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CONTROLLED ENVIRONMENTAL RADIOIODINE TESTS AT THE NATIONAL REACTOR TESTING STATION

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PRELIMINARY EXPERIMENT REPORT
C. A. Hawley, Jr., C. W. Sill, G. L. Voelz,
Health and Safety Division, ID-AEC, and
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SUMMARY

The CERT project consists of a series of planned releases of radioiodine over different vegetation and during various meteorological conditions, with the prime objective being to measure the amounts of radioiodine through the air-vegetation-cow-milk-human chain. This paper deals with the first, or preliminary, experiment in the CERT series at the National Reactor Testing Station (NRTS) in southeast Idaho. The preliminary experiment consisted basically of releasing radioiodine (iodine-131) gas over a natural Crested Wheatgrass pasture and using the contaminated grass for milk cow grazing. The resultant radioactive milk was fed to seven human volunteers. It was desired from this experiment to determine if the experimental design would establish, under known natural release conditions, three basic relationships:

(1) The amount of radioiodine in the air to that on the soil and vegetation,

(2) The amount of radioiodine on the vegetation to that in the milk, and

(3) The quantity in the milk to that in the human thyroid after drinking the milk.

Two 4.6 x 10^4 m^2 pasture areas with an initial grass density of 150 g/m^2 and an average height of 13 cm were established, one for contamination (hot) and one for control and background (cold). Five iodine-131 generators were oriented along a 150-meter line normal to the expected prevailing wind to simulate a short line source. The source line was 50 meters upwind from the "hot" pasture. A sampling grid based on pretest meteorological studies extended 300 meters downwind. Background activities on soil and vegetation, as well as grass consumption and growth rates, were measured before and after the release. Milk production and activity levels were measured. The six cows used during the test were 1200- to 1600-pound fresh purebred Holsteins. Arrangements were

made to maintain the cows on their normal feed supplements; the cows were acclimated to the natural grass and new surroundings for two weeks prior to placing them on the contaminated pasture. The cows were milked at 6 a.m. and 6 p.m. daily. Milk from the evening and morning milking of one cow was daily combined, pasteurized, and counted each day. A 500 ml portion was consumed by seven volunteers over an 18-day period. Human thyroid activities were measured periodically over a 39-day period with a 256-channel gamma spectrometer employing a 3-inch thallium activated sodium iodide crystal in a low background whole-body counting vault.

A total of 970 millicuries of iodine-131 gas was released at 1500 MST on May 27, 1963, near ground level over a 30-minute period under moderately unstable meteorological conditions and an average wind speed of 6.6 meters per second.

About 13 percent of the total released iodine was deposited on the grid, with 1.5 percent being actually on grass. The Crested Wheatgrass covered about 15 percent of the total plot, the remaining surface being soil. Deposition velocities ranged from 0.4 to 0.8 cm/sec with an average of 0.6 cm/sec. The activity on the carbon fallout plates was found to be proportional to the grass measurements.

Controlled grazing, which consisted of daily changes of $2 \times 10^3 m^2$ crosswind grazing strips, progressed from 300 meters downwind, toward the source, permitting quantitative measurement of grass consumption and activity. The effective half-life on grass was found to be about 3.5 days. The "effective" cow consumption measurement, which represents the accumulation of activity within the cow from the current and previous days' grazing, based on a one day "half-life" retention factor, and the measured activity in the milk showed good correlation. The ratio of activities of milk and grass (pCi/l:pCi/g) was 240 ± 35. The average human thyroid uptake of ingested iodine-131 in milk was 19 percent. A model to predict thyroid activity levels was developed and shown to be accurate. Thyroid doses to the volunteers averaged 0.39 rad.

The preliminary experiment showed that the basic experimental procedures were adequate. Further tests in the series will employ the same general procedures in investigating the behavior of radioiodine under various meteorological and physical conditions.

CONTROLLED ENVIRONMENT RADIOIODINE TESTS
AT THE NATIONAL REACTOR TESTING STATION

CONTENTS

FIGURES

TABLES

I. INTRODUCTION

Recently, the well defined and rather universal questions pertaining to the behavior and effects of radioiodine have received much attention. Many of these questions are directed toward the fate of radioiodine after release from its point of origin. Studies in the laboratory can yield only limited information which can be applied to a large segment of a natural environment. When radioiodine is released into the environment, the size and degree of influence on this segment depend on a large number of variables.

The primary objective of this experiment was to ascertain, in part, if these variables could be defined, controlled, reproduced, and measured under actual field conditions without exorbitant expenditures of effort and money.

The results of the preliminary experiment are encouraging. Further controlled environmental radioiodine tests are being designed which will yield more general information. The CERT project is aimed at furnishing radioiodine information directly applicable to the NRTS and its environs in practical ways. These include establishing a basis upon which rapid, accurate decisions can be made during and after an accident situation, as an aid to developing realistic NRTS reactor siting criteria, and in the preparation and review of safety analysis reports.

II. CONSIDERATIONS IN DESIGN OF PRELIMINARY EXPERIMENT

1. GENERAL INFORMATION

During the formative stages of the CERT project two major approaches to experiment design, as dictated by NRTS "conditions", were discussed. One was to utilize large areas of Crested Wheatgrass (Agropyron desertorum) which are in existence as a result of noxious weed control programs, and the other was to establish, maintain, and utilize pasture grasses in accordance with local practices.

Both these approaches had merit. The overall project was divided into the "open-range" phase, with which this report deals, and the "established-pasture" phase, which is presently in the construction stage.

After surveying various open-range areas, an area was chosen which had good grass, accessibility, a safe release area, and would not likely be affected by reactor operation. This area also possessed topographic features which aided in contamination and animal control (Figures 1 and 2). The experiment called for two grazing areas: one was designated the "cold pasture"; and the other the "hot pasture", onto which the radioiodine was released.

The selected pastures were mowed to a uniform height of 10 centimeters to remove and pulverize previous years' growth of grass and sagebrush. Using information obtained from various sources, it was determined that about two thousand square meters would be needed to feed six cows for one day. The pasture areas were fenced with battery powered electric fencing. These areas also were designed so that electric cross-fencing would separate the desired $2 \times 10^3 m^2$/day.

Each area was designed to feed adequately six cows for at least three weeks. The plan was to place the cows on the cold pasture for one week in order to acclimate them to local conditions, move the cows to the hot pasture immediately following the release of radioiodine for a period of time (estimated at two weeks), then put them back on the cold pasture for a cleaning-out period.

2. DESIRED MEASUREMENTS

In planning the CERT project, it became evident that the information desired could be broken into three major categories. These are the relationships between: (a) quantity of radioiodine in the air and the amount on the soil and

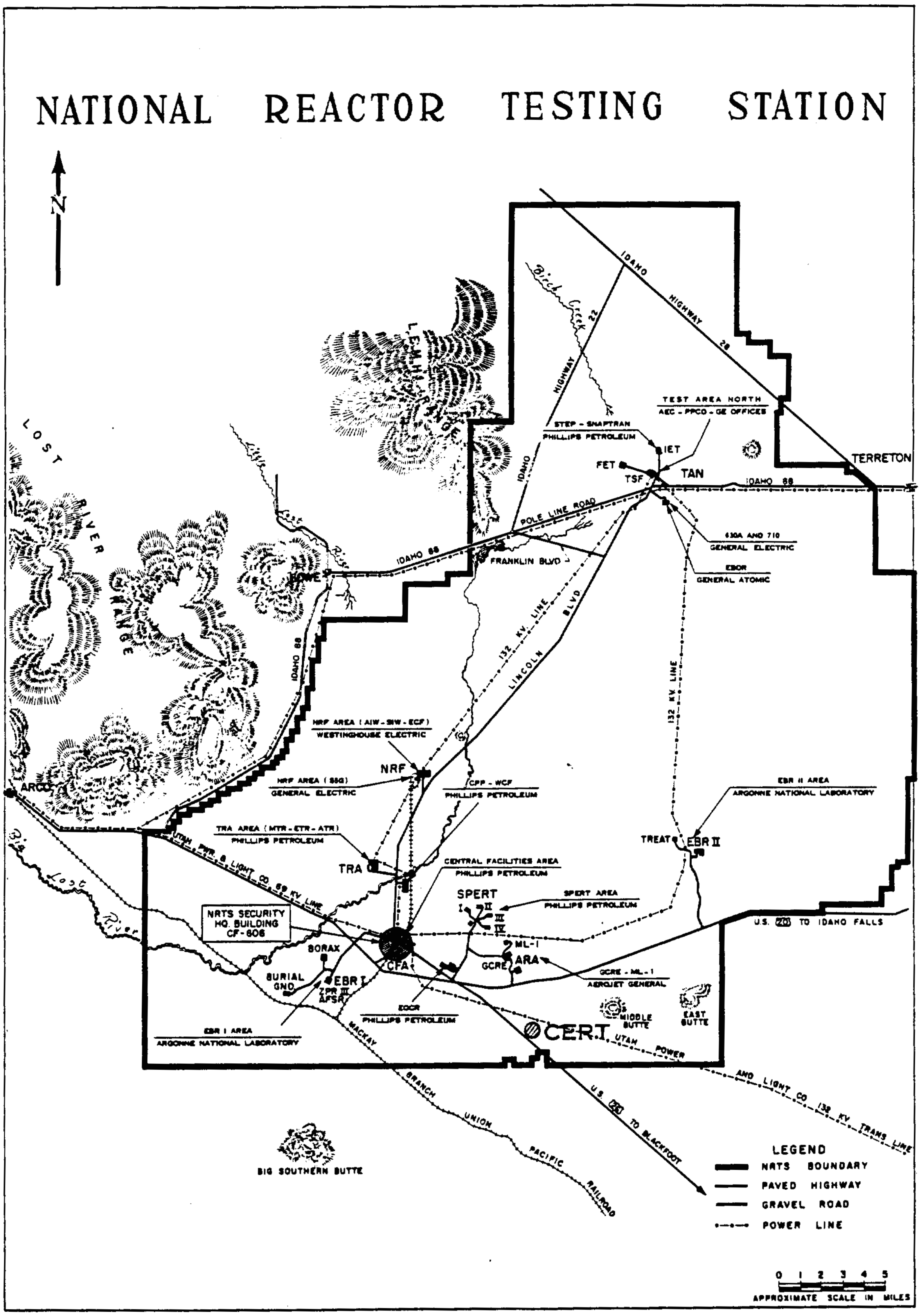

Fig. 1 Map of NRTS showing location of preliminary CERT experiment.

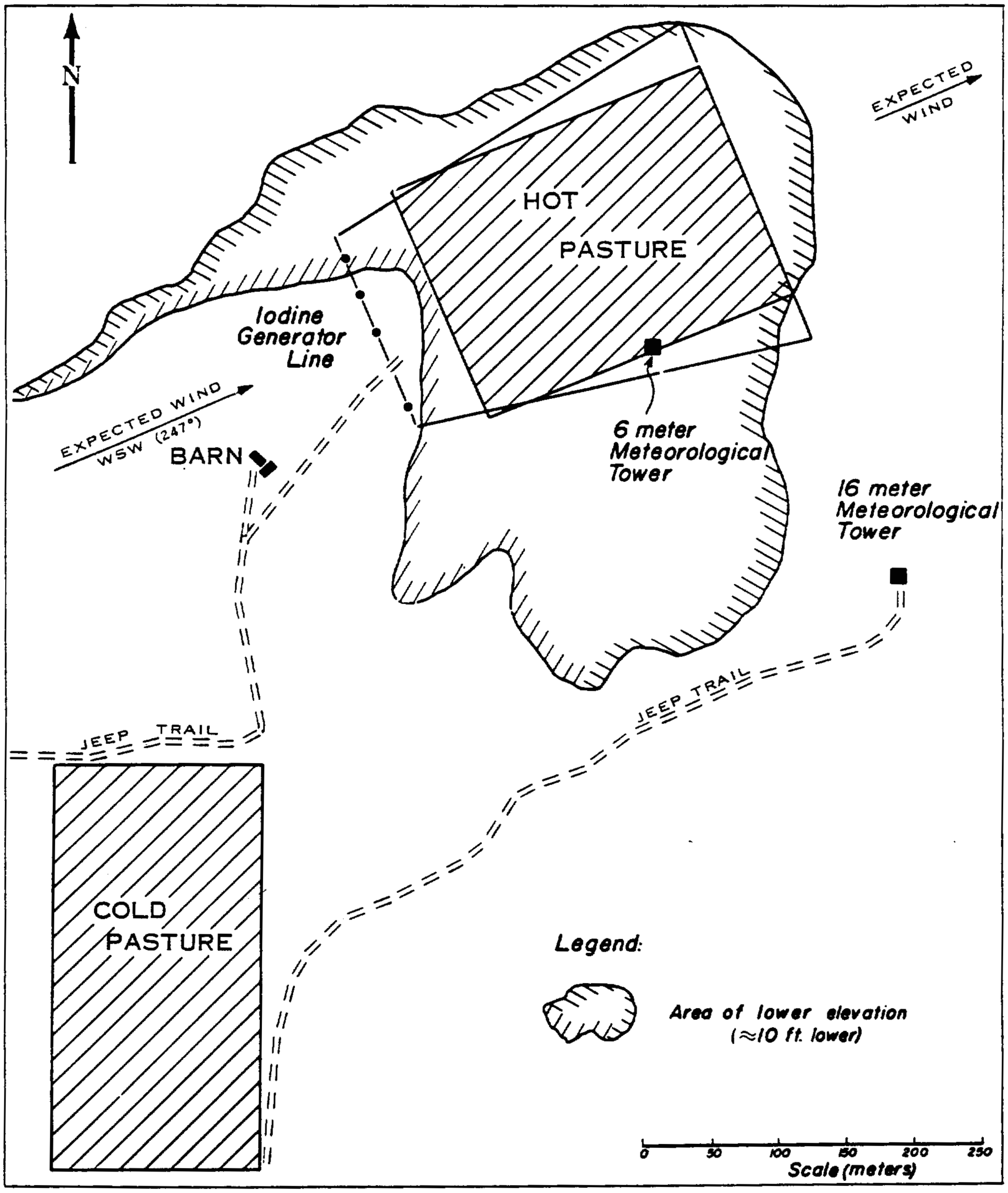

Fig. 2 Layout of CERT experimental area.

vegetation; (b) the amount on the vegetation and the amount appearing in the milk; and (c) the relationship between the activity in the milk and that in thyroid after ingesting the milk. With these three relationships in mind, arrangements were made to measure the following parameters during the preliminary experiment:

(1) The meteorological conditions existing during the release of radioiodine into the atmosphere and throughout the entire test;

(2) The unit-weight, growth rates, percentage of ground cover, activity per unit-weight, rates and quantities of consumption of the grass;

(3) The concentrations of radioiodine per unit volume of air, the chemical and physical form of the released isotope;

(4) The amount of radioiodine deposited on the soil per unit area;

(5) The rate of uptake of radioiodine in milk and milk production rate;

(6) The effective half-times of milk activity; and

(7) The rate of human uptake and effective half-times of radioiodine metabolized by the cows.

The experimenters were aware that several other parameters could be measured, but did not attempt to measure them during this preliminary experiment.

III. PRERELEASE PREPARATIONS

1. METEOROLOGICAL PLANNING

Meteorological studies were undertaken at the CERT site in advance of the planned date for the test in order to insure that the sampling grid would be properly oriented and to secure the desired amount of iodine-131 activity in the cows' milk. Further, since the conduct of the test involved the synchronization of a number of events, the most accurate weather forecasts possible were required.

Wind data collection at the CERT site was begun on April 12, 1963. The experiment was scheduled for about May 15, 1963; hence, little time was available to collect a history of meteorological data. Long period climatological records exist for the Central Facilities Area (CFA), which is about 11 kilometers NW of the CERT site. Comparisons of meteorological data at CERT and CFA were made. This method was used for the Special Power Excursion Reactor Test (Spert I) destructive test in the fall of 1962, and proved quite satisfactory. The experiment was under meteorological control with the required conditions being wind direction downgrid (WSW), wind speed 5-10 m/sec, lapse stability conditions, and no precipitation. Since the release was to take place over a one-hour period the meteorological conditions had to prevail for at least two hours to allow adequate preparation time after meteorological conditions were suitable. It was desirable, though not mandatory, that the probability of precipitation be slight for several days after the release of the iodine-131 to eliminate any effect from this variable for the initial phase of the experiment. The layout of the sampling grid was based on the observed meteorological data.

Scatter diagrams of CFA versus CERT wind directions were made for 242 cases. Wind speeds were restricted to $\gtrapprox$ 2 m/sec. The prevailing wind at the CERT location was found to be westsouthwest, and this occurred most frequently when the wind at CFA was in its prevailing direction, which is southwest. To reduce any bias introduced by the short period of sample, the observed distribution of the Cert winds was corrected by the ratio of the short-period to the long-period average wind direction frequencies observed at CFA. The corrected frequency of the maximum direction, WSW (11), observed at CERT was 28.6 percent. The next most frequent direction was west (12) at

18.0 percent which indicates a considerable tendency for the westsouthwest direction. The CFA wind frequencies indicated a similar strong tendency to southwest (10). A similar type of correlation was shown between the CFA winds and other areas on the southern part of the NRTS. This correlation held very well operationally which added confidence to the CERT data even though it was a short sample.

Due to the short period allotted for preparation for the CERT experiment a practice forecast program was not conducted. The first test day for which preparations were completed was May 20, 1963. Forecasting was commenced on this date. Two forecasts a day were made. A ten-hour forecast was issued at 0830 MST and a 27-hour forecast issued at 1530 MST for the next day. Six morning forecasts and five afternoon forecasts were all that were issued before the test was successfully completed on May 27. All of the forecasts issued were for unsatisfactory meteorological conditions until the date of the final forecast.

2. DESIGN OF GRID

It was desired to have as uniform as possible lateral distribution of iodine-131 upon the vegetation and soil over the entire test area. Further, as the cows were allowed to graze on narrow strips beginning with the outermost strip (referenced with the release line) and proceeding successively inward with time, a more constant daily intake of iodine for the cows could be achieved. A level of iodine activity in the cows' milk between 10^3 to 10^4 picocuries per liter was desired.

The radioiodine generator line and air sampling lines were laid out normal to the expected wind direction which was WSW (247°). The grazing plots were about 150 meters wide and 300 meters long. To achieve a uniform crosswind distribution of iodine-131, five iodine generators were spaced 30 meters apart along the upwind side of the plot, thereby simulating a short-line source. Air sampling arcs were established at 50, 100, 200, 300, and 1000 meters downwind normal to the center line of the grid and equal in length to the 150-meter width of the iodine release line, plus an additional 10° spread from the source line to allow for lateral plume dispersion. Twelve high-volume air samplers were equally spaced on each of the first four air sampling arcs and five air samplers were operated on the 1000-meter arc. Deposition surveys were made along the first four sampling arcs and also along an additional five arcs placed between

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the air sampling arcs. The entire air and vegetation sampling grid is shown in Figure 3.

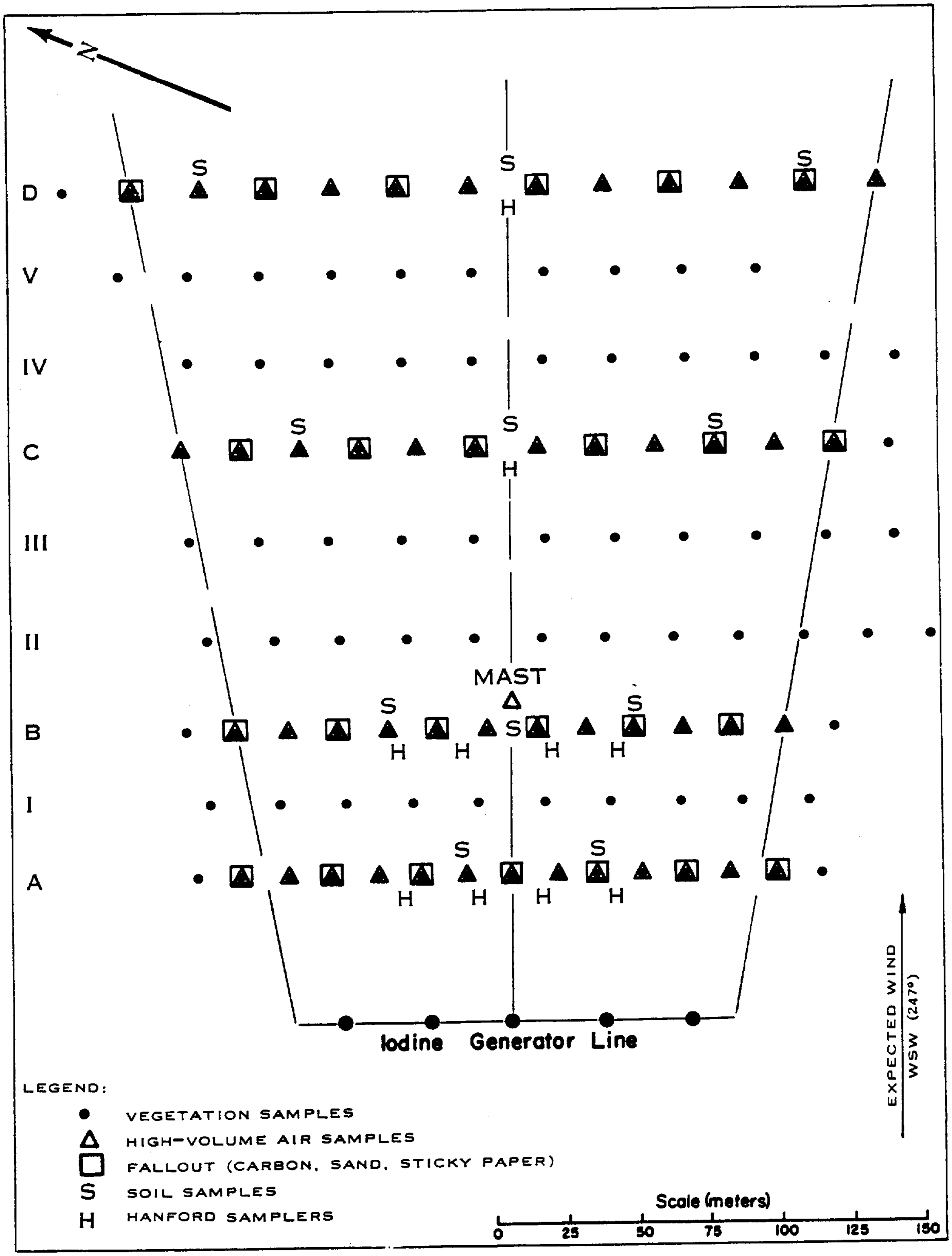

Fig. 3 Air and vegetation sampling grid.

