1990
79	7	--	1570
80	9	12	850
81	7	7	----
82	6	17	1150
83	8	18	1190
84	6	8	980
85	9	12	1340
86	4	--	1330
87	11	13	1330
88	8	16	1200
89	8	8	600
90	6	12	650
91	5	5	1310
92	10	9	----
93	7	10	1980
94	10	9	----
95	7	27	1310
96	9	7	1320
97	13	6	960
98	11	5	540
99	10	9	1010
100	8	12	1300
101	10	10	1520
102	9	--	----

TABLE 11-B. AVERAGE DAILY QUANTITIES OF FEED

Week Number	Intake (kg/day - cow)					
	<u>Grain</u>	<u>Hay</u>	<u>Ensilage</u>	<u>Pasture Grass</u>	<u>Sudan Grass</u>	<u>Alfalfa</u>
11	8.3	8.2	4.7	0	0	0
12	8.3	8.2	4.7	0	0	0
13	8.3	8.2	4.7	0	0	0
14	8.3	8.2	4.7	0	0	0
15	8.3	8.2	4.7	0	0	0
16	8.3	8.2	4.7	0	0	0
17	8.3	8.2	4.7	0	0	0
18	11.6	9.8	0	0	0	0
19	11.6	9.8	0	0	0	0
20	11.6	0	0	8.6	0	0
21	11.6	4.1	0	3.0	0	0
22	11.6	4.1	0	1.9	0	0
23	11.6	4.1	0	1.0	0	0
24	11.6	4.1	0	2.9	0	0
25	11.6	7.8	0	3.6	0	0
26	11.6	7.8	0	1.3	0	0
27	8.3	7.8	0	0.9	0	0
28	8.5	0	0	0	11.4	0
29	9.0	0	0	0	15.5	0
30	8.3	4.1	0	0	7.9	0
31	8.3	4.1	0	0	11.0	0
32	8.4	4.1	0	5.2	0	0
33	8.8	4.2	0	2.8	0	0
34	8.6	8.1	0	2.7	0	0
35	8.6	4.2	0	0	5.5	0
36	8.8	4.1	0	1.7	0	0
37	8.8	4.0	0	1.2	0	0
38	8.8	4.0	1.4	1.2	0	0
39	8.6	4.0	0	0.8	0	0
40	8.8	3.9	1.2	0.8	0	0
41	8.8	8.3	1.9	0	0	0
42	8.8	7.8	2.8	0	0	0
43	8.8	8.4	2.9	0	0	0
44	8.9	8.3	2.9	0	0	0
45	8.9	8.6	3.3	0	0	0
46	8.4	8.7	2.6	0	0	0
47	8.1	8.4	2.6	0	0	0
48	8.0	8.5	2.8	0	0	0
49	8.0	8.2	2.8	0	0	0
50	7.9	8.8	3.6	0	0	0
51	7.8	8.0	2.8	0	0	0
52	8.1	8.5	2.7	0	0	0
53	7.9	7.8	2.4	0	0	0
54	8.0	8.5	2.5	0	0	0
55	7.9	8.7	2.9	0	0	0
56	7.7	8.1	2.5	0	0	0
57	7.8	8.4	3.0	0	0	0

