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PROJECT SUNSHINE

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January 8, 1954

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This report summarizes the results to date of various investigations undertaken by the Health and Safety Laboratory on Project SUNSHINE.

The basic purpose of this report is to present new data on the distribution of Strontium-90 and this, to the best of our ability, we have done. However, data are only useful when they serve as the basis for interpretations and conclusions. We are compelled to point out that the data are as yet relatively few and the conclusions must therefore be regarded as tentative, more so in some areas of the report than in others.

SCOPE OF WORK AND PRINCIPAL FINDINGS

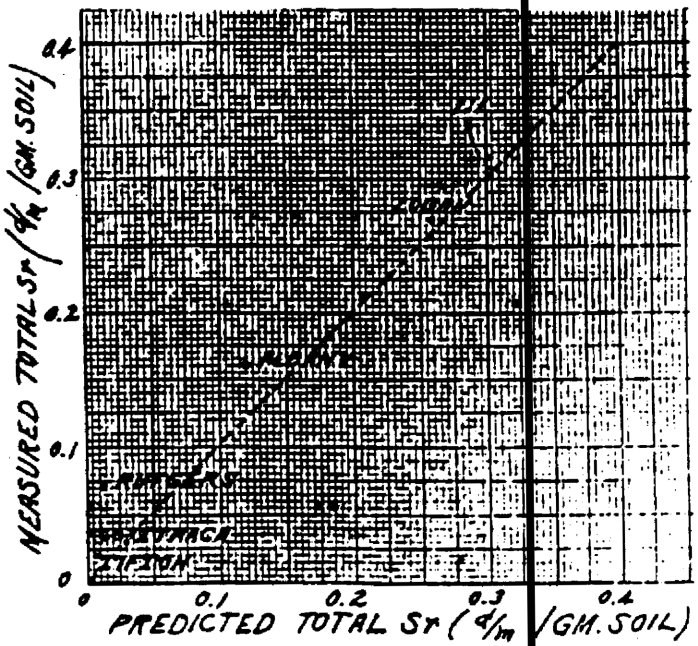
The specific questions which the Laboratory attempted to answer, the methods of study and the principal findings can be summarized as follows:

1. DO DATA FROM THE GUMMED PAPER NETWORK ENABLE A SATISFACTORY ESTIMATE OF Sr^{89-90} FALLOUT TO THE EARTH'S SURFACE?

Method of Study

amples of soil from ive locations in the nited States were nalyzed for radioactive trontium. The results ere compared with the mounts of radioactive trontium predicted by ur fallout measurements.

Principal Findings



2. WHAT IS THE EFFICIENCY OF THE GUMMED PAPERS IN SEPARATING PARTICULATES FROM RAIN?

Method of Study	Principal Findings
Suspensions of radioactive iron were prepared in the laboratory and artificial rain produced under various conditions of temperature. The effectiveness of the gummed papers in separating the iron particles from the "rain" was determined.	Retention at 1" rainfall per hour varied from 80% of all particles less than 2 µ to 10% of all particles less than .3 µ. Data for less severe rainfall rates are not as yet available.

3. TO WHAT EXTENT IS THERE VARIABILITY IN THE FRACTIONS OF Sr^{89} AND Sr^{90} IN BOMB DEBRIS?

Method of Study	Principal Findings
Samples of fallout and atmospheric dust from various bursts were analyzed for total activity and the two isotopes of Sr.	Fallout during the weeks immediately following a burst is deficient in both strontium isotopes. Samples of both fallout and airborne dust collected towards the end of 1953, at which time MIKE appears to have been the principal contributor, are enriched in both isotopes. In some samples the measured Sr$^{89-90}$ deviated from theoretical by an order of magnitude, but in most cases by less than a factor of two.

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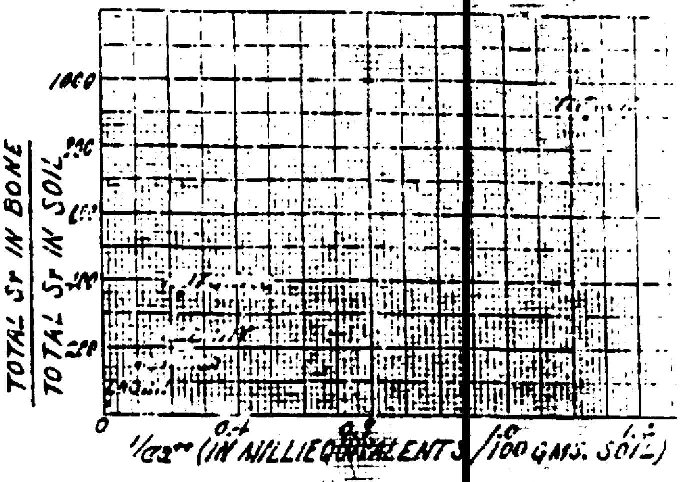
1. WHAT FACTORS GOVERN THE BIOLOGICAL UPTAKE OF RADIOSTRONTIUM FROM SOIL?

a. Is the uptake of Sr^{89-90} by livestock influenced by the ionic calcium concentration in the soil from which their food is derived?

<u>Method of Study</u>

Soils from five pastures in various parts of the United States were analyzed for radiostrontium and ionic calcium. Bones from lambs dropped in Spring '53 and fed in those pastures were analyzed for radiostrontium.

<u>Principal Findings</u>

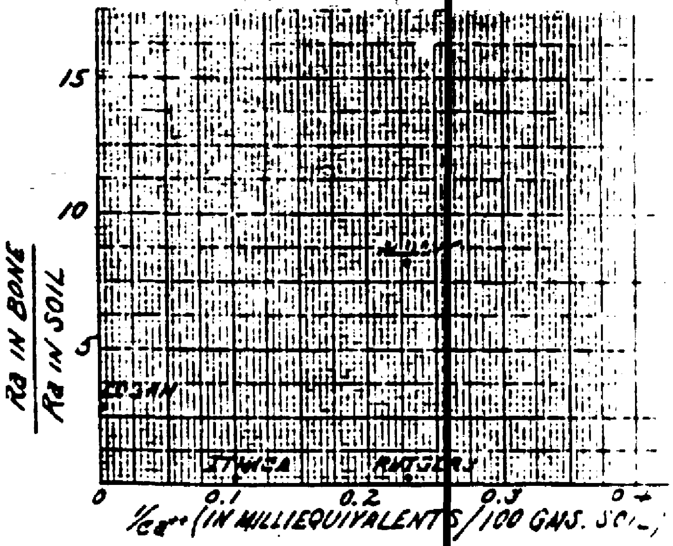


b. Is radium uptake similarly related to ionizable calcium?

<u>Method of Study</u>

The above soil and bone samples were analyzed for radium.

<u>Principal Findings</u>



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5. WHAT IS THE Sr^{89-90} CONTENTS OF CALCIUM DERIVED FROM LAMB BONE, FETAL BONE, COWS MILK AND HUMAN MILK IN THE NEW YORK MILKSHED?

Method of Study	Principal Findings
Analyses of material from various sources.	Expressed as d/m/gm Ca, the Sr^{89-90} content varied as follows:

	d/m/gm Ca
Lamb Bone	7 to 11 ±
Cow Milk	5.9 ± 0.8 to 6.4 ± 0.9
Human Milk	10 ± 7 to 20 ± 9
Fetal Bone	1 ± .25 to 10 ± 7.5

6. WHAT FRACTION OF THE DEBRIS FROM MIKE IS STORED IN THE ATMOSPHERE?

Method of Study	Principal Findings
Atmosphere dust samples were collected at altitudes of 88,000, 40,000 and 200 feet.	Data thus far suggests that approximately 1% of the MIKE fission product yield is uniformly mixed in the atmosphere up to 88,000 feet with evidence that an undefined quantity of additional debris from this detonation continues to exist as slugs which have not completely diffused. The atmospheric dust is considerably enriched in both Sr^{89} and Sr^{90}. About 4% of the Sr^{90} yield from MIKE is tentatively estimated to be stored in the lower 100,000 feet of the atmosphere.

~~SECRET~~ Slugs? UNCLASSIFIED

7. IS THERE EVIDENCE OF "DRIP" OF DEBRIS STORED IN THE UPPER ATMOSPHERE BY SUPER BOMBS?

Method of Study	Principal Findings
Analysis of samples from worldwide fallout network.	This problem has been made difficult by detonations in this country and the USSR since MIKE. If we attribute what is now in the atmosphere to MIKE, weekly fallout in November-December 1953 was approximately 0.1% of the calculated residual activity from this detonation. The mean weekly fallout at all stations is continuing to diminish with a halflife of perhaps one to two months.

MISCELLANEOUS HIGHLIGHTS

1. Fallout recorded by the worldwide network, operated on a skeleton basis between tests, was less than 1 d/m/ft^2/day in December. The origin of the debris is in doubt but the 89/90 ratio suggests MIKE. This rate of fallout is equivalent to .02% per week of the total residual radioactivity from MIKE.

2. Taking all our data into consideration, we find we are unable to account for more than 5% of the MIKE fission product yield from M Day to the present. A preliminary estimate, based on our air samples to date, indicate that present atmospheric storage, when precipitated, will contribute about as much Sr^{90} to the earth surface as is already present.

ANALYTICAL PROCEDURES*

The Health and Safety Laboratory SUNSHINE studies required analysis for total radiostrontium, Sr^{90}, normal strontium, and radium in a variety of sample types. Where radioactive measurements were involved it was necessary that the chemical procedures produce samples suitable for the counting equipment available in the laboratory. For this reason the methods which were developed were designed to handle relatively large samples.

In uptake studies, where relative values between different sample types taken in the same location were to be analysed, the determination of total radiostrontium was preferable because of the relatively high activity compared with Sr^{90} alone. In some cases, the main purpose of the study required Sr^{90} determinations and, where necessary, this was done.

With the lower activity levels of Sr^{90} the confidence in the results is reduced as is shown by the counting errors given with each analytical result. It should be emphasized that the lower confidence is purely a matter of counting statistics and is not related to confidence in the chemical methods used to prepare samples.

The determination of total radiostrontium, Sr^{90} and normal strontium all require separation of strontium from the sample matrix. Our experience indicates that the most satisfactory method is the precipitation of strontium, with added carrier if necessary, from 75% nitric acid solution. This yields a clean precipitation which is readily collected on filters for counting of total radiostrontium or for the further treatment required for Sr^{90} or normal strontium determination. Different sample types require different treatments to prepare them for this separation step. The majority of our samples could be classified as soil, bone, vegetation and liquids (milk, water, urine and the like). The preliminary separations are solution of the sample and collection of the strontium and matrix materials and their conversion to nitrates. The nitrate separation is then carried out in a volume of nitric acid appropriate to the total quantity of nitrates obtained. Two nitrate separations are always performed and where the bulk of the matrix material is high, an additional separation may be required.

The final nitrate precipitate may be directly counted for total radiostrontium. This precipitate may then be analyzed for its Sr^{90} content by measurement of the Y^{90} daughter in equilibrium with the Sr^{90}. After allowing the yield to build up in the nitrate precipitate, which requires approximately 12 days, Y^{90} may be separated by an ammonium hydroxide precipitation with lanthanum carrier. This precipitate is collected on a filter for counting.

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* The details of all the analytical procedures used in obtaining results for this report are given in Appendix A.

Both Sr^{89} and Y^{90} are measured by beta counting. The precipitates are collected on 1-1/8 inch paper or glass filters. The filters are mounted on Tracerlab brass ring-and-disc holders, and covered with 0.001 pliofilm. This shows negligible absorption and prevents contamination and loss of samples during handling.

Counting is performed with 1 inch diameter Anton flat halogen-filled G.M. tubes mounted in simple lead castles. The background counting rate of these counters is maintained at six counts per minute and the efficiencies at about 15-20%. Higher efficiencies could be obtained but are not considered to be necessary. The counters are standardized with potassium carbonate mounted on the same holders. A 0.200 gram quantity of potassium carbonate which should show 163 d/min (from the K^{40} content) gives suitable counting rates for standardization.

The counting times were of the order of 30 minutes for background and samples and all results are reported with the standard deviations calculated for the error of the sample when the background error is taken into account. Figures 1 to 3 show the 2s values for background conting rates of 4, 6 and 8 c/min and counting times of 30, 60 and 120 minutes where the sample and background counting times are equal. (In our normal work, 2s values are used, but in this report, the 1s deviations are reported to conform with general usage).

Y^{90} samples are followed for decay for identification purposes and residual activity, if any, is subtracted from the total Y. Y^{90} disintegration rates are determined by extrapolation back to the time of separation from the Sr^{90} parent but are not corrected for self-absorption by the sample. Further identification is possible by absorption measurements when the sample is sufficiently active.

Some samples were analyzed for normal strontium in order to study the uptake by plants and animals. The nitrate procedure is used for the separation of strontium from massive amounts of calcium and other elements. Strontium carrier cannot, of course, be used in this procedure but it has been found possible to obtain good recoveries with a barium carrier. The resulting precipitate is dissolved and analyzed for strontium with the flame photometer

Radium analyses were run on many of the samples. All samples except soils were analyzed by the standard method of co-precipitation of the radium with barium sulphate and alpha counting. This treatment is not practicable for soils, so a new procedure was devised in which the radium is coprecipitated with the heavy metals by ammonium hydroxide and sodium carbonate and the daughter product, radon, measured in our standard radon ionization chambers.

Newer methods of analyses are in the development stage but have not been used on any of the samples reported in this paper as it was felt that standardization was very important where many results are to be compared with one another. As noted earlier, the complete analytical procedures are given in Appendix A.

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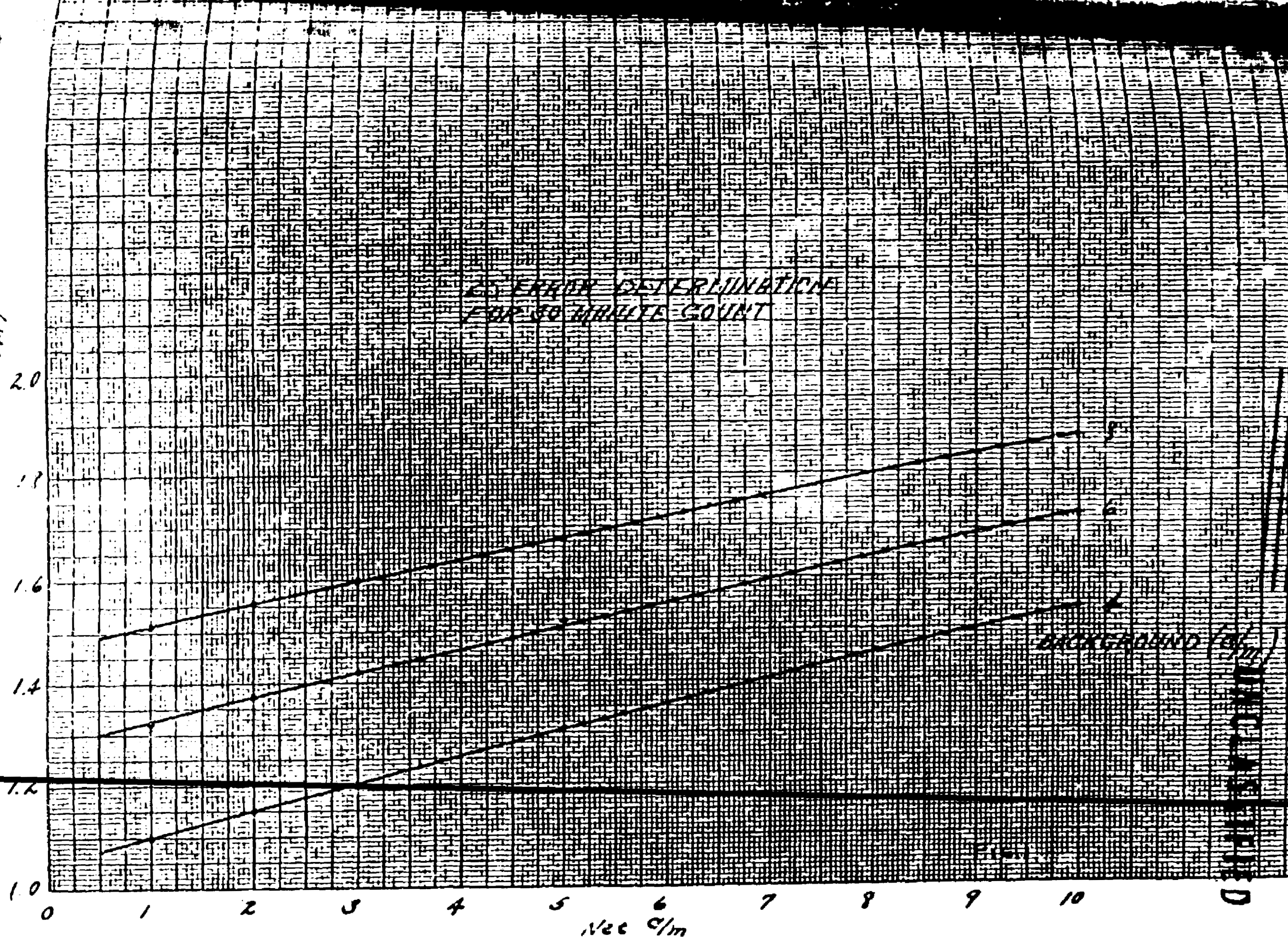