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A 16-meter tower was installed just off the east side of the test plot for micro-meteorological observations pertinent to calculations of dispersion and deposition. High-speed bivanes were installed at the 1 and 16-meter levels for the recording of the vertical and horizontal fluctuations of the wind direction at those two levels. The vane has a time response of 0.5 second, so that eddies with a period of one second or longer are recorded. This information is recorded on a multi-channel, high-speed data acquisition system, in which the information is stored on punched tape. Wind speeds were recorded at the 1, 4, and 16-meter heights by Beckman and Whitley anemometers. The air temperatures were measured at the same three levels using unaspirated copper-constantin thermocouples shielded from the radiation of the sun and sky. At the center of the grazing plot, an aerovane was installed at the 6-meter level for use in the forecast program.

3. QUANTITY ESTIMATES

In order to estimate the amount of iodine-131 that had to be released to secure the desired iodine activity in the cows' milk, the following equations and parameters were used:

(1) Air concentration (χ): $= \chi \dfrac{2\,Q}{\pi\, Cy\, C_z\, \bar{U}\, x^{2-n}} \exp\left(- \dfrac{y^2}{Cy^2\, x\, 2-n)}\right)$

(2) Activity on the grass (Dep): Dep $= V_g/\chi$

(3) Activity in the milk (C): C = 50 Dep

The values of the parameters used were as follows:

- C_y - Lateral dispersion coefficient = 0.35
- C_z - Vertical diffusion coefficient = 0.35
- u - Wind speed = 7 m/sec
- n - Stability parameter = 0.2
- V_g - Deposition velocity = 0.002 m/sec
- d - Vegetation density = 50 grams/m^2
- Q - Source strength = 0.1 curies per generator
- χ - Air concentration

The ratio of activity in milk to activity on grass (picocuries per liter to picocuries per gram) was assumed to be 50 [1]. The concentrations and expected deposition were computed by adding the contributions from the five sources,

0023440

each being 0.1 curie. The estimated activity on the grass at the several sampling arcs is shown in Figure 4. The expected activity on the grass for each strip at the time of grazing was estimated from the initial deposition and the radioactive decay, and is shown in Figure 5. It can be seen from the constants given above that iodine-131 activity in the milk of 10^4 picocuries/liter should be expected from the first day's grazing. A level of 1.5×10^4 picocuries/liter in the milk should be expected from the last day's grazing. A release time of between 30 and 60 minutes was planned so that the normal wind direction variations could smooth the activity as much as possible over the plot. Comparisons of the actual measured deposition values to those predicted in Figures 4 and 5 are made below.

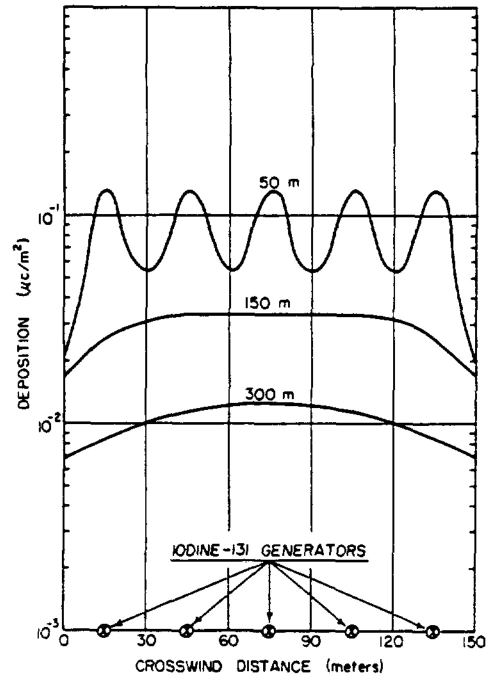

Fig. 4 Computed deposition of iodine-131 on the vegetation at several downwind distances for the design of the grid.

4. ANIMAL AND EQUIPMENT ARRANGEMENTS

4.1 Equipment

A 4 x 7 meter metal building (barn) was erected on temporary foundations about halfway between the hot and cold pastures. Lanes were conducted from the barn to each pasture using single strand electric fencing. A corral was constructed of picket-type snow fencing. Two trailer houses were established adjacent to the barn. One was used for sample preparation and feed storage and the other was used for contamination control in the sense of a "change room". Electric power to the barn and trailer houses was supplied by a 9-kW trailer-mounted gasoline-powered generator. All water needs were satisfied by hauling water from CFA in a 500-gallon trailer-mounted tank. Installed in the barn were six metal stanchions and a bucket-type milking machine. Also in the barn was a constant radioiodine-in-air monitor which operated whenever the generator was being used.

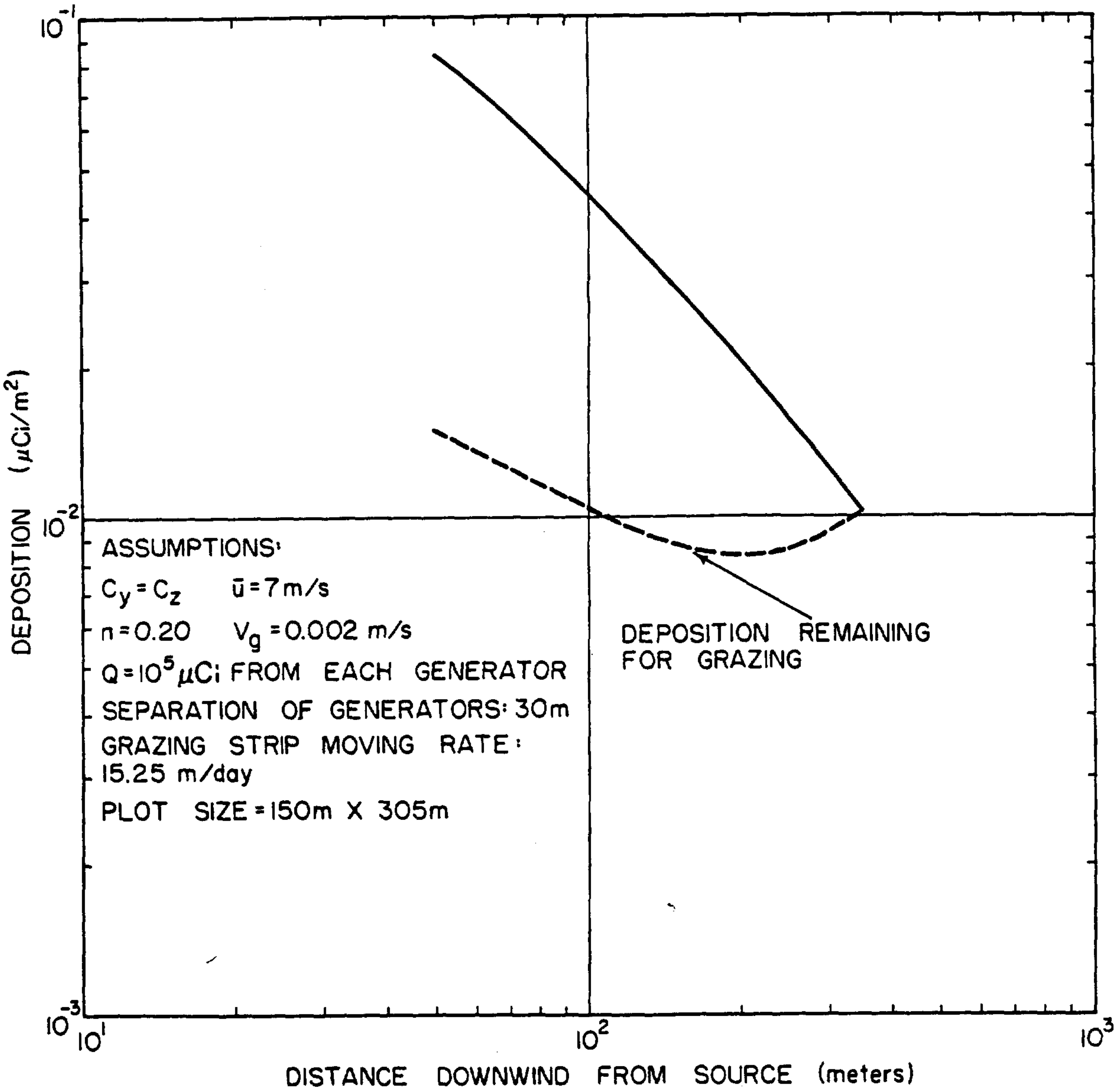

Fig. 5 The estimated deposition of iodine as a function of distance initially and also available for cow-intake at the time of grazing.

4.2 Animals

Six 1200 - 1600 pound fresh pure-bred Hereford cows were obtained. The cows were placed on the cold pasture on May 14, and were milked at 0600 and 1800 hours, daily. Before the test, the cows were fed a 14 percent protein grain supplement with a fixed amount fed to each cow. This diet supplement was continued while the cows were at the NRTS. The cows also had available blocks of iodized salt. Milk production of each cow was recorded throughout the test.

5. PRELIMINARY GRASS MEASUREMENTS

5.1 Quantity

Just prior to the time the cows were placed on the cold pasture, the grass quantities were measured. Random sampling was carried out by throwing a circular loop which encloses one square meter. The grass within the hoop was then clipped to the grazing height of 10 cm. The samples collected were taken to the laboratory and weighed for fresh weight, air-dried for 15 to 20 days, and reweighed. This was done three times during the test to measure growth changes. At the time the cows were placed on cold pasture, the average grass height was 13 cm and produced 130 g/m^2 fresh weight and 46 g/m^2 dry weight [a].

5.2 Background Activity

Random samplings were taken from both the cold and hot pastures prior to the arrival of the cows. These samples were then fresh weighed and gross counted. Samples were then combined and the radioactivity contributors were identified by gamma spectroscopy. The average background activity was about 34 c/m/g fresh weight. Isotopes identified were Ce-144, K-40, Ru-106, and Zr-Nb-95. The fission products were considered to be a result of weapon testing fallout.

6. SOIL MEASUREMENTS

Since the hot pasture area was designed to be roughly square, with release points along one side, three lines of soil sample stations were established downwind from the mid-release line: one along the center line and two radiating from it by 15 degrees from either side (Figure 3). This would permit an approximate downwind sample line within 30 degrees of wind shift.

Eleven background samples were taken according to this plan on the day prior to the radioiodine release. The samples were 0.1 m^2 by 1 cm deep (approximately one liter). Spectrometer analysis showed the same activities as are listed in the preceding section.

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[a] This first series of measurements was made by clipping the grass down to a 5-cm level, rather than a 10-cm level. When the cows started grazing the grass, it was noted that they grazed down only to 10 cm, so the system was changed accordingly.

7. IODINE RELEASE SYSTEM

Several methods of releasing the radioiodine into the atmosphere were discussed. All these methods presented problems in the field. A system of release known as "sparging" (ie, to bubble a relatively nonreacting gas through a solution which purges another gas or substance) was used. Nitrogen gas was bubbled through a water solution containing iodine gas which released the iodine to the atmosphere. The mechanisms employed are schematically presented in Figure 6. Five curies of carrier-free Na I-131 solution were obtained from Oak Ridge. When the radioiodine was received, NaI carrier and additional sodium sulfite was added to maintain the iodide in the reduced state.

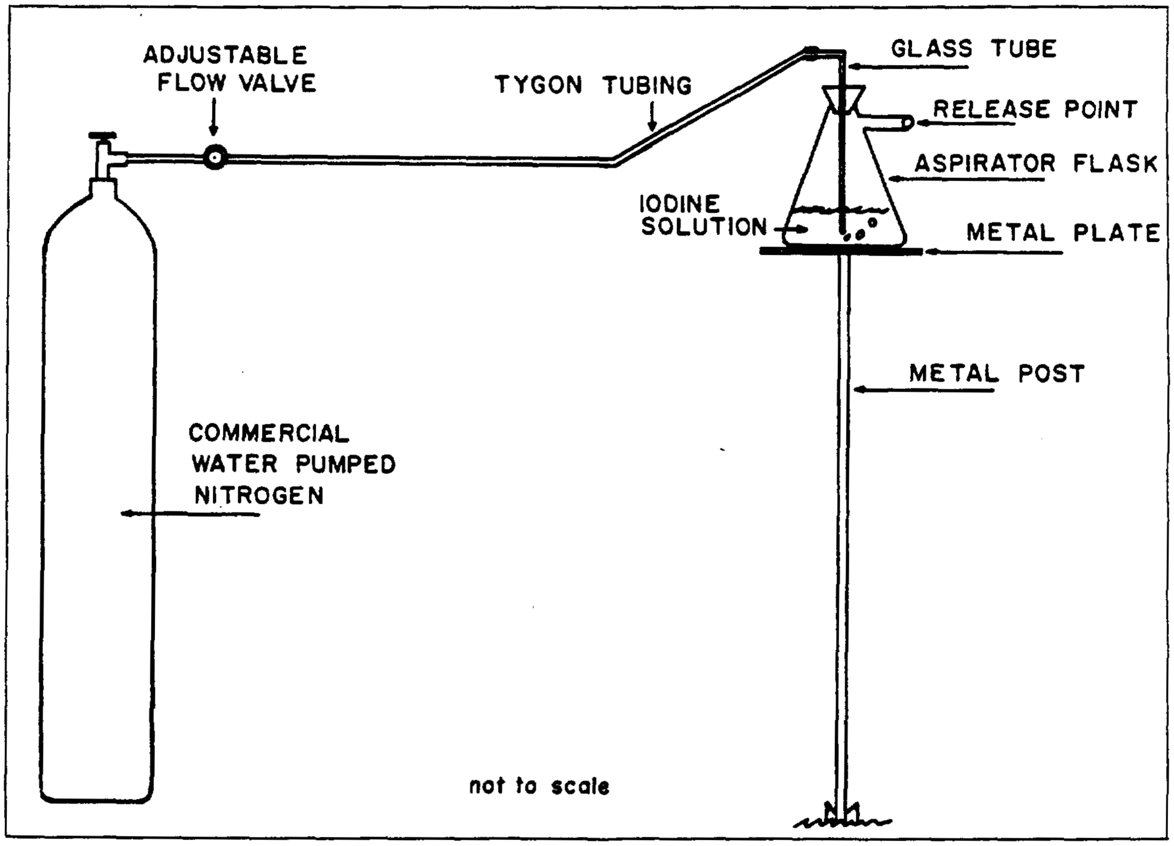

Fig. 6 Schema of iodine generator.

8. SAFETY

A safety analysis was performed using the conditions specified. These parameters were (a) the release of one curie of iodine-131 under strong lapse conditions (n = 0.2) and (b) a moderate wind speed (7 m/sec). This analysis showed that the expected inhalation dose at any NRTS facility which could

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conceivably be affected would be less than 1 mrad, and that the maximum dose from milk ingestion off-site also would be less than 1 mrad.

Direct radiation doses to those handling the radioiodine were estimated to be not more than 250 mrad/person. Appendix A contains a complete safety analysis of the CERT experiment.

9. HUMAN THYROID UPTAKE

The experimental plan to collect milk from cows grazing on the contaminated pasture for a period of two weeks following the single iodine-131 release afforded an opportunity to follow the radioactivity chain to humans. The primary purposes for feeding the milk to volunteers were:

(1) To test the applicability of this type of experimentation in an industrial setting. The use of ultra-sensitive counting equipment permitted the administration of small quantities of iodine-131 to working personnel without introducing significant radiation doses to the thyroid, and yet provide statistical accuracy which is better than the usual clinical methods available in hospitals.

(2) To provide a curve of thyroid uptake from a daily dietary feeding of milk containing a quantity of iodine-131 which may be representative of a milk activity curve anticipated from cows grazing on outdoor pasture following an iodine-131 release. A constant daily milk volume was fed so that the iodine-131 intake could be determined accurately.

(3) To determine actual human thyroid uptake values from the experiment would provide an opportunity to determine the relationships between activity values in air concentrations and vegetation samples as well as in milk.

Six male and one female volunteers were interviewed for initial medical history. There was no history of thyroid disease in any of the volunteers. Basal metabolism rates and radioactive iodine uptake studies or other thyroid function tests had never been performed on any of them.

A history survey also was taken for sources of stable iodine intake which might influence iodine uptake results. None had x-ray studies performed in which organic iodides might provide an unusual source of stable iodine in the system. Five of the volunteers were using iodized salt regularly at home. In addition, volunteer No. 2 was supplementing his diet with two kelp extract tablets daily. This material was labeled as containing 0.1 mg iodine per tablet. Volunteer No. 4 had been using plain table salt (not iodized) regularly at home since the fall of 1962. Volunteer No. 1 was using salt from a bulk sack at home which did not contain a label as to whether it was iodized or not. No other drug or vitamin-mineral preparation containing iodine was taken.

The group ranged from 29 to 43 years of age. They were all of average height and weight. Volunteer No. 2 was slightly overweight but otherwise each member of the group was within the desirable weight limits established by a major life insurance company.

IV. RELEASE CONDITIONS

1. METEOROLOGICAL CONDITIONS DURING THE TEST

The average meteorological conditions during the release of iodine-131 (1355-1545 MST) over the sampling grid are shown in Table I. The turbulence parameter values are shown in Table II.

TABLE I

AVERAGE METEOROLOGICAL DATA DURING RELEASE

Location	Height (m)	Winds Direction (°)	Winds Speed (m/s)	Temperatures (°C)
Grid	6	242	6.6	
Tower	1	231	5.2	22.3
Tower	4	236	7.1	21.1
Tower	16	235	8.4	20.5

TABLE II

VALUES OF TURBULENCE PARAMETERS

Height (m)	Bivane Standard Deviations (degrees) σ_θ[a]	σ_ϕ[a]	Log Linear Wind Profile Evaluation
			$U^* = 61$ cm/s
1	20.0	8.0	$Z_o = 3.1$ cm
16	14.3	6.1	$R_i = -0.07$ (1-16m)

[a] For period 1455 - 1604 from instantaneous 2-sec readings

σ_θ - horizontal wind direction standard deviation

σ_ϕ - vertical wind direction standard deviation

U^* - friction velocity

Z_o - roughness length

R_i - Richardson number

2. RADIOIODINE RELEASE

Just prior to the time of release five drops of 30 percent sodium sulfite and 5 mg of sodium iodide carrier (to dampen side reactions) were added to a 1-curie solution of the NaI-131. This solution was then diluted to 200 ml and separated into five 40 ml aliquots.

At the release site the 2-liter suction flasks (described in paragraph III-7) were affixed three feet above the ground on steel posts. In each flask was 200 ml of 2 N sulfuric acid. The nitrogen tanks were connected by tygon tubing to the release flasks. One of the 40-ml aliquots was added to each flask.

At release time, 3 ml of 10 percent sodium nitrite was added through the outlet in the suction flask. This oxidized the iodide into molecular iodine gas. The nitrogen bubbling was started, and the flow rates of the nitrogen were adjusted so that the iodine was released over a period of 30 minutes. The release rate was monitored through the use of pre-calibrated "Cutie-Pie" type portable ionization chamber instruments. Final readings indicated that about 95 percent of the total radioiodine was released.

V. POST-RELEASE DATA

1. METEOROLOGICAL

The wind speed, air temperature, and hourly precipitation were recorded for several weeks after the test for possible meteorological evaluation of the change of the iodine-131 activity on the grass with time.

The hourly precipitation is shown in Table III. The record from the rain gage commenced on the afternoon of May 29, two days after the test. However, no precipitation was observed in the area during the two days following the test.

