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^{131}I TRANSPORT THROUGH THE AIR-FORAGE-COW-MILK SYSTEM USING AN AEROSOL MIST (PROJECT RAINOUT)

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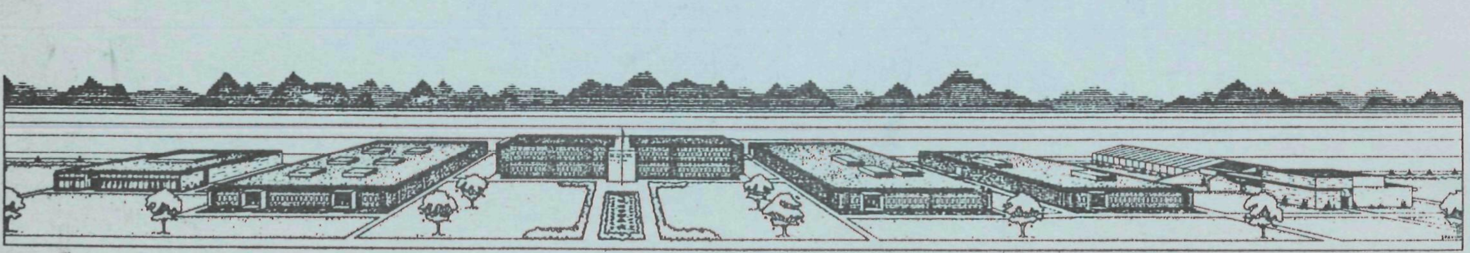
This study performed under a Memorandum of Understanding (No. SF 54 373) for the U. S. ATOMIC ENERGY COMMISSION



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*Formerly part of U. S. Department of Health, Education, and Welfare, Public Health Service, Environmental Health Service, Environmental Control Administration, Bureau of Radiological Health

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ABSTRACT

Project Rainout was an experiment conducted to determine the transfer of ^{131}I from forage to dairy cow milk when the radioiodine was sprayed on the forage as an aqueous solution. Growing alfalfa, cut as green chop, and spread hay were used as forage. The peak activity in milk from cows consuming both types of forage occurred about one day after the start of feeding. The peak milk-to-peak forage ratio was 0.013 for the cows fed hay and 0.041 for the cows fed green chop. The hay fed cows secreted in milk an average of 4.5% of the amount of ^{131}I they ingested, while the green chop fed cows secreted 6.1%.

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INTRODUCTION

The major mission of Radiological Research, a program of the Southwestern Radiological Health Laboratory, Environmental Protection Agency, is to study the transfer of radioiodine from the atmosphere to man via the route air-forage-cow-milk-man. Our program is strongly field-oriented, and includes an experimental farm at the Atomic Energy Commission's Nevada Test Site. This farm consists of 17 acres of irrigated land, a 24-cow dairy herd, and associated support facilities and equipment.[6] Whenever possible, we conduct our studies using contamination released from Plowshare cratering experiments, reactor runs, and inadvertent releases from underground weapons tests at the NTS.[1-5] Since these sources of radioactivity are relatively limited, we supplement them by semicontrolled releases of radioactive material at our farm. Two such studies (Projects Hayseed and Alfalfa) have been conducted prior to the present study.[7,8] They both involved the release of a ^{131}I-tagged diatomaceous earth aerosol over growing forage, which was subsequently cut and fed to dairy cows. Although these studies differed in aerosol particle size and the type of forage used, they were both designed to study the deposition and uptake of a dry particulate aerosol.

While deposition of radioiodine as a dry aerosol may be a major fallout mechanism, other methods are certainly possible. One of these is the removal of gaseous iodine from a cloud by the scrubbing action of rain, known as "rainout" or "washout". In such cases the iodine is presumably deposited on forage as an aqueous solution. For this type of deposition, very little information is available as to either the scrubbing mechanism or the behavior of the activity after deposition on forage. In addition, the decontaminating effects of clean water added after deposition of the activity, commonly referred to as washoff, are little understood. This additional precipitation might result from continuing rainfall after the cloud has passed, or from applying irrigation water after the contaminating event.

The experiment described in this report was named Project Rainout. It was designed to study the behavior of radioiodine deposited on forage as a solution, both with and without the application of additional water. For convenience, the ^{131}I-tagged solution is referred to as hydrosol, although it technically is a liquid aerosol.

The specific objectives of Project Rainout were:

1. To determine the concentrations of ^{131}I on spread alfalfa hay and growing alfalfa as a result of applying the ^{131}I as an aqueous solution.
2. To determine the amounts of ^{131}I in the milk of dairy cows consuming the two types of contaminated forage.
3. To relate the concentration of ^{131}I in forage to that in milk.
4. To study the retention of ^{131}I on growing alfalfa when various amounts of additional water were applied after the initial contamination.

PROCEDURES

A. Experimental Design

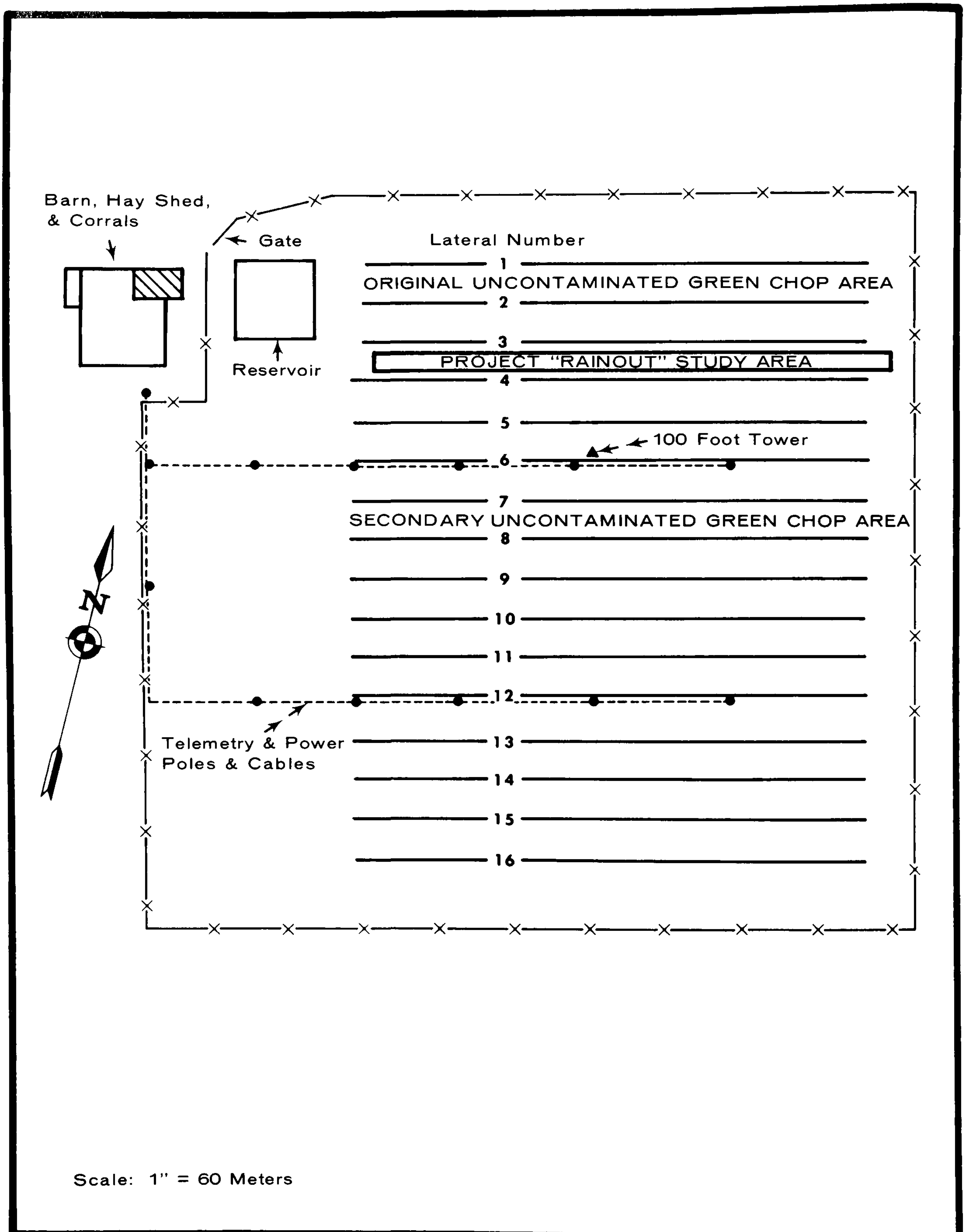
The study area for Project Rainout (actual area of the experiment) was a long narrow strip of growing alfalfa between two irrigation laterals at our farm at the Nevada Test Site (Figure 1). The design of the study area was based on feed requirements, forage sampling, hydrosol deposition methods, and various operational requirements (Figure 2). The resulting area was 235 meters long by 5 meters wide having a total area of 1175 square meters.