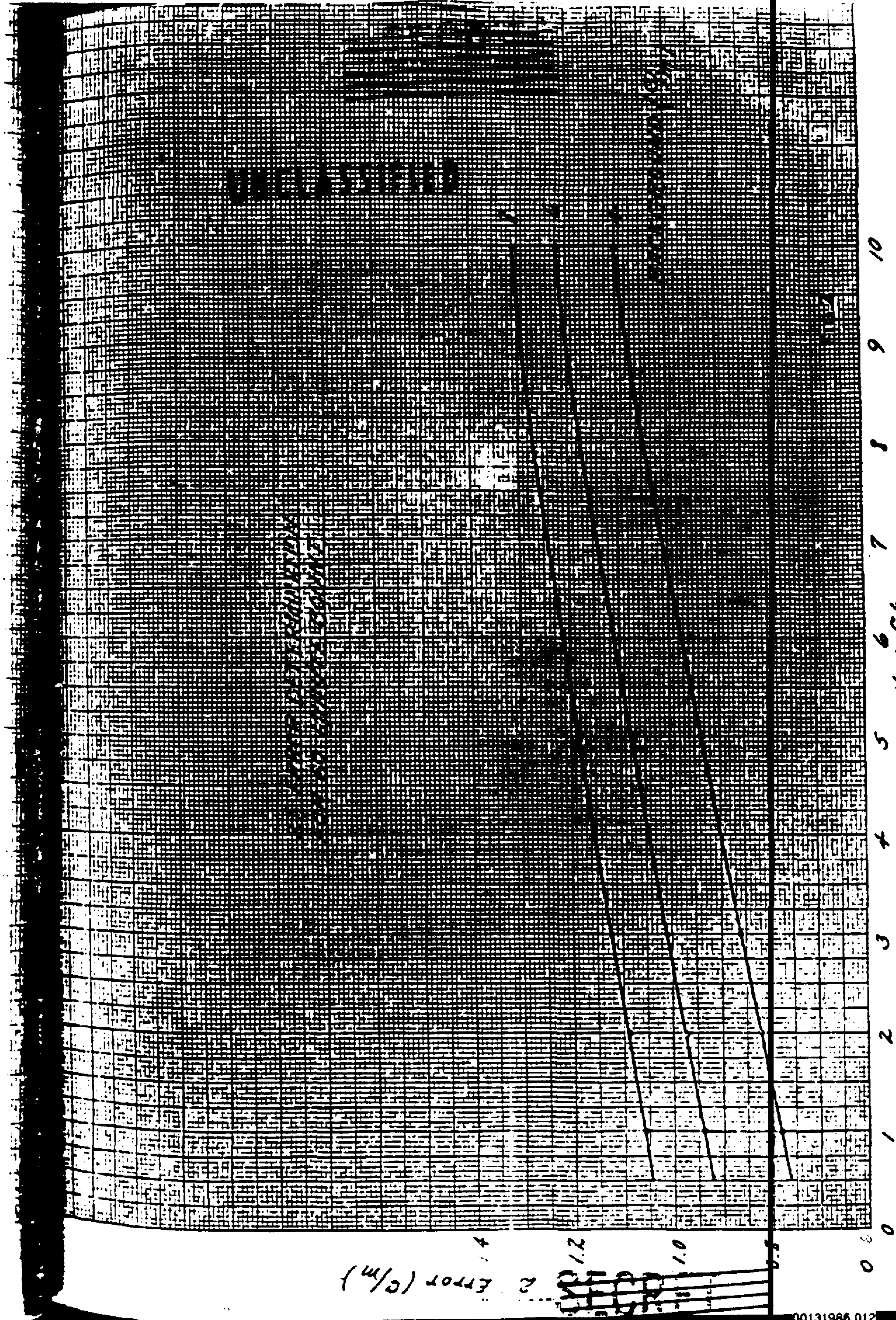
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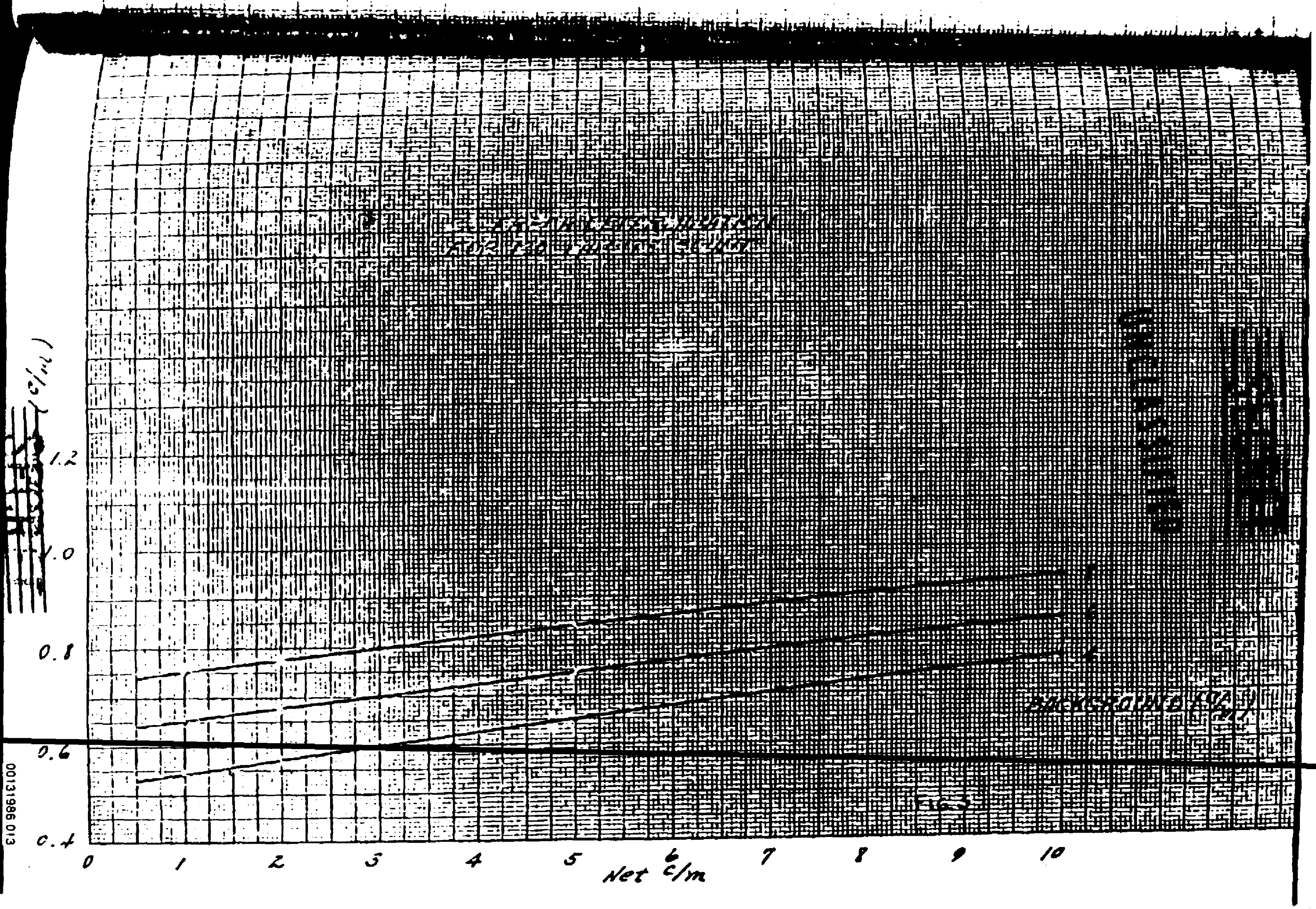
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FIG 3

THE HEALTH AND SAFETY LABORATORY SUNSHINE EXPERIMENTS

It is only natural that the role of this laboratory in the worldwide monitoring of debris from nuclear detonations should tend to orient our SUNSHINE studies towards the fallout data we have accumulated (1-4). Our studies were designed to achieve maximum utilization of these data.

Our choice of experiments were influenced by the ultimate objectives of both SUNSHINE and GABRIEL, and the state of knowledge as reviewed at the Rand Conference in early Summer 1953 (5). Our studies can be presented under four headings:

1. Validity of data from the monitoring network.
2. Fractionation of the strontium isotopes.
3. Some factors involved in the biological uptake of strontium.
4. Atmospheric storage of debris from super bombs.

Validity of Data From the Monitoring Network

Comparison of Predicted and Measured Concentrations of Radiostrontium in Soil

Soils from five selected areas in the United States were analyzed for strontium $^{89-90}$. The predicted Sr$^{89-90}$ concentration in soil varied from 0.0067 to 0.26 d/min/gm soil, a factor of 40.

Predicted values were calculated from the data of Table 1 which records cumulative fallout for each series of tests since BUSTER-JANGLE at network stations in the vicinity of each locality where soils were sampled. The theoretical fraction of the total activity due to strontium^{89} and strontium^{90} was obtained from Figures A-1 and A-2 (Appendix A) which have been constructed from data of Hunter and Ballou (6).

The radiostrontium content of the soil was estimated by assuming the soil density to be 1.5 and all of the activity to be contained in the upper inch of soil. Where radiochemical analyses showed radiostrontium in layers of soil below 0-1", this activity was added to the measured value from zero to one inch in order to make the results comparable.

Table 2 and Figure 4 summarize the comparison of predicted and measured values of Sr$^{89-90}$ in soils from five places in the United States.

The measured values in the soils were from 100 to 540% of the predicted concentration of radiostrontium. In view of the many uncertainties inherent in both fallout and soil sampling we regard these results as somewhat fortuitous but, nevertheless, encouraging. A more extensive sampling program seems justified.

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TABLE 1

ESTIMATED CONTRIBUTION OF Sr^{89-90} TO SOIL AT SAMPLING LOCALITIES

Location of Pasture	Test Series	Fallout Stations	Fission Products (d/m/ft²) on 1/1/54	Strontium 90 (d/m/ft²)	Strontium 89 (d/m/ft²)
Logan, Utah	BJ	Salt Lake City	27	2.4	-
	TS	"	4080	240.	4
	IVY	"	95	2.8	1.4
	UK	"	9000	45	630
		Totals	13000	290	630
Ithaca, N. Y.	BJ	Binghamton	78	7	-
	TS	Binghamton & Oswego (Average of 2)	250	62	2.5
	IVY	Binghamton	120	4	18
	UK	Binghamton	50	.25	3.5
		Totals	500	73	24
Albany, N. Y.	BJ	Hartford & Burlington (Average of 2)	75	6.7	-
	TS	Albany	440	26	-
	IVY	Binghamton, Rochester & New York City (Average of 3)	150	4.5	-
	UK	Albany	4950	25	350
		Totals	5600	60	350
Rutgers, N. J.	BJ	New York City	80	7.2	-
	TS	"	410	24	.4
	IVY	"	120	3.6	1.8
	UK	"	110	.5	7.7
		Totals	700	35	9.9
Tifton, Ga.	BJ	Atlanta, Tallahassee & Montgomery (Average of 3)	35	3.1	-
	TS	Atlanta, Tallahassee & Montgomery (Average of 3)	150	9.0	-
	IVY	Atlanta & Jacksonville (Average of 2)	100	3.0	1.5
	UK	Atlanta, Jacksonville & Montgomery (Average of 3)	100	-	7
		Totals	400	15	8.5

TABLE 2

COMPARISON OF PREDICTED AND MEASURED VALUES OF Sr^{89-90} IN SOIL

Place	Predicted (d/m/gm)	Measured (d/m/gm)	Measured / Predicted
Tifton, Ga.	0.0067	0.020	3.0
Rutgers, N. J.	0.013	0.07	5.4
Ithaca, N. Y.	0.028	0.03	1.1
Albany, N. Y.	.12	0.16	1.3
Logan, Utah	0.26	0.27	1.0

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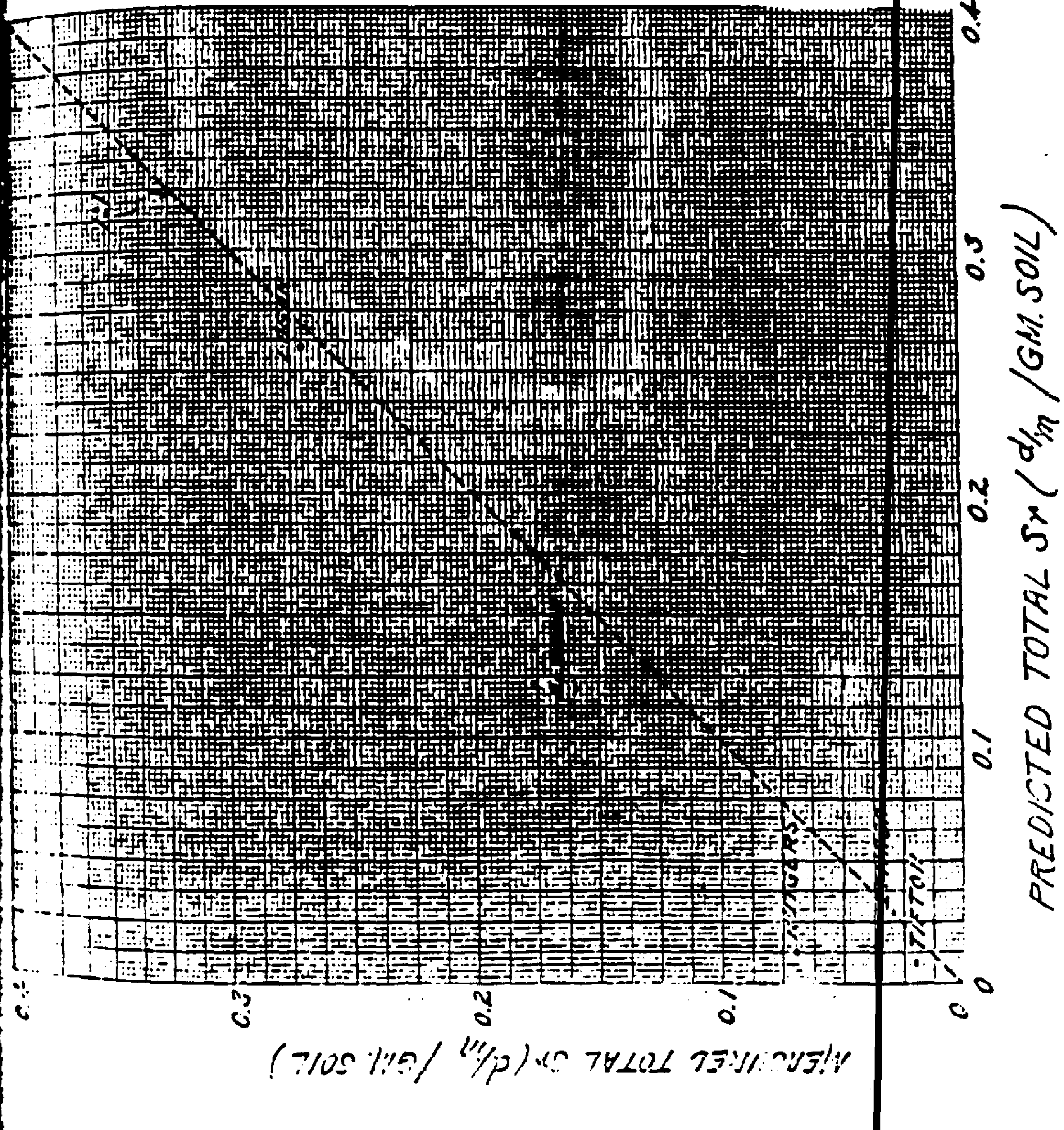

A pertinent question which remains unsettled is the variation in fallout from place to place in a given locality. A satisfactory program of replication has not been possible up to the present time. However, at Logan, Utah, we did collect replicates from two pastures about one mile apart. The total radiostrontium assay of these soils was .22 and .38 d/min/gm

Retention by Gummed Films of Particulates in Simulated Rain

An experiment was designed to measure the rention by gummed films of radioactive particulates suspended in raindrops. When we first began to use gummed sampling media in our fallout studies, field tests demonstrated that the activity collected by gummed paper was comparable to, and more reproducible than the results obtained using trays designed for total collection of the rain water. However, reliable controlled data have not been available previously. The following procedure was adopted:

Normal radioactive debris was simulated by finely divided pile irradiated iron having a mass median diameter of 3 µ. To suspend the iron powder, a few milligrams were added to two liters of distilled water and agitated.