TABLE III

CERT RAINFALL DATA (INCHES)

Date	1	2	3	4	5	6	7	8	9	10	11	Noon	1	2	3	4	5	6	7	8	9	10	11	Mid't	Sum
26	--	--	--	--	--	--	--	--	--	--	--	--	--	---	--	--	--	--	--	--	--	--	--	--	--
27	--	--	--	--	--	--	--	--	--	--	--	--	---	--	--	--	--	--	--	--	--	--	--	--	--
28	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
29	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.03	--	--	--	--	0.03
30	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.02	--	--	--	0.02
31	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.17	--	--	--	--	--	--	--	--	--	0.17
1	--	--	--	--	--	--	--	--	--	--	--	0.04	--	--	--	0.03	--	--	--	--	--	--	--	--	0.07
2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0
3	--	--	--	--	--	--	--	--	--	--	0.05	0.03	0.02	--	--	--	--	--	--	--	--	--	--	--	0.10
4	--	--	--	--	0.03	0.10	0.14	0.02	0.12	0.02	0.06	0.01	T [a]	0.01	T	T	0.01	T	0.01	T	T	T	T	--	0.53
5	--	--	--	--	--	--	--	--	--	0.02	0.01	T	T	--	--	--	--	--	--	--	--	--	--	--	0.03
6	--	--	0.07	0.17	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.24
7	--	--	--	--	--	--	0.01	0.01	T	0.01	T	T	0.02	--	--	--	--	--	--	--	--	--	--	--	0.05
8	--	--	--	--	--	--	0.03	0.01	0.01	0.01	0.01	0.02	0.01	--	--	--	---	--	--	--	--	--	--	--	0.10
9	--	--	--	--	--	--	--	--	--	--	--	--	--	0.01	0.02	--	--	--	--	--	--	--	--	--	0.03
10	--	--	0.04	0.09	0.20	0.10	0.05	0.10	T	T	0.03	--	--	--	0.02	--	--	--	--	--	--	--	--	--	0.63
11	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0
12	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0
13	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0
14	--	--	--	--	--	--	0.07	0.01	0.01	T	--	--	--	--	--	0.04	T	--	--	--	--	--	--	--	0.13
15	--	--	--	--	--	--	--	--	0.02	0.04	0.02	0.01	T	--	0.02	--	--	0.10	0.08	--	--	--	--	--	0.29
16	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0

[a] T = Trace

A more detailed tabulation of the wind and temperature is shown in Table IV. The turbulence quantities, $\sigma\theta$ and $\sigma\phi$, shown in Table II were obtained from instantaneous readings of the bivanes every two seconds. The wind direction standard deviations also were computed from time-averaged data, which will tend to eliminate the effect of overshoot and the finite time constant of the bivane from the records. This time averaging of the record of wind direction also eliminates the eddies which are too short to be of value in the dispersion

TABLE IV

DETAILED WIND AND TEMPERATURE DATA DURING CERT

Winds (5 min. averages)								Temperatures (°C) (4 min. instantaneous)		
		Tower						Tower		
Grid		1m		4m		16m		1m	4m	16m
DD [a]	VV [b]	DD	VV	DD	VV	DD	VV			
254	7.6	240	6.7	248	8.5	242	9.8	22.4	21.2	20.4
261	8.1	250	5.8	253	8.1	252	11.2	22.7	20.9	20.4
243	7.2	240	5.4	243	7.2	240	8.5	23.4	21.7	20.6
253	6.7	237	4.9	243	7.2	235	8.1	22.6	21.3	20.4
237	6.3	235	5.4	235	6.7	236	8.1	22.3	21.0	20.2
244	6.3	222	4.9	235	6.7	227	7.6	22.0	20.9	20.3
228	5.8	230	4.5	225	7.2	232	8.1	21.4	20.5	19.8
225	5.8	215	5.4	225	6.7	225	8.1	21.1	20.5	20.4
237	6.3	215	4.5	225	6.3	223	7.2	21.9	20.8	20.3
240	6.3	225	4.5	230	6.3	233	7.6	22.4	21.2	20.4
								23.1	21.3	21.4
								22.5	21.1	20.7
Average:										
242	6.6	231	5.2	236	7.1	235	8.4	22.3	21.1	20.5

[a] DD - Direction (degrees)

[b] VV - Velocity (m/sec)

and deposition processes over the sampling plot. The variation of the horizontal and vertical wind direction standard deviation, $\sigma\theta$ and $\sigma\phi$, with averaging time is shown in Figure 7. The average time of travel from the iodine-131 release line to the various sampling arcs on the plot was about 30 seconds. The Lagrangian-Eulerian time scale factor, β, has been found in previous

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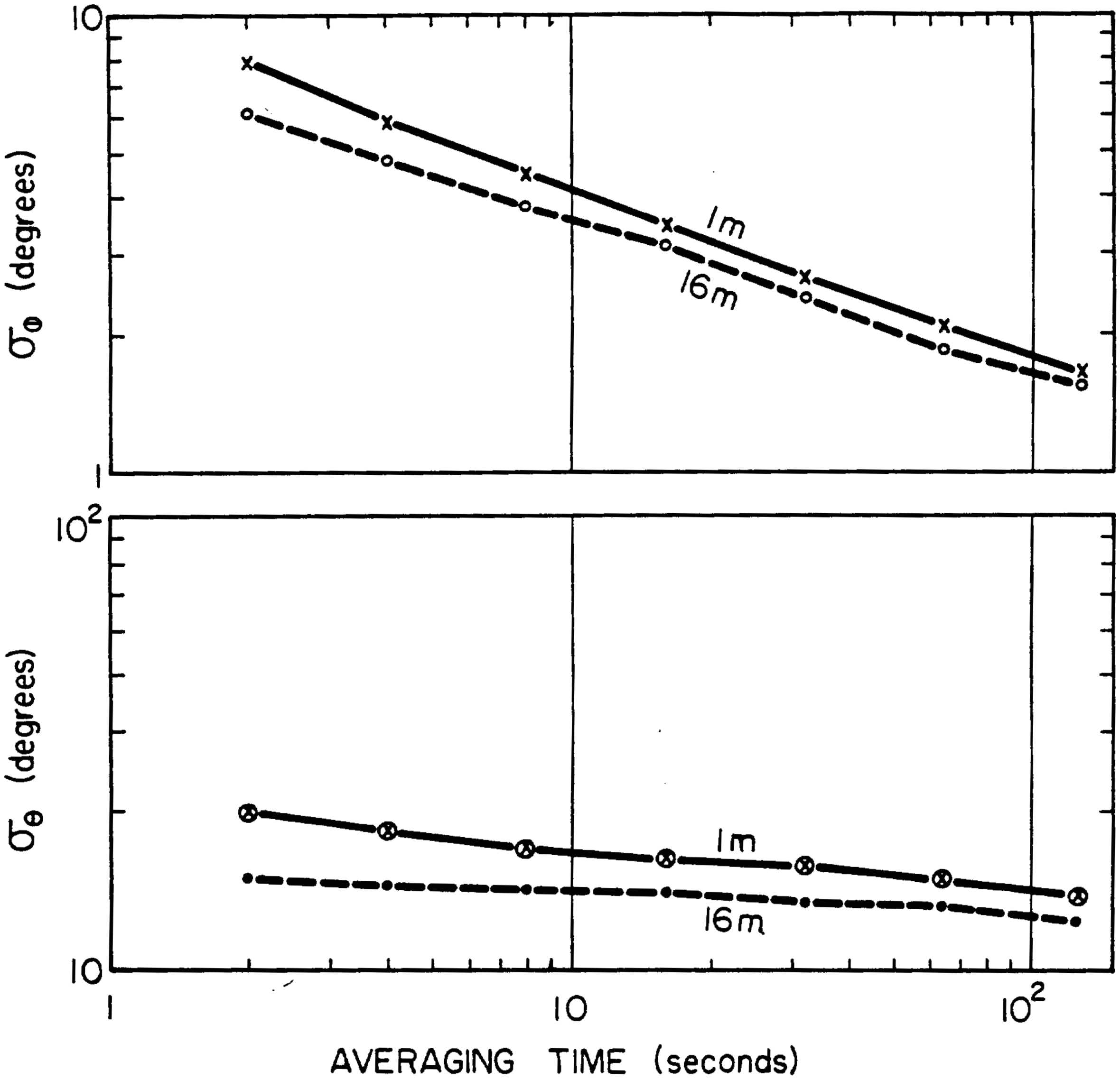

Fig. 7 The variation of the horizontal and vertical wind direction standard deviation, σ_θ and σ_ϕ, with averaging time for two heights.

studies at the NRTS to have a value of about three. This means that an appropriate averaging time for the wind direction records before computation of gustiness would be about 10 seconds. These standard deviations obtained from Figure 7 are probably more appropriate than the standard deviations from instantaneous readings listed in Table II, and will be used for the computation of deposition and dispersion quantities.

The wind profile with height was non-logarithmic in appearance. A log linear wind profile was assumed. From this profile, with measurements at three levels, the friction velocity, U*, and the roughness length, Z_o, are obtained.

Both are useful in characterizing the roughness of the site and the turbulence in the lower layers. The value of the friction velocity, 61 cm/sec, derived from the measurements, is typical for a moderately unstable atmosphere. The grazing plot was 150 meters wide and 300 meters long and was flat. However, the terrain in that area is rolling. There were knolls about six meters high on the upwind side and also on the east side on which the meteorological tower was located. Sixteen percent of the test area itself was covered by grass plants about 25 cm high at the time of the test. The grass was observed to have grown to greater heights at later times. There were about 7 to 10 plants per square meter of surface with an average weight at the time of the test of about 150 g/m^2. The Z_0 value of 3 cm does not appear to be unreasonable in view of the measured heights of the grass at the time of the test.

2. GRASS COLLECTION AND ANALYSIS

2.1 Initial Deposition

Samples were collected immediately following the release in accordance with the following description: Nine crosswind sampling arcs, or lines, intersected the pasture downwind from the release point; arcs designated A through D (Figure 3) were both air and vegetation sampling arcs, with grass samples collected at the base of the air sampling locations; arcs designated by Roman numerals were vegetation sampling points only. In effect, such an arrangement yielded four air sampling arcs and nine vegetation sampling arcs. On arcs I through III the vegetation samples were collected at approximately 23-meter intervals. On arcs IV and V, the samples were collected at 24-meter intervals. Each vegetation sample was composed of portions of several different clumps of grass selected at random, rather than only one grass clump cut in its entirety. The grass was cut at varying heights, but never lower than about 10 cm from the ground. Each sample was placed in a plastic bag, weighed, and placed inside a one-quart ice cream container for counting. The bag as well as the grass was counted, thus avoiding iodine loss. Counting was done in the well of a 5- x 5-inch thallium-activated sodium iodide well crystal, coupled to a conventional pulse scaler. The background activity, in Ci/m/g, was subtracted from the net count from each sample, and the proper efficiency and conversion factors were applied to yield the final amounts in terms of picocuries of iodine-131 per gram of grass.

2.2 Daily Sampling

The pasture was divided into strips for grazing and each strip (with one exception) was sampled daily to determine the activity on the grass. These samples were collected the day before the strip was opened to grazing, in accordance with the procedures described.

The samples were usually counted around noon on the same day that the pasture was utilized. The samples which were not counted at this time were corrected accordingly. Whenever corrections for decay were made, the 8-day half-life factor only was applied. The actual, or effective half-life of the activity on the grass was developed from the results shown in Tables V and VI.

2.3 Consumption Measurements

The grass was measured to determine the amount of grass consumed per cow per day. Table VII shows the results.

TABLE V

AVERAGE GRASS ACTIVITY

Date	95% Confidence Intervals for Mean of Average Activity on Pasture (pCi/g)
5-28	770 ± 198
5-29	416 ± 164
5-30	No sample
5-31	145 ± 27
6-1	180 ± 44
6-2	124 ± 29
6-3	81 ± 13
6-4	63 ± 18
6-5	78 ± 33
6-6	112 ± 28
6-7	93 ± 17
6-8	86 ± 16
6-9	38 ± 11
6-10	54 ± 7
6-11	24 ± 11

3. SOIL COLLECTION AND ANALYSIS

Soil samples were collected and counted within two hours following the release. These were 0.1 m^2 by 1 cm deep, and taken right adjacent to the sample stations for background. Values for iodine-131 ranged from 2.5 $\mu Ci/m^2$ at station A-8 to 0.01 $\mu Ci/m^2$ at station D-2. Deposition is discussed in Section 2.1, page 21.

TABLE VI

ACTIVITY OF PASTURE SAMPLES IN pCi/g, WET WEIGHT

Tues 5-28	Wed 5-29	Thurs 5-30	Fri 5-31	Sat 6-1	Sun 6-2	Mon 6-3	Tues 6-4	Wed 6-5	Thurs 6-6	Fri 6-7	Sat 6-8	Sun 6-9	Mon 6-10	Tues 6-11	Wed 5-29
920	310		90	170	120	80	30	20	130	60	70	30	50	10	930
950	280		90	180	160	70	90	40	70	90	80	60	50	30	470
1000	560		90	240	120	80	30	130	70	100	60	40	40	30	1390
1090	550		180	200	170	90	70	100	130	40	100	20	70	70	980
710	380		160	180	60	90	60	60	160	150	120	10	60	10	700
1330			130	150	170	110	30	80	50	120	110	60	60	40	1140
490			150	100	100	30	20	130	80	60	120	40	60	30	530
550			160	220	130	80	110	30	140	120	100	60	60	20	340
570			190	170	60	90	90	20	180	120	60	30	60	0	
			190	360	150	80	80	150	170	110	100	20	40	10	
			150	100	80	60	60	30	80	90	50	20	40	10	
			90	130	60	80	80	150	70	110	60	30	40	30	
			80			40				100					
										70					
										50					
7610/9	2080/5		1750/13	2200/12	1380/12	980/13	750/12	940/12	1330/12	1390/15	1030/12	420/12	630/12	290/12	6480/8
[a] $\bar{x}$ = 846	$\bar{x}$ = 416		$\bar{x}$ = 135	$\bar{x}$ = 183	$\bar{x}$ = 115	$\bar{x}$ = 75	$\bar{x}$ = 63	$\bar{x}$ = 78	$\bar{x}$ = 110	$\bar{x}$ = 93	$\bar{x}$ = 86	$\bar{x}$ = 35	$\bar{x}$ = 53	$\bar{x}$ = 24	[a] $\bar{x}$ = 810
[b] $\bar{x}$ = 770			[b] $\bar{x}$ = 145	[b] $\bar{x}$ = 180	[b] $\bar{x}$ = 124	[b] $\bar{x}$ = 81			[b] $\bar{x}$ = 112			[b] $\bar{x}$ = 38	[b] $\bar{x}$ = 54		[b] $\bar{x}$ = 692

[a] Values extrapolated from activity of pasture on 5-27

[b] Values corrected for decay, using 8-day half-life

TABLE VII

CONSUMPTION MEASUREMENTS

Pasture Day	Date	Ht. of Plant	Production grams/m^2 Fresh	Air-dry	Utilization	Ave. Consumption kg/day/cow
2	5-29	29.5 cm	134	44	80%	36.14
9	6-5	34 cm	196	68	55%	36.35
11	6-7	34.0 cm	221	82	50%	37.27

4. MILK COLLECTION AND ANALYSIS

All the cows were stanchioned in the barn at the same time and given a grain supplement at each milking. The grain supplement was identical with that given to each cow for a year prior to the test. The udder of each cow was thoroughly washed with an antiseptic solution before milking. Milking was carried out with a standard milking machine at 0600 and 1800 hours daily. The milk was transferred from the milker to a 13-liter stainless steel bucket, weighed, and covered for transport to the laboratory. At the laboratory the milk was strained and placed in a 900 milliliter container for counting. The milker and buckets were thoroughly washed before being returned to the barn for the next milking. Bacterial counts taken on the milk showed this to be a very clean method (<1000 colonies/ml). Table VIII shows the average milk production per day, and Table IX shows the average iodine-131 content in the milk per day. Figure 8 expresses the same thing graphically.

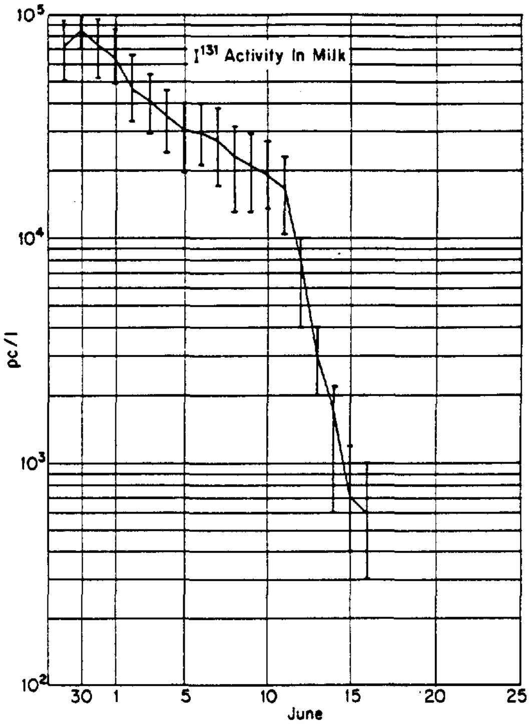

Fig. 8 Average daily iodine-131 content in milk.

TABLE VIII

AVERAGE PRODUCTION PER DAY

	Milk Production in Kilograms, Net Weight									
	5-29	5-30	5-31	6-1	6-2	6-3	6-4	6-5	6-6	6-7
High	8.16	9.92	10.06	10.33	9.65	8.16	8.16	9.65	4.48	10.33
Average	8.33	8.22	8.29	8.45	8.29	8.33	8.15	8.13	8.02	7.61
Low	6.12	6.12	5.57	6.39	5.84	5.71	5.71	5.98	5.71	5.16
	6-8	6-9	6-10	6-11	6-12	6-13	6-14	6-15	6-16	6-17
High	10.06	9.38	9.65	9.92	9.65	9.51	9.38	8.16	9.57	8.43
Average	8.35	7.88	7.81	7.75	7.95	7.47	7.34	7.68	7.31	6.52
Low	5.44	5.44	5.03	5.03	4.48	3.40	3.53	3.94	4.48	3.94
	6-18	6-19	6-20	6-21	6-22	6-23	6-24	6-25	6-26	
High	9.57	8.16	9.65	8.70	9.10	8.83	7.88	8.97	8.43	
Average	7.58	7.85	7.31	6.90	7.15	6.95	6.12	6.66	6.52	
Low	4.35	4.89	3.80	3.94	4.35	4.48	3.59	3.67	3.94	

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TABLE IX

µCi/l OF I-131 ACTIVITY IN MILK

	5-28 PM	5-29 AM	5-29 PM	5-30 AM	5-30 PM	5-31 AM	5-31 PM	6-1 AM	6-1 PM
Count Time	29-0830	29-0900	31-0830	31-0930	31-1000	31-1100	1-0800	1-0900	2-0830
High	0.026	0.082	0.094	0.11	0.11	0.096	0.090	0.094	0.078
Average	0.018	0.061	0.073	0.082	0.079	0.071	0.071	0.069	0.058
Low	0.008	0.044	0.058	0.066	0.064	0.051	0.051	0.055	0.041
Corrected Activity									
High	0.027	0.082	0.107	0.1198	0.115	0.0973	0.0939	0.094	0.0814
Average	0.0187	0.061	0.083	0.0893	0.083	0.072	0.0741	0.069	0.060
Low	0.0083	0.044	0.066	0.0719	0.067	0.517	0.053	0.055	0.0427

Daily Average

	5-29	5-30	5-31	6-1
High	0.094	0.1045	0.0956	0.0847
Average	0.074	0.0861	0.0730	0.064
Low	0.050	0.0704	0.0523	0.0488

	6-2 AM	6-2 PM	6-3 AM	6-3 PM	6-4 AM	6-4 PM	6-5 AM	6-5 PM
Count Time	2-0930	3-0830	3-1000	4-0830	4-1100	5-1100	5-1300	6-0900
High	0.071	0.062	0.059	0.050	0.050	0.043	0.038	0.039
Average	0.044	0.049	0.044	0.039	0.037	0.033	0.029	0.028
Low	0.037	0.030	0.029	0.027	0.026	0.023	0.020	0.018
Corrected Activity								
High	0.071	0.0648	0.0594	0.0521	0.0507	0.0455	0.0391	0.0407
Average	0.044	0.0511	0.0443	0.0407	0.0375	0.0349	0.0298	0.0292
Low	0.037	0.0313	0.0292	0.0281	0.0263	0.0243	0.0205	0.0187

Daily Average

	6-2	6-3	6-4	6-5	6-6
High	0.066	0.054	0.046	0.0399	0.0345
Average	0.046	0.041	0.035	0.0295	0.0292
Low	0.033	0.0286	0.024	0.0196	0.0210

	6-6 AM	6-6 PM	6-7 AM	6-7 PM	6-8 AM	6-8 PM	6-9 AM	6-9 PM
Count Time	6-1000	7-0930	7-1100	8-0930	8-1000	9-1000	9-1030	10-0900
High	0.031	0.036	0.041	0.036	0.033	0.030	0.029	0.029
Average	0.029	0.028	0.029	0.026	0.025	0.023	0.022	0.020
Low	0.021	0.020	0.018	0.016	0.014	0.012	0.014	0.012

TABLE IX (Cont.)

	6-6 AM	6-6 PM	6-7 AM	6-7 PM	6-8 AM	6-8 PM	6-9 AM	6-9 PM
Corrected Activity								
High	0.0312	0.0378	0.0415	0.0378	0.0332	0.0315	0.0292	0.0302
Average	0.0292	0.0292	0.0182	0.0168	0.0141	0.0141	0.0221	0.0208
Low	0.0211	0.0210	0.0182	0.0168	0.0141	0.0126	0.0125	0.0125

Daily Average

	6-7	6-8	6-9	6-10	6-11
High	0.0385	0.0315	0.029	0.027	0.023
Average	0.0275	0.024	0.021	0.019	0.0165
Low	0.017	0.013	0.013	0.0135	0.0105

	6-10 AM	6-10 PM	6-11 AM	6-11 PM	6-12 AM	6-12 PM	6-13 AM	6-13 PM
Count Time	10-1030	11-0830	11-1100	12-0830	12-0930	12-1815	13-1000	14-0900
High	0.027	0.027	0.026	0.020	0.012	0.008	0.005	0.003
Average	0.019	0.019	0.018	0.015	0.010	0.006	0.004	0.002
Low	0.014	0.013	0.012	0.009	0.005	0.003	0.002	0.001
Corrected Activity								
High	0.0271	0.0281	0.0263	0.0208	0.012	0.0083	0.005	0.0031
Average	0.091	0.0198	0.0181	0.0156	0.010	0.0062	0.004	0.002
Low	0.0141	0.0135	0.0121	0.0093	0.005	0.0031	0.002	0.001

	6-14 AM	6-14 PM	6-15 AM	6-15 PM	6-16 AM	6-16 PM
Count Time	14-1100	17-1100	17-1030	17-1030	17-1000	17-0930
High	0.002	0.002	0.001	0.001	0.001	0.001
Average	0.002	0.0012	0.0006	0.0007	0.0006	0.0007
Low	0.0007	0.0005	0.0004	0.0003	0.0002	0.0004
Corrected Activity						
High	0.002	0.0024	0.0012	0.011	0.001	0.001
Average	0.002	0.0015	0.0007	0.0008	0.00065	0.00073
Low	0.0007	0.0008	0.0005	0.00034	0.00024	0.00042

Daily Average

	6-12	6-13	6-14	6-15	6-16
High	0.0101	0.0040	0.0022	0.0011	0.001
Average	0.0081	0.003	0.0017	0.0007	0.0006
Low	0.0040	0.002	0.0007	0.0004	0.0003

5. MILK INGESTION

A four-liter sample of milk was taken from the same cow (No. 6) at each milking. The evening and morning milk sample for each day was combined to form the supply for feeding to the volunteer group on the following day. An eight-liter home pasteurization unit was used to pasteurize the milk.