The criteria for deposition of the ^{131}I solution were:

1. That the study area be uniformly contaminated in a manner simulating a mist or light drizzle.
2. That precipitation levels be on the order of 0.01 inch.
3. That droplet size be on the order of 70 to 500 microns.
4. That the contamination level be on the order of 10^5 pCi ^{131}I/kg of wet forage.
5. That the wind speed be in the range of 1-8 miles per hour, with wind direction unimportant.

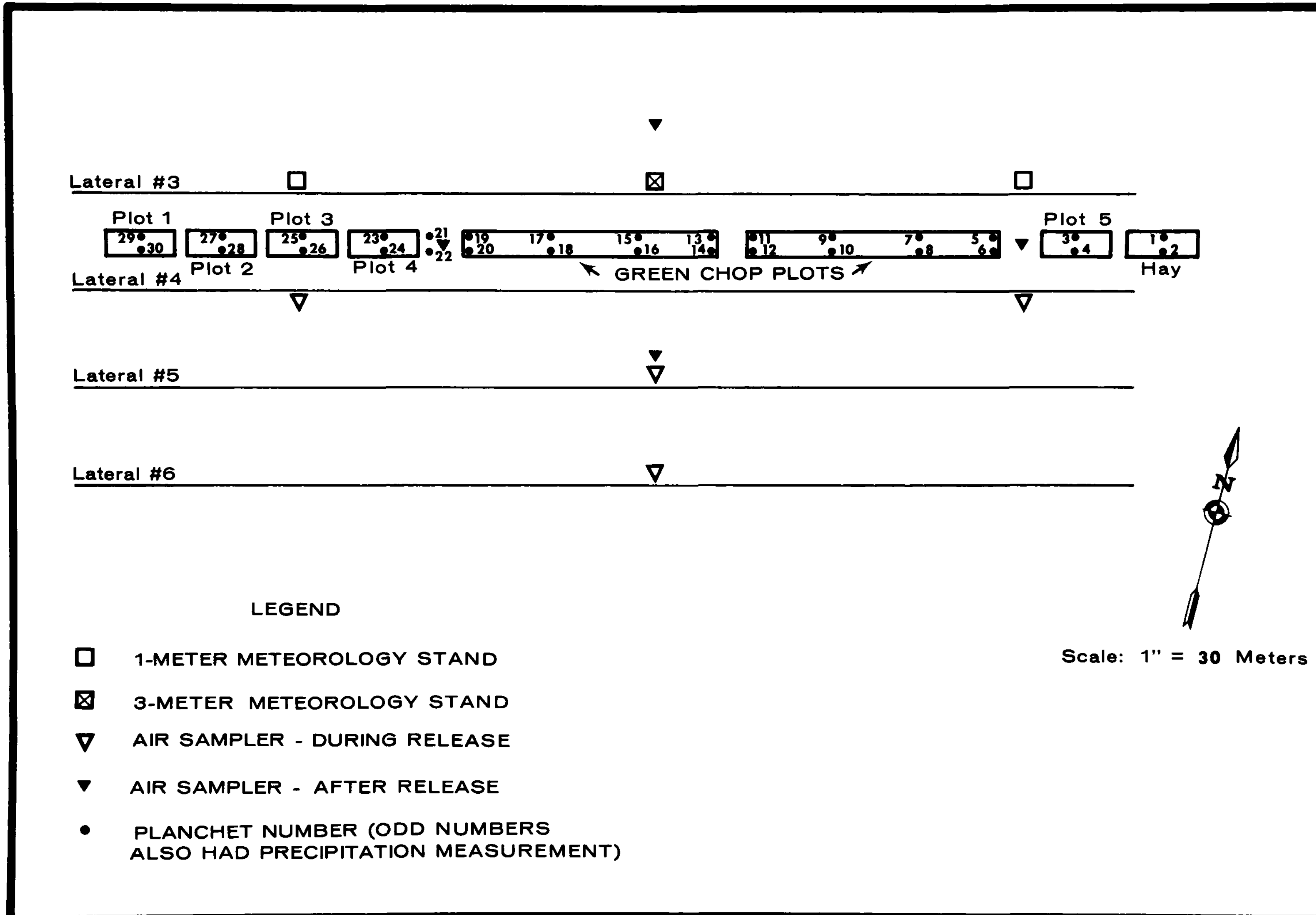
We felt that the mist or light drizzle criteria, with associated precipitation levels and droplet size, would be optimum for applying contamination, since more water or larger drops might tend to flood the contamination off the alfalfa. Based on our previous experiments[7, 8], the above cited forage contamination level would give milk activity levels which could be easily measured.

The lactating dairy herd was divided into three groups of six cows each as shown in Table 1. Cow assignments to each group were



LAYOUT OF EPA EXPERIMENTAL FARM

FIGURE 1



PROJECT RAINOUT STUDY AREA

FIGURE 2

Table 1. Groups of cows and feeding schedule

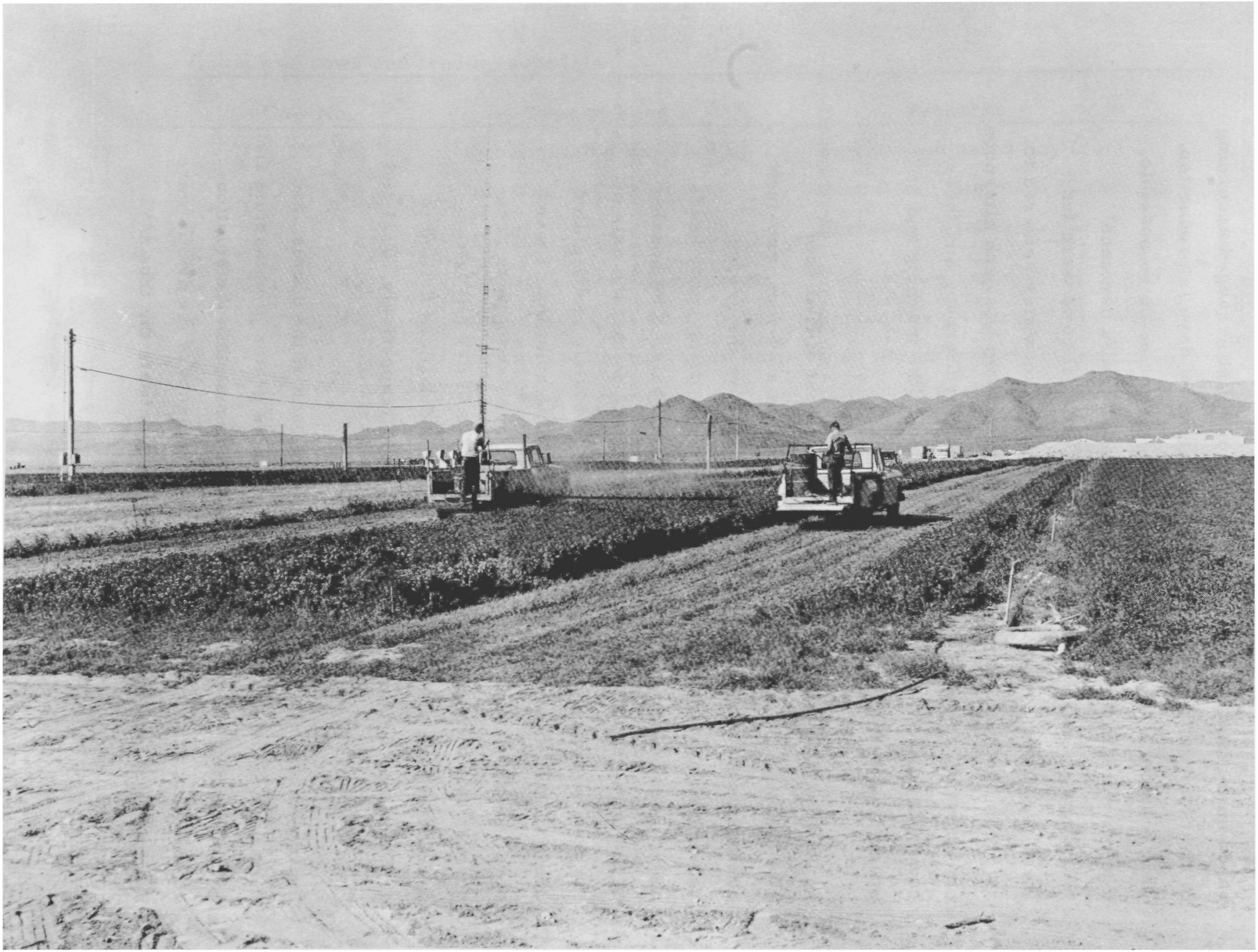
Group	Cow No.	Type of Feed	Remarks
I	12, 13, 16, 18, 27, 28	Contaminated hay (7.5 kg morning and afternoon).	Fed contaminated hay from afternoon September 29 through afternoon October 6.
II	19, 26, 43 45, 46, 47	Contaminated alfalfa green chop (12.5 kg - 20 kg morning) and uncontaminated hay (7.5 kg afternoon).	Fed contaminated green chop from afternoon September 29 through morning October 6, then uncontaminated green chop to the end of the study.
III	2, 5, 11, 15, 21, 44	Uncontaminated green chop (20 kg morning) and uncontaminated hay (7.5 kg afternoon).	Control cows fed green chop from Land #2 - September 29 through October 3. From Land #8, October 4 through October 6.

based on a stratified selection made from a list arranged according to the cows' milk production and the number of days in production. This resulted in each group being as nearly the same as possible. The cows in Group I were fed contaminated alfalfa hay each morning and afternoon for eight days. Group II cows were fed freshly chopped contaminated alfalfa forage (hereafter referred to as green chop) each morning and uncontaminated hay each afternoon for the same period. Group III was the control group, and these cows were fed uncontaminated green chop in the morning and uncontaminated hay in the afternoon.