TABLE 11-B. Continued

Week Number	Grain	Hay	Intake (kg/day - cow)		Sudan Grass	Alfalfa
			Ensilage	Pasture Grass		
58	7.9	8.2	2.7	0	0	0
59	7.9	7.8	2.9	0	0	0
60	7.3	8.5	3.1	0	0	0
61	6.7	8.4	3.2	0	0	0
62	8.2	7.6	2.9	0	0	0
63	8.1	7.6	3.0	0	0	0
64	8.0	8.4	3.0	0	0	0
65	8.0	8.0	2.9	0	0	0
66	8.1	8.8	2.9	0	0	0
67	8.1	8.0	2.8	0	0	0
68	8.3	8.2	2.8	0	0	0
69	8.3	8.6	2.9	0	0	0
70	8.2	8.2	2.6	0	0	0
71	8.2	8.3	2.4	0	0	0
72	8.2	---	0	0	0	0
73	8.7	0	0	0	0	10.5
74	8.6	0	0	0	0	10.5
75	8.7	0	0	0	0	10.5
76	8.7	0	0	0	0	10.5
77	8.7	0	0	0	0	10.5
78	8.6	0	0	0	0	10.5
79	8.5	0	0	0	0	10.5
80	8.5	0	0	0	9.4	0
81	8.4	0	0	0	9.4	0
82	8.7	0	0	0	9.4	0
83	8.5	0	0	0	0	11.7
84	8.9	0	0	0	11.3	0
85	8.8	0	0	0	11.1	0
86	8.6	0	0	0	0	11.7
87	8.7	0	0	0	0	11.7
88	8.7	0	0	0	0	11.7
89	8.8	0	0	0	10.3	0
90	8.4	0	0	0	9.7	0
91	8.5	0	0	0	9.7	0
92	8.6	0	0	0	10.8	0
93	8.6	0	0	0	0	11.7
94	8.5	0	0	0	0	11.7
95	8.3	11.5	3.6	0	0	0
96	8.1	7.7	3.6	0	0	0
97	7.5	7.7	3.6	0	0	0
98	7.8	8.2	3.5	0	0	0
99	7.5	8.3	3.2	0	0	0
100	7.5	7.2	3.2	0	0	0
101	7.6	8.6	3.2	0	0	0
102	7.3	7.9	2.8	0	0	0

TABLE 12-B. CONCENTRATIONS OF POTASSIUM IN EACH FEED

<u>Week Number</u>	<u>Grain</u>	<u>Hay</u>	<u>Concentration (g/kg)</u>			<u>Alfalfa</u>
			<u>Ensilage</u>	<u>Pasture Grass</u>	<u>Sudan Grass</u>	
11	4.9	8.8	10.0	---	---	---
12	4.7	11.2	6.6	---	---	---
13	5.9	5.7	7.7	---	---	---
14	6.7	17.4	7.7	---	---	---
15	7.1	18.6	9.2	---	---	---
16	6.7	18.6	8.7	10.8	---	---
17	6.6	18.6	15.1	20.9	---	---
18	6.3	12.8	---	32.6	---	---
19	6.6	5.9	---	40.8	---	---
20	6.5	---	---	37.3	---	---
21	6.0	17.4	---	35.1	---	---
22	6.7	19.8	---	27.9	---	---
23	6.4	9.5	---	19.8	---	---
24	6.6	13.9	---	31.4	---	---
25	6.3	18.6	---	26.8	---	---
26	7.2	15.1	---	26.8	47.7	---
27	6.6	10.8	---	25.6	37.3	---
28	6.7	---	---	19.8	30.3	---
29	6.3	---	---	26.8	31.4	---
30	6.6	27.9	---	31.4	33.8	---
31	7.1	18.6	---	30.3	29.1	---
32	7.1	15.1	---	24.4	---	---
33	7.4	19.8	---	20.9	---	---
34	7.1	16.3	---	26.7	---	---
35	8.1	23.3	---	59.3	29.1	---
36	6.9	22.1	---	31.4	---	---
37	7.4	25.6	---	32.6	---	---
38	7.2	19.8	12.8	38.4	---	---
39	7.8	19.8	---	25.6	---	---
40	7.9	20.9	10.2	19.8	---	---
41	8.0	15.1	12.8	25.6	---	---
42	7.0	25.6	11.6	---	---	---
43	6.9	17.5	14.0	---	---	---
44	7.2	20.9	12.8	---	---	---
45	7.6	15.1	11.0	---	---	---
46	8.1	19.8	11.6	---	---	---
47	7.4	20.9	14.0	---	---	---
48	7.7	20.9	12.8	---	---	---
49	7.0	20.9	11.4	---	---	---
50	7.6	17.5	10.3	---	---	---
51	5.5	23.2	10.1	---	---	---
52	7.9	17.5	9.5	---	---	---
53	---	---	8.3	---	---	---
54	---	---	12.0	---	---	---
55	---	---	11.1	---	---	---
56	---	---	9.0	---	---	---
57	6.3	20.5	10.2	---	---	---
58	7.5	18.6	9.8	---	---	---