A 500 ml portion of the milk was drunk by each individual daily beginning on May 30, and ending on June 17. The milk was usually drunk between noon and 1630 after the thyroid count for that day had been performed. The thyroid activity of most of the subjects was measured each day from May 31 to June 21, except for June 10, when no counts were taken. After June 21, additional counts were taken at varying intervals until July 8. The thyroid measurements were performed 18 to 30 hours following consumption of the milk. Times of consumption were not controlled rigorously but, in general, occurred within a period of two hours following each day's thyroid count.

The activities in the milk samples used for volunteer consumption and the resultant average are plotted in Figure 9. The milk activities portrayed on Figure 9 are plotted pertaining to the day the milk was actually drunk, but the activity value is shown as determined 24 hours earlier (not corrected for decay since counting time). As noted on the graph, the cows were maintained on the hot pasture for 14 days. The ingested milk reached its peak activity, as shown by counting in a calibrated well gamma counter, on the second day and then decreased with an initial effective half-life of about four days. The curve had flattened to approximately a 10-day half-life by the second week. After the cows were removed to uncontaminated grass, the activity dropped sharply with about a 1-day half-life.

The activity determined in the thyroid was measured by focusing a collimator on the thyroid of the person, detecting with a 3- x 3-inch solid thallium-activated sodium iodide crystal which was coupled to a multichannel gamma-ray spectrometer. The data for the seven volunteers are shown in Figure 10. The curve reached a relatively flat plateau about eight days after the initial milk dose. The peak of the curve occurred on day 10. The curves show that five of the seven volunteers were very similar and overlapped appreciably. The average thyroid uptake for the group was 19 percent. It is of interest to note that volunteer 4 had a relatively higher uptake of about 30 percent. This may be due to the fact that he was using plain (not iodized) table salt and therefore possibly had a lower

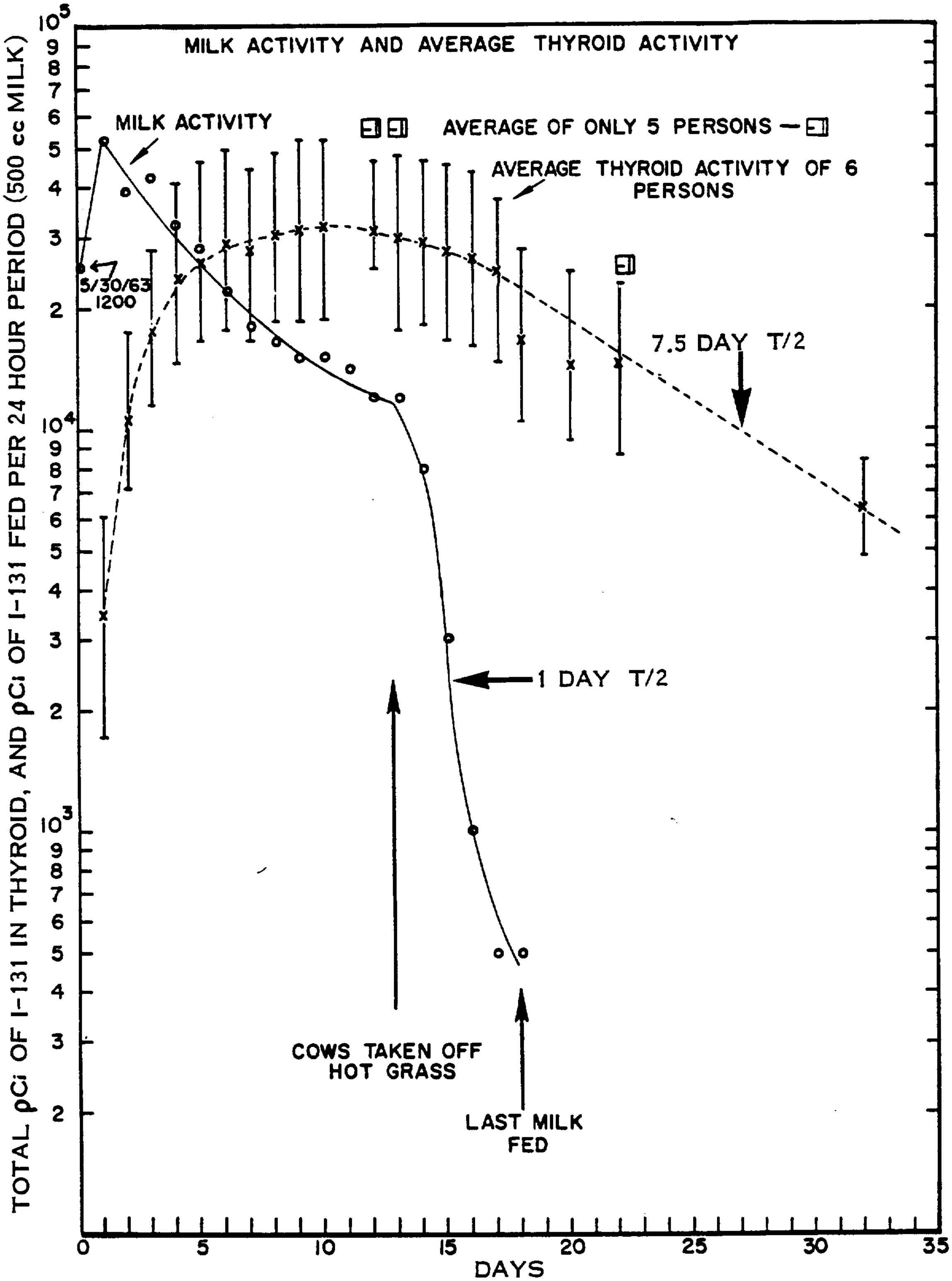

Fig. 9 Average thyroid uptakes and milk levels.

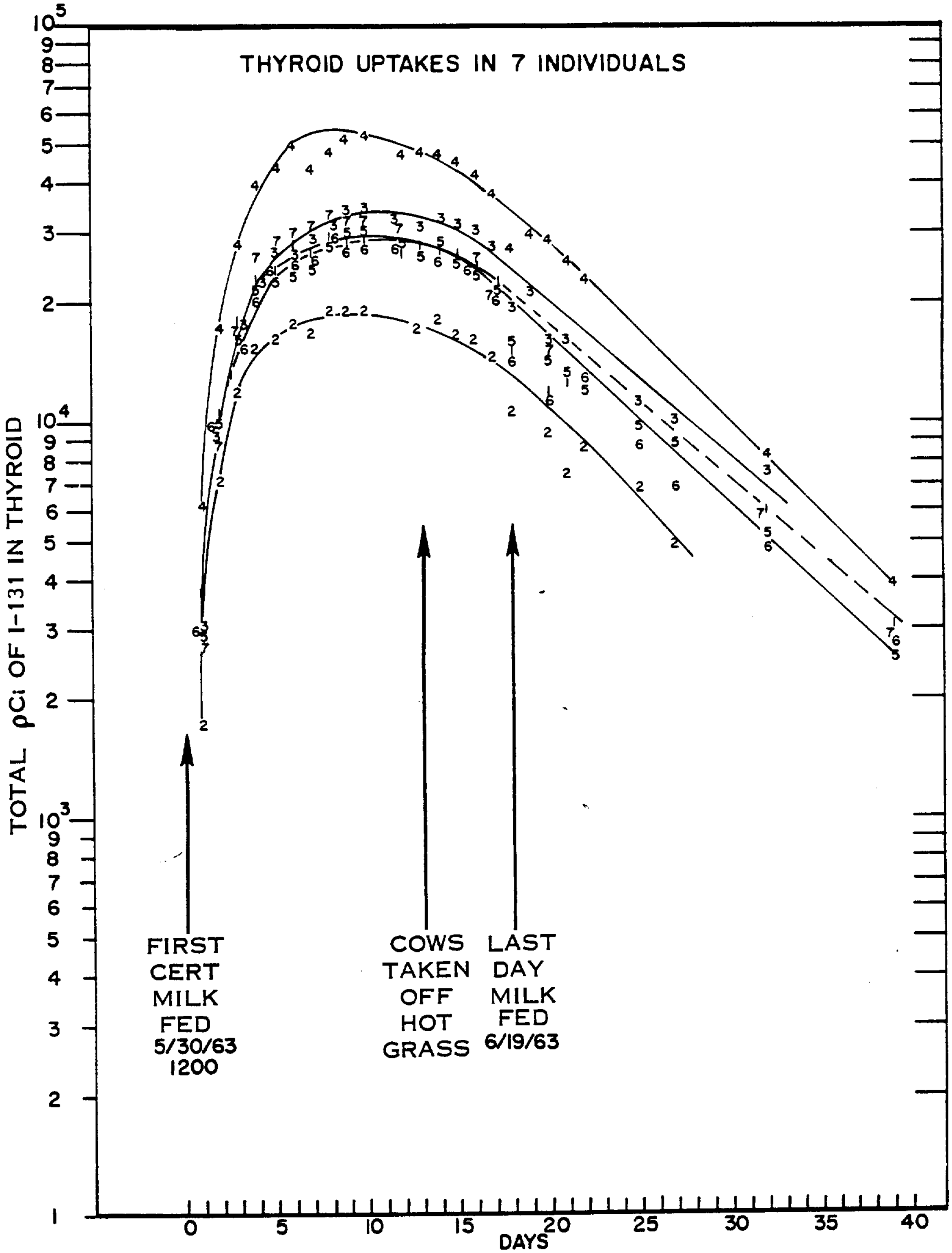

Fig. 10 Individual thyroid uptakes.

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stable iodine intake. Conversely, the lowest uptake (about 12 percent) occurred in volunteer 2 who had received about 0.2 mg of iodine per day in kelp extract tablets plus the use of iodized table salt.

A mathematical model which permits the calculation of activity at various times was formulated from a consideration of the experimental conditions. In the derivation of the model, both the ingestion of milk and the fraction, f, of the activity taken-up by the thyroid were assumed to be instantaneous [a]. The general equation giving thyroid activity as a function of time and total I-131 intake is:

$$A_n = f \sum_{i+1}^{n} C_i \exp - \lambda E \left[T_n - T_{i-1}\right]$$

A_n is the activity of iodine-131 in the thyroid at the end of the n'th time interval following the initial intake; f is the fraction taken-up by the thyroid at each ingestion; C_i is the activity ingested at the beginning of the i'th time interval; λ_E is the effective decay constant for I-131 in the thyroid; T_n is the total time elapsed from the initial I-131 intake (T_o = 0) to the end of the n'th time interval and T_{i+1} is the time elapsed from T_o to the end of the (i + 1)'th interval. Because of the additional iodine added to the system each day, the maximum time interval used must begin at the time of a given ingestion and terminate just prior to the beginning of the next one.

Calculations involving the above summation can be simplified by expressing the thyroid activity at the end of the (n+1)'th time interval, A_{n+1}, in terms of the thyroid activity at the end of the preceding time interval, A_n, and the activity ingested at the beginning of the (n+1)'th time interval, C_{n+1}:

$$A_{n+1} = (A_n + fC_{n+1})\, e^{-\lambda_E \left[T_{n+1} - T_n\right]}$$

The above equation was used to predict thyroid activities by letting n take on successive values from zero to 18, setting f equal to 0.19 and λ_E equal to $0.693/T_E$, with T_E being equal to 7.3 days, the average effective half-life for all subjects. The actual activities found in the milk were corrected for

[a] The assumption of instantaneous uptake results in a model which predicts thyroid activity as shown by the dashed curve in Figure 11 whereas the actual thyroid activity is clearly approximated by the dotted curve.

decay to the time of consumption. The time intervals used were those between thyroid measurements. In Figure 11 the centers of the circles represent the calculated thyroid activities and the other points the measured thyroid activities.

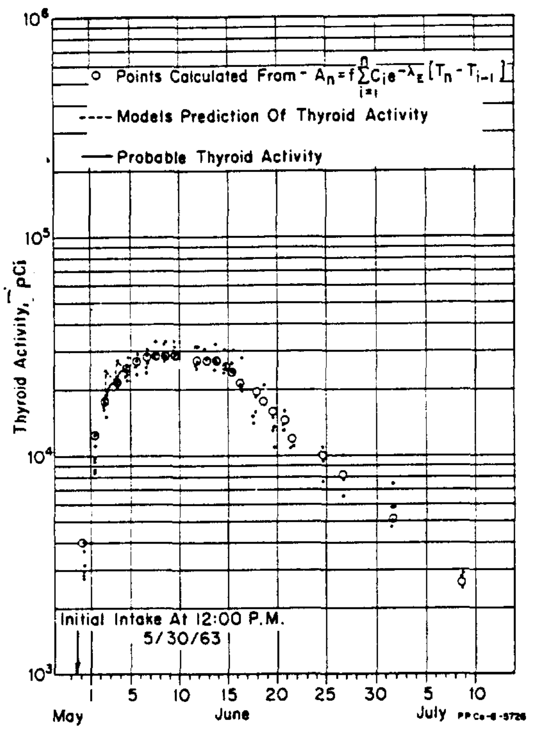

Fig. 11 Thyroid activity prediction model.

Daily spot urine samples were collected at the time of the thyroid counts on all the subjects. Samples, usually 75 ml, were analyzed by the routine well-counting procedure used for gross gamma determinations at the NRTS. Representative curves of urine excretion of I-131 activity are shown in Figures 12 and 13. The scatter of data from urinalysis compared to the direct thyroid activity determinations is readily apparent. This effect possibly may be due to biological excretion factors which were not controlled on spot sample determinations. Counting statistical variations does not account for the variability noted. The excretion curve follows more closely the intake curve of I-131 than the thyroid activity. It reflects the 80 percent of I-131 which is not incorporated into the thyroid. The curve reached a peak at about 72 hours after the initial intake of the milk samples. There followed an exponential fall in activity which relates to the milk intake activity. The advantages of using direct thyroid counts in this situation precludes any practical use for urinalysis data except possibly as a rough screening method in populations where direct counting apparatus is not immediately available.

The radiation thyroid dose received during the course of this experiment was calculated for each of the subjects using the in vivo thyroid counts. The results were as follows: Volunteer 1 received 0.38 rad, volunteer 2 - 0.23 rad, volunteer 3 - 0.42 rad, volunteer 4 - 0.63 rad, volunteer 5 - 0.36 rad, volunteer 6 - 0.32 rad, and volunteer 7 - 0.39 rad.

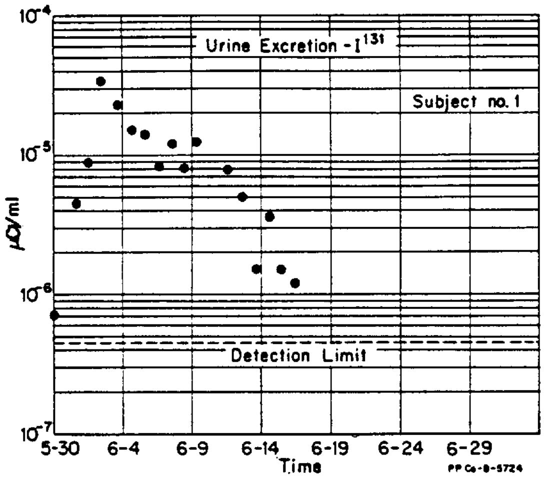

Fig. 12 Urinalysis results.

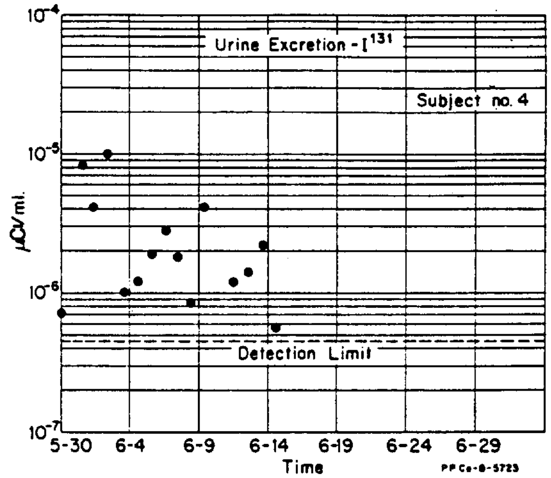

Fig. 13 Urinalysis results.

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VI. DATA ANALYSIS AND COMPARISONS

1. METEOROLOGICAL EVALUATIONS OF AIR CONCENTRATION AND DEPOSITION DATA

1.1 Iodine-131 Dispersion

The analysis of the air concentration and the deposition data indicated that the iodine-131 was kept over the sampling grid during the period of release. This is shown by the isopleths of deposition on the vegetation in Figure 14. It is apparent that there is a slight maximum of iodine-131 in the center of the plot with a tendency for this maximum to veer slightly from left to right downwind. The variation of both the activity of iodine-131 on the grass and the air concentration laterally across the grid are shown in Figures 15 through 20. The deposition data are in terms of picocuries/gram while air concentration units are in terms of total integrated dose (μCi - sec/m^3). Part of the air samplers on the right side of arcs A and B were found not running upon the termination of the test and the data from these have been excluded. The missing parts of the arcs are shown by the dotted lines. The air concentration and grass deposition on arc A show that up and down fluctuations predicted by Figure 4, are due to the proximity of the generators to the particular air sampler and grass sample which shows the highest readings. The other arcs show rather smooth distribution of air concentration and deposition across the plots. The deposition measurements in Figure 14 show that about six times as much iodine-131 activity was measured as predicted, when compared to the computed values in Figure 5 after converting the latter values to deposition per unit mass. Half of this is accounted for by the increase from 0.5 as planned to one curie for the total release. The main variation, about a factor of three, is apparently due to the larger deposition velocities measured than were used in the design of the grid, 0.2 cm/sec.

The crosswind integrated deposition and air concentration were obtained by integrating the area under each lateral distribution of these parameters shown in Figures 15 through 20. The missing parts of arcs A and B for the air concentration data were estimated assuming symmetry. The change of the crosswind integrated deposition and air concentration with distances is shown in Figures 21 and 22. It can be seen that the deposition decreases more slowly with distance than does the air concentration. The reason for this is not known since no specific attempt was made to measure the particle size of the iodine-131, but there is an indication that the deposition velocity is increasing with distance.

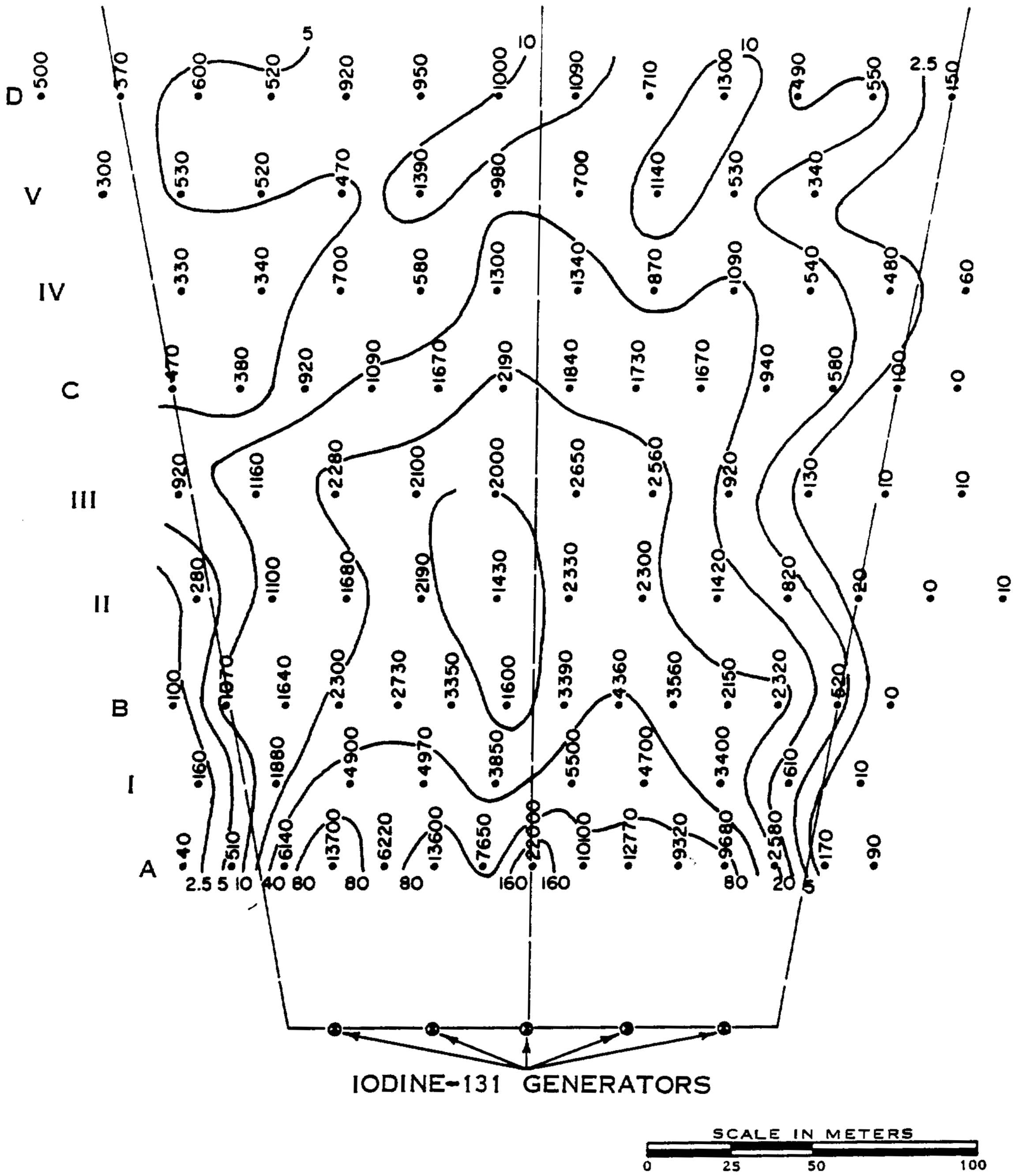

Fig. 14 The isopleths of measured iodine-131 activity on the grass in terms of pCi/g. Isopleths are labeled by the horizontal numbers (x 100).