Particle size control over the suspended particulates was obtained by elutriation of the original suspension. At a given time, 700 millimeters at the top of the cylinder was decanted into a sprinkling arrangement (Figure 5) which provides for continued agitation of the suspension until the sample enters a capillary tube from which droplets are permitted to fall to the gummed film. Under the conditions reported here, the rate of "rainfall" was 1" per hour. The retention of the gummed film was expressed as the percentage of suspended activity recovered by the film.

A cumulative frequency curve of particle size versus time was calculated, using Stokes Law (with Cunningham's correction as necessary). From this curve, and the data on retention at various times, Figure 6 was developed.

The retention of the gummed films in these tests was not as high as was expected. This may be because of the heavy rate of simulated rainfall. Similar tests at lower rainfall rates are being planned but have not as yet gotten under way.

Experiments to determine the effect of 24 hours of temperature conditions of the gummed papers are given in Table 3. Conditioning at 5°C and at 85°C do not appear to significantly influence the retentivity of the films.

In order to determine if the iron was going into solution, samples of suspensions of various ages were passed through a Millipore filter. Essentially 100% of the activity was recovered on the filters, indicating that solubility is not a factor in the above procedure.

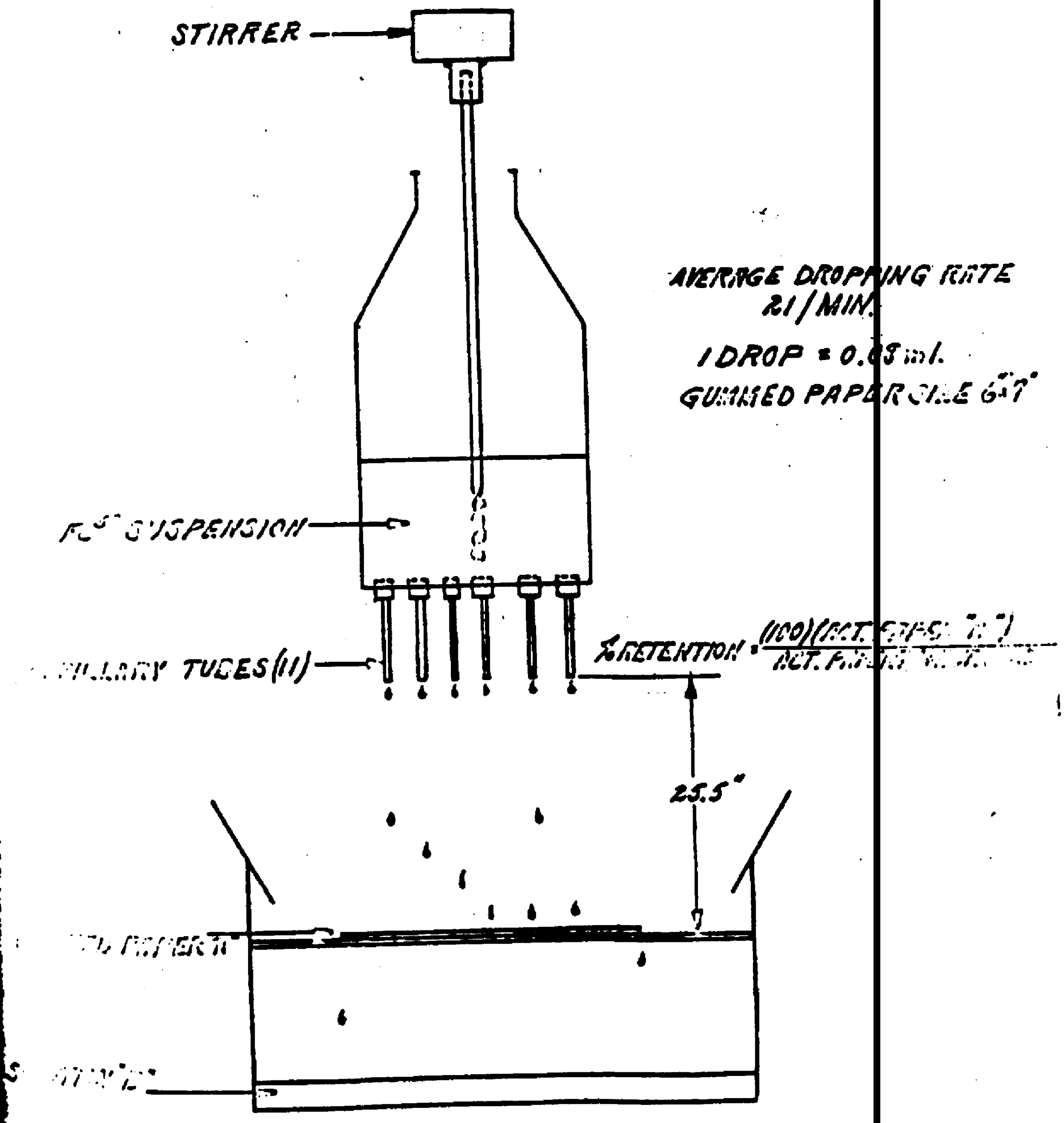
STIRRER
SUSPENSION
PILLARY TUBES(11)
AVERAGE DROPPING RATE
21/MIN.
1 DROP = 0.08 ml.
GUMMED PAPER SIZE 6"×7"
% RETENTION = (100)(ACT. [illegible]) / ACT. [illegible]
25.5"
PAPER

FIG. 5

TABLE 3

EFFECT OF TEMPERATURE CONDITIONING OF GUMMED PAPER

Sample No.	Gum Paper Retention %	Time of Final Elutriation	Temp. Conditioning of Film for Past 24 Hours
1	96	0	room temperature
2	97	0	room temperature
3	96	0	- 5°C
4	75	0	- 5°C
5	71	0	75°C
6	88	0	75°C
7	82	60 min	room temperature
8	87	60 min	room temperature
9	89	60 min	- 5°C
10	83	60 min	- 5°C
11	72	60 min	- 5°C
12	83	60 min	85°C
13	51	60 min	85°C
14	84	60 min	85°C

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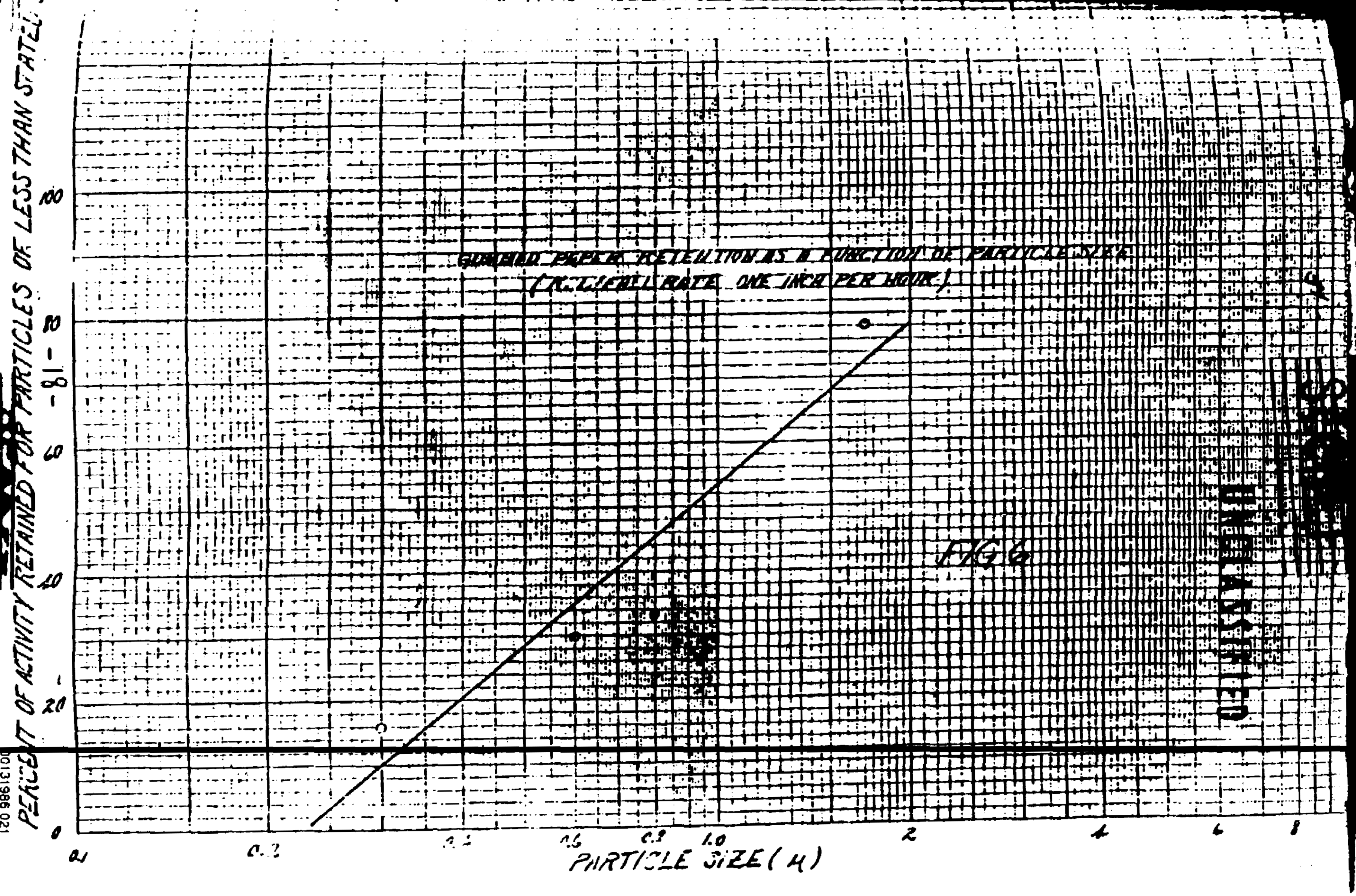

GUMMED PAPER RETENTION AS A FUNCTION OF PARTICLE SIZE
(RAINFALL RATE ONE INCH PER HOUR)

FIG 6

Fractionation of Radiostrontium in Bomb Debris

The two radioisotopes of strontium, Sr^{89} and Sr^{90} are chiefly formed by the decay of primary fission products according to the schemes,

$$Kr^{90} \xrightarrow[25\ s]{\beta} Rb^{90} \xrightarrow[Short]{\beta} Sr^{90} \xrightarrow[\cancel{65\ d}]{\beta} 25\ yr.$$

$$Kr^{89} \xrightarrow[2.5\ m]{\beta} Rb^{89} \xrightarrow[15.4\ m]{\beta} Sr^{89} \xrightarrow[\cancel{25\ y}]{\beta} 58\ d$$

It is therefore possible that the bulk of the radiostrontium may not be produced until the fireball has cooled below the solidifying point of the fallout debris. If this is true, the relative amount of Sr^{89} or Sr^{90} in the close-in fallout should not be as great as would be predicted from fission yields, and should also be quite variable. This has been confirmed by measurements made by AFOAT-1 (Sr^{89+90}/Mo^{99} ratios) and by most of the results of our own analyses.

The extreme variability of our initial radiostrontium results for fallout samples led us to question the precision of our chemical methods. As a test, three samples of finely powdered Jangleite were run by the same chemical procedure. The relative Sr^{90} activity was found to be 2.6, 2.1 and 2.1%, compared with the theoretical value of 5.5%.

This discrepancy may be possibly accounted for by considering that some of the initial activity was induced, rather than fission product activity. In any case, the precision of measurement is reasonable and indicates that the variability of fallout radiostrontium is real.

The fallout samples run for radiostrontium were taken from our stock of decay samples from Tumbler-Snapper, Ivy and Upshot-Knothole. These results, along with the theoretical radiostrontium values from Hunter and Ballou are given in Tables 4-6.

Table 4

TUMBLER-SNAPPER FALLOUT
(Airborne Dust)

Location	Date	Initial d/m	Sr^{89-90} d/m	%
Hanksville, U	5/26/52	137	9.6	7.0
		108	8.7	8.1
		74	9.3	12.7
		106	16	15.1
		114	12.4	10.5
		120	5.8	4.8
		Average		9.7
		Theoretical		8.0

(This is the only series that shows higher measured radiostrontium values than predicted by the Hunter and Ballou curves)

Table 5

IVY FALLOUT (Gummed Paper)

Location	Date	Initial d/m	Sr^{89-90}d/m	%
Guam	11/3/52	1995	12.8	0.64
	11/4/52	562	3.1	0.55
	11/6/52	376	14.5	3.8
	11/18/52	975	70	7.2
Iwo Jima	11/3/52	2130	68	3.2
	11/7/52	484	6.2	1.3
Luzon	11/5/52	1700	9.3	0.55
	11/8/52	724	80	11.1
			Average	3.5
			Theoretical	6.3

Table 6

UPSHOT-KNOTHOLE FALLOUT (Airborne Dust)

Location	Date	Initial d/m	Sr^{89-90}d/m	%
Winslow, Ariz.	4/19/53	2,980	116	3.9
		4,180	81	1.9
Grand Junction, Colorado	5/20/53	38,800	822	2.1
Prescott, Ariz.	5/25/53	4,900	406	8.3
Cortez, Colorado	6/5/53	7,960	719	9.0
			Average	5.0
			Theoretical	8.8

Following the Upshot-Knothole series, a skeleton monitoring network was maintained by NYO to take gummed paper samples. The samples from this network were pooled in groups and run for radiostrontium. The results per gram of dust are given in Table 7.

Table 7

No. of Samples	Date Processed	Initial d/m/grm	Total Sr d/m/grm	Total Sr %	Sr^{90} d/m	Sr^{90}/Sr^{89}
119	8/21/53	55.2	0.6	1.1	0.[illegible]	1.0
120	9/2/53	61.2	7.9	13	3.[illegible]	0.8
121	9/3/[illegible]	96.3	104	—*	33	0.5
122	9/[illegible]	[illegible]	[illegible]	0.6	1.[illegible]	—*
123	9/[illegible]	250	[illegible]	[illegible]	2.[illegible]	1.0
124	[illegible]	224	[illegible]	3.0	—	—
125	10/[illegible]	127	10.[illegible]	[illegible]	3.1	0.4
126	11/4/[illegible]	100	[illegible]	6.4	21	—*

*Values not used in averages

Average	4.9	0.7
Theoretical (Ivy)	[illegible]	1.4
Theoretical ([illegible])	11.5	0.04

Three samples each [illegible] the Ivy and Upshot-Knothole groups reported in the previous tables were analyzed for Sr^{90}. These results are shown in Table 8.

Table 8

Series		Location	$Sr^{89}+Sr^{90}$	Sr^{90}	Sr^{90}/Sr^{89}
Ivy	[illegible]	Iwo Jima	32	14.7	0.90
	[illegible]	Luzon	39	16.5	0.77
	[illegible]	Guam	61	24.2	0.68
Upshot-Knothole	[illegible]	Grand Junction	104	16.5	0.19
	[illegible]	[illegible]	[illegible]	26.8	0.29
	[illegible]	Cortez	123	25.6	0.26

The 90/89 ratios predicted from the data of Hunter and Ballou would be 1.4 for Ivy and [illegible] for Upshot-Knothole.

A series of samples were taken by Air Force jets at about 40,000 feet. The papers from the jet filters were radioautographed and analyzed for total radiostrontium and Sr^{90}. The autographs showed the presence of relatively few particles of high activity. The results of radiochemical analyses are given in Table 9.

Table 9

Flight Date	Initial Activity	$Sr^{89}+Sr^{90}$	% Sr^{89-90}	Sr^{90} d/m	Sr^{90}/Sr^{89}
8/27	4,800 d/m	3,560	74	383	0.12
11/30	274 d/m	272	99	67	0.33
12/8	38,800 d/m	18,500	46	1240	0.08
12/15	1,400 d/m	885	63	210	0.31
			Theoretical (Ivy)		1.4
			(UK)		0.18
			(USSR)		0.04

Air samples collected on the roof at NYO during the week of December 21st showed an average of 0.08 $d/m/m^3$, of which 0.02 $d/m/m^3$ was radiostrontium. The strontium percentage, as for the jet samples, was much higher than expected.

A 12-gallon stainless steel pot was used to collect accumulated rainfall and dry fallout on the roof at NYO during the period of July 15th to December 23rd of 1480 d/min., of which 745 d/min. were radiostrontium. Again the strontium percentage is higher than expected.

The analyses of samples taken during the test period indicate a lower radiostrontium content than expected, while those taken well after detonation show a relatively high radiostrontium content. Since the recent high altitude measurements give the highest strontium percentage, as will be discussed, it is probable that fractionation has occurred. The late formation of Sr^{90} and Sr^{89} compared to the life of the fireball make it possible that they are more highly dispersed. The early fallout is deficient in radiostrontium, since the smaller particles remain suspended, while the later fallout and particularly the material stored in the upper atmosphere contains an excess.