TABLE 12-B. Continued

<u>Week</u> <u>Number</u>	<u>Concentration (g/kg)</u>					<u>Alfalfa</u>
	<u>Grain</u>	<u>Hay</u>	<u>Ensilage</u>	<u>Pasture</u> <u>Grass</u>	<u>Sudan</u> <u>Grass</u>	
59	7.0	20.9	10.3	---	---	---
60	6.9	17.5	11.1	---	---	---
61	5.6	18.6	9.7	---	---	---
62	7.8	18.6	9.1	---	---	---
63	7.7	18.6	10.3	---	---	---
64	---	---	---	---	---	---
65	7.7	23.3	9.7	---	---	---
66	7.6	23.3	11.9	---	---	---
67	7.8	18.6	11.3	---	---	---
68	9.2	21.0	11.6	---	---	---
69	7.1	17.4	12.5	---	---	---
70	8.4	21.0	6.7	---	---	---
71	7.2	---	11.9	---	---	---
72	7.2	---	---	---	---	19.8
73	8.2	---	---	---	---	24.4
74	7.3	---	---	---	---	23.3
75	7.2	---	---	---	---	21.0
76	---	---	---	---	---	19.8
77	7.6	---	---	---	---	20.9
78	7.3	---	---	---	---	15.1
79	8.0	---	---	---	---	21.0
80	7.3	---	---	---	40.7	---
81	7.3	---	---	---	30.3	---
82	7.8	---	---	---	22.1	---
83	7.6	---	---	---	---	22.0
84	6.4	---	---	---	26.8	---
85	6.9	---	---	---	---	30.3
86	8.5	---	---	---	---	19.8
87	7.9	---	---	---	---	18.6
88	9.3	---	---	---	---	17.4
89	7.9	---	---	---	31.4	---
90	8.4	---	---	---	30.3	---
91	9.0	---	---	---	24.5	---
92	8.6	---	---	---	---	24.4
93	8.6	---	---	---	---	22.1
94	9.0	---	---	---	---	21.0
95	7.6	22.1	14.0	---	---	---
96	8.7	27.9	16.3	---	---	---
97	7.6	25.6	18.6	---	---	---
98	7.3	30.3	12.8	---	---	---
99	7.3	22.1	14.0	---	---	---
100	7.9	28.0	14.0	---	---	---
101	8.4	23.3	14.0	---	---	---
102	8.3	33.8	14.0	---	---	---

TABLE 13-B. CONCENTRATIONS OF POTASSIUM IN MILK, URINE AND FECES

Week Number	Concentration		
	Milk (g/liter)	Urine (g/liter)	Feces (g/kg)
11	1.4	---	5.7
12	1.4	---	4.9
13	1.4	---	5.2
14	1.5	---	6.3
15	1.5	16.3	7.8
16	1.5	14.0	5.8
17	1.5	12.8	8.6
18	1.4	12.8	6.5
19	1.4	11.5	6.5
20	1.5	9.9	11.6
21	1.5	12.8	8.7
22	1.7	15.1	12.8
23	1.5	10.2	10.5
24	1.4	9.1	8.6
25	1.5	6.0	10.5
26	1.5	11.6	8.7
27	1.6	16.3	10.6
28	1.6	9.5	16.3
29	1.5	7.9	8.8
30	1.6	11.2	15.1
31	1.5	14.0	6.2
32	1.5	15.1	8.1
33	1.5	12.8	9.7
34	1.5	11.6	9.3
35	1.6	16.3	9.4
36	1.5	14.0	10.8
37	1.6	13.9	8.1
38	1.5	7.0	10.4
39	1.4	12.8	10.4
40	1.4	11.6	9.0
41	1.5	12.8	8.5
42	1.6	12.8	8.5
43	1.5	10.3	9.1
44	1.6	12.8	8.7
45	1.6	9.1	10.4
46	1.6	14.0	8.6
47	1.5	11.6	8.8
48	1.6	7.8	7.9
49	1.6	12.8	9.6
50	1.6	11.6	9.6
51	1.7	12.8	7.4
52	1.6	11.4	8.9
53	1.8	9.6	7.7
54	1.7	13.4	7.0
55	1.7	10.0	5.8
56	1.7	14.1	8.9