It appeared that most of the iodine-131 was either in gaseous or extremely small-particulate form. The air sampler, consisting of a membrane prefilter backed by a carbon trap, showed that most of the activity was collected on the carbon trap. The ratio of the iodine activity on the carbon trap to the prefilter is shown in Table X. Except for stations A-1, C-11, and C-12 the ratios of the

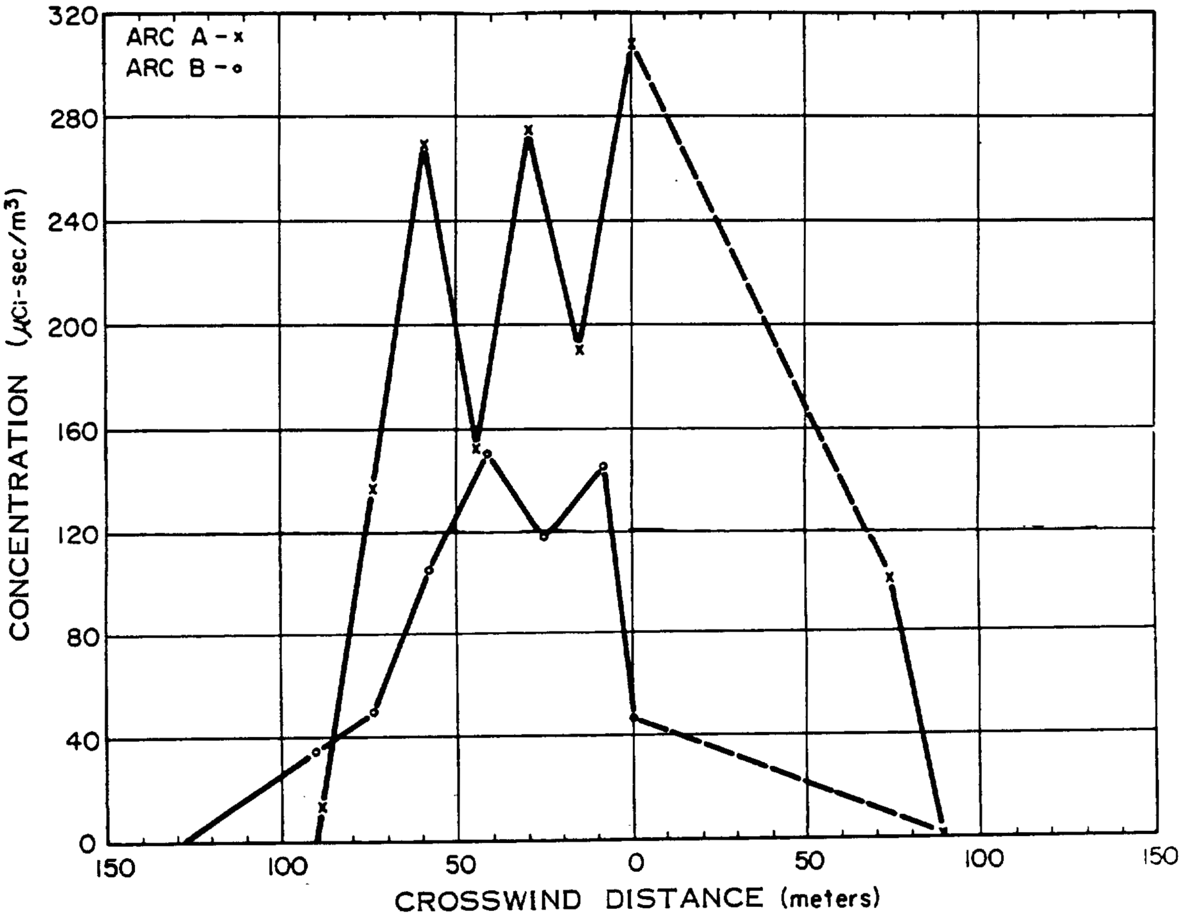

Fig. 15 Measured total integrated concentration on arcs A and B.

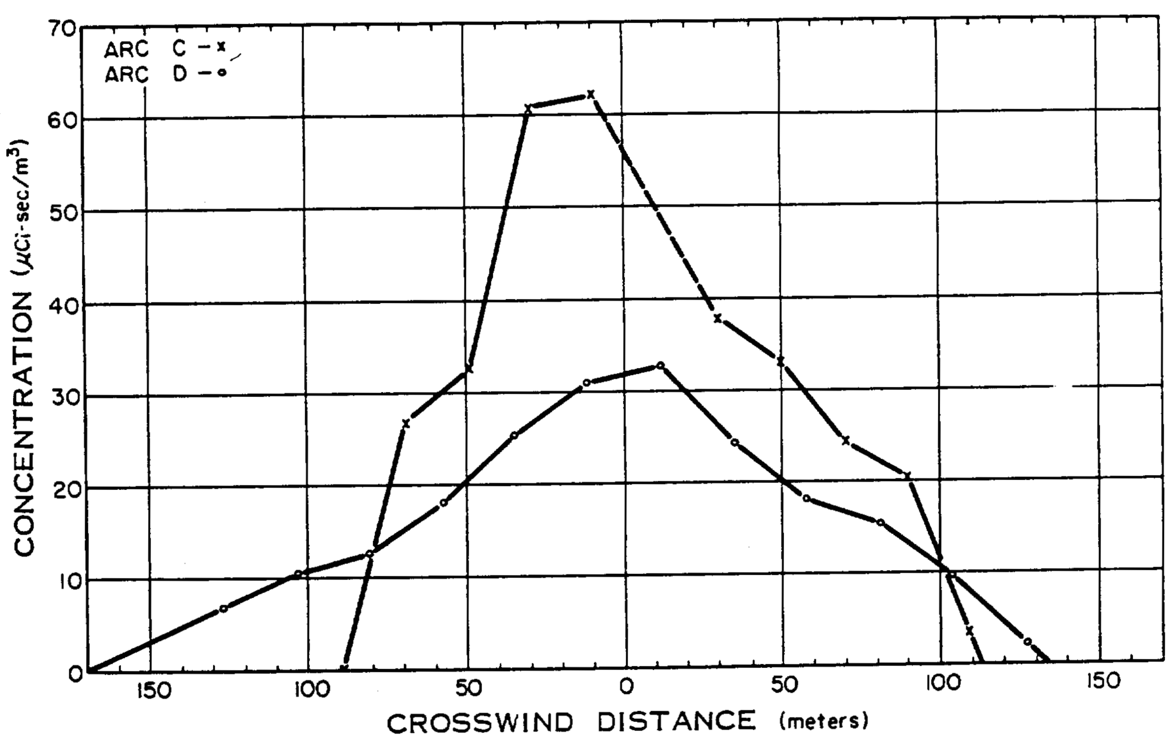

Fig. 16 Measured total integrated concentration on arcs C and D.

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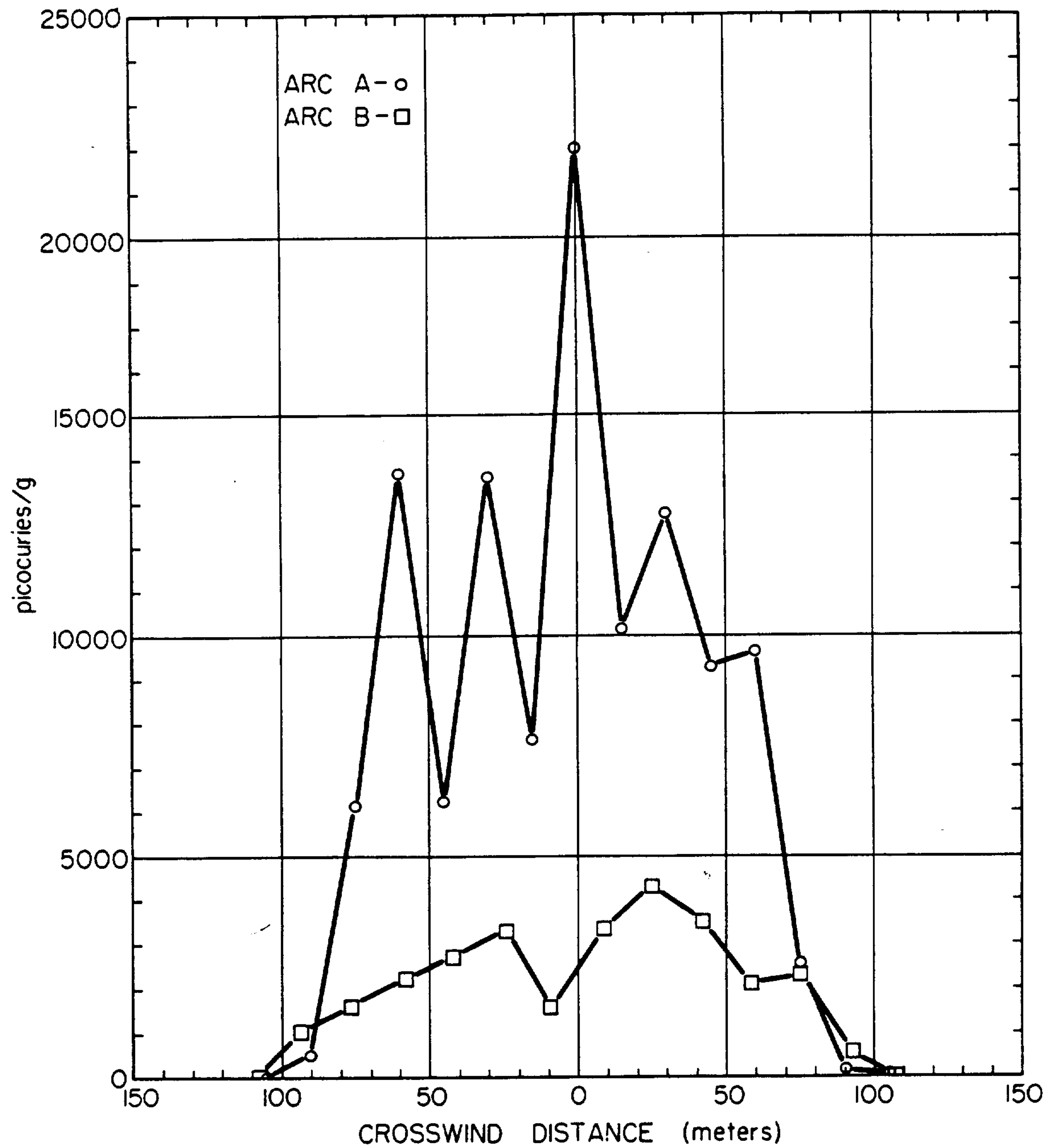

Fig. 17 Measured deposition of iodine-131 on the vegetation on arcs A and B.

carbon trap to the prefilter activities are fairly constant to arc D. On the average it appears that between 65 and 75 percent of the activity was collected on the carbon traps out to arc D, which is 300 meters downwind. Between D and T there was a change of this ratio. Arc T was a distance of about 1000 meters downwind. The reason for this change between arc D and T can only be speculative at this time but there may have been some change in particle size or the compound of iodine that existed between the two arcs.

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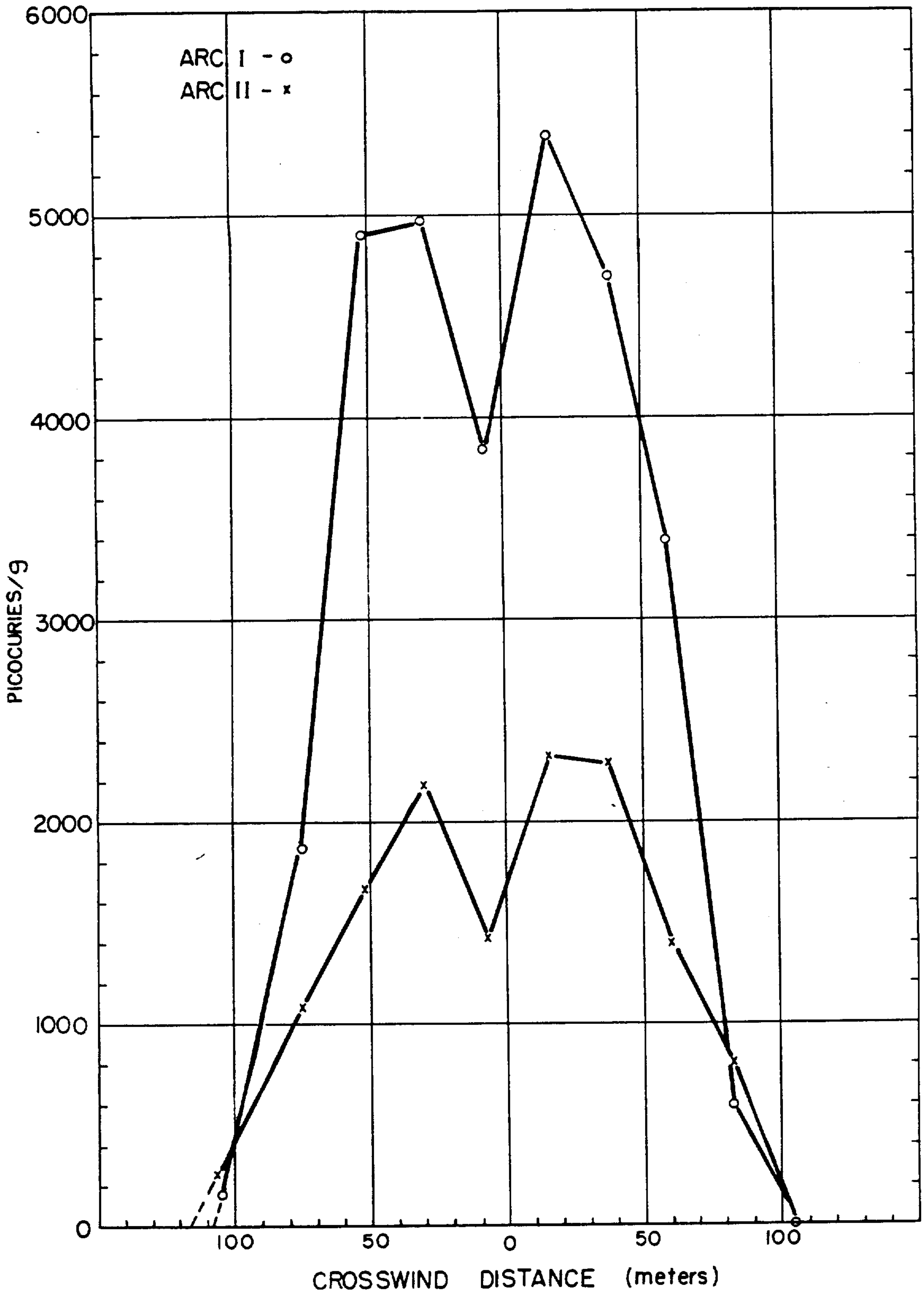

Fig. 18 Measured deposition of iodine-131 on vegetation.

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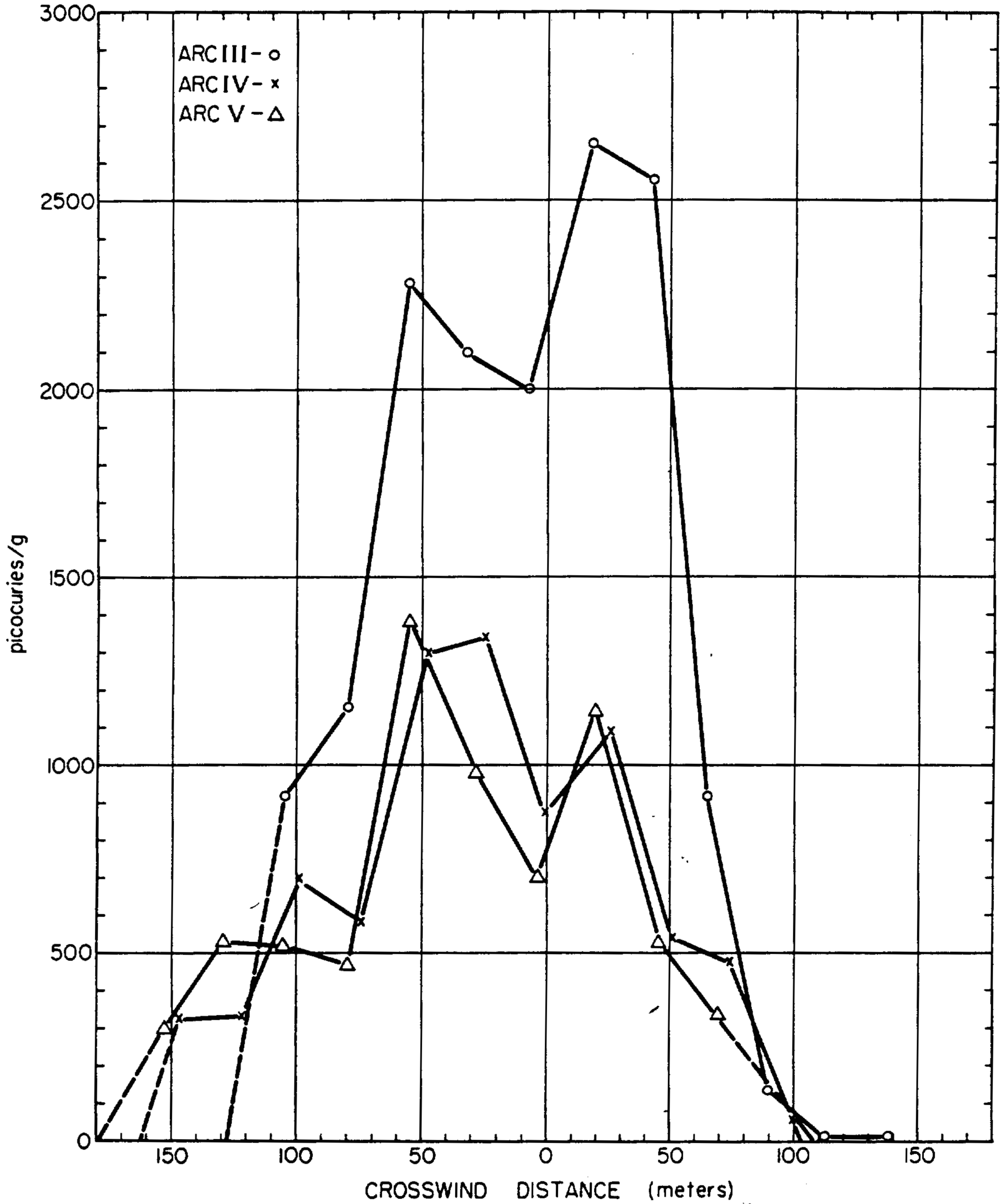

Fig. 19 Measured deposition of iodine-131 on vegetation on arcs III, IV, and V.