The Sr^{90}/Sr^{89} ratios are quite constant for a given time since detonation, as shown in Table 8. However for mixed fallout from more than one series the Sr^{90}/Sr^{89} ratio can probably be used only as an approximation of the relative amount of material from each series.

The net effect of fractionation appears to be minimal. As noted earlier, the Sr^{89-90} measured in soil is in good agreement with the predicted activity, based on measurements of total fallout in the area and the theoretical contribution of Sr^{89-90}.

Of interest, is the comparison of 89/90 measured in bone with the ratio predicted in soil. The latter is based on fallout measurements, and takes the age of the fallout into consideration. As seen in Figure 7, the ratio in bone is higher than predicted by a factor of about 2.

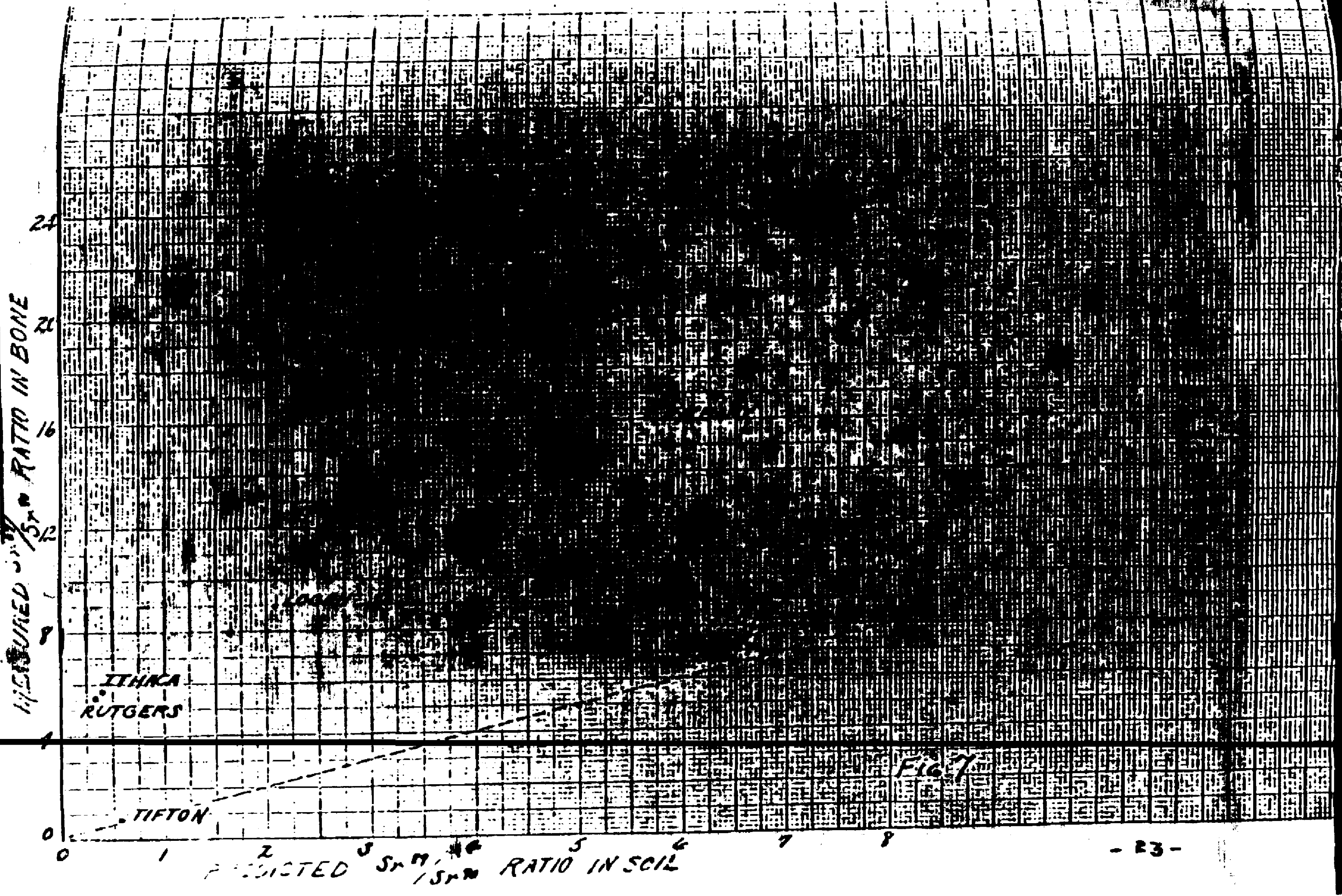
24
20
16
12
8
4
0
MEASURED Sr^{90}/Sr RATIO IN BONE
ITHACA
RUTGERS
TIFTON
0
1
2
3
4
5
6
7
8
PREDICTED Sr^{90}/Sr RATIO IN SOIL

FIG. 7

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Studies of Factors Involved in the Biological Uptake of Radiostrontium

Identification of the properties of soil which influence the uptake of radiostrontium by biological systems is a prerequisite to understanding the significance of the deposition of radiostrontium in soil.

Dependence of Sr$^{89-90}$ Uptake on Soil Calcium

The Beltsville Experiment Station has demonstrated that in laboratory soils containing Sr^{89}, the uptake of this isotope by Cow Peas is dependent on the exchangeable calcium in the soil in which the plant is grown. They have demonstrated that this is likewise true for radiobarium and the Health and Safety Laboratory has demonstrated a relationship between radium uptake and exchangeable calcium in soil.

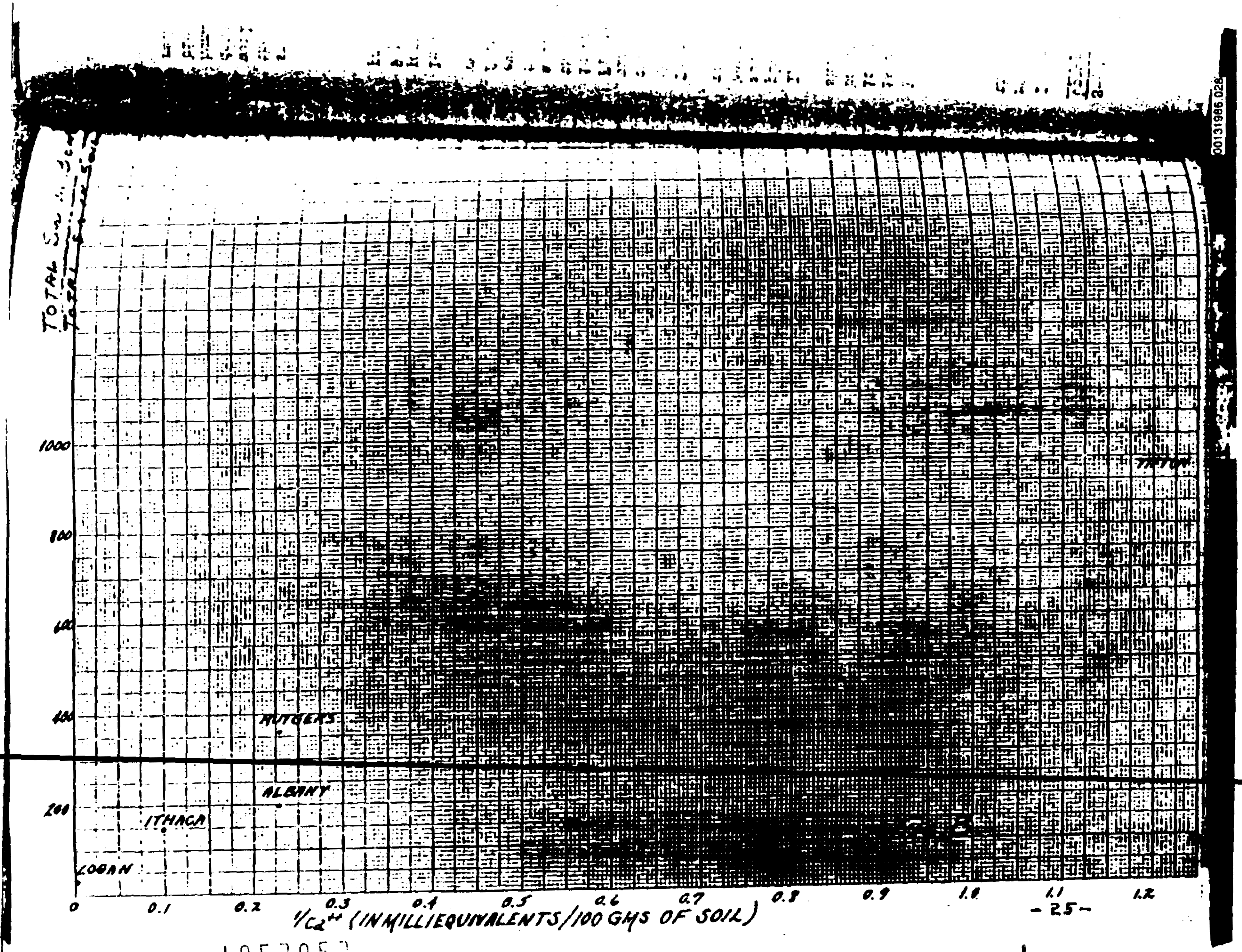
If, as the Beltsville experiment suggests, the radiostrontium content of plants is dependent not alone on the amount of radiostrontium in the soil, but on exchangeable calcium as well, a correlation should exist between exchangeable calcium and the ratio of Sr$^{89-90}$ in livestock bone to Sr$^{89-90}$ in soil from which their food is derived.

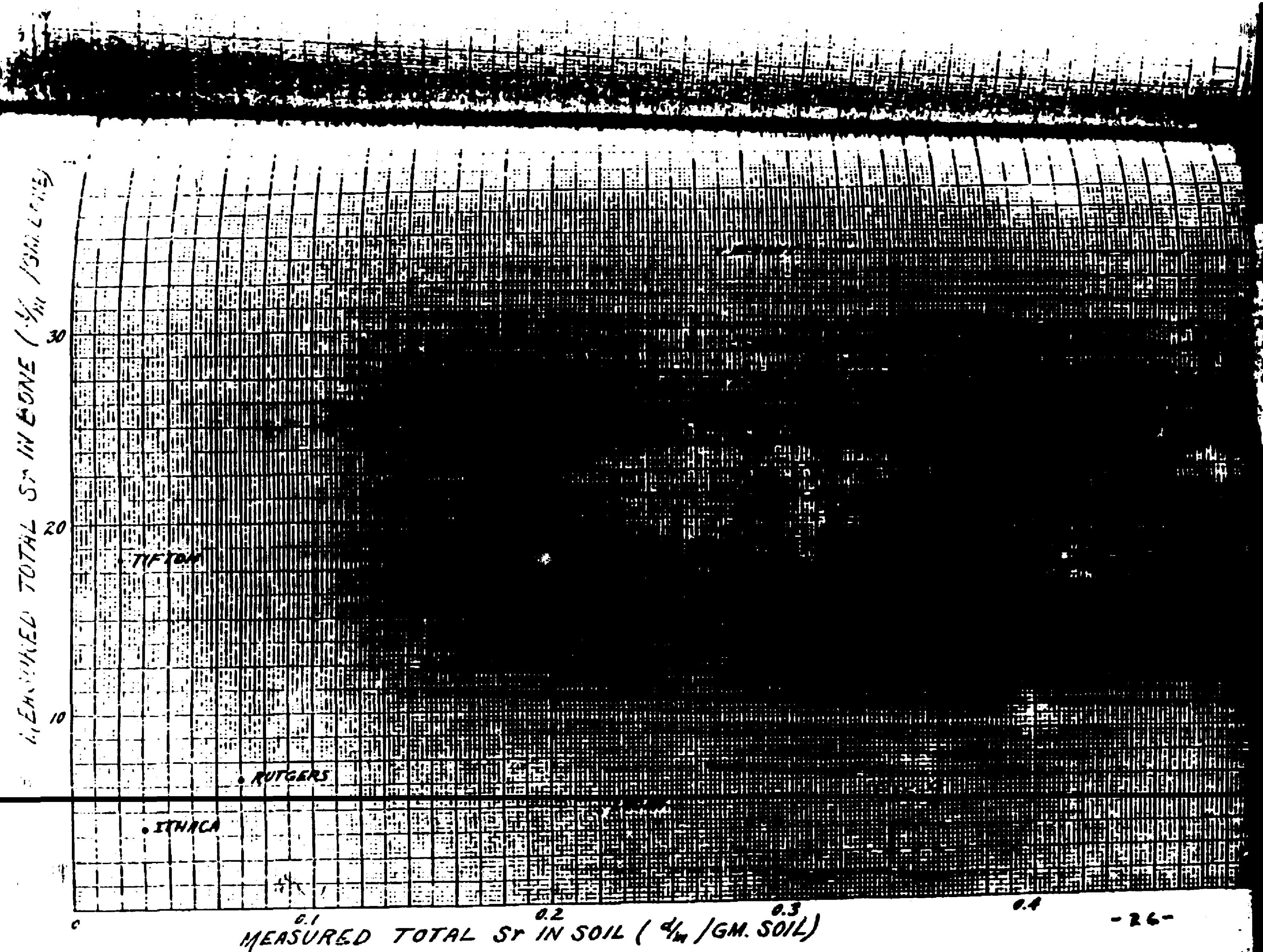
To test this hypothesis, soils from five pastures in various parts of the United States were analyzed for radiostrontium and exchangeable calcium. Three lambs and two calves that had spent their entire lifetime in these pastures were sacrificed and samples of skeleton obtained. Figure 8 is a presentation of our data in the form Sr$^{89-90}$ in bone/Sr$^{89-90}$ in soil versus the reciprocal of exchangeable calcium. These data take the form which would be predictable from the Beltsville experiments where a linear regression with a slope of 529 was obtained. Because of the few data, a curve through the points in this figure is not shown. However, a least squares fit of the data gives a slope of 760 which is in fair agreement with the Beltsville data considering the few observations we have and the possible differences between field and laboratory conditions.

In order to emphasize the importance of the exchangeable calcium as a parameter in the relationship between bone and soil radiostrontium, Figure 9 presents bone radiostrontium versus soil radiostrontium. The data thus presented are not so orderly as in comparison with Figure 8.

Dependence of Ra Uptake on Soil Calcium

If a similar dependence on exchangeable calcium could be demonstrated for natural radium, we would have a useful tool for evaluating the significance of radiostrontium deposition in soils. The range of world wide Ra in soil is known to a first approximation and can be better determined if need be. The relationship of this deposition to radium in human bone has been under study for some time. Our knowledge of the geo-bio radium equilibrium could be used to estimate the ultimate fate of radiostrontium.