B. Preparation, Deposition, and Assessment of Hydrosol

The hydrosol generation system consisted of a 29-foot, two-inch channel beam suspended about one meter above the ground between two pickup trucks. Twenty-two atomizing spray heads were spaced along the beam at 15-inch intervals. The nozzles of the spray heads pointed up and to the rear so that the axis of the cone of spray was about 15^{o} above horizontal. A 55-gallon drum in each truck contained the radioiodine solution. Eleven spray heads were fed from each drum. The drums were pressurized at a constant 40 psi from cylinders of dry nitrogen carried in each truck. Alternate heads had orifices drilled to 1.59 mm and 1.19 mm. These delivered, respectively, 0.34 and 0.26 gallons per minute (Figure 3).

Twenty-three mCi of ^{131}I were added to each of the drums, and the drums filled with distilled water. Five grams of potassium iodide carrier and enough 0.10 N NaOH to maintain the solution at $_{p}$H 8 was added to each drum. The contents of the drums were thoroughly mixed and aliquots taken to quantitate the true ^{131}I concentration.



AEROSOL SPRAY PROCEDURE

FIGURE 3

The tagged hydrosol was sprayed over the study area on September 29, 1966. The application was made in a single pass over the area, starting at 1028 hours PDT and taking about 26 minutes.

At the end of the contamination run, clean drums were substituted for the contaminated ones and the spray system was flushed before starting the washoff spray. The washoff water was applied by spraying clean tap water over three plots (Plots 1, 2, and 3, Figure 2) after the contaminated spray pass. The vehicles were driven in reverse over all three plots, then forward over 3 and 2, then in reverse again over 2, thus giving three different levels of precipitation on the plots. Plot 4 did not receive any additional precipitation. On Plot 5, the irrigation system was used to add a large amount of water for washoff. This water was added between 1530 hours, September 29, and 1100 hours, September 30.

The amount of precipitation was determined from the weight differences of fifteen plastic petri dishes containing anhydrous calcium sulfate. They were unsealed prior to the spray pass and resealed with a silicon lubricant as soon as possible after the pass. Thirty 4-inch diameter stainless steel planchets were used to quantitate the deposition of activity on the study area. They were placed on wooden stakes 15" above the ground (the average height of the alfalfa). Whatman 541 filters were placed in these planchets following the release to absorb the solution and facilitate drying prior to counting.

Gelman "Tempest" air samplers were operated on the anticipated downwind side of the study area during the release (See Figure 2). Following the release, sampler 4 was moved to the opposite side of the area at approximately the same distance from the field as sampler 3. Samplers 1 and 2 were moved to cleared areas near their original positions but within the study area in order to quantitate the resuspension of radioiodine. The sampling train consisted of a four-inch diameter Whatman 541 prefilter to collect particulate activity and a MSA charcoal cartridge to collect gaseous iodine.

Glass slides coated with a phenol red/n-Propanol film were momentarily exposed to the hydrosol by use of a special container. These slides were subsequently used to determine the size and size distribution of the droplets, uncorrected for any spread factor, by measuring the diameter of the characteristic print remaining after the liquid evaporated. A laboratory study was conducted following the field exercise to determine the spread factors. For this study, a vibrating reed was used to generate monodispersed droplets of water. A stroboscope synchronized with the droplet frequency effectively stopped the droplets in space so they could be photographed. The droplets were allowed to impact on glass slides prepared with the phenol red/n-Propanol film and the prints thus formed were compared in size with the size of the droplet recorded on the photograph. The procedure was repeated for various sized droplets and a spread factor curve was developed. A more detailed description of these methods is given in a report now in preparation.

C. Meteorological Instrumentation

Since weather conditions greatly influence the deposition and retention of radioactive material, we routinely document the micrometeorology at the farm during and after a release. For Project Rainout, meteorological instrumentation was installed at the study area as shown in Figure 2. Wind speed and direction instruments, with sensors at a height of one meter, were placed in two locations within the study area. Another wind speed and direction instrument with sensors at three meters was placed at the midpoint and immediately north of the grid. Instrumentation to measure temperature, relative humidity, and evaporation was also placed at this point.

The wind data were recorded on continuous-trace analog recorder charts. Prior to and during the release the data were integrated and tabulated at one-minute intervals. Following the release and for the next seven days, the data were integrated and tabulated at one-hour intervals.

D. Forage Collection and Animal Husbandry

The alfalfa hay to be contaminated was placed in the study area in a stack 15 meters long by 5 meters wide by 24 centimeters deep. The hay was placed on a plastic sheet and covered with screen wire. Following the release, the hay rations (7.5 kg each) for that day's feeding were weighed into polyethylene feed tubs. The remainder of the hay was collected by weighing feeding rations into plastic bags. The bags were sealed and stored near the corral.

Fresh green chop was cut each day. Uncontaminated green chop was cut first, then the contaminated green chop. After cutting the contaminated green chop, the tractor, chopper, and wagon were decontaminated with a high-pressure water spray. The daily ration of contaminated green chop (12.5 to 20 kg, depending on the amount available) for each cow of Group II was weighed directly into a feed tub from the wagon. The uncontaminated green chop for the control cows was fed free-choice from the feed bunk.

Unconsumed contaminated forage was weighed before disposal. This amount was subtracted from the original ration in order to have an accurate record of each cow's consumption. The "uncontaminated" green chop was cut from an area north of the study area for the first five days (Figure 1). When this forage was found to be contaminated by resuspended ^{131}I, the cutting area was moved south of the study area.

The Group I and II cows were kept in individual pens at all times except during milking. Each cow had an individual watering bowl, feed tub, and milking bucket. At each milking, the control cows were milked first, followed by the Group I cows, then the Group II cows.

The cows of Groups I and II were removed from the individual pens on October 10. They were, however, held as separate groups in divided areas of the corral. Cows of Groups II and III were placed together on October 12. On October 14, all cows of all groups were turned into a common corral.

Blood samples for blood chemistry and hematology were taken from each cow before and after the experiment.

The details of animal care, feeding and milking procedures, sampling techniques, record keeping, and equipment decontamination are described in References 7 and 9.

E. Sampling Techniques

Hay and green chop samples were taken from each cow's feed tub. The forage was spread evenly in the tub, and a handful was taken from each surface corner and a handful from the bottom center. The entire sample was sealed in a plastic bag.

Milk samples were collected by filling a one-gallon plastic container (Cubitainer)® directly from the milking bucket. After filling, the outside of the Cubitainer® was rinsed to remove any spilled milk. For composite milk samples, all milk from each cow was poured into a common container and mixed thoroughly and the sample taken from this composite.

Grain samples were collected daily from the bulk supply. Water samples were collected daily by filling a Cubitainer® from each group's common source.

Five samples of growing alfalfa were collected from each of the five treatment areas at each sampling time. Samples were taken by placing a metal ring having an area of $0.15\,m^2$ in the center of the designated area and cutting all plants within the ring two inches above the ground level. The cut alfalfa was then sealed in plastic bags.

F. Sample Analysis

The ^{131}I content of the samples was determined by gamma spectroscopy. Our system consisted of a TMC Model 404C 400-channel pulse height analyzer, Model 520 P punch control, Model 522 Resolver-Integrator, Model 500 printer, and a Tally Model 420 perforator. The detectors were two 4- by 9-inch NaI(Tl) crystals mounted facing each other with vertical spacing variable from direct contact to 14-inch separation. Each crystal had a separate high voltage supply and was viewed by four three-inch photomultiplier tubes. The crystal assembly was mounted in a steel shield with six-inch walls. The inside dimensions of the shield were 39- by 42- by 42-inches, and it was lined with lead, cadmium, and copper sheets.

Table 2 shows the types of sample containers used and the minimum sensitivity for each type sample. The minimum sensitivity was based on a 40-minute count and average sample size. The resolution of the system was 10.2% based on the ^{137}Cs photopeak.

Table 2. System efficiency and minimum sensitivity for ^{131}I

Sample type	Container	Efficiency	Minimum Sensitivity*
Milk and water	4-liter Cubitainer	17.3%	10±5 pCi/l
Grain	400-ml plastic	27.8%	80±10 pCi/kg
Hay	400-ml plastic	28.1%	100±15 pCi/kg
Charcoal (from air sampler)	400-ml plastic	27.8%	30±5 pCi/sample
Green chop	400-ml plastic	34.8%	80±10 pCi/kg
Filter paper	400-ml plastic	48.0%	15±5 pCi/sample
Fallout planchet	400-ml plastic	48.0%	15±5 pCi/sample

*Based on a 40-minute count.