Ten air samplers of a different type were operated in this test by General Electric Company personnel, Hanford Atomic Power Laboratories, Richland, Washington. Each sampler was composed of a membrane prefilter, a silver nitrate treated section, and a charcoal bed, respectively. The total iodine air activity, consisting of the sum of the three stages on the Hanford-type filters, compares,

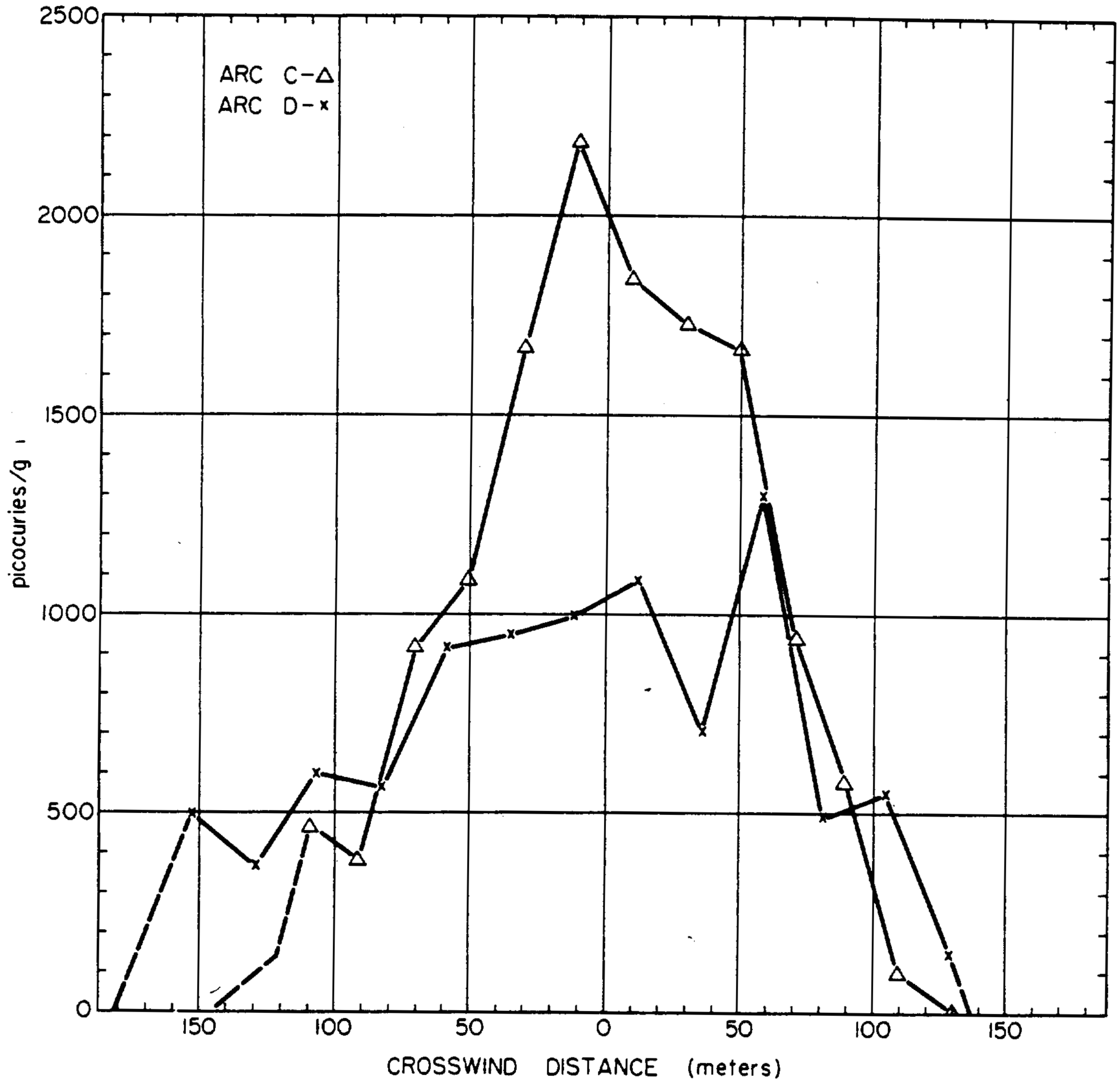

Fig. 20 Measured deposition of iodine-131 on vegetation on arcs C and D.

quite well to the sum of the prefilter and carbon trap measurements made with the NRTS high volume air samplers. Table XI shows this comparison for the average data for each arc. Since the two different samplers were not located at exactly the same locations, it was not possible to compare individual stations but rather the average for the appropriate sections.

1.2 Deposition Velocities

The deposition velocities were computed for every air concentration and vegetation sampling station. In addition a total of 11 samples of deposition on the bare soil was collected, in which a 0.1-meter slice of top soil was extracted and analyzed. The locations of the soil sampling stations are shown in a later

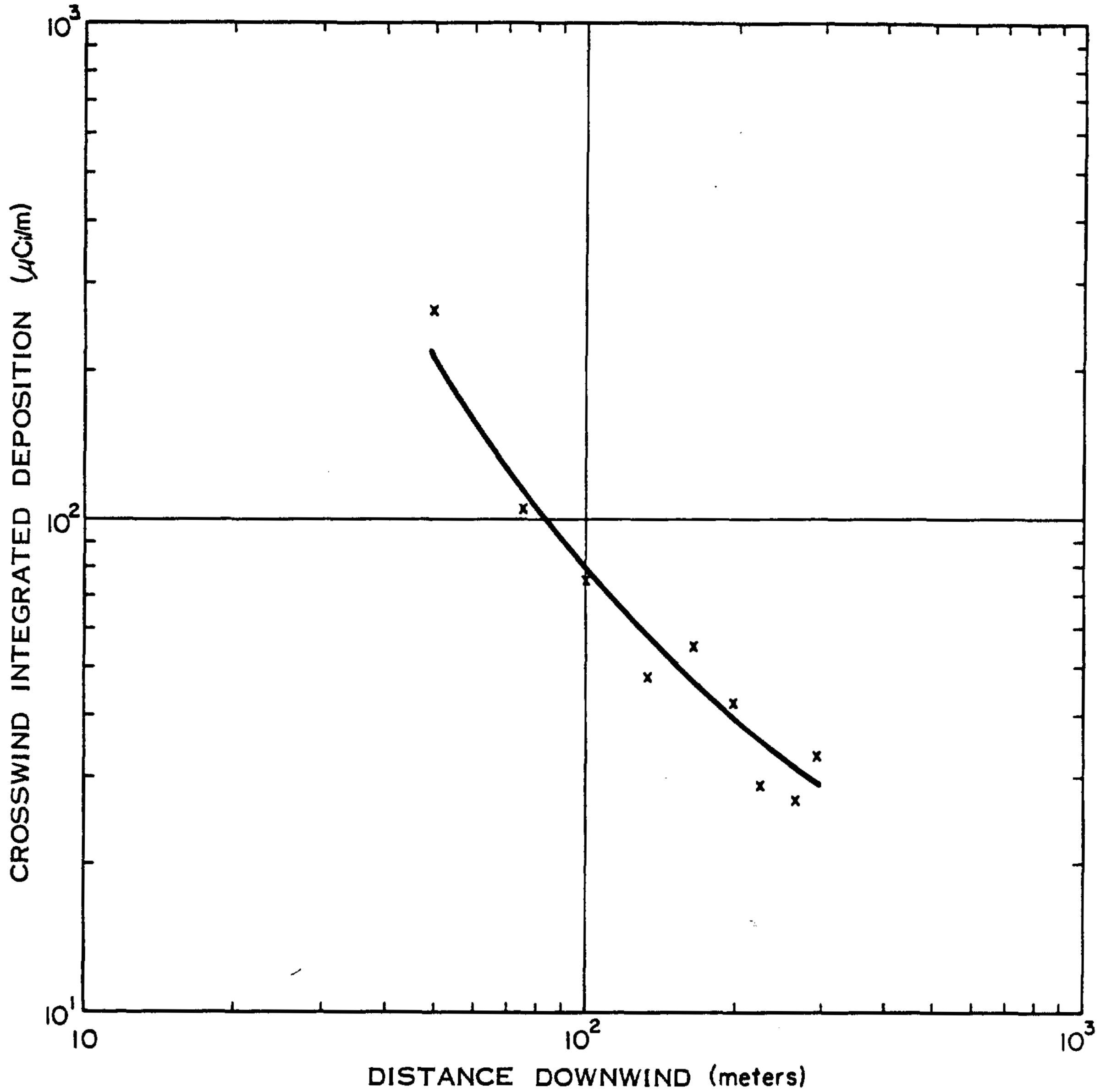

Fig. 21 The crosswind integrated deposition on the vegetation as a function of distance downwind.

table. The deposition per unit mass of vegetation was converted to deposition per unit area by multiplying by the density of grass, 150 g/m^2.

The results of deposition velocity computations are shown in Table XII. It can be seen from the table that there is a mean value of about 0.6 cm/sec. The mean value seems to have some variations with distance. The mean value increases steadily out to the limit of the arcs in which deposition and air sampling data were measured at the same locations, except for the first arc. The anomolous behavior of the first arc may have been due to source effects. The ensemble average value of 0.61 cm/sec is three times the value originally assumed

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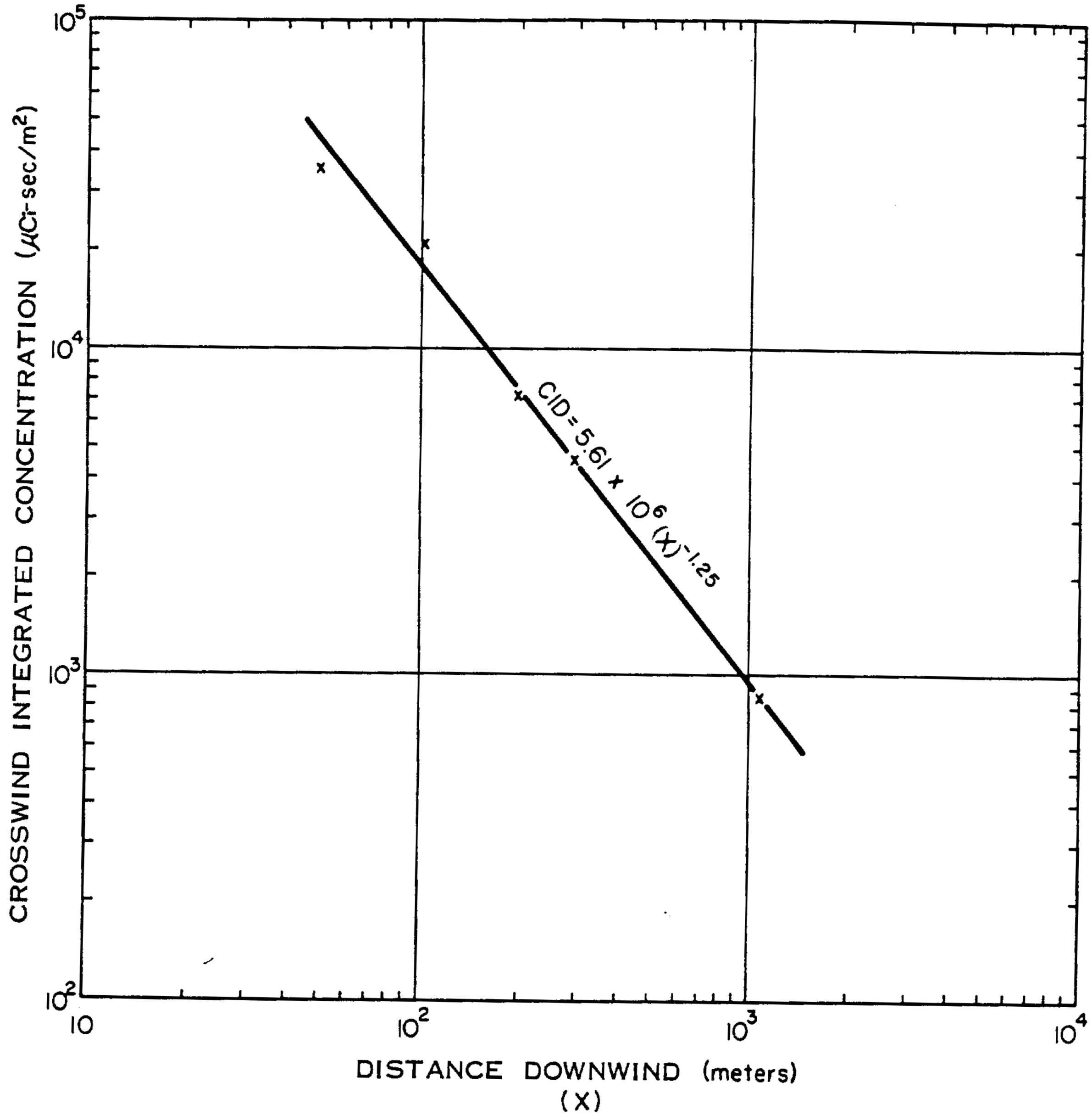

Fig. 22 The crosswind integrated concentration as a function of distance downwind.

in the designing of the experiment, 0.2 cm/sec. The ratio of deposition velocities on the soil to that over grass, although quite sparse in number, is shown in Table XIII and seems to be on the order of unity. The one sampling station, D-2, apparently is not representative and has been discarded from the analysis. The average ratio of the deposition velocity on soil to that over grass is 1.38. These values of the deposition velocity appear to be in reasonable agreement with those reported by other authors. A. C. Chamberlain [2] has recently summarized the results of many investigations into the deposition of

TABLE X

RATIOS OF CARBON TRAP TO PREFILTER MEASUREMENTS ON THE HIGH VOLUME AIR SAMPLERS

Arc Station	A	B	C	D	T
1	0.88		1.05	2.67	1.46
2	1.89		3.25	2.46	1.01
3			2.08	2.31	1.60
4			2.24	2.72	1.40
5			2.05	2.52	1.15
6			2.42	2.68	
7	2.51	2.30	2.50	2.98	
8	2.32	2.38	2.96	2.79	
9	2.63	2.18	3.78	3.26	
10	2.08	2.69	2.26	2.73	
11	2.52	2.24	0.29 [a]	2.27	
12	1.94	2.02	0.31 [a]	2.13	
13	2.22				
Average	2.11	2.30	2.46	2.63	1.32

[a] Omitted from the average

TABLE XI

COMPARISON OF AIR CONCENTRATION VALUES BETWEEN THE HANFORD AND NRTS SAMPLERS

ARC	No. of Samplers	Total Integrated Concentration (μCi-sec/m^3)		Ratio (Hanford/NRTS)
		NRTS	Hanford	
A	4	322	251	0.78
B	4	124	132	1.06
C	1	55.1	62.1	1.13
D	1	44.9	31.8	0.71

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TABLE XII

DEPOSITION VELOCITY COMPUTATIONS

Sta. No.	DOSE μCi/sec/m^3	Dep μCi/m^2	V_g(cm/s)	Sta. No.	DOSE μCi/sec/m^3	Dep μCi/m^2	V_g(cm/s)
A-2	1.00×10^{2}	3.95×10^{-1}	0.40	B-7	1.46×10^{2}	2.45×10^{-1}	0.17
A-7	3.08×10^{2}	3.37×10^{0}	1.09	B-8	1.18×10^{2}	5.13×10^{-1}	0.43
A-8	1.94×10^{2}	1.17×10^{0}	0.60	B-9	1.50×10^{2}	4.18×10^{-1}	0.28
A-9	2.75×10^{2}	2.08×10^{0}	0.76	B-10	1.05×10^{2}	3.52×10^{-1}	0.34
A-11	2.70×10^{2}	2.10×10^{0}	0.78	B-11	5.00×10^{1}	2.51×10^{-1}	0.50
A-12	1.37×10^{2}	9.40×10^{-1}	0.69	B-12	3.48×10^{1}	1.64×10^{-1}	0.47
A-13	1.36×10^{1}	7.80×10^{-2}	0.57				
		Average	0.70			Average	0.37
C-1	3.32×10^{0}	1.53×10^{-2}	0.46	D-1	2.24×10^{0}	2.30×10^{-2}	1.03
C-2	2.03×10^{1}	8.87×10^{-2}	0.44	D-2	9.83×10^{0}	8.42×10^{-2}	0.86
C-3	2.41×10^{1}	1.44×10^{-1}	0.60	D-3	1.53 x 10-1	7.50×10^{-2}	0.49
C-4	3.29×10^{1}	2.56×10^{-1}	0.78	D-4	1.80×10^{1}	1.99×10^{-1}	1.11
C-5	3.78×10^{1}	2.65×10^{-1}	0.70	D-5	2.42×10^{1}	1.09×10^{-1}	0.45
C-7	6.21×10^{1}	3.35×10^{-1}	0.54	D-6	3.27×10^{1}	1.67×10^{-1}	0.51
C-8	6.07×10^{1}	2.55×10^{-1}	0.42	D-7	3.08×10^{1}	1.53×10^{-1}	0.50
C-9	3.24×10^{1}	1.67×10^{-1}	0.52	D-8	2.53×10^{1}	1.45×10^{-1}	0.57
C-10	2.66×10^{1}	1.41×10^{-1}	0.53	D-9	1.8×10^{1}	1.41×10^{-1}	0.78
C-11	2.07×10^{-1}	5.81×10^{-3}	2.81 [a]	D-10	1.26×10^{1}	8.72×10^{-2}	0.69
C-12	1.11×10^{-1}	7.20×10^{-3}	6.49 [a]	D-11	1.05×10^{1}	9.19×10^{-2}	0.87
				D-12	6.89×10^{0}	5.66×10^{-2}	0.82
		Average	0.55			Average	0.72

Grand average - 0.61

Median value - 0.5

[a] Excluded from analysis.

iodine-131, which seem to indicate that iodine-131 in a purely gaseous form will deposit at about 1 cm/sec. The Windscale accident experience indicated that values on the order of 0.3 to 0.4 cm/sec were appropriate. Planned experiments at the NRTS and also experience from the SL-1 accident indicated values at about 0.1 to 0.2 cm/sec would apply over sagebrush [3]. These latter data were found, however, under more stable atmospheric conditions and could be expected to be somewhat less.

TABLE XIII

SOIL TO VEGETATION COMPARISONS OF DEPOSITION

Station Number	Vegetation Deposition $\mu Ci/m^2$	Soil Deposition $\mu Ci/m^2$	Soil/Vegetation
A-5	1.95	1.49	0.76
A-8	1.17	2.50	2.14
B-4	0.54	0.32	0.59
B-9	0.42	0.85	2.02
C-3	0.14	0.11	0.79
C-10	0.14	0.15	1.07
D-2	0.08	(0.01)	(0.125)[a]
D-11	0.09	0.20	2.22
B-	0.38	0.39	1.03
C-	0.31	0.50	1.61
C-	0.16	0.25	1.56
		Average	1.38

[a] Not included in the average.

Ecological surveys indicated that about 16 percent of total surface area was covered by the grass, the remaining 84 percent being exposed soil and small surface debris. By plotting the crosswind integrated deposition against downwind distance, the total amount of iodine-131 deposited on the grazing plot between the 50 and 300 meter arcs can be estimated. This value is about 1.5 percent of the total iodine-131 released. Another 11.2 percent of the iodine-131 was estimated to have been deposited on the ground surface in this area from the few measurements of soil collected. This indicates that between the 50 and 300 meter arcs a total of 12.7 percent of the released iodine-131 was deposited.

The vertical change of concentration of iodine-131 in air was measured at one point on a six-meter mast, located halfway between stations B-5 and B-6. Low volume air samplers were used to obtain these air concentrations which are shown plotted as a function of height in Figure 23. The air concentration rises to a maximum at about three meters and then gradually decreases. A nearly linear

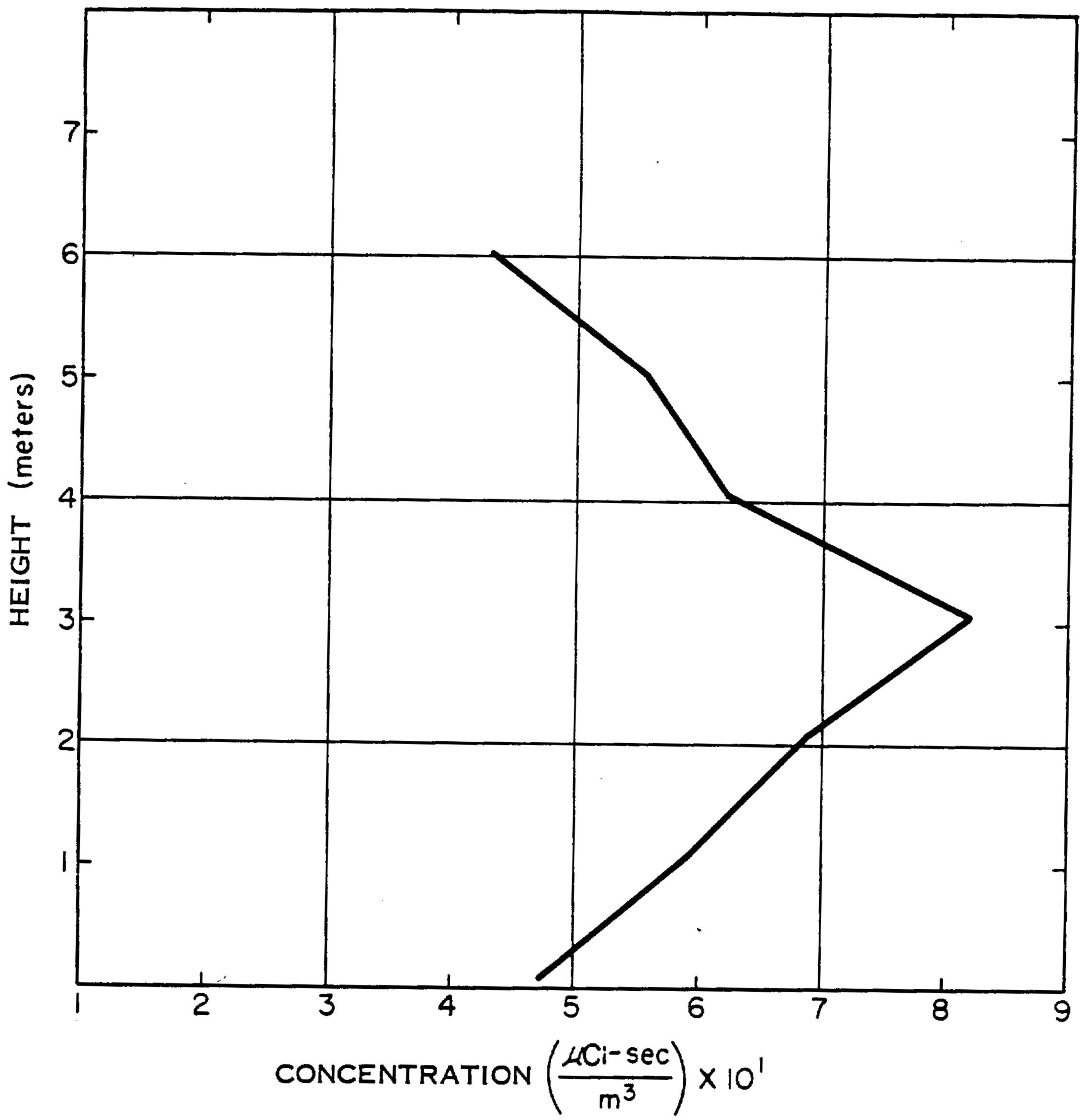

Fig. 23 Total integrated concentration versus height.

change of air concentration with height is experienced below three meters. The height of the maximum appears to be roughly equal to the average height of the iodine generator line above the flat part of the grazing plot. Theodolite triangulations from the six-meter tower indicated that the generator line was on the average about three meters above the grazing plot, varying from about two meters at one end to about five meters at the other end above the plot. The iodine generator line was near the base of the ridge which formed the upwind end of the grazing plot.