TOTAL Sr in Soil
TOTAL
1000
800
600
400
200
TETON
RUTGERS
ALBANY
ITHACA
LOGAN
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1/Ca++ (IN MILLIEQUIVALENTS/100 GMS OF SOIL)


MEASURED TOTAL Sr IN BONE (d/m/GM. BONE)
30
20
10
TIFTON
RUTGERS
ITHACA
0
0.1
0.2
0.3
0.4
MEASURED TOTAL Sr IN SOIL (d/m/GM. SOIL)

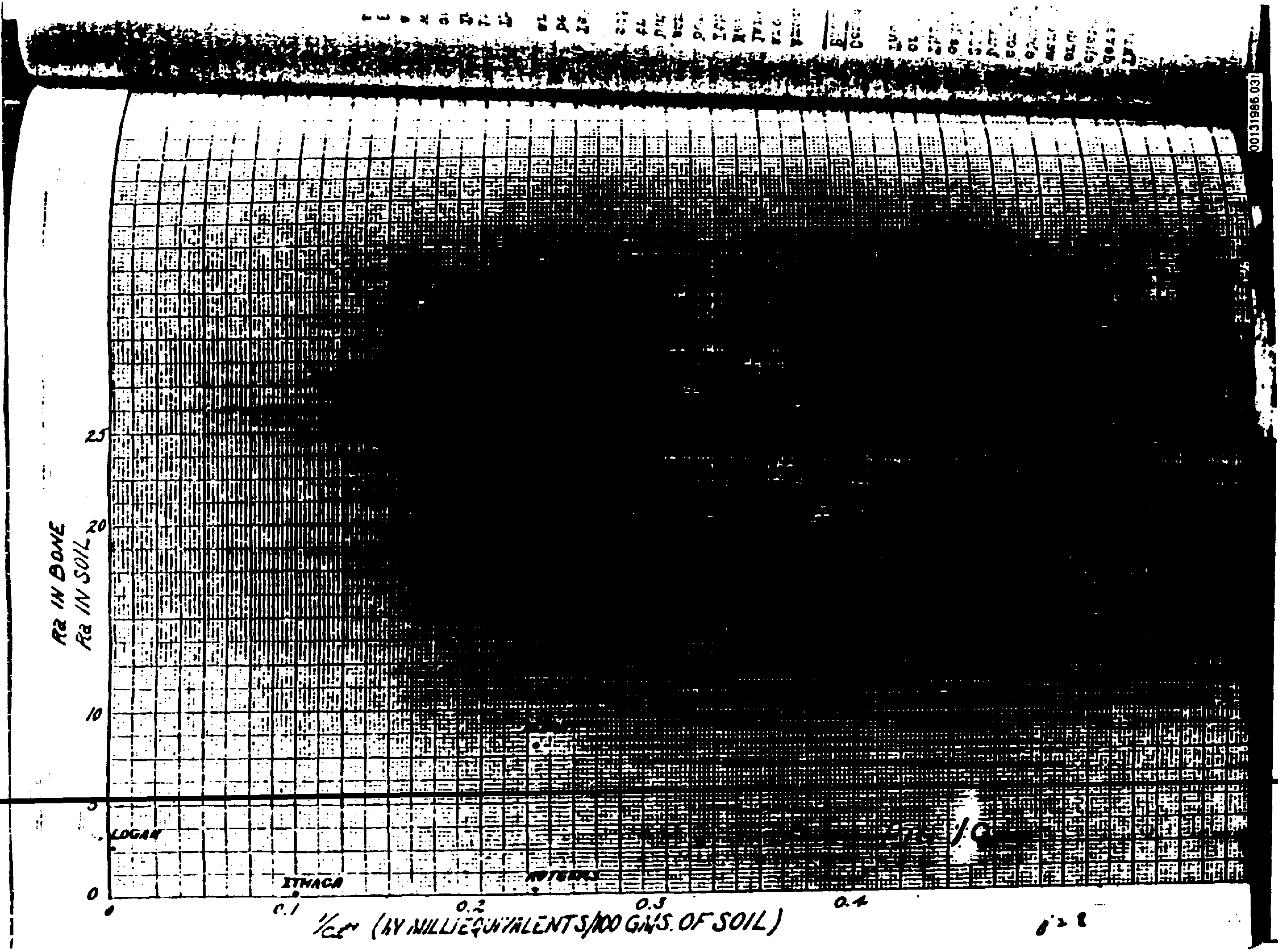
This laboratory, working in conjunction with the Beltsville group, has developed some evidence that the uptake of radium is dependent on exchangeable calcium in a manner similar to radiostrontium and barium. In order to further explore this possibility, the soils from five pastures were analysed for radium, as were the bones of the livestock. The data obtained are plotted in Figure 10. Radium determinations could not be completed on the Tifton samples because these arrived too late to permit build up of daughter product activity following separation of the radium-226. The four ratios obtained when plotted against reciprocal exchangeable calcium do not show as clear a linear regression as was true for strontium. This may be due to the fact that radium does not behave as strontium does, or to analytical difficulty with the low radium concentrations in soil. The results are not completely discouraging and further work seems indicated.

Comparison of Radiostrontium in Various Biological Materials

Among the various materials which have been analysed for radiostrontium are some which have in common the fact that the isotopes originated to a large extent from soils in the region of southern New York and northern New Jersey. These samples include the lambs and calves from pastures at Ithaca and Rutgers, the New York City milk supply, human milk and stillborns from the metropolitan New York area. For the last two kinds of samples, the primary origin of the radiostrontium is, of course, in doubt but in human milk and stillborn alike there is likely to be a large contribution of calcium, and therefore strontium which has its origin in the soils from this area.

Table 10 summarises the results of analysis of these materials. It will be noted that the Sr^{89-90} activity when expressed in d/min/gm of calcium are of the same order.

This is again a test of the constancy of the calcium:radiostrontium ratio in calcium obtained from various places in the biological feeding chain. These samples have in common the fact that in one way or another the calcium was derived via vegetation, the calcium:radiostrontium ratio of which was determined by the cumulative fallout in the geographical area and the exchangeable calcium of the soil. A more liberal sampling program and a more careful study of the dietary habits of humans in the area studied seem indicated.


00131986.031
Ra IN BONE
Ra IN SOIL
25
20
10
5
0
LOGAN
ITHACA
AUBURN
0
0.1
0.2
0.3
0.4
1/Ca (BY MILLIEQUIVALENTS/100 GMS. OF SOIL)

~~SECRET~~

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TABLE 10

COMPARISON OF Sr^{89-90} IN VARIOUS MILK AND BONE SAMPLES

Type Sample	Source	Date	Sr^{89-90}	
			d/m/gm Ca	d/m/l
Cow Milk				
(powdered)	Starlac	1953	4.2 ± 0.83	5.0 ± 1.0
	Alba	1953	3.9 ± 0.83	4.7 ± 1.0
(whole)	NYC	9/30/53	5.2 ± 0.58	6.3 ± 0.7
	NYC	12/8/53	6.4 ± 0.92	7.7 ± 1.1
	NYC	12/22/53	4.1 ± 0.12	4.9 ± 1.4
Lamb Bone	Rutgers	10/53	11 ±	
	Ithaca	10/53	7	
Human Milk	Newark	12/2/53	20 ± 9	57 ± 26
	Newark	12/16/53	10 ± 7	3.5 ± 2.5
Fetal Bone	N. Y.		10 ± 7.5	
			1 ± .25	

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Atmospheric Storage of Strontium

The atmosphere has been sampled at various altitudes to estimate the Sr^{90} presently stored in suspended form.

Methods of Sampling

Lower Atmosphere (200 feet) — Samples were collected at a flow of 15 cubic feet per minute through an MSA Comfo filter which has an efficiency of over 90% at 0.3 micron. The samples were collected on the roof of the New York Operations Office. Samples have been collected continuously from 12/21 - 28/53.

Tropopause (35 - 42,000 feet) — The region of the tropopause has been sampled by a jet aircraft (F84) equipped with cellulose filters. Duplicate samples are collected at a flow of approximately 6000 cubic feet per minute. The efficiency of collection of the filter paper appears to be in the range 90-95% (Appendix B). Four flights have been completed.

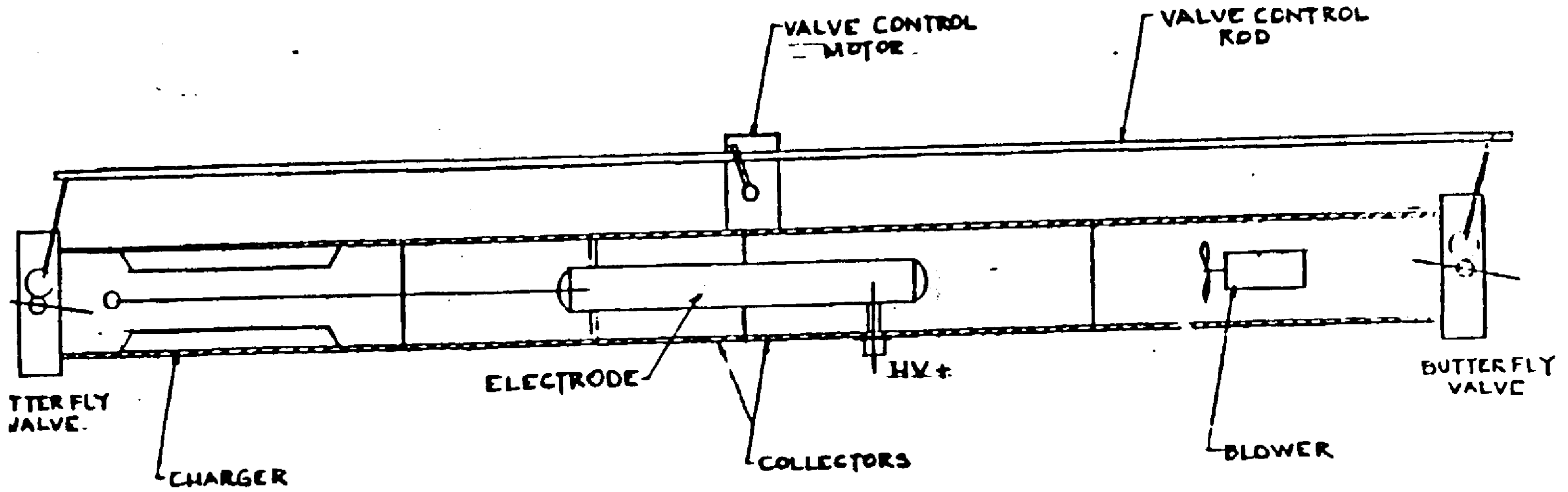
Stratosphere (40 - 100,000 feet)— It was necessary for the Laboratory to design and build special equipment for sampling in this region of the atmosphere from which dust had not previously been collected.

Although many devices are available for dust sampling in the lower atmosphere, the problems presented in the sampling at 100,000 feet make these devices entirely unsuitable. Preliminary calculations based on the best estimates of expected concentration of activity set the requirement of volume of air to be sampled at approximately 1000 cubic meters. Since the only practical means of attaining this altitude is by means of non-extensible helium filled balloons, consideration of weight of the sampler and its self-contained power supply were of great import. These factors in addition to the great reduction in air pressure and temperature at this altitude prompted the investigation of electrostatic precipitation for the solution of this problem.

The most inviting feature of the electrostatic precipitator is the free passage of air through the device without restriction allowing the greatest air moving efficiency. At these altitudes, the ease of producing corona ionization without the use of excessively high voltages greatly reduces the power requirements in the charging device.

Preliminary tests in an evacuated bell jar demonstrated the feasibility of obtaining contolled corona discharge restricted to a small region around the central wire at this pressure by using a quasi-constant current power supply. Calculations indicated reasonable dimensions would efficiently precipitate the dusts of interest.

Figure 11 illustrates the basic features of the device. It consists of four sections of 4" O.D. by 1/16" wall aluminum tubing each 13" long. The first section contains an insert 8" long reducing the inner diameter to 2.785". A nichrome wire .012" in diameter is supported on an insulator and runs centrally



ELECTROSTATIC PRECIPITATOR
Scale: None

FIG. 11

along the axis to the second section. Corona is produced at the wire within the 6" long insert.

The second and third sections have an inside diameter of 3.875" and contain a central axial electrode 1.25" in diameter. The corona wire enters the hemispherical end of this electrode and is maintained taut by means of an internal spring. The high voltage supply connects to this electrode (and the wire) through a suitable insulator. This dimensional configuration was selected so that no corona is produced except in the wire section.

The fourth section contains an axial type of blower designed for aviation use, but never previously tested at stratospheric altitudes.

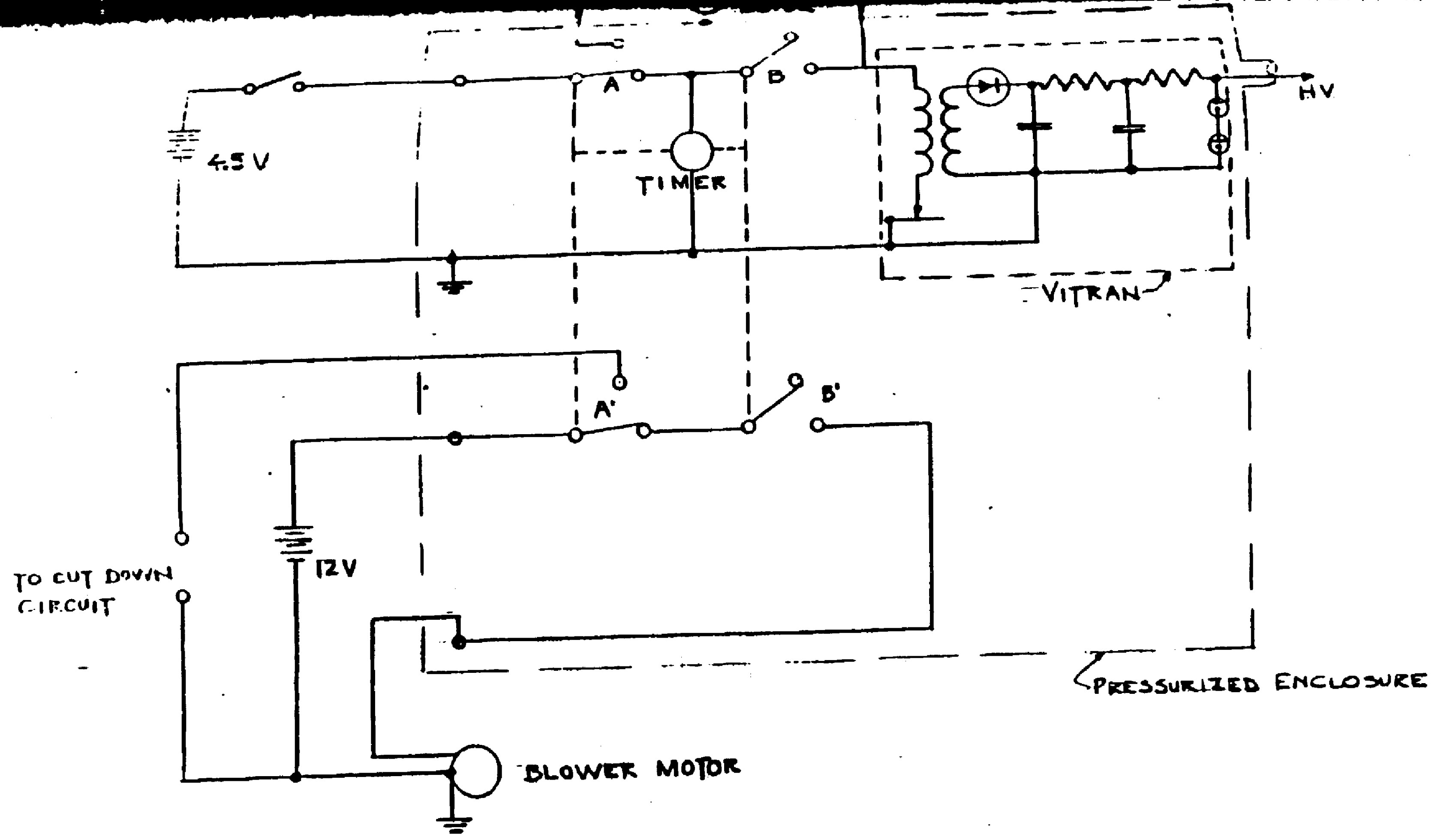
Both ends of the assembly are fitted with butterfly valves operated by a small motor mounted on the external surface of the tube. The active portions of the precipitator are lined with 3 mil aluminum foil upon which the sample is collected.

The high voltage power supply uses a "vitran" (vibrator-transformer) operating at a primary voltage of 4.5 volts. The no-load rectified and filtered D.C. voltage of this device is approximately 2750 volts and it delivers under normal operating conditions about 170 μa at 1450 volts. This unit together with a 24 hour electrical impulse timer are contained ~~in a pressurized~~ container (3 atmospheres air). The circuit used is extremely simple (Figure12). A dual cam on the timer operates two sets of two switches in accordance with the time settings. The first cam is set to close switches B and B^1 after the time for ascent has elapsed,(Normally 2 hours). These switches actuate the valve motor, opening the valves, turning on the high voltage and starting the blower. After the set sampling time (6 hours) at altitude has elapsed, the normally closed switches A and A^1 are actuated, turning off the timer and power supply, and causing the valves to close (through a back contact on the switch, A). The blower is also turned off by switch A^1. A back contact on the blower switch may be used for cutting down the balloon load.

Power for the blower is obtained from a group of silver cells providing 12 volts for 12 ampere hours. Under these conditions (altitude and voltage) the blower moves 100 cfm at altitude and consumes 1.25 amperes. In 6 hours at 100 cfm this unit samples the required 1000 cubic meters. A 4.5 volt 3 AH set of batteries power the timer, H.V. supply and valve motor.

The batteries and pressurized container are housed in an insulated aluminum container. The precipitator assembly is spring mounted in a separate aluminum angle frame. The entire assembly including batteries and cables weighs approximately 35 pounds.

Calculations indicate that within the range of dust particle sizes of interest, .05 to 10 μ, the unit is 100% efficient. Due to the lack of time, efficiency tests have not yet been made on this unit. Preparations are now being made to perform these tests under simulated conditions. The theory of electrostatic precipitation and calculations based on this unit are contained in Appendix D .



CIRCUIT DIAGRAM FOR ELECTROSTATIC PRECIPITATOR

FIG. 12

date, only one sample from 1000 cubic meters of air at 88,000 feet has was obtained. Sampling was prevented by mechanical failures in two other events. Flights were made from Holloman AFB, New Mexico.

Sampling Results

The results of atmospheric sampling to date are given in Table 11. It will be noted that except for two of the four jet aircraft flights, the concentrations reported are remarkably uniform.