TABLE 13-B. Continued

Week Number	Concentration		
	Milk (g/liter)	Urine (g/liter)	Feces (g/kg)
57	1.6	15.8	6.4
58	1.7	12.3	8.0
59	1.8	10.8	6.0
60	1.7	14.2	8.4
61	1.6	13.4	8.2
62	1.6	10.8	7.0
63	1.6	10.4	4.8
64	1.4	10.6	---
65	1.4	14.9	6.5
66	1.7	14.3	7.8
67	1.7	13.4	6.7
68	1.5	7.6	6.0
69	1.5	10.4	4.9
70	1.4	12.1	7.4
71	1.4	13.7	8.4
72	1.6	10.9	6.5
73	1.4	15.5	5.5
74	1.4	12.8	9.2
75	1.5	11.9	9.4
76	1.4	10.9	4.0
77	1.5	11.6	9.5
78	1.4	13.2	9.5
79	1.6	---	9.3
80	1.7	12.4	8.1
81	1.7	13.6	13.8
82	1.4	12.2	7.0
83	1.5	11.4	6.6
84	1.6	13.0	10.4
85	1.5	13.4	8.4
86	1.5	11.2	9.8
87	1.5	11.8	10.6
88	1.7	12.9	9.4
89	1.6	12.4	16.8
90	1.5	11.2	14.5
91	1.5	14.4	15.2
92	1.5	9.9	10.9
93	1.6	11.9	12.7
94	1.5	13.1	14.1
95	1.5	12.1	8.4
96	1.5	15.0	7.3
97	1.5	13.8	12.6
98	1.5	12.5	9.1
99	1.5	12.1	11.4
100	1.5	11.1	11.9
101	1.5	12.6	9.0
102	1.5	---	7.8

TABLE 14-B. CONCENTRATIONS OF CALCIUM IN EACH FEED

Week Number	Concentration (g/kg)					
	Grain	Hay	Ensilage	Pasture Grass	Sudan Grass	Alfalfa
11	---	---	---	---	---	---
12	---	---	---	---	---	---
13	---	---	---	---	---	---
14	---	---	---	---	---	---
15	---	---	---	---	---	---
16	---	---	---	---	---	---
17	---	---	---	---	---	---
18	---	---	---	---	---	---
19	---	---	---	---	---	---
20	---	---	---	---	---	---
21	5.1	11.3	---	---	---	---
22	4.7	16.4	---	---	---	---
23	4.3	12.5	---	---	---	---
24	4.2	11.4	---	---	---	---
25	4.1	14.6	---	---	---	---
26	4.4	---	---	---	---	---
27	5.6	10.5	---	---	---	---
28	5.1	---	---	---	---	---
29	4.1	---	---	---	3.9	---
30	3.6	6.4	---	---	5.2	---
31	4.3	13.1	---	---	4.9	---
32	---	10.8	---	8.9	---	---
33	5.1	9.2	---	9.9	---	---
34	4.0	8.7	---	5.9	---	---
35	1.8	9.9	---	---	11.0	---
36	3.9	6.4	---	8.7	---	---
37	4.7	10.6	---	4.2	---	---
38	3.0	7.7	2.8	8.3	---	---
39	5.2	10.3	---	4.8	---	---
40	4.0	8.7	2.7	9.1	---	---
41	4.8	4.4	2.6	7.4	---	---
42	2.9	9.6	2.3	---	---	---
43	2.5	4.9	3.4	---	---	---
44	3.4	5.9	2.6	---	---	---
45	3.4	7.2	2.3	---	---	---
46	4.0	5.6	2.5	---	---	---
47	5.4	5.7	2.4	---	---	---
48	7.3	6.2	2.9	---	---	---
49	3.6	6.0	2.6	---	---	---
50	4.9	7.3	2.3	---	---	---
51	1.7	4.5	2.1	---	---	---
52	7.4	9.0	2.4	---	---	---
53	4.9	5.9	2.3	---	---	---
54	7.5	6.7	2.8	---	---	---
55	6.6	7.5	2.4	---	---	---
56	5.9	10.3	3.2	---	---	---
57	6.0	8.7	1.9	---	---	---
58	5.8	10.1	2.6	---	---	---