RESULTS AND DISCUSSION

A. Deposition and Assessment of Radioiodine Solution

Of the 46 mCi of ^{131}I in the drums, 44.3 mCi were sprayed out. At the end of the contamination run, four gallons of solution remained in the drums. The fallout planchets showed an average activity deposition of 24.6 μCi/m^2 (Table 3). Using this figure, we calculated that 28.9 mCi, or 65.2% of the ^{131}I released, was deposited on the study area. This contamination was deposited with an average of 0.007 inches of precipitation on the study area (Table 4).

Two planchets had extreme deposition values which can be explained. The high deposition of 55.29 μCi/m^2 at No. 4 was due to a stop for sprayer adjustments at this point. The low deposition of 3.82 μCi/m^2 at No. 27 was probably due to sputtering of the spray caused by movement of the solution in the nearly empty tanks. After deleting these two values, the activity deposition varied by a factor of about 4 (10.58 to 45.64 μCi/m^2). This variation is attributed to variable wind speed and direction (Table 5), and uneven ground speed of the trucks carrying the spraying system.

The levels of uncontaminated precipitation for the washoff study were:

Plot 1 - 0.003"	Plot 4 None
Plot 2 - 0.041"	Plot 5 - 8.23"
Plot 3 - 0.032"	

Table 3. ^{131}I deposition on planchets

Sample Position	Activity ($\mu Ci/m^2$)
1	32.02
2	17.48
3	29.11
4	55.29
5	22.96
6	15.24
7	24.76
8	24.76
9	38.54
10	11.69
11	22.01
12	19.10
13	19.78
14	45.64
15	22.20
16	*
17	39.97
18	20.22
19	27.04
20	22.37
21	28.93
22	30.76
23	25.96
24	*
25	17.80
26	16.32
27	3.82
28	25.96

Table 3. ^{131}I deposition on planchets (Continued)

Sample Position		Activity ($\mu Ci/m^2$)
29		10.58
30		18.81
	Average =	24.6 ± 10.6 $\mu Ci/m^2$ **

*Planchet dropped from stake

**Mean ± one standard deviation

Table 4. Amount of precipitation at each sample position

Sample Position	Precipitation (inches)
1	0.009
2	0.010
3	*
4	0.007
5	0.012
6	0.006
7	0.005
8	0.008
9	0.015
10	0.006
11	0.008
12	0.007
13	0.003
14	0.001
15	0.003
	Average = 0.007 ± 0.004 inches**

* Sample dropped from stake
** Mean ± one standard deviation

The data from the four air samplers (Table 6) indicate some resuspension of activity after the deposition. The ratios of gaseous-to-particulate activity generally increased during the afternoon and correlate roughly with temperature rise. This is attributed to volatilization and/or transpiration of the iodine from the plants.

Figure 4 is a histogram showing the distribution of droplet sizes, uncorrected for the spread factor. The curve does not represent a statistical best fit, but only implies an outline of the distribution. A log-normal distribution of the droplet size has a geometric mean of 283 μ and a geometric standard deviation of 2.05. When the spread factor is applied to the size distribution, the geometric mean is reduced to 139 μ.

Table 5. Meteorological data during and after deposition September 29, 1966

Time (PDT)	East 1 Meter Dir*	East 1 Meter Speed**	West 1 Meter Dir*	West 1 Meter Speed**	3 Meters Dir*	3 Meters Speed**	Temperature °F	Rel. Hum. Percent
1028(1)	060	07	070	05	030	09	74	27
1029	085	07	090	06	040	09	75	27
1030	090	05	070	06	060	09	75	27
1031	085	06	050	04	090	07	75	28
1032	050	08	055	04	030	07	75	28
1033	045	07	035	06	050	09	75	28
1034	045	05	050	05	045	09	75	28
1035	050	04	090	05	050	07	75	28
1036	080	06	090	05	030	07	75	28
1037	095	08	085	05	035	07	75	28
1038	075	08	070	06	075	09	75	28
1039	060	07	075	06	085	11	75	28
1040	065	06	085	07	080	11	75	28
1041	070	04	070	06	055	10	75	28
1042	085	05	070	05	055	09	75	28
1043	080	05	085	04	060	07	75	28
1044	080	05	050	05	070	07	75	28
1045	075	06	060	04	070	07	75	28
1046	055	06	060	04	060	06	75	28
1047	055	07	070	07	075	09	75	29
1048	055	08	065	07	055	09	75	29
1049	065	07	065	08	045	08	75	29
1050	060	06	070	07	040	12	75	29
1051	045	06	060	07	045	11	75	29
1052	040	06	055	07	060	10	75	29
1053	045	06	080	07	060	10	75	29

Table 5. Meteorological data during and after deposition September 29, 1966 (Continued)

Time (PDT)	East 1 Meter Dir*	East 1 Meter Speed**	West 1 Meter Dir*	West 1 Meter Speed**	3 Meters Dir*	3 Meters Speed**	Temperature ^0F	Rel. Hum. Percent
1054(2)	040	05	070	04	040	10	75	29
1055	065	07	085	05	035	08	75	29
1056	075	06	090	05	055	09	75	29
1057	085	06	080	06	035	08	75	29
1058	085	07	075	06	035	10	75	29
1059	090	08	085	05	060	08	75	29
1100	090	05	065	05	065	08	75	29
1200	090	05	090	05	090	07	77	29
1300	180	06	170	05	180	08	80	27
1400	200	06	215	04	215	08	80	29
1500	160	04	160	06	OUT	06	78	28
1600	190	05	170	07	OUT	07	78	29
1700	185	06	180	06	OUT	10	74	29
1800	190	05	180	03	OUT	08	72	30
1900	255	02	160	02	OUT	04	67	35
2000	315	02	315	02	OUT	02	63	37
2100	315	03	320	02	OUT	04	60	39
2200	325	03	315	02	OUT	05	58	40
2300	335	03	330	02	OUT	05	58	41

*Azimuth wind is blowing from

**Miles per hour

(1) Start of Deposition

(2) End of Deposition

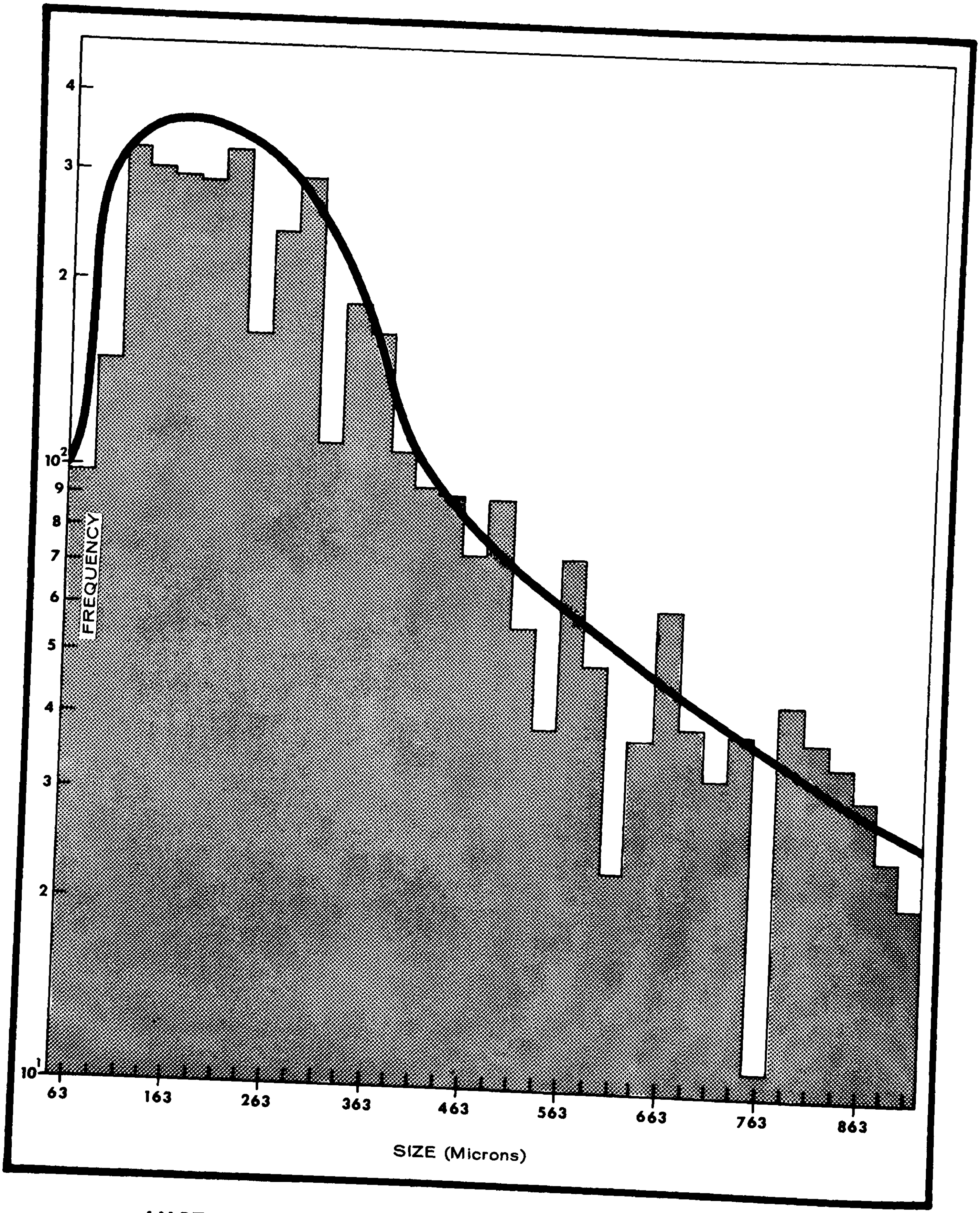
Table 6. Air sampler data during and after deposition