The value of 0.06 d/min/M^3 from the single 88,000 ft. sample compares favorably with the samples collected at roof level (mean 0.08 d/m/M^3, range .04-.12 d/m/M^3). Neglecting the two high values from the jet flights, the remaining two samples average .07 d/min/M^3.

We can offer no conclusive explanation for the two high pairs among the samples collected by jet aircraft. One might speculate that because these two samples are characterized by somewhat higher 89 to 90 ratios (Table 12) that the samples are dominated by debris from the USSR detonations in mid-August. However, this is not too plausible an explanation in view of the fact that the first sample was collected shortly after the Russian thermonuclear detonation and the second high sample about four months later.

Relation of Atmospheric Samples to the Residual Activity from MIKE

If the fission yield of MIKE was 5 MT, the residual activity at this time is 2.3×10^7 curies of which the Sr^{90} component is approximately 2.6%, or 6×10^5 curies. If this activity were uniformly distributed throughout the blanket of air 10^5 feet in thickness (volume = $5.4 \times 10^{19} ft^3$.) the concentration of fission product activity would be 6 d/min/M^3. The concentration of Sr^{90} would be 0.8 d/min/M^3.

Neglecting the two high values for the moment, the data suggest that there is a rather uniform dispersion (.06 d/min/M^3) of fission products in the atmosphere up to about 100,000 feet. This is equivalent to about 1% of the residual activity from MIKE. In addition, there are an undetermined number of curies in "slugs" which to date have been observed only in the region of the tropopause.

The Sr$^{89-90}$ content of these samples is given in Table 12 . It will be seen that these isotopes are present in all samples in amounts that exceed by a considerable factor the percentages predicted theoretically in debris from IVY, UPSHOT-KNOTHOLE or the recent USSR series. Only the samples collected by jet aircraft have been analyzed for Sr^{90} to date. If these samples are representative, this isotope represents about 10% of the total activity, about four times the expected percentage, if the debris is due to MIKE. Thus, about 4% of the Sr^{90} yield from MIKE is estimated to be stored in the lower 100,000 feet of the atmosphere.

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TABLE 11

CONCENTRATION OF FISSION PRODUCTS IN AIR AT VARIOUS ALTITUDES

Date and Place	Altitude (feet)	Time of Sampling (hours)	Number of Samples	Method of Collection	d/min/M^3
8/27/53 (Calif.)	40,000	.75	2	Filters on Jet Aircraft	1.2, 1.0
11/30/53 (N.M.)	39,500	2.0	2	"	0.04, 0.03
12/8/53 (N.M.)	88,000	6.0	1	Electrostatic Precipitator	0.06
12/8/53 (N.M.)	35,000	2.0	2	Filters on Jet Aircraft	1.9, 1.7
12/15/53 (N.M.)	40,300	2.0	2	"	0.09, 0.12
12/21/53 (N.Y.)	200	19	1	Hi-Vol.(MSA Comfo)	0.09
12/22/53 (N.Y.)	200	24	2	"	0.04, 0.04
12/23/53 (N.Y.)	200	24	2	"	0.12, 0.12
12/24 - 28/53 (N.Y.)	200	96	2	"	0.08, 0.07

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TABLE 12

RADIOSTRONTIUM CONTENT OF AIR SAMPLES

Altitude	Date	Sr^{89-90}	Sr^{89}	Sr^{90}	89/90
			(Percent)		
88,000'	12/8/53	39%	-	-	-
35-40,000'	8/27/53	74	66	8	8.3
	11/30/53	99	75	24	3.0
	12/8/53	46	42	4	12
	12/15/53	63	48	15	3.2
200'	12/21-28	25	-	-	-

PERCENT OF RADIOSTRONTIUM IN DEBRIS FROM RECENT TESTS
(Theoretical)

	Sr^{89}	Sr^{90}	89/90
	(Percent)		
IVY	1.8	2.6	.71
UK	5.4	1.0	5.5
USSR	9.7	0.4	25.

Evidences of Atmospheric Storage in Fallout Data

In Figure 13 are plotted the mean daily fallout, during the latter half of 1953, at 24 stations operated in various parts of the world. The individual data ought to be found in Table 13.

The rate of fallout in late June is largely from UPSHOT-KNOTHOLE. The sharp rise in late August is due to the test series then in progress in USSR. It will be noted that the sharp decline which began in mid-September appears to be continuing in late December.

Further studies will be required in order to satisfactorily identify the test series that contribute to this low level deposition. As noted earlier, the recent debris is considerably enriched in both isotopes of strontium and the gradual accretion of these isotopes during the coming months is likely to be larger in amount than the strontium that has been deposited up to the present time.

Estimate of the Total Deposition of Debris from MIKE

The Rand SUNSHINE group has estimated that less than 1% of MIKE debris could be accounted for during the period November 1 to December 31, 1952. Our estimate, derived independently, is about 4%. The discrepancy is understandable in view of the arbitrary decisions that must be made in interpolating the data over large ocean areas where no measurements were made.

From January 1 to March 1, 1953, we can account for an additional 0.6% (0.018%per week). In the following months, the debris was dominated by the UPSHOT-KNOTHOLE and USSR series, and differentiation of MIKE debris was not possible by our methods of sampling and analysis.

During the period of November 16 to December 13, 1953, we accounted for fallout activity equivalent to a deposition of 0.35% of the residual activity from MIKE. This is of the order of 0.1% per week and as noted from Figure 13 the decline in activity appears to be continuing. We cannot at this time say that the activity currently observed is due to MIKE and not from more recent detonations in this country or abroad. However, if we do assign it to MIKE, we conclude that at most we can account for only an additional fraction of a percent of the debris from this detonation.

Estimate of Future Fallout, Based on Atmospheric Samples

Based on the few data available, we would estimate the activity of the atmosphere up to 100,000 feet to be of the order of .06 d/min/m^3 (.002 d/min/ft^3).

Approximately 10% of this activity appears to be Sr^{90}. If all of this activity is to be deposited on the earth's surface in a time which is short in relation to the half life of Sr^{90}, the deposition would be of the order of 20 d/min/sq. ft. This is an amount which is equivalent to the Sr^{90} deposited by all detonations up to the present in most of the United States.

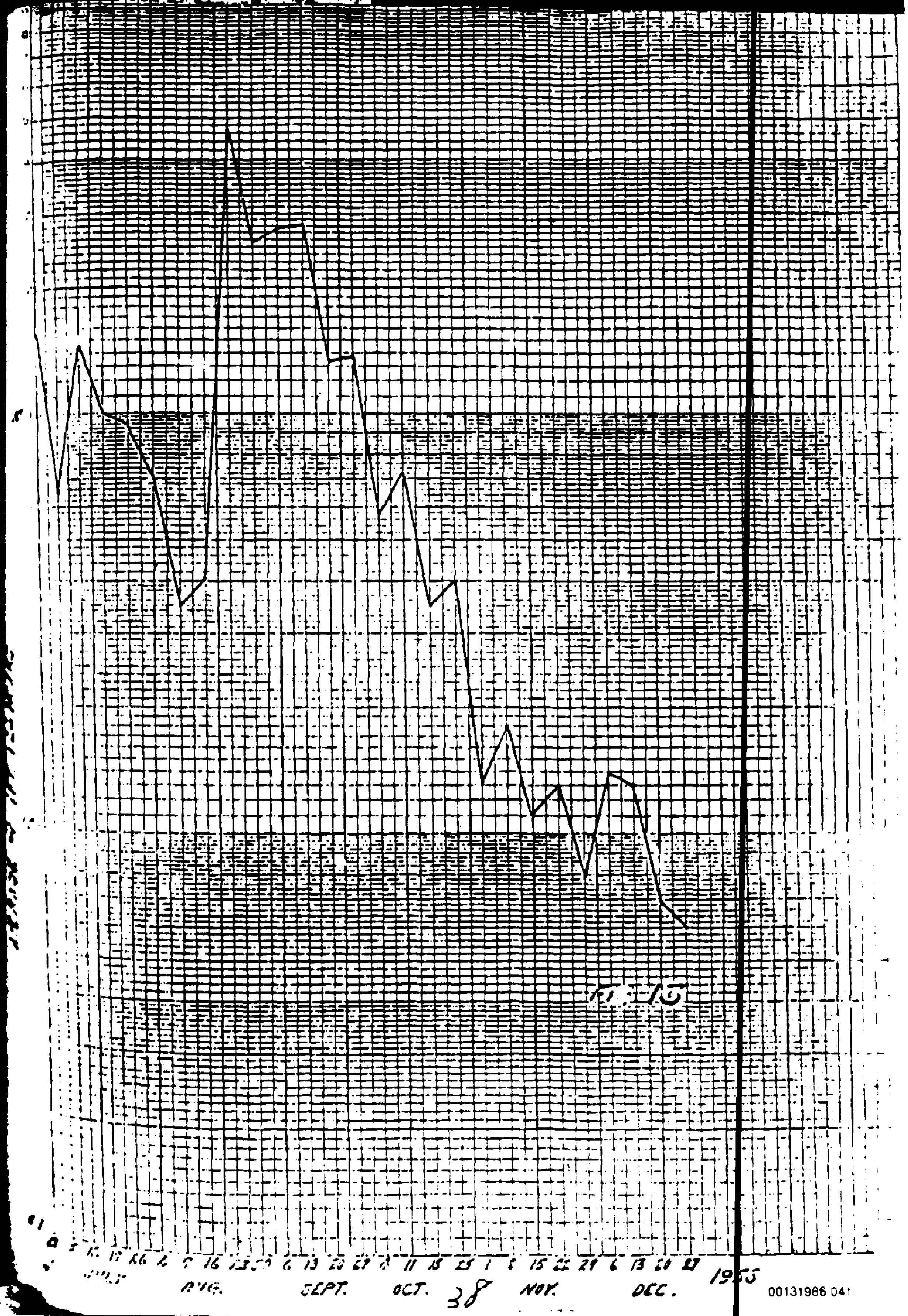
5
12
19
26
JULY
2
9
16
23
30
AUG.
6
13
20
27
SEPT.
4
11
18
25
OCT.
1
8
15
22
29
NOV.
6
13
20
27
DEC.
1955

Fig. 15

TABLE 13

FALLOUT AT STATIONS IN WORLD-WIDE NETWORK

DURING PERIOD NOVEMBER 16 TO DECEMBER 13, 1953

(Mean Daily Fallout, d/min/ft²/day)

STATION	11/16-11/22		11/23-11/29		11/30-12/6		12/7-12/13	
Detroit		2.5		1		2.4		3
Knoxville				1		1		1
Pittsburgh		2				3.2		2
Binghamton		.6		1		1.7		
Rochester		2	0	1.4		2		
New Haven								
Boston		.8		.7		1.7		1.3
Washington		.4		2		1.4		
Las Vegas		1						1.4
Ely		1.1		0		.8		
Los Angeles		0				0		2
Anchorage		1		0		0		0
Thule		.3		0		1		0
Prestwick		2		.6		1		1.4
Nagasaki	.5	.5	.9	.5	.6	.1		
Guam								
Honolulu		.3		1		1		.3
Keflavik		2	1	1.3	3	4	2	1.4
St. Louis		4.,		2		1		2
Hiroshima	0.61	0.60	1.1	.5	.9	1	.4	.3
Canal Zone								
Goose Bay	.1	.2	1	1	2.4	1.2	3	1
Newfoundland								
San Bruno, Calif.		1.2		.4		.2		

Zero is equivalent to less than 0.1 d/min.

GENERAL CONCLUSIONS

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We believe our most significant findings are:

1. The dependence of radiostrontium uptake on soil calcium.

2. The remarkable uniformity in the radiostrontium activity in biological materials when the concentration is expressed as d/min/gm Ca.

3. Our inability to account for the bulk of the debris from MIKE.

4. The absence of gross fractionation of either Sr^{89} or Sr^{90} in samples analyzed.

The data provide a tentative measure of the significance of Sr^{90} from nuclear detonations to date. What would we find a few years hence if there were no intervening detonations? Milk being the principal source of human Ca, we have estimated the rate at which Sr^{90} would be depleted from soil, assuming the availability remains as it is. Appendix F discusses this question for two extreme situations and concludes that the biological half life from soil can vary widely in pastures that feed milk cows: 1.5 to 4.5 years for fields from which cowpeas are cropped continuously and shipped to cows that feed elsewhere, and 170 years for pastures in which the cows feed. The bulk of the Sr^{90} in Case I is transferred to fields manured by cows fed by cowpeas grown elsewhere. Here is an example of one problem of the many that make it difficult to generalize about the data we have obtained.

6 d/m/gm Ca is a representative figure for Sr^{89-90} of which about 1.5 d/m is Sr^{90}. This compares with 870 d/m/gm Ca at tolerance (1 μc in a 7 Kg skeleton containing [redacted] Ca). The ratio of the observed activity to the tolerance activity is thus approximately 1/[redacted]. Potential deposition of material now stored in the atmosphere could easily double this figure. Thus, we can tentatively conclude that if the Sr^{90} in soil is not depleted by biological and/or physical processes in a decade or two, and if newly formed biological calcium in Eastern United States is now at equilibrium with the soil (as seems to be the case), a skeleton which begins to develop at this time would be expected to contain 1/[redacted] of the tolerance burden. This burden will diminish slowly with radioactive decay but can be markedly reduced by a shift in the equilibrium between soil and biological calcium.

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RECOMMENDATIONS FOR FUTURE STUDY

1. Studies in the five pastures should be continued. An additional pasture or two having intermediate values of soil calcium should be included in these studies.

2. In order to provide information on uptake rates after a period of several years, the "pasture approach" should be used in Hiroshima and Nagasaki selecting areas within the localities in which relatively heavy fallout is known to have occurred. (This was included in our original program and Dr. Harley is planning to visit Japan for this purpose in February).

3. The program of atmospheric sampling should be expanded:

   a. Balloon ascents to the stratosphere should be conducted on a weekly schedule during CASTLE and for about 1 year thereafter.

   b. The feasibility of obtaining dust samples from rockets fired into the upper atmosphere should be explored.

   c. Samples of the filters from aircraft engaged in daily intelligence flights should be made available to the Atomic Energy Commission.

   d. The filter equipped F84's assigned to Eniwetok should be used to collect samples in that region prior to CASTLE.

4. The milk and water supplies from 2 or 3 selected communities in the United States should be analysed weekly for Sr^{90}. This data should be correlated with periodic pooled samples of urine and bone.

5. The world-wide monitor network should continue intact for at least a year following CASTLE. Collection should be on a weekly rather than daily basis beginning about 30 days after conclusion of the operation.

6. The tumor producing burden of Sr^{90} in livestock should be determined.

7. Better measurements than are now available should be made of the long lived alpha activities of bomb debris.

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REFERENCES

1.	NYO-1576 (SECRET)	"Radioactive Debris from Operations Buster and Jangle"- January 28, 1952, Health and Safety Division, USAEC, NYOO.
2.	NYO-4505 (SECRET)	"Radioactive Debris from Operations Tumbler and Snapper." - Part I, Health and Safety Division, USAEC, NYOO - January 12, 1953.
3.	NYO-4522 (SECRET)	"Radioactive Debris From Operation Ivy"-April 28, 1953, Health and Safety Division, USAEC, NYOO.
4.	UPSHOT-KNOTHOLE	In preparation
5.	R-251-AEC (SECRET)	The Rand Corporation - "World-Wide Effects of Atomic Weapons - Project SUNSHINE" - Aug. 6, 195 .
6.	NRDL NS085-001	"Simultaneous Slow Neutron Fission of U-235 Atoms I. Individual and Total Rates of Decay of the Fission Products, H. F. Hunter and N. E. Ballou

APPENDIX A

ANALYTICAL PROCEDURES

The analytical methods used for determining total radiostrontium, total strontium, Sr^{90} and radium are given in detail in this appendix. The majority of the samples encountered were bone, soil, vegetation and foods. Where different procedures are required for handling these different types of samples, the methods are given separately.

The actual methods are prefaced by charts for determining the theoretical contribution of radiostrontium to total fission product activity and the Sr^{90}/Sr^{89} activity ratio as a function of time since burst.

The methods reported are those actually used in the analyses shown in this report, but a summary of analytical developments in progress is given at the end of this appendix.

CHARTS FOR STRONTIUM IN MIXED FISSION PRODUCTS

In a given sample containing the fission products of Pu or U^{235} it is necessary to have a theoretical measure of the $(Sr^{89} + Sr^{90})/$(total fission activity) ratio as a function of time.