A number of flat plates covered with different types of surfaces were placed at various points to compare the deposition on the plates to that on the grass. These plates were 25 x 25 cm, covered with sticky paper, a fine quartz sand spread over sticky paper, and charcoal powder spread over sticky paper. The ratio of the deposition velocities on carbon plates to that over sand and sticky paper plates as well as vegetation is shown in Table XV. All the different types of sampling media were placed as close together as possible. The sand-covered plates usually recorded a slightly higher total deposited activity than the sticky paper plate and the charcoal-covered plates showed considerably higher than either. The ratio of the deposition on the charcoal-covered plates to that on the grass is near unity with some scatter of values. This scatter is shown in Table XIV which shows the ratio of the carbon plate to grass deposition velocities. The standard deviation of the grass and carbon plate deposition velocities were 0.20 and 0.17, respectively, indicating no significant superiority of one type sample over the other as far as reliability is concerned. The isopleths of deposited activity on the carbon plates in Figure 24 show an appearance quite similar to the isopleths of vegetation deposition given in Figure14. It appears that charcoal covered plates may be suitable for estimating the deposition rates of iodine-131 on vegetation.

TABLE XIV

RATIO OF CARBON PLATE TO VEGETATION DEPOSITION VELOCITIES

		(24 measurements)			
Ratio	0.25-0.29	0.50-0.74	0.75-0.99	1.00-1.24	1.25-1.49
	1.50-1.74	1.75-1.99	2.00-2.24		
Frequency by number	2	4	9	4	3
	1	0	1		

1.3 Prediction of Deposition Velocities from Micrometeorological Variables

The theoretical prediction of deposition velocities is an extremely complicated problem to formulate. Some of these attempts have recently been summarized by Chamberlain [2]. If it is assumed that the ratio of the vertical flux to the vertical gradient is the same for the gas or vapor as it is for atmospheric momentum transfer, and that the boundary conditions are the same, and that the vertical profiles of concentration and windspeed are identical in shape, the

TABLE XV

RATIO OF DEPOSITION VELOCITIES ON CARBON TO SAND, STICKY PAPER, AND GRASS

Station	Carbon/Sand	Carbon/Sticky Paper	Carbon/Vegetation
A-3	3.4	3.4	0.83
A-5	2.5	3.0	0.63
A-7	3.5	4.0	0.55
A-9	5.6	7.1	0.94
A-11	2.5	4.3	0.95
A-13	2.9	2.9	0.61
B-2	3.3	4.0	1.24
B-4	2.0	2.7	0.60
B-6	2.5	3.5	1.24
B-8	2.2	3.9	1.15
B-10	4.2	9.2	1.33
B-12	1.8	3.4	0.75
C-1	2.5	3.2	2.00
C-3	2.7	4.4	0.99
C-5	4.0	3.9	0.85
C-7	4.0	5.7	1.09
C-9	2.6	-	1.28
C-11	3.2	4.1	1.72
D-2	2.4	2.4	0.47
D-4	2.5	3.5	0.41
D-6	2.5	2.0	0.98
D-8	2.6	3.7	0.77
D-10	4.3	5.7	1.40
D-12	2.8	4.4	0.79
Average	2.94	4.03	0.98

ratio of flux to concentration at a given height also should be the same. Then the deposition velocity is given by $V_g = \frac{U^{*2}}{U}$. Using the measured values of U = 6m/sec near the surface and a friction velocity of about 60 cm/sec this results in a deposition velocity of 6 cm/sec compared to a measured average value of 0.6 cm/sec. The friction velocity had to be derived from quantities

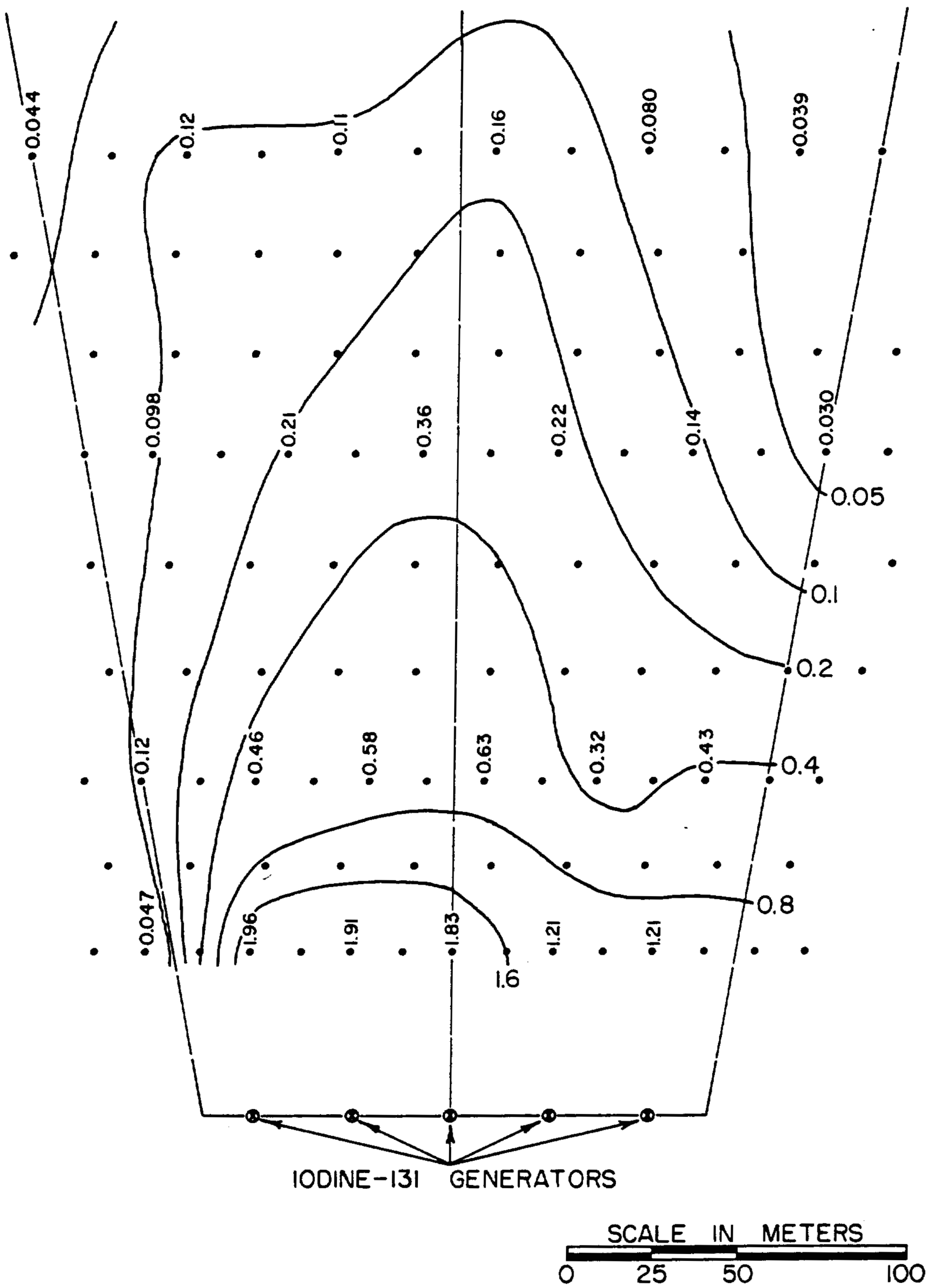

Fig. 24 Isopleths of activity on carbon fallout plates ($\mu Ci/m^2$).

which were measured no closer than one meter to the surface, which may be completely inadequate for the deposition of matter on the surface. A more recent

0023479

treatment by Chamberlain [2] involved the introduction of the molecular diffusivity which results in an expression involving U* and the coefficient of molecular diffusivity. This expression results in values roughly about 1/2 as large as those given by the above expression; but, these also are much too large.

A different approach summarized by Chamberlain [2], known as Colburn's formula is applicable for very small particles on the order of 10^{-2} to 10^{-3} microns in diameter. In this formula it is assumed that the transfer of mass is analogous to the transfer of heat and depends upon the 2/3 power of the diffusivity. For a 0.01 micron diameter particle and the wind speed and friction velocity as measured in the CERT experiment, it appears that a deposition velocity of about 0.2 cm/sec would be expected. The particle size of the iodine-131 is not known, but it was probably extremely small if not in gaseous form so that this technique seems to give a deposition velocity of proper magnitude.

Recently, Owen [4] has developed some expressions for the deposition rate for small particulates to both vertical and horizontal walls based upon conditions experienced in a wind tunnel. This results in the expressions:

$$\text{vertical wall: } V_g = \frac{U^*}{\frac{608}{\lambda^2} - 8.14 + 0.714\frac{U}{U^*}}$$

$$\text{horizontal wall: } V_g = \frac{\sigma w}{\sqrt{2\pi}}$$

The latter expression for the horizontal wall apparently is the approximate resulting term if the terminal velocity of the particle is small. The value of the constant λ, which depends upon the stopping distance of the particles after they have left the turbulent air stream and are ejected to the surface, is said to be 1.6. The r.m.s. value of the vertical velocity, σw, is approximately given by $\bar{U}\sigma\phi$. With the values of U and U* given above, it can be seen that the computed deposition velocity for a vertical wall is 0.25 cm/sec. This appears to be a proper order of magnitude but the results may have been entirely fortuitous considering the difference between wind tunnel and atmospheric turbulence.

The expression for the vertical deposition involves only the term w ($=\bar{U}\sigma\phi$). For 10 second averages $\sigma\phi$ is about 4° (=0.07 radian) from Figure 7, and $\bar{U}$ equal to 5.2 m/sec is appropriate. This results in a value of 15 cm/sec for V_g. This is considerably excessive of that which was measured and indicates that if Owen's treatment is to hold at all, the vertical velocity must be measured very close to the ground beyond the range of such transducers as large bivanes [4].

If similarity between the vertical transfers of momentum and of matter in the lower layers is assumed, the deposition on the surface could be predicted from a consideration of the gradient of air concentration in the vertical near the surface and exchange coefficient. An appropriate value of the exchange coefficient for momentum at two meter height, taken from the values reported by Deacon [5] for the Richardson number given in Table II, seems to be about 0.4 m^2/sec. The vertical gradient of air concentration in the lower level appears to have a value of about 11.4 μCi-sec/m [4]. This indicates a total integrated deposition of 4.5 μCi/m^2. This is about an order of magnitude higher than that which was measured, indicating difficulty in using this approach unless extremely detailed measurements are made near the surface.

Theoretical derivations can be found in the literature, most of which hardly satisfy the models that are experienced in the atmosphere, which predict deposition velocities approximately in the right range. This problem is still subject to considerable investigation. All the treatments listed indicate that the deposition velocity should vary with U* and therefore with the atmospheric stability. A significant change in the deposition velocity between the strongly stable atmospheres found at night and the unstable atmospheres of midsummer afternoons could be expected. This experiment was conducted under moderately unstable conditions. Future tests should show a variation with atmospheric stability if any of the above relationships are to be valid.

1.4 Post-Test Iodine-131 Behavior

The iodine on the vegetation was sampled on a daily basis on the strips before the cows were allowed to graze. The deposition could be evaluated as a function of time after the release. The deposition measurements made on these successive days have been back-corrected for radioactive decay to account for the lapse of time between sampling the grass and laboratory analysis, which was about one day. These can then be compared to the initial measurements of deposition right after the release.

The percent of the original iodine-131 activity on the grass that remained is shown in Figure 25. Irregular variations from day to day were experienced but they were not correlated to the observed precipitation or other meteorological variables such as wind speed. The vegetation activity plotted in Table VII was corrected for plant growth, which was 16 g/m^2/day. Most striking is the

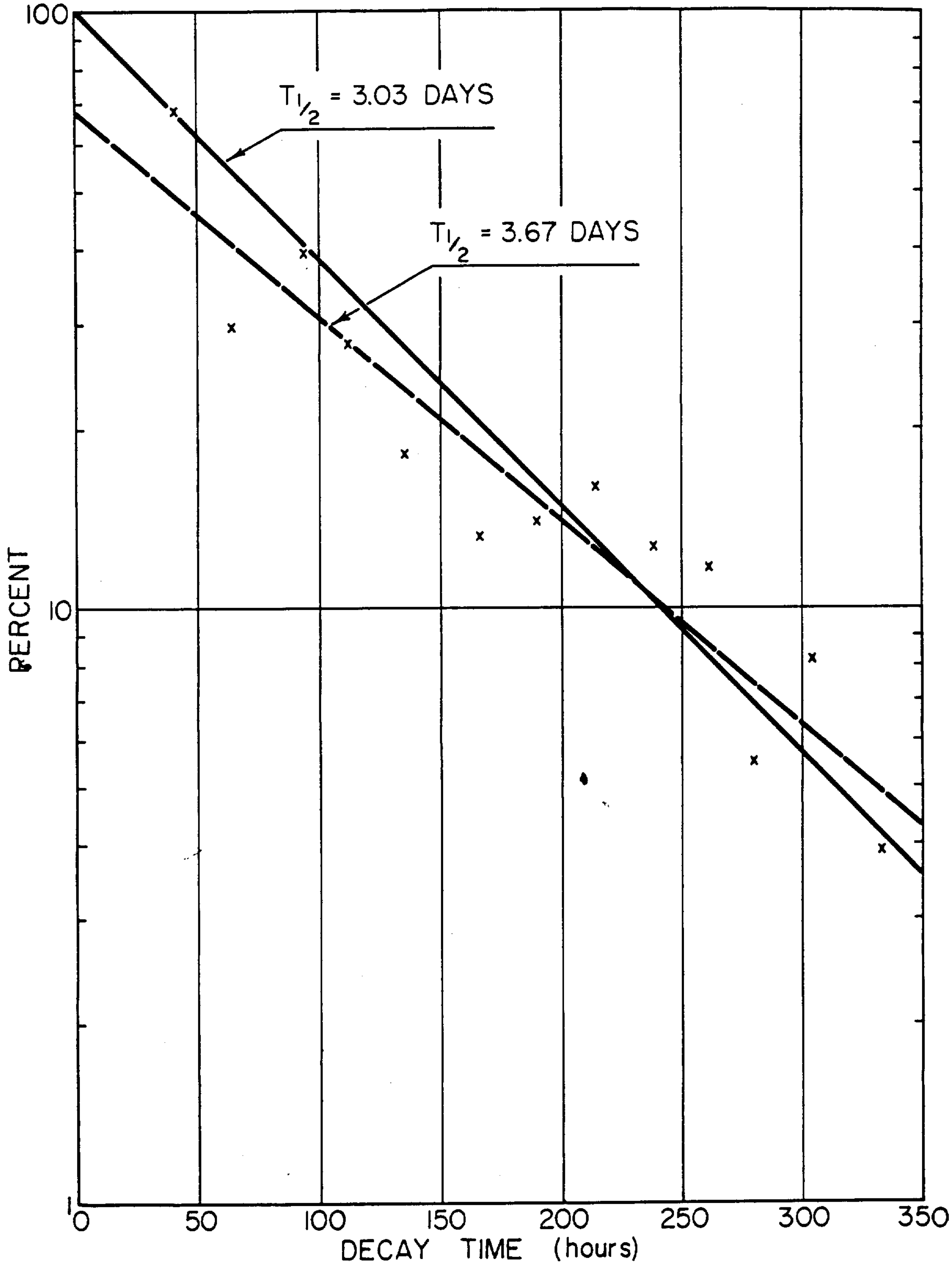

Fig. 25 Percentage activity on grass versus time.

0023482

apparently shorter effective half-life of the iodine-131 than the 5 to 6 days reported in the literature. A 3- to 3.7-day half-life is computed by regression depending on whether the regression line is forced to go through the 100 percent point at zero time or not.

The 3.6 or 3.5 $T_{1/2}$ is the better number. The 3.5 day (roughly) half-life reported here differs appreciably from the 5.5 day half-life reported by Martin [6] based on the Sedan shot and the 5 day half-life reported by Chamberlain and Chadwick [7] and used by Knapp [8]. The release, collection, and meteorological conditions under which these data were derived are not directly comparable with those during the preliminary CERT test. Holland [9] has discussed Lane's experimental results from the Sedan shot which can be interpreted as being reasonably close to those reported here.

2. CALCULATED INHALATION VERSUS INGESTION DOSES

Of considerable importance in reactor hazards evaluation is the relative magnitude of the infinite thyroid dose from iodine-131 due to the ingestion of contaminated milk compared to inhalation. The relative magnitude of these potential doses to humans can be estimated for this experiment. From Figure 9, which gives the milk activity for each day, and from the air concentration data given in Figures 15 and 16, the relative activity in a liter of milk to that inhaled into the lungs by a person standing directly downwind in the plume during its entire passage was computed. Table XVI gives the potential inhaled activity at various distances downwind assuming a breathing rate (Br) equal to 2.32×10^{-4} m^3/sec. The distance for which the mean concentration was taken was appropriate to the distance of the grazing strip downwind for which the associated milk activity on a given date is given. The mean concentration is taken along the grazing strip laterally with respect to the prevailing wind direction interpolating between air sampling arcs when necessary. The data listed for the appropriate milk activity is the day after the cattle were grazed on the strip at the distance indicated in the first column. A liter of milk was taken as typical of the normal daily human consumption. Since Figure 9 shows that the half-life of milk activity for iodine-131 in a cow is about one day, the contribution to the total milk activity on a given day is equal to that activity minus 1/2 of the activity given on the previous day minus 1/4 of the activity given two days before, etc. This, of course, reduces to the expression that the activity in the milk on a certain day is

0023483

TABLE XVI

POTENTIAL IODINE-131 ACTIVITY IN LUNGS FROM INHALATION COMPARED TO MILK ACTIVITY ON A DAILY BASIS

x Distance Downwind (meters)	χ Mean Concentration (μcuries-sec/m³)	D_1 Inhaled Activity (μcuries) x10⁻³	Date	Dm Milk Activity (μμc/liter) x10⁴	Dm* Daily Milk Uptake (μμc/liter) x10⁴	Ratio $\frac{Dm^*}{D_1}$
278	25.6	5.96	5/29	7.2	7.2	12.1
267	26.8	6.20	5/30	8.4	4.8	7.74
257	27.0	6.25	5/31	7.2	3.0	4.80
246	28.4	6.60	6/1	6.3	2.7	4.09
235	30.6	7.10	6/2	4.6	1.45	2.04
225	32.8	7.16	6/3	4.1	1.80	2.51
214	35.0	8.10	6/4	3.5	1.45	1.79
203	37.0	8.60	6/5	3.0	1.25	1.45
193	40.3	9.36	6/6	2.9	1.40	1.49
182	43.7	10.1	6/7	2.7	1.25	1.23
171	49.0	11.4	6/8	2.3	0.95	0.83
161	54.7	12.7	6/9	2.1	0.95	0.74
150	60.0	13.9	6/10	1.9	0.85	0.61
139	68.0	15.8	6/11	1.7	0.75	0.47

$D_I = XBr$ $\quad$ $Br = 2.32 \times 10^{-4} m^3/sec$

$Dm^* = Dm(t) - [1/2\ Dm^*(t-1\ day) + 1/4\ Dm^*(t-2\ day) + \ldots]$
$\quad = Dm(t) - 1/2\ Dm(t-1\ day)$

equal to the total measured activity in the milk on that day minus 1/2 the measured activity on the previous day. This daily contribution to the activity of iodine-131 in the milk is shown in Table XVI. The final column in Table XVI, showing the ratio of the daily milk uptake to the potential inhaled intake, can be

0023484

considered to be the relative magnitude of ingestion to inhalation if previously unexposed cows are continuously brought into graze on each day. The first value of 12.1 is the ratio of ingested to inhaled activity for a cow that was allowed to graze one day after contamination of the grass.