Sampler	Time Collected	Total Activity[1] (pCi)	Charcoal/Prefilter Ratio
1	1130[2]	$3.80x10^4$	3.2
	1230	$1.19x10^5$	17.3
	1340	$1.07x10^4$	13.4
	1450	$1.92x10^4$	13.7
	1550	$5.14x10^3$	10.8
	1650	$4.44x10^3$	6.2
2	1130[2]	$2.61x10^4$	2.9
	1230	$3.41x10^4$	10.8
	1340	$3.33x10^3$	10.8
	1450	$8.05x10^3$	11.0
	1550	$6.89x10^3$	30.6
	1650	$7.28x10^2$	17.3
3	1130[2]	$3.68x10^3$	2.6
	1230	$3.53x10^2$	4.3
	1340	$4.05x10^1$	N.A.[3]
	1450	$8.16x10^1$	N.A.[3]
	1550	$2.13x10^2$	0.2
	1650	$7.42x10^1$	N.A.[3]
4	1130[2]	$3.67x10^1$	22.0
	1230	$1.55x10^4$	5.2
	1340	$1.16x10^4$	7.7
	1450	$5.85x10^3$	6.7
	1550	$3.31x10^3$	5.3
	1650	$3.12x10^3$	12.7

(1) Total of prefilter and charcoal cartridge activities.

(2) These samples collected during and immediately after deposition.

(3) Filter activity was non-detectable.



HISTOGRAM OF DROPLET SIZE DISTRIBUTION

FIGURE 4

B. Effective Half-life on Growing Alfalfa

The means of the ^{131}I concentrations in the five samples collected from each of the five plots at each sampling period are plotted in Figure 5. The effective half-life, based on the best-fit regression line from the mean values from all five plots, was 7.0 ± 0.7 days.*

Statistical analysis indicates that the addition of various amounts of water after contamination did not affect the decrease of activity with time. The decrease of activity with time did not follow a simple exponential function. Future investigations are planned in an attempt to explain this.

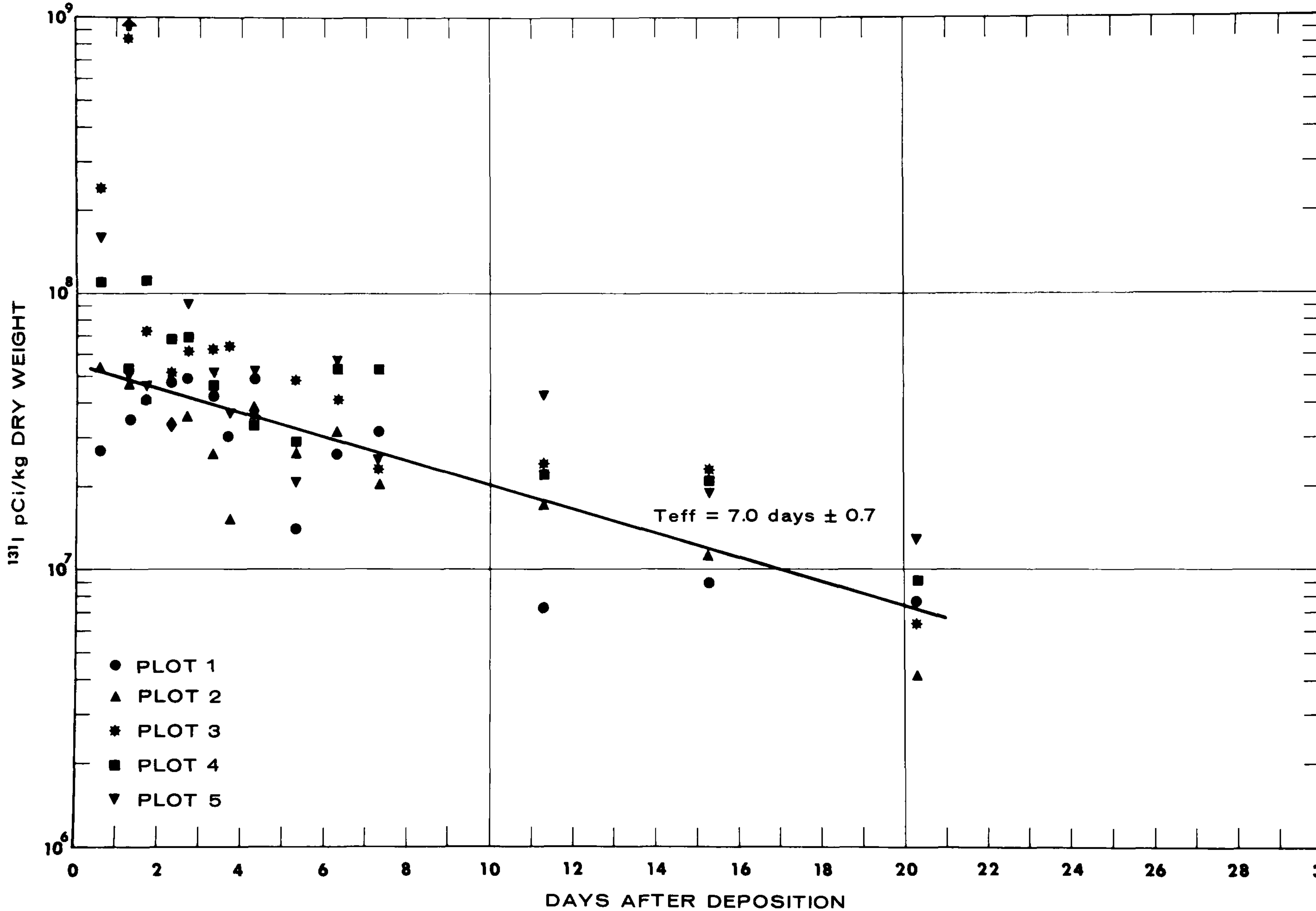
C. ^{131}I Activity in Dairy Cow Forage

The daily averages of ^{131}I concentrations in green chop and hay are summarized in Table 7. The peak activity level of 2.1×10^7 pCi/kg in green chop was obtained on the day after the release while the peak of 9.8×10^6 pCi/kg in hay occurred on the afternoon of the day of release. The daily averages of ^{131}I in green chop and hay are plotted in Figures 5 and 6 respectively. The effective half-life in green chop was 4.5 ± 1.6 days, and in hay, 3.6 ± 0.9 days. These half-lives were calculated on the basis of a best fit regression line.

Since the hay was bagged and sealed shortly after contamination, the short (3.6 days) half-life is puzzling. The rapid loss of ^{131}I apparently was due to evaporation from the hay and the ultimate escape of the ^{131}I vapor through punctures in the bag or through the plastic itself. The variation in effective half-life on growing alfalfa (7.0 days) and green chop (4.5 days) is probably due to adsorption of activity on the chopping machinery.

In both types of forage, a rise in activity levels occurred toward

*Mean ± one standard deviation.