Hunter and Ballou have derived approximate expressions for total fission product activity as a function of time. If it is expressed in minutes, these equations are:

$$A(t) = (156000)t^{-1.26} \qquad 1 \text{ day} \leq t < 4 \text{ days}$$

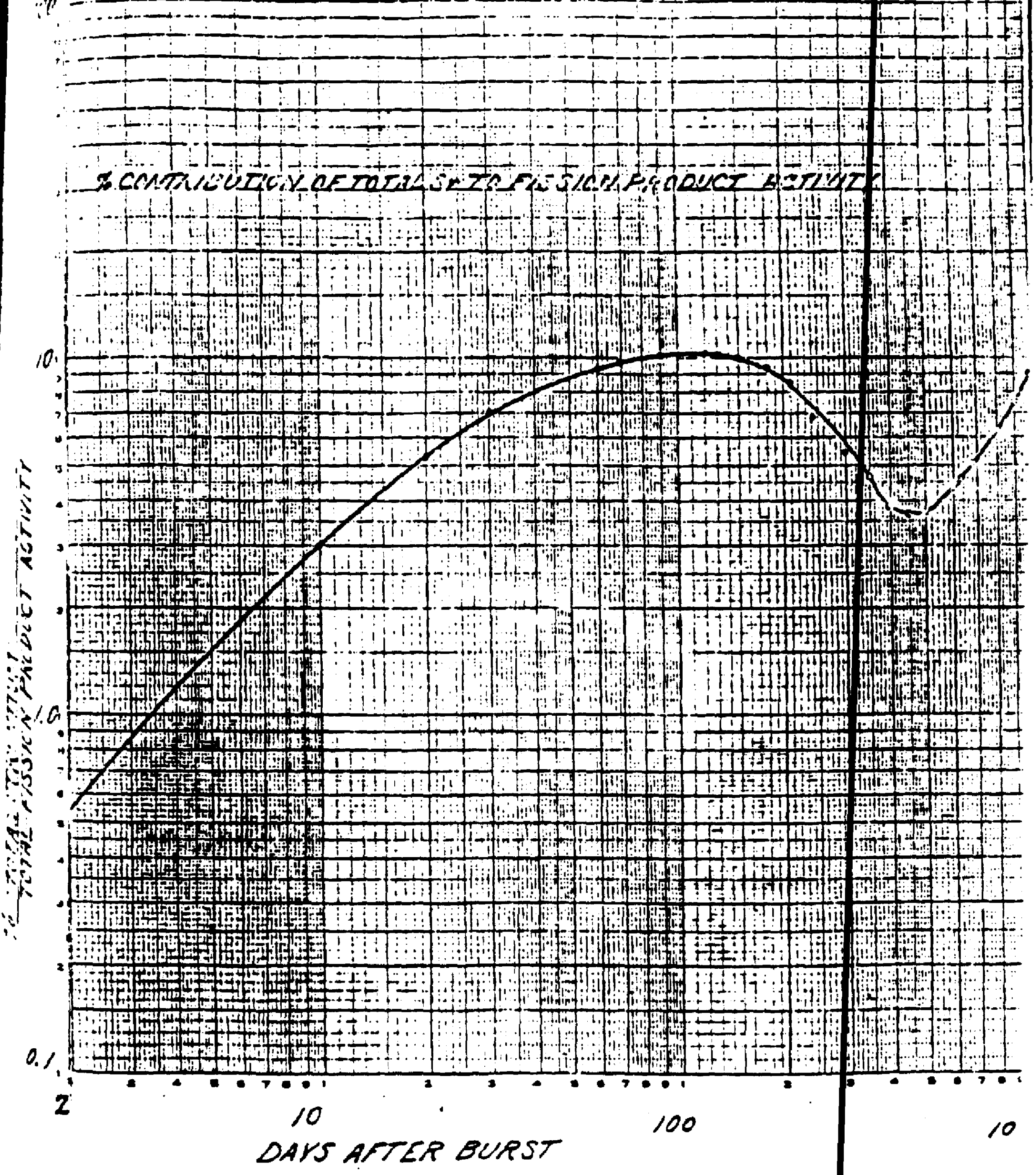
$$A(t) = (2400)t^{-1.03} \qquad 4 \text{ days} \leq t < 100 \text{ days}$$

$$A(t) = (2\text{-}16 \times 10^{8})t^{-1.60} \qquad 100 \text{ days} \leq t < 3 \text{ years}$$

At 130 days after burst time, Sr^{89} and Sr^{90} contribute 10% and 0.35% respectively to fission product activity. The ratio of $\frac{\Sigma Sr}{\Sigma F.P.A}$ for any time is then calculated from the Sr half lives and the A(t) formulae. This ratio has been plotted in Fig. A-1.

With a knowledge of the percent contribution of each Sr isotope to total activity, the disintegration rates of Sr^{89} and Sr^{90} at any time are readily obtained using the A(t) data. The ratio of Sr^{90}/Sr^{89} has been plotted from 1-1000 days in this manner in Fig. A-2.

FIG. A-1



% CONTRIBUTION OF TOTAL Sr+Zr FISSION PRODUCT ACTIVITY
% TOTAL ACTIVITY / TOTAL FISSION PRODUCT ACTIVITY
10
10.
1.0
0.1
2
10
100
10
DAYS AFTER BURST

Table A-6

Sample Weight	Isotope	Amount Added	Amount in ppt	%
(5 gm.	Cs^{137}	65,000 d/m	none	0
(5 gm.	Cs^{137}	65,000 d/m	none	0
(5 gm.	$Ce^{144} + Pr^{144}$	140,000 d/m	none	0
(5 gm.	$Ce^{144} + Pr^{144}$	140,000 d/m	none	0
(5 gm.	Pm^{147}	96,000 d/m	none	0
(5 gm.	Pm^{147}	96,000 d/m	none	0

The final conclusion is that these isotopes do not interfere in the method of analysis used for bone samples.

ANALYTICAL PROCEDURE FOR THE SEPARATION OF TOTAL RADIOSTRONTIUM FROM A 100 GRAM SAMPLE OF SOIL

1. Dry the entire sample in an oven at 110°C.

2. Sample, using standard sampling procedure (quartering process) until approximately 125 grams of soil is obtained as a representative sample.

3. Ignite in a nickel crucible at 900°C.

4. Weigh out 100 grams of the ignited material.

5. Add 400 grams of Na_2CO_3 and mix thoroughly.

6. Fuse in a muffle at 900°C (minimum temperature) for 45 minutes, (minimum time) until the melt is clear and homogeneous.

7. Cool by immersing in a beaker of cold water, withdrawing quickly at first. Continue immersing and withdrawing until the crucible is cool enough to place on a transite board. The Na_2CO_3 should not be wet at any time.

8. When the crucible is cool, turn it upside down, tap the bottom with a pestle and allow the solid fused material to fall into a mortar.

9. Break up the fused material in a hand grinder, transfer to an automatic grinder and grind to a fine powder.

10. Transfer the ground fused material to a 3-liter beaker containing 500 ml of hot distilled water, stirring constantly until the particles are dispersed.

11. Add slowly with continued stirring, 1000 ml of 60% $HClO_4$. This is sufficient to neutralize the fused material and allow for an excess of acid.

12. Evaporate with mechanical stirring until dense white $HClO_4$ fumes are detected. The silica is now dehydrated.

13. Dilute to 2.5 liters with distilled water and allow to settle.

14. Filter the silica on No. 5 Whatman paper with suction. Wash with 250-500 ml of hot 5% HCl, then with 250 ml of distilled water. Transfer the filtrate and washings to the original beaker. Wash the silica with 1% H_2SO_4, and discard the washings.

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15. Remove the silica from the filter paper and dry in a 110°C oven overnight. Break up the aggregated material with a mortar and pestle, then transfer to a 250 ml platinum dish.

16. Moisten the silica with 10% H_2SO_4, then add about 100 ml of HF.

17. Evaporate on a sand bath to SO_3 fumes to volatilize the silica. Cool and dilute with distilled water, transferring the resulting solution to the original soil filtrate, and add 20 mg Sr^{++} carrier.

18. Neutralize the filtrate with NaOH pellets until the pH is 4-4.5. At this point add slowly, with stirring, 50 grams of Na_2CO_3 and allow the precipitate to settle. Filter through No. 5 Whatman paper with suction and discard the filtrate.

19. When the precipitate is dry, remove from the filter paper and transfer to the original beaker. Dissolve in 200 ml of concentrated HCl and evaporate slowly to dryness. Do not bake.

20. Now add 460 ml of distilled water and stir mechanically until the residue is completely dispersed.

21. Add slowly, 1540 ml of 90% HNO_3 with continuous mechanical stirring and allow to remain stirring for 1/2 hour.

22. Allow to settle until the supernatant is clear, then decant as much 75% HNO_3 as possible.

23. Transfer the precipitate and remaining acid to a 250 ml centrifuge bottle, centrifuge and decant, discarding the supernatant.

24. Carry out another 75% HNO_3 separation using a volume of 200 ml.

25. At this point the bulk of the calcium should be removed leaving strontium nitrate and insoluble material. Add 100 ml of hot distilled water to the precipitate, centrifuge and decant into a 250 ml beaker.

26. Wash again with 50 ml of hot distilled water adding the supernatant liquid to the beaker after centrifugation. The residue can now be discarded.

27. Evaporate the filtrate slowly to dryness.

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28. Now carry out a final 75% HNO_3 separation in the 250 ml beaker. (100 ml volume)

29. Filter through a fluorothene funnel on a glass fibre filter. Transfer the funnel to a clean filter flask and wash out the acid with anhydrous ethyl ether.

30. Place the filter on a brass disc and ring assembly (Tracerlab), cover with 0.001 inch pliofilm and β count.

Recovery values are of the order of 75% for the procedure as shown. This method was selected initially to be certain of obtaining the strontium regardless of its state. However, tests of leaching methods showed good recoveries, and they are to be preferred for handling large samples of soil. The following data gives a comparison of results by different methods.

Sample No.	Source	Method (d/m/g) 1	2	3
112	Albany, N.Y.	0.14±0.08	0.11±0.007	0.09±0.006
114	Logan, Utah	0.16±0.05	0.012±0.002	-
98	Lamont Labs.	.08±.04	.08±.04	-

Methods

1. Complete solution as described.
2. Leaching 10 minutes with 6 N HCl.
3. Leaching 10 minutes with 1 N Ammonium Acetate.

The properties and abundance of the long-lived fission products were given in the section on bone analysis. The effect of addition of the following mixture of possible interferences in the analysis of 100 gram soil samples is given in Table A-7.

The simplest method of analysis is the direct solution of bone ash in HNO_3, dilution to suitable volume and determination of strontium content by flame photometry. This method is subject to errors of suppression by extraneous elements in the solution. The degree of this suppression was determined by the addition of known quantities of strontium to solutions of bone ash which had previously been measured.

The direct analysis did not have sufficient sensitivity, so the separation of strontium from calcium was made by a double nitrate precipitation. The results of the first set of tests on spiked bone samples are shown in Table A-8.

Table A-8

Recovery of Strontium

Sample No.	Sr Added	Sr Found	%
1	0 mg	0 mg	-
2	10	7.5	75
3	20	20	100
4	30	26	87
5	50	47	94

The low recovery of the 10 mg quantity and the absence of strontium in the non-spiked sample is attributed to the lack of suitable material to form sufficient precipitate to carry down the low concentration of strontium. It is suggested that 10 mg of barium be used as a collecting agent for low concentrations of strontium.

With the carrier, the recovery for low strontium was brought up to over 90%. A set of spiked bones were run at lower strontium levels, with the results shown in Table A-9.

Table A-9

Strontium Recovery (Barium Carrier)

Sample No.	Sr Added	Photometer Reading	Sr Found
1	0 mg	9	0.95
2	1	39	1.9
3	3	46	2.4
5	5	Off-scale	-

The bone sample used for spiking (Amputation from Bellevue Hospital) was shown to contain 0.019% Sr.

ANALYTICAL PROCEDURE FOR THE SEPARATION OF TOTAL RADIO-STRONTIUM FROM SAMPLES OF VEGETATION AND FOODS

1. Ash the sample in a nickel crucible at 900°C.

2. Estimate the amount of ash, add four times this weight of Na_2CO_3 and fuse.

3. Dissolve, remove silica, and collect the strontium by carbonate precipitation as for soil.

4. Run a double nitrate precipitation as for bone using acid volumes of 200 ml for the first precipitation and 50 ml for the second.

ANALYTICAL PROCEDURE FOR DETERMINATION OF NORMAL STRONTIUM IN BONE

1. Ash the bone sample in a nickel crucible at 900°C.

2. Grind in a mortar to a fine powder.

3. Weigh out 5 grams into a 250 ml centrifuge bottle.

4. Add 44 ml of water and then slowly add 154 ml of 90% nitric acid to bring concentration to 75% HNO_3.

5. Add 20 mg of Ba^{++} carrier (as $BaCl_2$) in 2 ml of solution.

6. Stir rapidly for thirty minutes (mechanically).

7. Centrifuge for ten minutes at about 2000 r.p.m.

8. Decant and repeat steps 4 thru 7 at 1/2 the original volume.

9. Decant as much of the liquid as possible and transfer to a 100 ml beaker with water.

10. Evaporate to dryness and pick up with 10 ml of concentrated nitric acid.

11. Add 5 ml of 1000 ppm Li solution, dilute to 100 ml and run by flame photometry.

There is no agreement in the literature as to the strontium content of the normal human being. In part this is due to the variability of available strontium in different sections of the country or the world, and in part the disagreement is due to the methods of analysis used.

To resolve the differences for our own laboratory studies, a test was made of two methods of analysis. Time did not permit a complete program of sampling and analysis of bones from several individuals in several localities to be made.

The data of Hodges, et al (UCLA-47) showed a range of 0.015 to 0.040% of strontium in human bone. Preliminary tests here showed the percentage to be in this range, which eliminated gravimetric procedures. Therefore, flame photometry was selected as the analytical method.

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ANALYTICAL PROCEDURES FOR DETERMINATION OF Sr^{90} BY SEPARATION AND COUNTING OF Y^{90}

1. After the sample on the brass holder has been counted for total strontium and has reached equilibrium, it may be used for Y^{90} separation.

2. Count the sample and record data.

3. Remove the sample from the brass holder. Wash the holder with about 25 ml of water. Allow washings to fall into beaker with the bulk of the paper.

4. Bring to a boil and filter thru No. 41 paper into a 50 ml platinum dish. Wash the beaker and paper with approximately 15 ml more of water.

5. Evaporate to dryness on a sand bath. Add approximately 20 ml of HF and evaporate to dryness again.

6. Pick up the residue with approximately 5 drops of HCl. Transfer to a beaker with water. Bring volume to about 50 ml. Add 10 mg of lanthanum carrier. (This carrier must have negligib e β activity).

7. Bring to a boil and adjust pH to 6-7. Allow to stand for abo t 15 minutes and filter thru a 1-1/8 glass fiber paper. Place n brass holder. Cover with pliofilm and count.

8. Record time that filtration was completed. Count and record counting date and counting time.

9. Observe decay by counting at approximately 3-day intervals for a period of about 12 days.

The procedure was tested by measuring the recovery of Y^{91} added to solutions containing 20 mg of Sr as the nitrate. The recoveries found with either paper or glass fiber filters were 94-99%.

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ANALYTICAL PROCEDURE FOR SEPARATION AND DETERMINATION OF RADIUM IN BONE

1. Dissolve 5 grams of bone ash in 10 ml of HCl, heating gently. Add distilled H_2O until the volume is 100 ml.

2. Adjust pH to 8 with NH_4OH, centrifuge and decant. This precipitates the phosphates and hydroxides, coprecipitating the radium.

3. Pick residue up with HCl and H_2O, following the procedure in Step 1.

4. Adjust pH to 3.5, add 10 mg of $SO_4^=$ as $(NH_4)_2SO_4$, and 3 mg of Ba^{++}. $BaSO_4$ and some $CaSO_4$ will precipitate at this point. Centrifuge and decant, saving only the precipitate.

5. Add HCl dropwise, until the bulk of the $CaSO_4$ goes into solution.

6. Dilute to 100 ml with H_2O and adjust the pH to 3.5. Allow the $BaSO_4$ to settle and digest overnight.

7. Filter through No. 42 Whatman Filter paper and ignite paper at 700°C in a platinum crucible in muffle.

8. Add 3 ml of concentrated H_2SO_4 to the platinum crucible and 25 ml of HF. Allow to evaporate slowly on a sand bath until SO_3 fumes are given off.

9. Reprecipitate $BaSO_4$ in a 50 ml centrifuge tube, using a rubber policeman to transfer the precipitate from the platinum to the tube. Allow to digest overnight. Take note of time of precipitation.

10. Centrifuge for 5 minutes and decant. Wash twice, first with 10 ml distilled water, and last with 10 ml ethyl alcohol.

11. By means of a transfer pipet and ethyl alcohol, transfer the precipitate quantitatively to a nickel disc.

12. Allow 30 days for the radium daughters to come to equilibrium and count with an alpha scintillation counter. Or alternatively, the final equilibrium value may be calculated from the measured disintegration rate at any time and a factor for the fraction of equilibrium value existing at that time.