TABLE 14-B. Continued

<u>Week</u> <u>Number</u>	<u>Concentration (g/kg)</u>					
	<u>Grain</u>	<u>Hay</u>	<u>Ensilage</u>	<u>Pasture</u> <u>Grass</u>	<u>Sudan</u> <u>Grass</u>	<u>Alfalfa</u>
59	6.4	6.4	2.5	---	---	---
60	3.8	10.7	3.6	---	---	---
61	1.4	6.6	3.4	---	---	---
62	4.8	4.6	3.4	---	---	---
63	5.4	9.8	4.8	---	---	---
64	5.2	8.4	2.7	---	---	---
65	4.1	10.1	2.7	---	---	---
66	2.8	7.9	2.8	---	---	---
67	3.3	7.2	3.2	---	---	---
68	4.9	7.5	2.8	---	---	---
69	3.7	8.7	3.0	---	---	---
70	3.0	6.4	4.9	---	---	---
71	3.3	4.7	2.8	---	---	---
72	5.3	---	---	---	---	---
73	4.7	---	---	---	---	---
74	5.1	---	---	---	---	---
75	3.3	---	---	---	---	20.3
76	---	---	---	---	---	16.8
77	1.9	---	---	---	---	15.9
78	2.7	---	---	---	---	12.8
79	3.9	---	---	---	---	13.3
80	4.2	---	---	---	6.6	---
81	3.2	---	---	---	4.6	---
82	3.1	---	---	---	4.9	---
83	---	---	---	---	---	17.0
84	---	---	---	---	4.9	---
85	---	---	---	---	---	14.0
86	4.8	---	---	---	---	16.0
87	7.2	---	---	---	---	17.0
88	5.5	---	---	---	---	18.0
89	---	---	---	---	4.9	---
90	3.3	---	---	---	4.0	---
91	---	---	---	---	3.6	---
92	3.2	---	---	---	---	16.0
93	4.6	---	---	---	---	14.0
94	3.2	---	---	---	---	15.0
95	3.6	10.4	---	---	---	---
96	5.3	12.4	---	---	---	---
97	4.4	9.5	---	---	---	---
98	5.1	9.5	---	---	---	---
99	4.3	14.6	---	---	---	---
100	2.2	5.7	---	---	---	---
101	---	---	---	---	---	---
102	---	---	---	---	---	---

TABLE 15-B. CONCENTRATIONS OF CALCIUM IN
MILK, URINE AND FECES

Week Number	Concentration		
	Milk (g/liter)	Urine (g/liter)	Feces (g/kg)
11	---	---	---
12	---	---	---
13	---	---	---
14	---	---	---
15	---	---	---
16	---	---	---
17	---	---	---
18	---	---	---
19	---	---	---
20	---	---	---
21	1.2	---	14.3
22	---	---	16.7
23	---	---	13.6
24	---	---	16.4
25	---	---	17.1
26	---	---	19.7
27	---	---	17.6
28	1.1	---	14.6
29	1.1	---	16.6
30	---	---	---
31	---	---	---
32	---	---	16.8
33	---	---	14.7
34	1.1	0.11	17.9
35	1.1	0.14	14.7
36	1.0	0.09	13.1
37	1.0	0.11	16.6
38	1.0	0.32	14.5
39	1.1	0.17	9.3
40	1.0	0.06	11.5
41	1.0	0.07	14.4
42	1.0	---	14.9
43	0.6	0.10	14.5
44	---	0.26	11.8
45	0.9	0.13	10.8
46	1.0	0.33	19.4
47	0.9	0.24	15.1
48	0.9	0.22	17.4
49	1.0	0.25	12.2
50	1.0	0.22	---
51	0.9	0.56	19.0
52	1.2	0.35	19.9
53	0.8	0.31	18.7
54	1.0	0.26	23.1
55	1.0	0.23	18.5
56	1.1	0.21	13.7