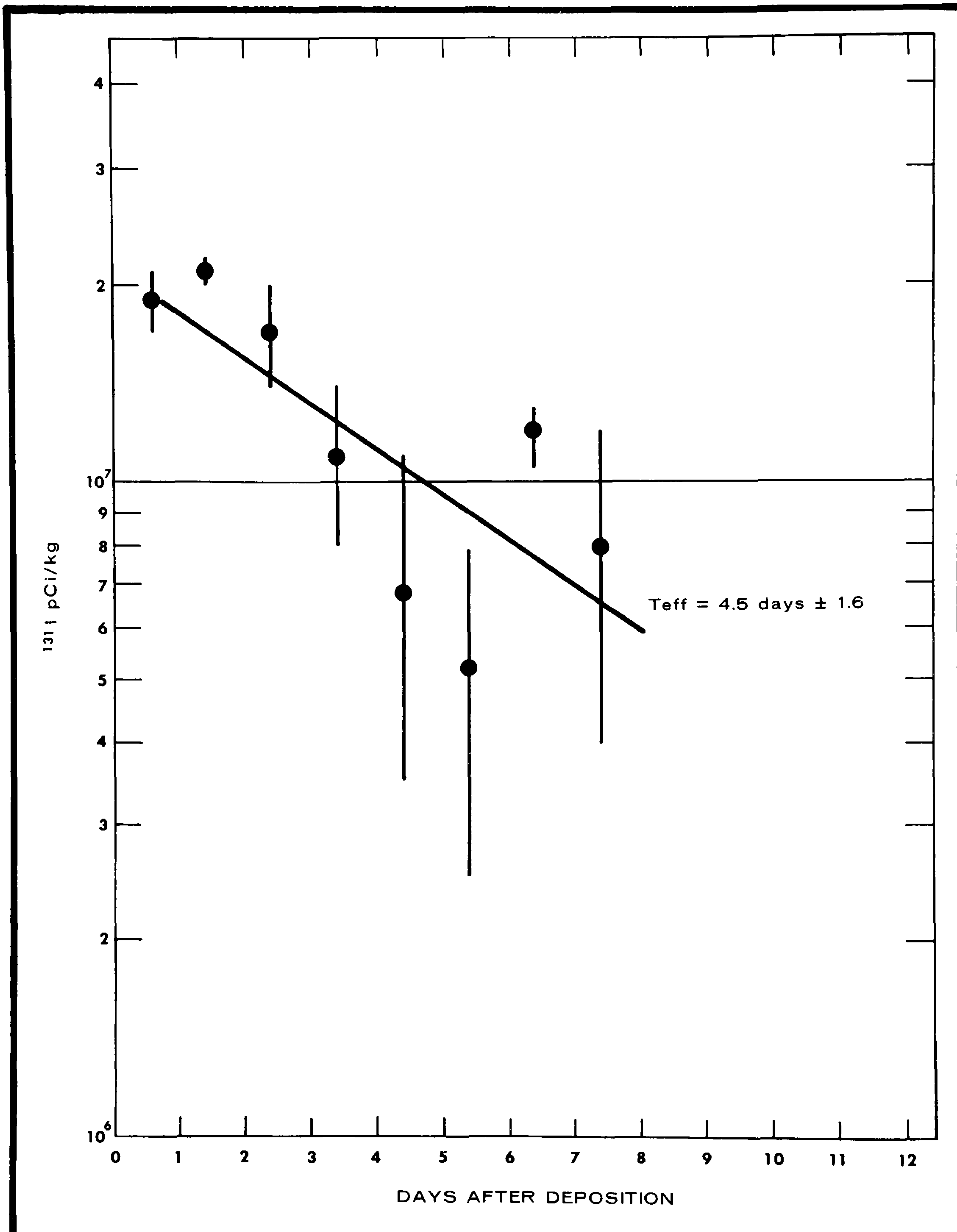
MEAN CONCENTRATIONS OF ^{131}I IN GROWING ALFALFA

FIGURE 5

Table 7. Summary of the daily averages of ^{131}I concentrations ($\mu Ci/kg$) on forage

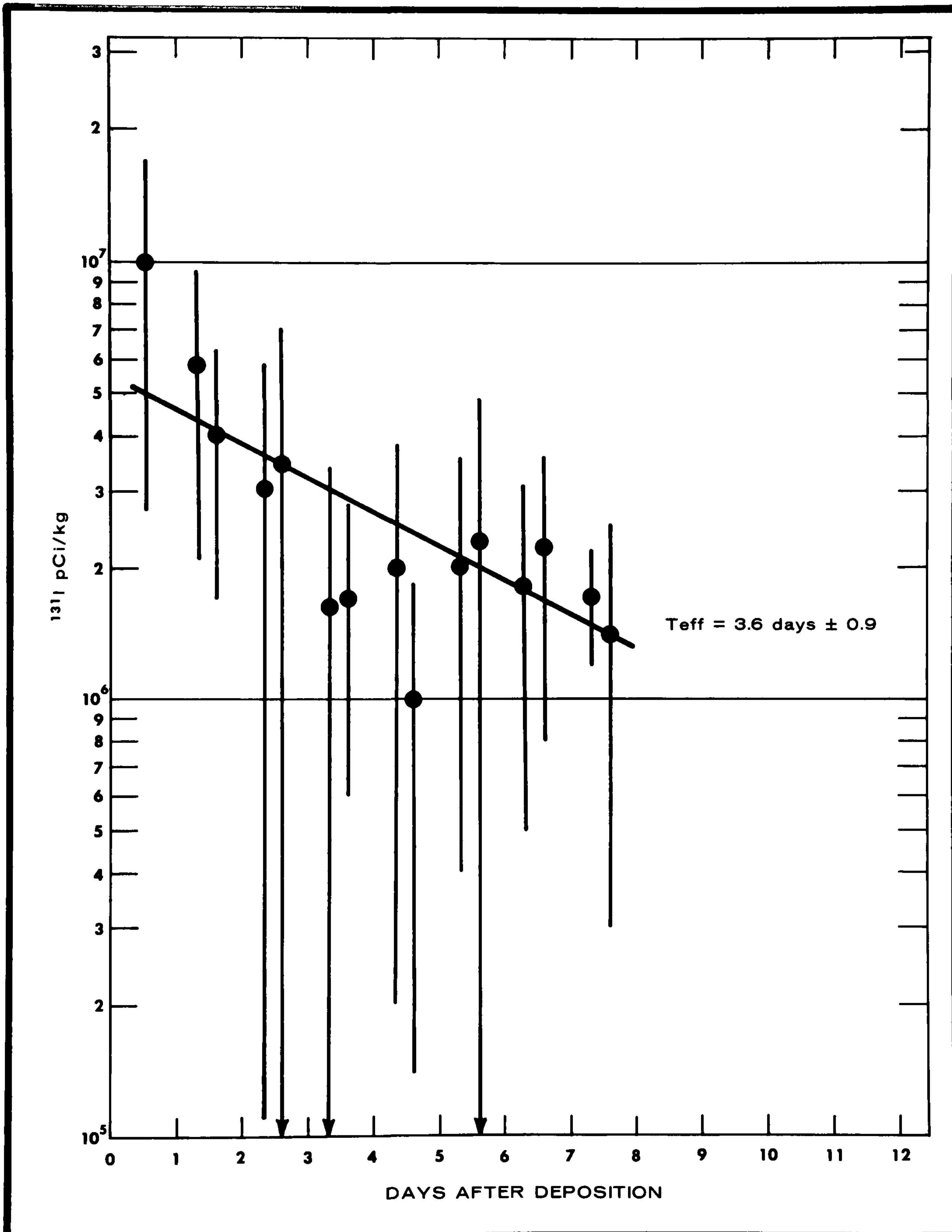
Collection Date	Collection Time	Green Chop	Hay
9/29	p.m.	19 ± 2*	9.8 ± 7.1*
9/30	a.m.	21 ± 1	5.8 ± 3.7
	p.m.		4.0 ± 2.3
10/1	a.m.	17 ± 3	3.0 ± 2.9
	p.m.		3.4 ± 3.7
10/2	a.m.	11 ± 3	1.6 ± 1.8
	p.m.		1.7 ± 1.1
10/3	a.m.	6.8 ± 3.3	2.0 ± 1.8
	p.m.		0.99 ± 0.85
10/4	a.m.	5.2 ± 2.7	2.0 ± 1.6
	p.m.		2.3 ± 2.6
10/5	a.m.	12 ± 1	1.8 ± 1.3
	p.m.		2.2 ± 1.4
10/6	a.m.	8.0 ± 0.4	1.7 ± 0.5
	p.m.		1.4 ± 1.1

*Mean ± one standard deviation.



MEAN VALUES OF ^{131}I IN GREEN CHOP

FIGURE 6



MEAN VALUES OF ^{131}I IN HAY

FIGURE 7

the end of the feeding period. This rise is especially sharp in the green chop. As with the other erratic values discussed previously, no logical explanation except uneven deposition over the study area can be offered for this.

The intended uncontaminated green chop was found to have low level contamination due to the resuspension of activity. Concentrations of 4.3×10^4 pCi/kg were detected on the day after the deposition. After the eighth day, when the "uncontaminated" green chop was being fed to the Group II cows, the ^{131}I concentration did not exceed 2.7×10^3 pCi/kg. Since this was three orders of magnitude below the lowest value on contaminated green chop, it could not have contributed more than 0.1% to the cows' intake of ^{131}I. Activity levels slightly above the minimum detectable were found in some grain and water samples, but these were also considered insignificant.

D. ^{131}I Activity in Milk

The mean values of ^{131}I in the milk of Groups I and II are shown in Table 8. The same data are presented graphically in Figures 8 and 9. Data for Group III cows are not included as they are considered controls and do not add significantly to the discussion.

The levels of ^{131}I in the milk from both groups of cows rose toward the end of the feeding period, giving a double peak effect in the curves. These secondary peaks follow the peaks of the forage curves very closely, and the increased milk activities are attributed largely to the combination of increased forage activity concentrations and increased forage consumption. Toward the end of the feeding period, the Group II cows were eating a larger amount of more highly contaminated forage; apparently the green chop was more palatable because of more succulent growth during the latter stages of the study.