The ratio of the total ingested activity from cows allowed to graze a given number of days continuously from the second day after the grass contamination compared to the inhalation activity is shown in Table XVII. The average air concentration over the appropriate part of the grazing plot was used to compute

TABLE XVII

ACCUMULATED IODINE-131 INGESTION FROM DAILY CONSUMPTION OF ONE LITER OF MILK COMPARED TO POTENTIAL INHALATION UPTAKE

Date	$\sum^{n}$ [a] Dm Total Iodine-131 Ingestion ($\mu\mu$Ci x 10^4)	$\sum^{n}$ [a] D_I/n Average Inhaled Iodine-131 (μCi x 10^{-3})	Ratio of Ingested to Inhaled Activity
May 29	7.2	5.95	12.1
May 30	15.6	6.07	25.7
May 31	22.8	6.13	37.1
June 1	29.1	6.25	46.5
2	33.7	6.42	52.4
3	37.8	6.54	57.7
4	41.3	6.62	62.3
5	44.3	6.99	63.3
6	47.2	7.25	65.1
7	49.8	7.54	66.0
8	52.2	7.89	66.1
9	54.3	8.29	65.5
10	56.2	8.72	64.4
11	57.9	9.23	62.6

[a] n = number of days

0023485

the average inhalation shown in this table. In the last column the ratio of ingestion to inhalation activity varies from 12.1 to 66.1 after milk is consumed successively from cows that were allowed to graze continuously on contaminated pasture for 11 days. The ratio decreases slightly after the 11th day of grazing which is a reflection of the decreasing deposition velocity experienced as one progresses inward towards the source on this part of the pasture (See Table XII). An estimate of the ratio of ingested to inhaled dose for continuous grazing from the start of the test until the grass activity had decayed to near background was made with the resulting value of 80. The ratio of ingested dose for continuous milk consumption at the rate of one liter per day compared to the first day's dose is about 5.5. This is about half the theoretical ratio assuming an 8-day half-life for iodine-131 and is a result of the measured 3.5-day half-life of the iodine-131 on the vegetation.

3. ACTIVITY CONSUMED BY COWS VERSUS MILK ACTIVITY LEVELS

One of the objectives of the experiment was to determine a ratio of grass activity to that appearing in the milk. Table VII, page 22, lists the activities of the grass samples collected during the time the cows were grazing the contaminated pasture. These activities are expressed in terms of picocuries of iodine-131 per gram of grass, whereas the average milk activity in Figure 26 is expressed in picocuries of iodine-131 per liter of milk. In order to reach a meaningful comparison, the half-life in the cow and the sampling time increments must be considered. Figure 10 shows that the milk activity dropped off at the rate of a one-day half-life when the cows were removed from the hot pasture. This is in good agreement with the findings of the Kahn et al [10]. Considering this, and the fact that the evening and morning milkings were combined to form one sample, the activity ingested per cow per day must be corrected to some "effective" number. The method used to calculate the points plotted in Figure 26, "Effective Cow Consumption", was to multiply the grass activity in picocuries per gram by the amount consumed in kilograms per day per average cow. These numbers were then corrected in time. One-half of the first day's activity was used because the sampling period encompassed one whole day, during which time only one-half of the activity ingested by the cow on that day would appear in the milk. Added to this was 1/2 the preceding day's activity, 1/4 of the day before that, 1/8 of the day before that, 1/16 of the day before that, etc. The net result is a composite of all ingested activity which influences the milk activity levels. The slopes of the "Effective Cow Consumption" lines and the "Milk Activity" line

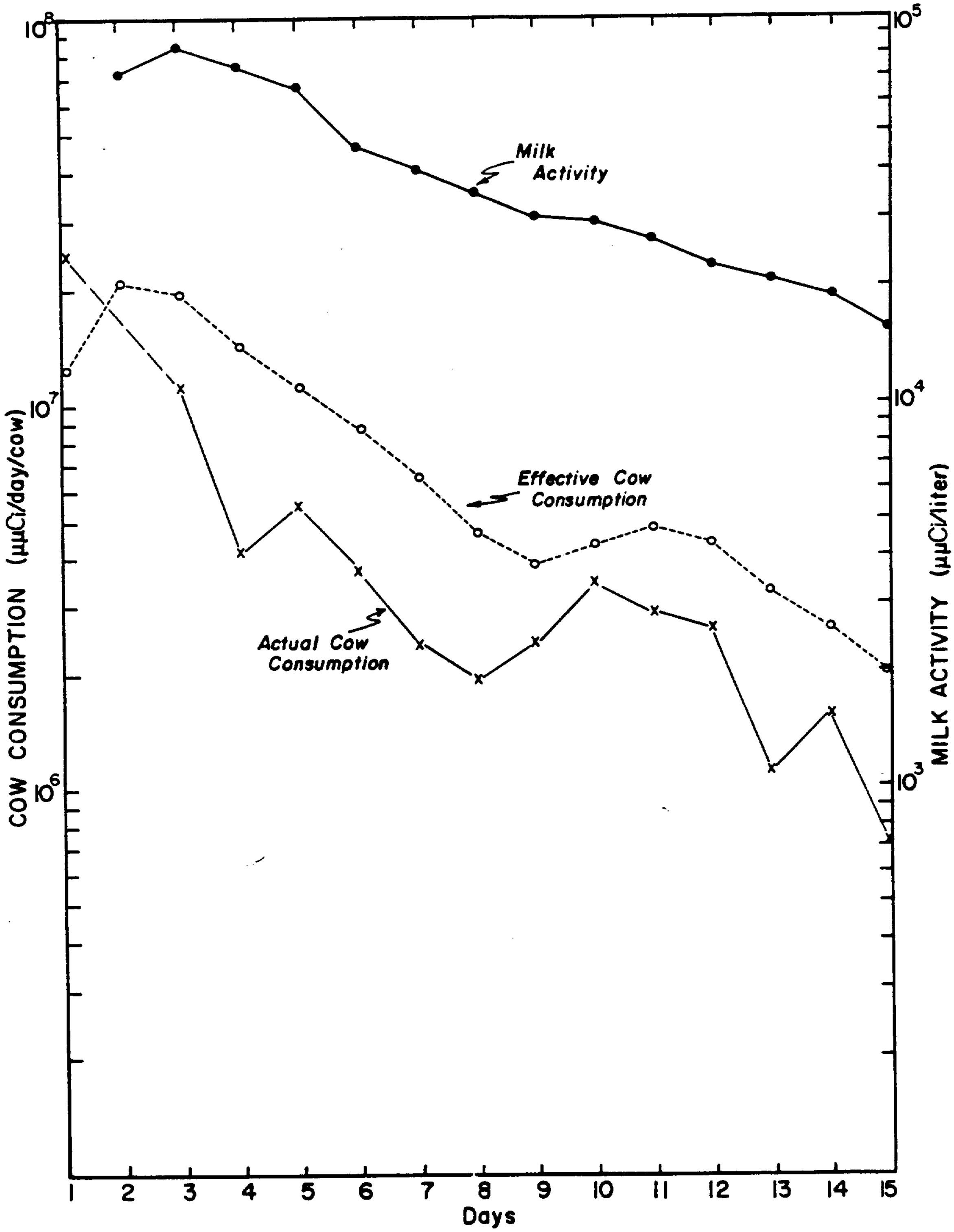

Fig. 26 Cow activity consumed versus milk activity.

are comparable, which indicated that the data which was used to develop the "effective" curve were reasonably good. Tables XVIII and XIX show that the ratio of milk activity (pCi/l) to grass activity (pCi/g) was found to be 240 ± 35. This ratio expresses only the continuing intake situation.

TABLE XVIII

PICOCURIES CONSUMED X 10^7

DATE	5-28	5-29	5-30	5-31	6-1	6-2	6-3	6-4	6-5	6-6	6-7	6-8	6-9	6-10	6-11
Corrective Fractions	Initial Consumption 2.5	1.7	1.0	0.42	0.55	0.37	0.24	0.19	0.24	0.34	0.29	0.130	0.055	0.075	0.037
1/2	1.25	0.850	0.500	0.210	0.275	0.185	0.120	0.095	0.120	0.170	0.145	0.145	0.130	0.055	0.075
1/4	0.625	0.425	0.250	0.105	0.138	0.092	0.060	0.048	0.060	0.085	0.072	0.085	0.072	0.065	0.028
1/8	0.307	0.212	0.125	0.052	0.069	0.046	0.030	0.024	0.030	0.042	0.036	0.030	0.042	0.036	0.032
1/16	0.154	0.106	0.063	0.026	0.034	0.023	0.015	0.012	0.015	0.021	0.018	0.012	0.015	0.021	0.018
1/32	0.077	0.053	0.031	0.013	0.017	0.012	0.008	0.006	0.008	0.010	0.009	0.008	0.006	0.008	0.010
1/64	0.039	0.026	0.015	0.007	0.008	0.006	0.004	0.003	0.004	0.005	0.004	0.006	0.004	0.003	0.004
DATE															
28	1.25	1.250	0.500	0.210	0.275	0.185	0.120	0.095	0.120	0.170	0.145				
29		0.850	0.850	0.500	0.210	0.275	1.85	0.120	0.045	0.120	0.170				
30			0.625	0.425	0.250	0.105	0.138	0.092	0.060	0.022	0.060				
31				0.307	0.212	0.125	0.052	0.069	0.046	0.030	0.011				
1					0.154	0.106	0.063	0.026	0.034	0.023	0.015				
2						0.077	0.053	0.031	0.013	0.017	0.012				
3							0.039	0.026	0.015	0.007	0.008				
Totals	1.250	2.100	1.975	1.442	1.101	0.873	0.650	0.459	0.383	0.415	0.434	0.416	0.324	0.263	0.204

4. HUMAN THYROID LEVELS AND RATES

As stated in section V, the average fraction of uptake in the thyroid of six individuals proved to be 0.19, ranging from a low of 0.12 to a high of 0.30. These milk ingestion data compare rather well with those reported by Bernard [11] et al (low of 0.80, high of 0.29, average of 0.16), although in the Oak Ridge study the milk used was pretreated to remove the ionic fraction from the protein bound fraction. As Dr. Bernard stated, "We do not have sufficient data to determine whether or not the metabolism of the protein-bound I-131 is different from ionic I-131 in milk" [11]. As was shown in Dr. Bernard's report, only about four percent of the I-131 was in the ionic form. This and a comparison of his data with those reported here would suggest that his calculations would hold true for whole milk as well as the resin-treated milk.

TABLE XIX

RATIO OF GRASS ACTIVITY TO MILK ACTIVITY

pCi(cons.)x10[7] (From Table XVII)	pCi/l(milk)x10[5]	Date	"Eff"pCi/gx10[2]	Ratiox10[2]
2.10	0.74	29	5.74	1.29
1.975	0.861	30	5.40	1.59
1.442	0.730	31	3.94	1.85
1.101	0.640	1	3.01	2.12
0.873	0.460	2	2.38	1.93
0.650	0.410	3	1.78	2.30
0.459	0.350	4	1.25	2.80
0.383	0.295	5	1.05	2.81
0.415	0.293	6	1.13	2.58
0.434	0.275	7	1.19	2.31
0.416	0.240	8	1.14	2.10
0.324	0.210	9	0.89	2.36
0.263	0.190	10	0.72	2.64
0.204	0.165	11	0.56	2.95

$\epsilon = 2875$ 58593

-57398

$\epsilon^2 = 703121$ 1195

N = 12

Mean = 239.58 = 240 ± 35

$\sigma = 35$

3.0864
1.5432   34.94

VII. CONCLUSIONS

The conclusions are that the general experimental plan is adequate and can be used for further studies of this nature. The question of whether or not the sparse type of grass used in this experiment is representative of a true pasture situation will not be answered until a release onto the pasture is accomplished. (Plans are to duplicate this preliminary experiment using an irrigated pasture, in the summer of 1964, to verify the below mentioned relationships and to prove or disprove the validity of using Crested Wheatgrass for deposition and uptake studies.)

The data gained during the experiment is summarized below:

(1) Gaseous iodine-131 was released at ambient temperature.

(2) Deposition velocity was 0.6 cm/sec (average).

(3) Effective half-life on grass was 3.5 days.

(4) Ratio of milk (pCi/l) to grass (pCi/gm) was 240.

(5) Peak activity in milk was at 2 days.

(6) Effective half-life in milk (after removal from hot pasture) was 1 day.

(7) Human thyroid uptake factor was 0.19.

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APPENDIX A
SAFETY ANALYSIS

1. CONTROLLED ENVIRONMENTAL RADIOIODINE TEST

1.1 Introduction

The initial Controlled Environmental Radioiodine Test will involve the release of one curie of iodine-131 to the atmosphere with the subsequent contamination of a controlled grazing area. This report investigates the possible hazards to the technicians involved in the test, to people at the NRTS due to the resultant radioiodine cloud, and to the general population due to off-site milk contamination.

1.2 Radiological Safety of Experiment Personnel

The potential hazards to people involved in the initial CERT experiment are twofold. These hazards are the exposure of the people handling the one curie source and the possible contamination of people and the spread of contamination from the controlled area.

The Analysis Branch has estimated that the maximum exposure to the person loading the iodine release mechanisms is 250 mrad. The maximum exposure to people operating the mechanisms is 50 mrad. Further exposures to these people will be carefully restricted if necessary.

Extensive contamination controls will be in effect throughout the test period. The "hot area" will be delineated by laths and posted with radiation signs. Daily surveys of the general area will be conducted to ensure against contamination spread. A "hot line" will be established at the barn area and the hot change trailer to control the movement of personnel to and from the contaminated area. Field sample collectors will be required to wear respirators with carbon impregnated filters in addition to standard anti-contamination clothing and self-reading dosimeters. Collectors and samples will be surveyed and checked out through the hot change trailer. The milker will wear protective gloves and will have Health Physics monitoring. All of the milk produced by the cows will be accounted for and destroyed.

Vehicles used for transporting samples will be protected with disposable paper and surveyed at the completion of each trip. All equipment will be surveyed prior to leaving the hot area and at the completion of the test.

These contamination controls and exposure restrictions provide adequate minimizing of the radiological hazards.

1.3 Radiological Safety of NRTS Personnel

The release of iodine-131 to the atmosphere will produce a radioactive cloud that is a potential hazard to personnel at the NRTS. However, the distances required for cloud travel to NRTS facilities provide ample diffusion of the iodine so that no hazard exists.

The integrated concentration of iodine-131 as a function of downwind distance is calculated using Sutton's diffusion equation. The meteorological parameter in the equation for windspeed is 6.7 m/s. For simplification of the calculation, the total amount of iodine-131, one curie, is assumed to be released from a point source. Such a simplification is conservative. Figure A-1 is a graph of the integrated iodine-131 concentration as a function of distance. These concentrations are used to determine the dosage at specific distances due to inhalation of the iodine and to submersion in the iodine cloud.

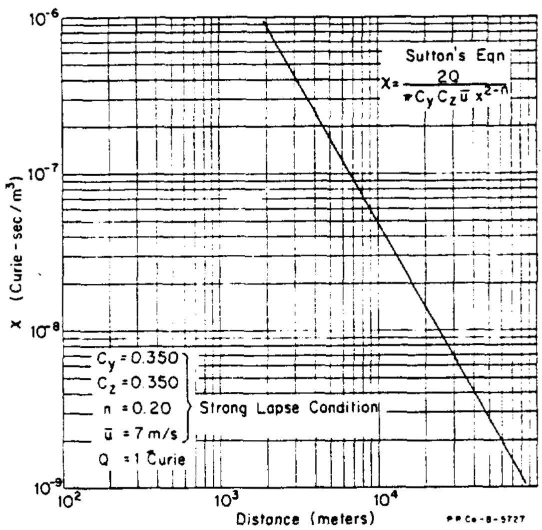

Fig. A-1 Integrated iodine-131 concentration as a function of distance.

The infinity inhalation dose to the thyroid is D_{∞} (rads) $= 8.54 \times 10^2 \times \frac{RFET\chi}{W}$,

- R = breathing rate = 3.47×10^{-4} m^3/sec,
- F = iodine retention in the thyroid = 23 percent,
- E = effective energy = 0.23 MeV,
- T = effective half-life = 6.57×10^5 sec,
- W = mass of thyroid = 20 grams, 8.54×10^2 is the conversion factor to rads,
- χ = integrated iodine concentation

Thus, $D_{\infty} = 515$.

The external gamma dose due to submersion in the cloud has been estimated by Burnett [12] not to exceed D(rad) = $0.26\ E\gamma\chi$. The estimation assumes an semi-infinite, uniform cloud so that the calculation is conservative. For iodine-131 $E\gamma = 0.4$ MeV, $D = 0.104\chi$. The external dose due to cloud submersion and

0023493

due to deposition on the ground and to beta exposure from cloud submersion are negligible.

Table A-I lists the calculated infinite dose due to the passage of the iodine cloud at three distances. These distances correspond to the locations of EBR-II, SL-1, and the nearest northeast distance to Highway 20. These locations are not in the same direction and the doses assume an exposure time corresponding to the entire passage of the iodine cloud. Since the iodine is to be released over a one hour period, any exposure time will most likely be less than the time of cloud passage. The doses are again conservative.

TABLE A-1

CALCULATED INFINITE DOSE DUE TO IODINE CLOUD PASSAGE

Location	Distance (kilometers)	Dose (mrads)
Highway 20	2.3-3.7	0.145
SL-1	2.9-4.7	0.096
EBR-II	11.3-18.2	0.008

1.4 Radiological Safety of General Population

The rapid diffusion of the iodine cloud with distance (Figure A-1) eliminates the inhalation hazard at the nearest site boundary. However, the concentrating effect of biological systems could conceivably cause a hazard to the general population through milk contamination. For purposes of calculation, a farm is hypothesized to exist at the nearest site boundary in the direction of the prevailing summer winds at CERT. This distance is about 32 kilometers ENE of the iodine-release point. The integrated iodine concentration is only $6 \times 10^{-9} \frac{\text{(curie-sec)}}{m^3}$ at this distance. The calculation of the infinity dose due to ingestion of contaminated milk is similar to that due to inhalation.

$$D_{oo} = 8.54 \times 10^2 \, IKV_g \frac{FET}{w},$$

where

I = ingested milk in liters,

K = ratio of milk contamination to grass contamination = 0.16,

V_g = deposition velocity - 2 cm/sec,

F = thyroid retention from ingestion = 30 percent.

0023494

The deposition velocity determined by the British [13] for iodine over grassland has been used here. This value is pessimistic since the grasses around the NRTS do not constitute as great a ground cover as do the British grasses. The ratio of milk contamination to grass contamination is the most pessimistic value determined by the British [14]. Thus, the ingestion dose is D_{oo} (rads) = 3.77×10^{-5} I (liters) for the hypothesized situation. If the milk consumption is assumed to be about one liter, then $D_{oo} = 3.77 \times 10^{-2}$ mrads for an adult. There is no hazard to the general population from the initial CERT test.

2. RADIOLOGICAL SAFETY OF EXPERIMENTERS

The procedures for handling and releasing the iodine-131 were established by the Analysis Branch. The procedures and release method have been kept simple and quick in order to minimize radiation exposures.

The radioiodine was shipped from Oak Ridge in a solution of sodium sulfate (Na_2SO_3) solution. The iodine-131 is in its iodide form while in such a reducing solution and cannot become gaseous in the case of a spill or container breakage. The solution will be transferred, under laboratory conditions, via pipettes to five, unbreakable, polyethylene bottles with the use of long-handled tongs. The transfer will be made from behind a body shield of lead bricks. Each of the five small, wide-mouthed bottles will then have 200 millicuries of iodine-131 to be released to the atmosphere over the CERT grazing area. These bottles will be transported in a lead pig to the CERT area.

When meteorological conditions are satisfactory, five people will transfer the separate solutions into five large flasks stationed at the established release points. The people transferring the solutions will have glove protection and pocket dosimeters. A predetermined amount of sodium nitrate ($NaNO_2$) will then be added to the flask through a small spout in order to oxidize the iodide to the desired iodine form. The iodine gas will then be swept from the flask by bubbling nitrogen through the solution. The nitrogen flow rate will be controlled from a distance of 15 feet, corresponding to the length of hose to be used, to provide a one hour release interval. This flow rate has already been determined. As a check, however, radiation levels from the flasks will be measured as necessary to ensure proper release of the iodine.

The only handling of the radioiodine outside of a laboratory will be with unbreakable containers and with the iodine in an uninhalable form.

A quick estimate of direct radiation exposures to the people handling the iodine source can be made. The initial source solution will have, according to Oak Ridge measurements, a 30 r/hr gamma field at a distance of three inches on the expected test day, May 21. It is estimated that the transfer to the five smaller containers will require no longer than 12 minutes and that by using tongs a minimum distance of 15 inches can be maintained; thus, the maximum exposure will be less than 250 mr (30 r/hr x 1/5 hr x $3^2/15^2$ = 0.240 r). This calculation does not consider the use of body shielding which will substantially reduce the whole body exposure. The transfer of 200 millicuries of iodine to one of the release flasks would require less than a minute. Control of the flow rate from the minimum distance of 15 feet would be for one hour. As an approximation, an effective distance of 10 feet for a one hour period is assumed.

Thus, the initial exposure rate is $I(r/hr) = 6\ CE/D^2 = 0.48/10^2 = 4.8$ mr/hr, so that the maximum exposure is less than 3 mr. This calculation neglects shielding by the flask and assumes a very pessimistic distance. Actually, once the proper nitrogen flow rate is established, the five people involved can retreat to a safer distance.

The possibility exists that a reversal of wind direction could occur shortly after the iodine release begins. If such a situation did happen, the iodine could be quickly shut off. Neglecting such a shut off, the inhalation doses at one-fourth mile and 50 meters have been calculated. For one-fourth mile (402 meters) $\chi = 1.43 \times 10^{-5}$ so that $D = 515\,\chi = 7.4$ mr to the thyroid. This calculation assumes exposure for the entire one hour release and assumes a point source of 1 curie. At 50 meters, the maximum iodine concentration is that due to the release from a single flask. At this distance $\chi = 1.3 \times 10^{-4}$ so that D = 67 mr.

The above calculated exposures show that the CERT test will be radiologically safe for the experimenters. Nevertheless, the entire radioiodine handling procedure will be performed under the surveillance of a health physicist in order to further minimize the probability and consequences of an accident.