TABLE 15-B. Continued

Week Number	Concentration		
	Milk (g/liter)	Urine (g/liter)	Feces (g/kg)
57	1.0	0.24	15.4
58	1.0	0.12	---
59	0.9	0.13	15.6
60	1.1	0.14	17.1
61	0.8	0.20	16.0
62	1.3	0.13	17.1
63	1.2	0.10	16.6
64	1.3	0.13	17.4
65	1.0	0.10	17.4
66	0.8	0.04	14.9
67	1.2	0.13	18.4
68	1.0	0.06	18.8
69	1.0	0.08	15.3
70	0.8	---	21.0
71	0.9	---	14.6
72	---	< 0.03	16.1
73	1.1	< 0.03	32.4
74	---	< 0.03	---
75	0.9	0.16	24.8
76	0.9	< 0.03	23.7
77	0.9	0.06	26.1
78	0.8	0.04	22.0
79	0.9	---	21.8
80	0.8	< 0.03	19.2
81	1.0	< 0.03	14.0
82	0.9	< 0.03	---
83	---	---	---
84	0.9	< 0.03	23.4
85	0.9	0.05	20.5
86	0.9	< 0.03	---
87	1.0	0.03	23.4
88	1.0	0.03	21.1
89	1.0	< 0.03	16.5
90	0.9	< 0.03	10.6
91	1.0	< 0.03	9.8
92	1.0	0.08	16.7
93	1.1	< 0.03	21.3
94	---	0.09	24.9
95	1.1	< 0.03	19.3
96	1.0	< 0.03	19.6
97	1.0	< 0.03	19.4
98	1.0	0.05	17.2
99	1.0	0.06	12.4
100	1.0	---	15.5
101	0.9	---	---
102	---	---	---

APPENDIX C. RECORDING EMISSION SPECTROGRAPH
FOR THE ANALYSIS OF PLANT MATERIALS AND SOIL EXTRACTS

The instrument used for these analyses was a 1.5-meter Jarrell-Ash Atom-Counter, which consists of an excitation source, entrance slit, grating, exit slits, and phototubes.

The instrument was programmed for the determination of the 16 elements listed below. Lithium served as an internal standard, while mercury provided for continuous optical alignment between the entrance and exit slits.

Elements, spectral lines, accuracy, and ranges
in concentration in plant material

Element	Line	Range, %	Accuracy, %
K	4044.0	0.10-10.0	0.01
P	2553.3x2*	0.05-1.00	0.01
Ca	3158.8	0.10-5.00	0.01
Mg	2795.5	0.05-2.00	0.01
SiO ₂	2881.6x2*	0.10-5.00	0.01
		<u>ppm</u>	<u>ppm</u>
Mn	2593.7	1-500	1
Fe	2599.4x2*	10-1000	1
B	2496.8x2*	3-100	1
Cu	3274.0	2-50	1
Zn	2138.6	10-200	1
Al	3944.0	10-700	1
Sr	4607.3	2-500	1
Mo	2816.2x2*	0.01-6.0	0.01
Co	3453.5	0.01-6.0	0.01
Na	5889.9	10-2000	1
Ba	2385.2	2-100	1

*Second order.

Sample preparation: 1g of green dried material was ashed at 500°C for 4 hours. When the ash was cooled, 5 cc of HNO₃ - Li buffer was added. The mixture was allowed to stand for 1 hour, mixed, and introduced into the emission source.

The data are presented by an electric IBM typewriter. Since the length of exposure is controlled by the internal standard, the counts can be directly compared to standard curves for translation into concentration. This comparison was made with an IBM 1620 Computer. Time for the analysis of one sample for 16 elements was about 2 minutes. The instrument was calibrated daily, although little variance occurred from day to day.

VIII. REFERENCES

1. G. Hoyt Whipple, Charles A. Pelletier, Harold L. Wedlick. Investigations Into the Cycling and Recycling of Certain Radionuclides Through the Milk Food Chain. Progress report No. 1. (period, December 15, 1963 to December 14, 1964) The University of Michigan 06160-1-P, Sept. 1964.
2. Ibid. Progress report No. 2. (period, December 15, 1964 to December 14, 1965) The University of Michigan, Sept. 1965.
3. Ibid. Progress Report No. 3. (Period, December 15, 1965 to December 14, 1966) The University of Michigan, C00-1333-(3), Sept. 1966.
4. Federal Radiation Council Report No. 7. Background material for the Development of Radiation Protection Standards - Protective Action Guides for Strontium-89, Strontium-90 and Cesium-137, May, 1965.
5. Irving Langmuir. The Production of Rain By a Chain Reaction in Cumulus Clouds at Temperatures Above Freezing. Journal of Meteorology 5: 175-192, Oct. 1948.
6. A. C. Best. The Size Distribution of Raindrops. Quarterly Journal of the Royal Meteorological Society 551.578.11, 1950.
7. A. Nelson Dingle, Donald F. Gatz. Rain Scavenging of Particulate Matter From the Atmosphere, Final Report, University of Michigan, 02921-4-F.
8. A. C. Chamberlain. Aspects of Travel and Deposition of Aerosol and Vapour Clouds. AERE HPIR 1261 (1955).
9. R. J. Engelmann. Rain Scavenging of Particulates. HW-79382 (Dec. 1963).
10. S. M. Greenfield. Rain Scavenging of Radioactive Particulate Matter From the Atmosphere. Journal of Meteorology 14: 115-125, April 1957.
11. P. J. Drevinsky, J. Pecci. Size and Vertical Distribution of Stratospheric Radioactive Aerosols. Proceedings of the Second Conference on Radioactive Fallout from Nuclear Weapons Tests, November 3-4, 1964, CONF-765, Dec. 1965. Hereafter this reference is referred to as RFFNWT, 1964.