Table 8. Mean concentrations of ^{131}I in milk by groups (pCi/liter)

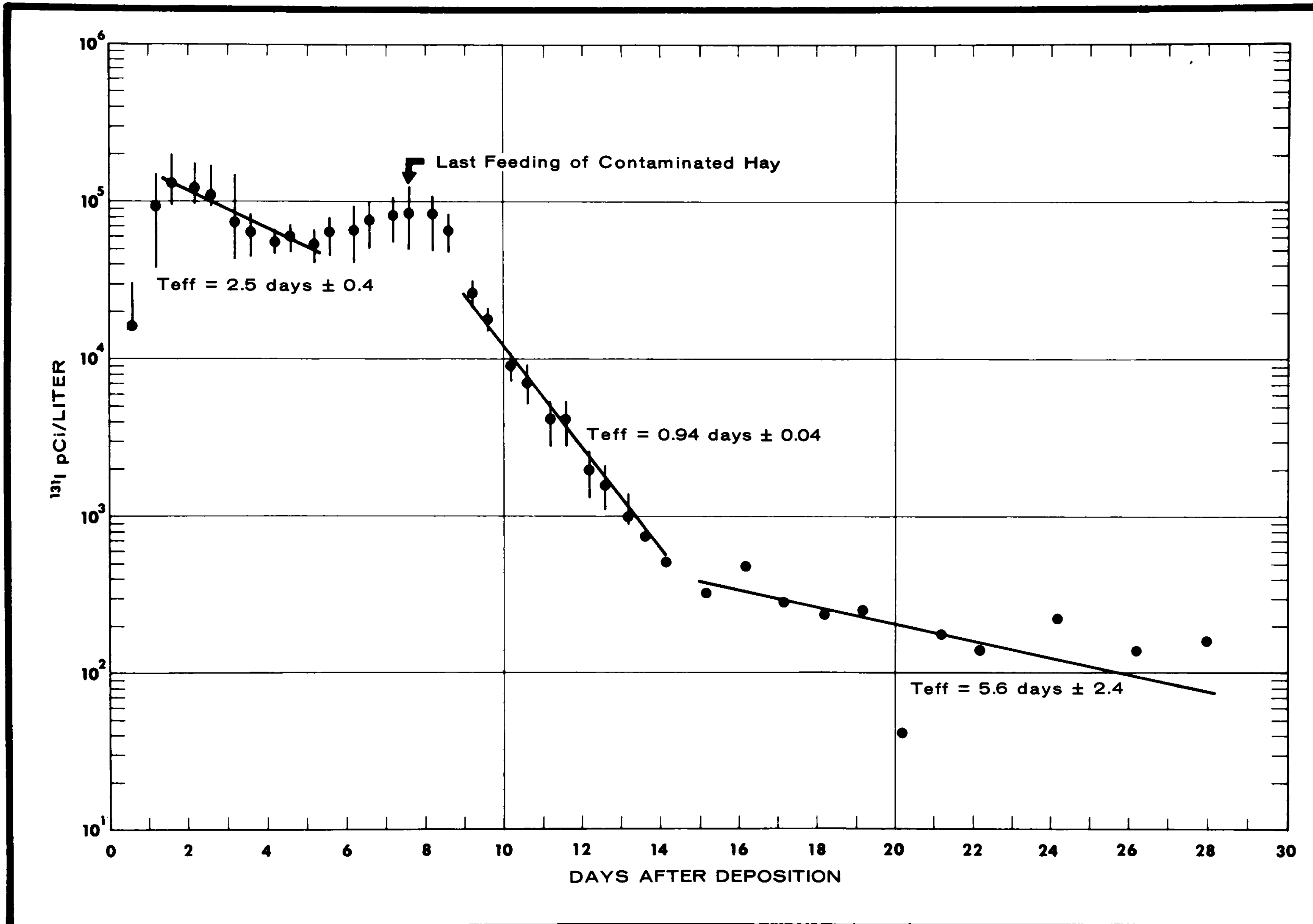
Date	Time	Group I (Hay)	Group II (Green Chop)
9/29	p.m.	$1.6 \times 10^4 \pm 1.6$*	$1.6 \times 10^5 \pm 0.5$*
9/30	a.m.	$9.5 \times 10^4 \pm 5.6$	$4.5 \times 10^5 \pm 1.1$
	p.m.	$1.3 \times 10^5 \pm 0.7$	$8.6 \times 10^5 \pm 1.8$
10/1	a.m.	$1.2 \times 10^5 \pm 0.6$	$5.3 \times 10^5 \pm 1.2$
	p.m.	$1.1 \times 10^5 \pm 0.6$	$8.1 \times 10^5 \pm 1.5$
10/2	a.m.	$7.2 \times 10^4 \pm 3.0$	$5.9 \times 10^5 \pm 1.1$
	p.m.	$6.5 \times 10^4 \pm 1.8$	$7.7 \times 10^5 \pm 1.5$
10/3	a.m.	$5.6 \times 10^4 \pm 1.1$	$5.3 \times 10^5 \pm 2.1$
	p.m.	$6.0 \times 10^4 \pm 1.3$	$6.1 \times 10^5 \pm 1.8$
10/4	a.m.	$5.5 \times 10^4 \pm 1.4$	$4.7 \times 10^5 \pm 1.7$
	p.m.	$6.4 \times 10^4 \pm 1.9$	$6.1 \times 10^5 \pm 2.3$
10/5	a.m.	$6.8 \times 10^4 \pm 2.6$	$3.7 \times 10^5 \pm 1.3$
	p.m.	$7.6 \times 10^4 \pm 2.5$	$7.5 \times 10^5 \pm 1.9$
10/6	a.m.	$8.5 \times 10^4 \pm 2.8$	$4.7 \times 10^5 \pm 1.1$
	p.m.	$8.8 \times 10^4 \pm 3.7$	$7.8 \times 10^5 \pm 2.0$
10/7	a.m.	$8.1 \times 10^4 \pm 3.1$	$5.6 \times 10^5 \pm 1.2$
	p.m.	$6.7 \times 10^4 \pm 1.8$	$4.2 \times 10^5 \pm 1.3$
10/8	a.m.	$2.7 \times 10^4 \pm 0.6$	$2.1 \times 10^5 \pm 0.7$
	p.m.	$1.8 \times 10^4 \pm 0.3$	$1.7 \times 10^5 \pm 0.8$
10/9	a.m.	$9.2 \times 10^3 \pm 1.9$	$8.5 \times 10^4 \pm 3.7$
	p.m.	$7.2 \times 10^3 \pm 2.0$	$6.8 \times 10^4 \pm 3.4$
10/10	a.m.	$4.2 \times 10^3 \pm 1.4$	$5.4 \times 10^4 \pm 2.0$
	p.m.	$4.2 \times 10^3 \pm 1.4$	$3.3 \times 10^4 \pm 1.7$

Table 8. Mean concentrations of ^{131}I in milk by groups (pCi/liter) (Continued)

Date	Time	Group I (Hay)	Group II (Green Chop)
10/11	a.m.	$2.0 \times 10^3 \pm 0.7$	$1.8 \times 10^4 \pm 0.8$
	p.m.	$1.6 \times 10^3 \pm 0.5$	$1.4 \times 10^4 \pm 0.8$
10/12	a.m.	$1.0 \times 10^3 \pm 0.4$	$7.1 \times 10^3 \pm 3.9$
	p.m.	7.8×10^2 **	$7.0 \times 10^3 \pm 3.2$
10/13	a.m.	5.6×10^2	$3.6 \times 10^3 \pm 1.7$
	p.m.	5.8×10^2	$3.1 \times 10^3 \pm 1.2$
10/14	a.m.	5.1×10^2	$2.6 \times 10^3 \pm 0.9$
10/15	a.m.	3.1×10^2	$2.2 \times 10^3 \pm 0.3$
10/16	a.m.	4.8×10^2	$1.6 \times 10^3 \pm 0.4$
10/17	a.m.	2.9×10^2	$1.3 \times 10^3 \pm 0.4$
10/18	a.m.	2.4×10^2	$1.2 \times 10^3 \pm 0.4$
10/19	a.m.	2.5×10^2	$1.0 \times 10^3 \pm 0.6$
10/20	a.m.	4.2×10^1	$6.6 \times 10^2 \pm 3.1$
10/21	a.m.	1.7×10^2	$6.5 \times 10^2 \pm 1.6$
10/22	a.m.	1.4×10^2	$6.7 \times 10^2 \pm 1.8$
10/24	a.m.	2.3×10^1	$4.3 \times 10^2 \pm 3.0$
10/26	a.m.	1.4×10^2	$4.9 \times 10^2 \pm 1.9$
10/28	a.m.	1.6×10^2	$3.9 \times 10^2 \pm 1.0$