12. Eliahu Shalmon. Deposition of Some Radionuclides on Tropospheric Aerosols. Ph.D. Thesis. The University of Michigan. 1964.
13. Luther B. Lockhart, Jr., Robert L. Patterson, Jr. and Allen W. Saunders, Jr. Distribution of Airborne Radioactivity with Particle Size RFFNWT, 1964.
14. B. Schleien, N. A. Gaeta, A. G. Friend. Determination of Particle Size Characteristics of Old and Fresh Airborne Fallout by Graded Filtration. Health Physics 12: 633-640, May 1966.
15. T. G. Oweberg, T. A. Gaukler and Lavon H. Squier. Kinetics of Wetting in Washout of Dust. RFFNWT, 1964.
16. P. Goldsmith, H. J. Delafield and L. C. Cox. The Role of Diffusiophoresis in the Scavenging of Radioactive Particles From the Atmosphere. Quarterly Journal of the Royal Meteorological Society 89: 43-61. 1963.
17. Donald F. Gatz. Deposition of Atmospheric Particulate Matter by Convective Storms. Ph.D. Thesis. The University of Michigan. 1966.
18. Charles A. Pelletier, Audrey V. Wegst and G. Hoyt Whipple. Concentrations of Radioactive Particles in Surface Air, November 1962 through March 1963. Health Physics 10: 917-921. Dec. 1964.
19. Charles A. Pelletier, G. Hoyt Whipple, Harold L. Wedlick. Use of Surface Air Concentration and Rainfall Measurements to Predict Deposition of Fallout Radionuclides. RFFNWT, 1964.
20. H. L. Volchok. Strontium-90 Deposition in New York City. Science 156:1487-1439; 1967.
21. Robert E. Horton, Rainfall Interception, Monthly Weather Review 49, 603-623, 1919.
22. J. D. Zimbrick and P. G. Voillequé editors. Controlled Environmental Radioiodine Tests at the National Reactor Testing Station, 1967 progress report IDO, 12065 and TID 4500. December 1968.
23. Ven Te Chow editor in Chief, Handbook of Applied Hydrology, McGraw Hill, New York 1964, pages 6-9 to 6-10.
24. D. W. Wilson, G. M. Ward, and J. E. Johnson Fallout¹³⁷Cs: Direct Aerial Transfer as an Important Source of Foliar Deposition. Radiation Botany 7:313 to 319, 1967.

25. R. H. Burgy and C. R. Pomeroy "Interception Losses in Grassy Vegetation." Transactions, American Geophysical Union. 39: 1095-1100, 1958.
26. Charles A. Pelletier, The Sensitivity of Environmental Surveys to Atmospheric Releases from Nuclear Facilities. Ph.D. Thesis, University of Michigan 1966.
27. D. H. Pierson and J. R. Keane. Characteristics of Early Fallout from the Russian Nuclear Explosions of 1961. Nature 196: 801-807, 1962.
28. S. E. Thompson, "Effective Half Life of Fallout Radionuclides on Plants with Special Emphasis on Iodine-131," UCRL 12388 (Jan, 1965).
29. R. Scott Russell, "Interception and Retention of Airborne Material on Plants," Health Physics 11: 1305-1315, 1965.
30. R. Kirchmann, E. Fagneart, and S. van Puymbrock, "Studies on Foliar Contamination by Radiocaesium and Radiostrontium," Radioecological Concentration Processes, B. Åberg and Frank P. Hungate, editors. Pergamon Press, 1967, pages 475-483.
31. G. M. Melbourn and R. Taylor, "The Contamination of Grassland with Radioactive Strontium," Rad. Bot. 5: 337, 1965.
32. HASL Contributions to the Study of Fallout in Food Chains, HASL-147, 1964.
33. H. A. Knapp, The Effect of Deposition Rate and Cumulative Soil Level on the Concentration of Strontium-90 in U.S. Milk and Food Supplies. Radioactive Fallout from Nuclear Weapons Tests, Nov. 15-17, 1961, TID-7632.
34. Report of the United Nations Scientific Committee on the Effects of Atomic Radiation, Nineteenth Session Supplement No. 14 (A/5814), 1964.
35. H. L. Krieger, B. Kahn, and S. Cummings, Deposition and Uptake of ^{90}Sr and ^{137}Cs in an Established Pasture, in Radioecological Concentration Processes, Proceedings of an International Symposium. Stockholm, April, 1965, ed. by B. Åberg and F. P. Hungate.
36. L. Fredriksson and A. Eriksson, Expected Content of ^{90}Sr and ^{137}Cs in Swedish Crops and Milk at a Total Deposition in the Plowlayer of 1 Ci ^{90}Sr and 1 Ci ^{137}Cs per km^2 , FOA 4 Rapport C4354-28, 1968.

37. E. C. Anderson, G. M. Ward, J. Z. Holland, et al.,
Cesium-137 in United States powdered milk and in
the population; Radioactive Fallout from Nuclear
Weapons Tests, November 15-17, 1961, TID-7632.
38. L. F. Fredriksson, A. Eriksson, H. Lonajo and E. Haak,
Migration and Plant Availability of Fission
Products in a Lysimeter Experiment. 1. Plant
Uptake and Leaching of ^{137}Cs . FOA 4 Rapport
C4357-28, 1968.
39. C. L. Comar, Radio-Isotopes in Biology and Agriculture,
McGraw Hill Co., 1955.
40. F. W. Lengemann, Predicting the Total Projected Intake of
Radioiodine from Milk by Man. I. Health Physics,
12: 825-830, 1966.
41. F. W. Lengemann, Predicting the Total Projected Intake of
Radioiodine from Milk by Man. II. Health Physics,
12: 831-835, 1966.
42. C. L. Comar, R. H. Wasserman, F. W. Lengemann, and J. C.
Thompson, Jr., Fallout and the Food Chain Status
Review, Radioactive Fallout from Nuclear Weapons
Tests, TID-7632, Alfred W. Klement, Jr., editor,
1962.
43. C. L. Comar, R. H. Wasserman, F. W. Lengemann, Effect of
Dietary Calcium of Secretion Strontium in Milk,
Health Physics 12: 1-6, 1966.
44. C. L. Comar, R. H. Wasserman, A. R. Twardock, and F. W.
Lengemann, Sets of Various Substances of Secretion
of Radio-Strontium into Milk, Health Physics 12:
1661-1669, 1966.
45. D. F. Bunch, ed., Controlled Environmental Radio-Iodine
Tests, Progress Report II. IDO-12053, August, 1966.
46. R. J. Garner, An Assessment of the Quantities of Fission
Products Likely to be Found in Milk in the Event of
Aerial Contamination of Agricultural Land, Nature,
186: 1063, 1960.
47. J. F. Loutit and R. Scott Russell, eds, The Entry of
Fission Products into Food Chains, Progress in
Nuclear Energy Series, Pergamon Press, 1961.
48. Gerald M. Ward, James A. Johnson and Carol F. Stewart,
Cesium Passage from Precipitation to Milk, RFFNWT,
1964.
49. Gerald M. Ward and James E. Johnson, Study of Cesium 137
Passage from Precipitation to Milk, 4th Annual
Report to the USAEC, 1964.

50. R. J. Garner, A Mathematical Analysis of the Transfer of Fission Products to Cows Milk, Health Physics 13, 205-212, 1967.
51. James E. Johnson, Metabolism Fallout of Cesium-137 in Bovine. Ph.D. thesis, Colo. State University, 1965.
52. Frank B. Morrison, Feeds and Feeding, 18th Edition, Morris Publishing Co., 1923.
53. Radiological Health Handbook, PB 121784R Sept. 1960, U.S. Dept. of Health, Education and Welfare.