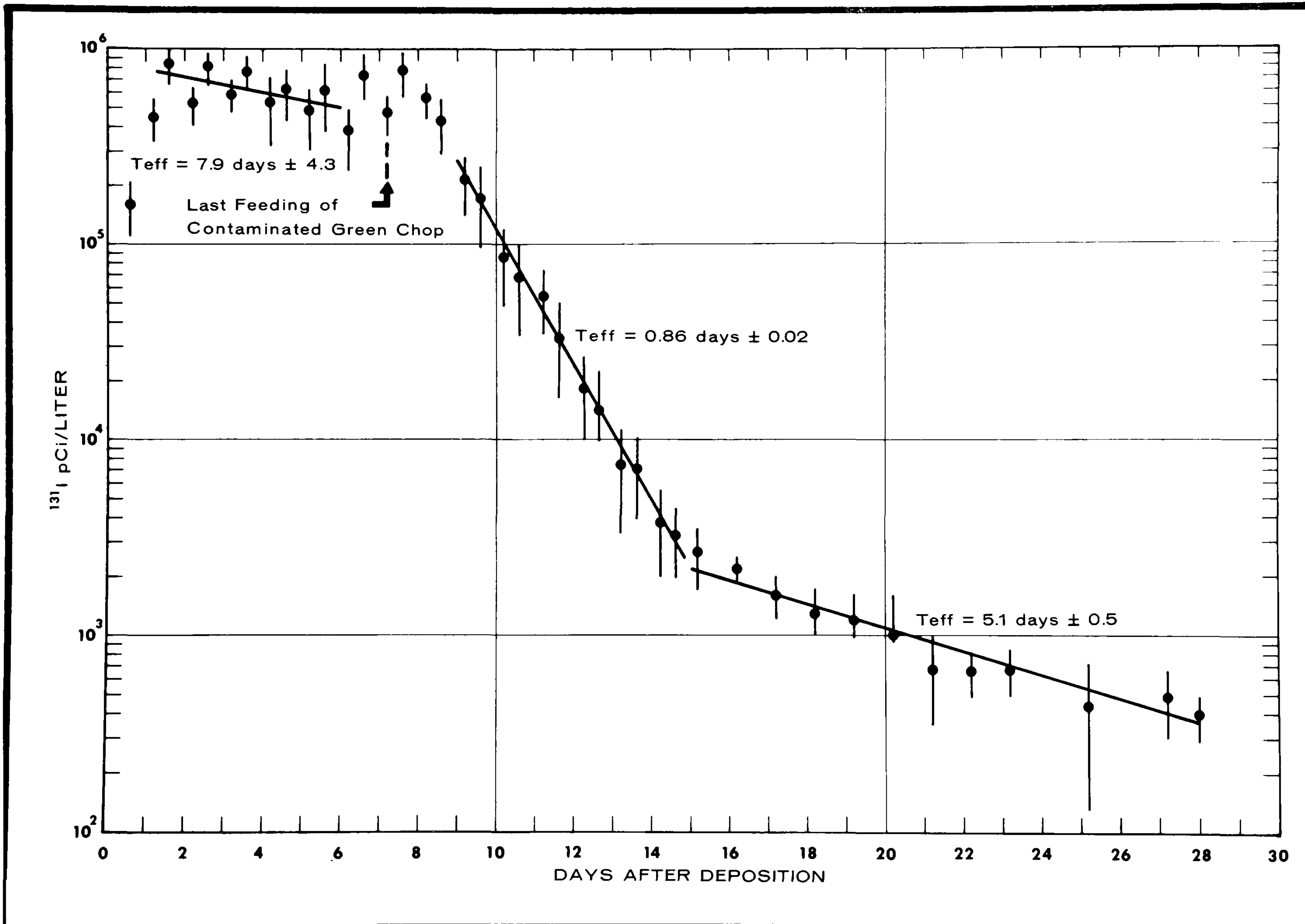
*Mean $\pm$ one standard deviation reported.

**Milk from all cows in this group was composited from this date on.



MEAN CONCENTRATIONS OF ^{131}I IN MILK OF GROUP I COWS

FIGURE 8



MEAN CONCENTRATIONS OF ^{131}I IN MILK OF GROUP II COWS

FIGURE 9

The nature of the feed data precludes a calculation of a meaningful effective half-life in the milk during the feeding period. Therefore, a reasonable approach is to calculate the effective half-lives from the peak milk to the valley of the double peak. Effective half-lives were also calculated for two distinct periods after the end of feeding. These half-lives are shown in Table 9.

Table 9. Effective half-lives of ^{131}I in milk

Days after start of feeding	Group I Cows (Hay)	Group II Cows (Green chop)
2nd through 6th	2.5 ± 0.4 days	7.9 ± 4.3 days
10th through 15th	0.94 ± 0.04	0.86 ± 0.02
16th through 28th	5.6 ± 2.4	5.1 ± 0.5

In Table 10 the results of this study are compared with the results from three of our previous studies. Projects Hayseed[7] and Alfalfa[8] were controlled releases of ^{131}I-tagged dry aerosols over grass or alfalfa-grass forage at our farm. We also conducted a field study at two commercial dairies following the Pike Event[1], an underground nuclear test which produced an inadvertent release of fission products to the atmosphere. During feeding, the effective half-life in milk from hay fed cows was close to that found on Hayseed, but considerably less than those from Alfalfa and Pike. For green chop fed cows, the effective half-life was two to three times that found in previous studies. After feeding of contaminated forage stopped, the half-lives were in reasonable agreement with those reported in the literature.

In both groups, the peak milk value occurred on the afternoon of the second day of feeding or about 24 hours after ingestion of the first contaminated feed. This is in reasonable agreement with

Table 10. Comparison of results from four studies

Study	Type of Contamination	Type of Green Chop	Forage: Peak Average Concentration (pCi/kg)		Milk: Peak Average Concentration (pCi/liter)		Milk: T_{eff} During Feeding (Days)		Milk: Time to Peak (Days)		Ratio: $\frac{\text{Peak Milk (pCi/l)}}{\text{Peak Forage(pCi/kg)}}$	
			Green Chop	Hay	Green Chop	Hay	Green Chop	Hay	Green Chop	Hay	Green Chop	Hay
Pike March 1964	Fission Products	Alfalfa	4.7×10^3	1.3×10^3	3.8×10^2	7.0×10^1	3.8	5.9	4	3	0.080	0.054
Hayseed October 1965	^{131}I-Tagged Aerosol (23 μCMD)	Sudan Grass	2.7×10^6	4.1×10^5	2.2×10^4	1.1×10^4	3.0	2.7	2	1	0.008	0.027
Alfalfa June 1966	^{131}I-Tagged Aerosol (2 μCMD)	Alfalfa-Oats	3.4×10^6	5.6×10^5	1.0×10^5	3.9×10^4	2.5	8.2	1.5	1	0.029	0.069
Rainout October 1966	^{131}I Solution	Alfalfa	2.1×10^7	9.8×10^6	8.6×10^5	1.3×10^5	7.9	2.5	1	1	0.041	0.013

our other experiments.

The ratios of peak average milk activity to peak average forage activity were 0.013 for the cows fed hay and 0.041 for the cows fed green chop. This indicates that for this type of contamination and forage, radioiodine is more biologically available from alfalfa green chop than it is from hay. The same trend was observed with actual fallout from Pike, but the reverse case was true on Hayseed and Alfalfa, where the milk/forage ratios were higher for the hay cows.

Table 11 shows the percent of the total ^{131}I ingested which was secreted in milk. The cows which ate hay secreted 4.5 ± 1.5% of the total ^{131}I ingested, while those which ate green chop secreted 6.1 ± 1.4%. While this would also indicate a greater biological availability of iodine on green chop, there is no significant difference between the two percentages.

The ratio of maximum milk concentration to minimum milk concentration at each milking was calculated. The mean of these maximum/minimum ratios was 2.98 ± 2.24 for Group I and 2.86 ± 0.96 for Group II. This is a measure of the variability between cows as a herd and as groups.

Table 11. Percent of ^{131}I ingested which was secreted in milk

Group	Cow No.	Total µCi Ingested	Total µCi Secreted	Percent Secreted	Mean ± One Standard Deviation
I	12	292.5	19.1	6.5	
(Hay)	13	302.3	14.4	4.8	
	16	251.0	13.7	5.5	4.5 ± 1.5%
	18	289.1	7.3	2.5	
	27	376.7	16.0	4.2	
	28	322.0	10.6	3.3	
II	19	1320.5	63.5	4.8	
(Green	26	1011.8	72.7	7.1	
Chop)	43	1474.6	88.6	6.0	6.1 ± 1.4%
	45	1648.2	71.5	4.3	
	46	1561.8	126.2	8.1	
	47	1472.8	96.0	6.5	

CONCLUSIONS

When radioiodine is deposited on forage (growing alfalfa and hay) in an aqueous solution under the conditions of this experiment, the following conclusions concerning the transfer of the radioiodine to cow's milk may be drawn:

1. ^{131}I on fresh green chop appeared to be more biologically available than it was on hay.

2. Following ingestion of the contaminated forage, the peak activity concentration in milk (pCi/liter) occurred in about one day. This concentration was one to two orders of magnitude lower than the peak concentration in the forage (pCi/kg).

3. After ingestion of the contaminated forage was stopped, the effective half-life of ^{131}I in milk was about one day for the first six days, then about five days until negligible concentrations were reached.

4. Dairy cows eating contaminated green chop secreted 6.1% of the ingested ^{131}I in their milk, while those eating contaminated hay secreted 4.5%.

5. Although it appeared that there was no washoff effect, the statistical design of the washoff experiment was not sufficient to allow any definite statements about the effect of additional precipitation. However, the effective half-life of ^{131}I on growing alfalfa was about seven days.

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