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ANALYTICAL PROCEDURE FOR THE SEPARATION AND DETERMINATION OF RADIUM IN 100 GRAMS OF SOIL

1. Except for the addition of 20 mg of Sr^{++} carrier, Steps 1 thru 15 of the $Sr^{89,90}$ procedure are carried out exactly the same way.
2. When the carbonate precipitate is dry, remove from the filter paper and transfer to a pyrex glass tray.
3. Place in a 100°C oven and dry overnight.
4. Now break up the aggregated material with a spatula and crush as well as possible with a pestle.
5. Return the material to a 100°C oven and dry again.
6. Finally place the dried precipitate in a copper radon collecting tube. Plug up both ends with pyrex wool, flush out the tube with hydrogen and then seal. Record the time.
7. For full equilibrium, allow a 30 day buildup, but shorter buildup times are useable. Measure the radon in an ionization chamber radon counting apparatus.

This method of radon collection is relatively untried, but a spiked sample gave the following result,

	g Ra per g Soil		
Sample	Added	Found	Difference
Soil No. 114	0	5.2×10^{-13}	——
Spiked soil No. 114	4.0×10^{-13}	8.4×10^{-13}	4.4×10^{-13}

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ANALYTICAL DEVELOPMENT IN PROGRESS

The Instruments Branch of the Health and Safety Laboratory has been developing a scintillation anti-coincidence counter for low level beta measurements. This is designed around a solution phosphor containing the active material in a volume of 5 to 10 ml. The problem has been worked on by three groups; the Analytical Branch developing the method of obtaining the active material in solution, Professor Kallmann of NYU working on the development of the optimum phosphor, and the Instruments Branch working on the development of instrumentation.

The chemical operations were largely devoted to the separation of Y^{90} from the radiostrontium plus strontium carrier obtained in our normal chemical procedures. It was desirable to extract the Y^{90} into an organic solvent that would also be a suitable solvent for the fluors; such as terphenyl and the substituted anthracene. Initial experiments showed that certain complexing agents which gave organic soluble compounds with Y also acted as quenchers for the phosphor. This was true of TTA (thenoyl trifluoroacetone). Other reagents such as oxine gave poor extraction coefficients.

Tributyl phosphate (TBP) has been used in the extraction of rare earths from very strong nitric acid solution. The resulting organic layers, however, were found to show very great quenching. This is due to the presence of nitric acid which also extracts into TBP. It was not possible to wash out the HNO_3, as the Y activity was also removed in the process.

Extracting Y from saturated ammonium nitrate solutions with TBP gave an organic layer which could be prepared as a good liquid phosphor. The pulse heights obtained are equivalent to phosphors prepared directly from TBP. Both 75% and 50% saturated ammonium nitrate solutions also gave good extraction results, allowing easier manipulation than if completely saturated.

This technique should allow the ready measurement of very low levels of Y^{90} as carrier-free isotope, since the background of such a scintillation counter could be maintained at a low level. This procedure may also be used for determination of Ce^{144} which is one of the known non-fractionating fission products present in aged fallout debris. The second development is the use of a comparative logarithmic absorption plot for isotope identification. In this method, the logarithm of the relative activity of the unknown with various aluminum absorbers is plotted against the logarithm of the relative activity of a known isotope such as P^{32}. The slope of the resulting [redacted] [redacted]

straight line is a function of the beta energy of the unknown isotope and the intercept of the line with the zero absorber axis represents the relative amount of that isotope present in a mixture.

The advantage of this method lies in its applicability to low counting levels. This is possible because the line slope can be determined from light absorbers rather than the heavy absorbers required for Feather analyses. The method is in tentative use for isotope characterization for mixtures of isotopes and should be applicable to determination of $Sr^{89/90}$ ratios.

APPENDIX B

ESTIMATE OF COLLECTION EFFICIENCY OF FILTERS USED IN JET AIRCRAFT

Filter papers were placed in series during two flights. If we assume the filters do not significantly discriminate according to particle size, the efficiency can be estimated as follows.

Let R = fraction of activity retained on filter

C = Activity in volume of air sampled

A_1 and A_2 = Activity collected by first and second filters respectively

Then

$$A_1 = RC$$

$$A_2 = (1-R)RC$$

$$R = 1 - \frac{A_2}{A_1}$$

The following data were obtained:

November 30, 1953

First filter in series	780 d/min
Second filter in series	60 d/min

$$R = 1 - \frac{60}{780}$$

$$= .92$$

December 15, 1953

First filter in series	2070 d/min
Second filter in series	140 d/min

$$R = 1 - \frac{140}{2070}$$

$$= .95$$

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APPENDIX C

Tabulation of Analytical Results

Three tabulations of analytical data are collected in this appendix. The first is the summary of results from the five selected sites, the second is a series of samples obtained from UCLA, and the third is a collection of miscellaneous analyses run during the period. While the results of the last two groups were not used in drawing the conclusions reached in this report, the values obtained are reported here for completeness.

The first group of samples from the five selected sites include analyses of soil, animal bone and vegetation for total radio-strontium, Sr^{90}, natural strontium, radium and exchangeable calcium. These results were used in evaluating strontium and radium uptake.

One group of samples was furnished by Dr. Kermit Larsen of UCLA. These materials from the Test Site and Almagordo showed only fair correlation of bone/soil and plant/soil ratios. The Jangle soil has previously been shown by Dr. Larsen to have low availability of strontium, but the other four test site samples should be equivalent. Their bone/soil ratios of 2.0, 1.6, 58, and [illegible] could not be fitted into the data from other sites, as available calcium analyses are not available.

The miscellaneous samples included many samples of animal and human bone but comparable soil or food figures were not available for strontium uptake studies.

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ALBANY

Type Sample	Total Radiostrontium d/m/g	Sr^{90} d/m/g	Natural Sr mg/g	Ra d/m/g	$\frac{1}{Ca^{++}}$
SOIL					
0-1"	0.16± .04	0.1± 0.05		1.2	0.23
1-6"					
6-12"					
ANIMAL BONES					
Calf					
Rib	33.6± 1.3				
Spine	35.4± 1.6				
Leg	33.9± 0.8	2.1± 0.1		1	
Hoof	35.6± 0.8			.7	
Woodchuck					
Rib	1.9± 0.2			061	
Spine	3.5± 0.2		.08	034	
Leg	2.8± 0.2		.09	108	

LOGAN

Type Sample	Total Radiostrontium d/m/g	Sr^{90} d/m/g	Natural Sr mg/g	Ra d/m/g	$\frac{1}{Ca^{++}}$
SOIL					
0-1"	.08± 0.2	.08± .02		1.0	∞
1-6"	.06± 0.02			0.9	
0-1"	.38± 0.05	.16± .02		0.9	
VEGETATION					
Grass	18± 0.8				
ANIMAL BONES					
Lamb					
Jaw	4.6± 0.5			.4	
Leg	5.1± 0.5	0.5± 0.1		.6	
Rib	5.3± 0.5			.2	

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TIFTON

Type Sample	Total Radiostrontium d/m/g	Sr^{90} d/m/g	Natural Sr mg/g	Ra d/m/g	$\frac{1}{Ca^{++}}$
SOIL (Measured)					
0-1"	0.02 ± .02			0.8	1.25
1-6"	0 ± .03				
VEGETATION					
Range Shrub	6.0 ± 0.6				
Cow Peas	2.3 ± 0.5				
Native Grasses	15.7 ± 1.2				
ANIMAL BONES					
Calf					
Spine					
Ribs	14.5 ± 0.9	8.6 ± 0.6			
Jaw	19.5 ± 1.0	13 ± 1.0			
Leg	20.9 ± 1.0	9.6 ± 0.1			
Hoof					

ITHACA

Type Sample	Total Radiostrontium d/m/g	Sr^{90} d/m/g	Natural Sr mg/g	Ra d/m/g	$\frac{1}{Ca^{++}}$
SOIL					
0-1"	0.03 ± 0.02			1.6	0.1
1-6"				1.8	
6-12"	0.004 ± 0.03			1.7	
VEGETATION					
Pasture Grass	15.0 ± 0.4				
"	39.4 ± 0.6				
"	34.5 ± 0.7	2.8 ± 0.7			
ANIMAL BONES					
Lamb					
Leg	6.0 ± 0.1	0.9 ± .05	0.18	.048	
Rib	6.6 ± 0.1		0.18	.075	
Spine	6.1 ± 0.1		0.16	.035	
Teeth	1.4 ± 0.1				
Jaw	5.7 ± 0.1		0.20	.035	

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RUTGERS

Type Sample	Total Radiostrontium d/m/g	SrSr^{90} d/m/g	Natural Sr mg/g	Ra d/m/g	1 Ca-4
SOIL					
0-1"	0.04± .02			1.4	0.23
1-6"	0.03± .02			0.4	
6-12"				1.1	
ANIMAL BONES					
Lamb					
Spine	8.0± 0.1		0.12	.11	
Ribs	2.4± 0.05	1.0± 0.7	0.12	.075	
Teeth	3.4± 0.4		0.10	.046	
Jaw	7.2± 0.1		0.11	.12	
Hoof	8.4± 0.2	0.77± .05	0.10	.20	
Leg	7.6± 0.05		0.12	.046	

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UCLA SAMPLES

	Sample	Source	Date Sampled	Radio-Strontium d/m/g		Sr^{90} d/m/g	
78	Soil	Chupadera Mesa	7/53	1.8	0.2		
79	Vegetation	" "		1.5	0.3		
80	Rodent bones	" "		2.2	0.7		
81	Soil	Jangle Soil	11/51	9.6	0.1		
82	Greenhouse plants	" "	8/52	3.8	0.7		
83	Lab. rats	" "	3/52	0.3	0.6		
84	Soil	Test Site (TS & BJ)	10/52	5.4	0.2		
85	Vegetation	" "		113.0	2.4		
86	Rabbit bones	" "		11.0	1.0		
87	Soil	Test Site (TS)	10/52	4.4	0.4		
88	Vegetation	" "		--			
89	Rabbit bones	" "		11.9	1.0	9.5	2.3
90	Soil	Test Site (UK TS BJ)	6/53	0.2	0.04		
91	Vegetation	" "		1.8	0.3		
92	Rabbit bones	" "		19.0	1.0	14.0	2.5
93	Soil	Test Site (Upshot)	6/53	98.0	0.3		
94	Vegetation	" "		24.0	0.3		
95	Rabbit bones	" "		327.0	8.5	48.0	12.0

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	Sample	Source	Radio-strontium d/m/g	Sr^{90} d/m/g	Normal Sr mg/g	Ra d/m/g
1	Calf; Rib	Test Site	2.2 ± 0.2		0.57	0.075
2	Spine	"	1.9 ± 0.2		-	0.084
3	Leg	"	2.7 ± 0.2		0.54	0.004
4	Hoof	"	2.6 ± 0.2		0.79	0.000
12	Calf, Scapula	Cedar City	4.4 ± 0.3		-	-
11	Ewe #1, Leg	"	1.0 ± 0.2		0.40	0.41
13	#2, Leg	"	3.2 ± 0.05		0.36	1.01
14	#3, Leg	"	5.3 ± 0.3		-	0.008
18	#4, Leg	"	2.3 ± 0.3		-	1.7
19	#5, Hoof & Leg	"	11.3 ± 0.4		0.48	3.9
15	#6, Leg	"	1.5 ± 0.3		0.35	2.0
16	Lamb #1, Leg	"	0.4 ± 0.2		-	-
17	#2, Leg	"	9.3 ± 0.1		-	0.54
102	Calf	Clark County Nevada	53.0 ± 0.8	0.98 ± 0.1	0.26	11.0
101	Human, Newborn	Utah	1.2 ± 2.1		-	-
135	80 yr. male	"	0.8 ± 1.0		-	-
136	46 yr. male	"	0.0 ± 0.04		-	-
137	unknown	"	1.4 ± 0.6		-	-
138	79 yr. male	"	4.2 ± 0.4		-	-
139	75 yr. male	"	1.1 ± 0.8		-	-
74	children's teeth NYC		0.0 ± 0.12		0.10	0.029
170	Human, Lab skeleton femur		0.08 ± 0.02		-	-

~~SECRET~~

Sample		Source	Radio-strontium d/m/g	Sr^{90} d/m/g	Normal Sr d/m/g	Ra d/m/g
6	Whole milk	St. George, Utah	1.3 ± 0.2	-	-	0.035
96	Powdered milk	Starlac, 1953	0.5 ± 0.04	0.2 ± 0.1	.086	0.115
97	" "	Alba, 1953	0.88 ± 0.08	0.5 ± 0.1	-	-
153	" "	Bordens, 1950	0.34 ± 0.12	-	-	-
113	Human milk	Syracuse	5.6 ± 4.8	-	-	-
152	Urine	Newark, (milk donor) *	0.0 ± 3.9/l	-	-	-
157	Urine	NYC	0.0 ± 0.6/l	-	-	-
155	Blood	NYC	0.75 ± 0.2/qt.	-	-	-
165	Cheese	Rumania	0.04 ± 0.01	-	-	-
166	"	Yugoslavia	0.04 ± 0.01	-	-	-
167	Tap water	NYC	0.88 ± 0.02/l	-	-	-
168	" "	NYC	0.93 ± 0.04/l	-	-	-
169	Distilled water	NYC	0.06 ± 0.04/l	-	-	-
171	Soil & Clam shells	Long Island	0.016 ± 0.001	-	-	-

APPENDIX D

NOTES ON ELECTROSTATIC PRECIPITATOR

By H. J. DiGiovanni

I. Laws of Motion of Small Particles Subjected to a Force

(a) A small particle subjected to a force is accelerated through the media in the surrounding space, the resulting motion through the particles of the media results in a resistive force to the motion given by Stokes as

$$R = k\, d\, v\, \mu \qquad (1)$$

For spheres $k = 3\pi$. When the velocity through the media is such that the resistive force is equal to the accelerating force, the acceleration will be zero resulting in a constant velocity termed the terminal velocity.

(b) For a spherical particle in a gravitational field

$$F = mg; \quad m = \frac{4}{3}\pi r^3 \rho = \frac{1}{6}\pi d^3 \rho$$

The terminal velocity will result when

$$F = R \text{ or } \frac{1}{6}\pi d^3 \rho g = 3\pi d\, v\, \mu$$

$$\text{or } v = \frac{1}{18}\frac{d^2 \rho g}{\mu} \qquad (2)$$

(c) If the particle acquires an electrical charge and is in an electrical field the force on the particle will be

$$F = Q\, E$$

The terminal velocity will then be

$$v = \frac{Q\, E}{3\pi d\, \mu} \qquad (3)$$

(d) For particles of a size approaching the mean free path of air molecules, a correction due to Cunningham is required to account for the additional velocity caused by the particle accelerating between impacts. This is given by

$$v = v_{Stokes}\left(1 + k_1 \frac{\lambda}{d}\right) \qquad (4)$$

For particles subjected to electrostatic and gravitational forces, the velocity is the vector sum of the velocities given by (2) and (3) corrected by equation (4).

II. Laws Governing the Charging of Particles

Particles may acquire charges by passing through a region containing ions of a given sign either by diffusion or field charging. In the former, the mechanism is one of impingement of the particles with the ions due to the kinetic energy of the gas, whereas in the latter the impingement is assisted by the energy imparted by the electrostatic field.

(a) For diffusion charging, the equation given by White

$$q = \left(\frac{d}{2}\,\frac{KT}{e^2}\right) \ln \left(1 + \frac{\pi d\, C\, N_o\, e^2 t}{2\, KT}\right) \qquad (5)$$

gives the number of electronic charges which will be acquired by a particle of diameter d.

(b) For field charging, Pauthenier has given the following equation as modified by Dallavale for a cylindrical electrostatic precipitator.

$$q = \left[1 + 2\left(\frac{k_2 - 1}{k_2 + 1}\right)\right] \cdot \left[\frac{d^2 E}{4 e}\right] \cdot \left[\frac{\pi t i}{E}\left(\frac{1}{1 + \frac{\pi t i}{E}}\right)\right] \qquad (6)$$

Although others have assumed that the particle will acquire the sum of the charges given by both methods, it is felt that considering the mechanisms involved, the particle charge will be given by the greater of the two effects. In any case, this gives a more conservative result.

(c) Electrical considerations of the charger.

Pauthenier has shown that the potential distribution in a cylinder with central co-axial wire changes from logarithmic to a linear function as the corona current increases from zero, except for a small region around the wire. Under these conditions the field intensity will be given by

$$E = \sqrt{\frac{2i}{k_3}}$$

Figure 14 gives the electrical characteristics of the charger at various altitudes. The charger dimensions are 8" long by 1.875" diameter, having a wire of .012" diameter. Neglecting end effects

$$i = \frac{170 \times 10^{-6} \times 3 \times 10^{9}}{8 \times 2.54} \quad \text{at 100,000 feet}$$

giving a value of 2.62×10^{4} statamps/cm. The mobility at

$$\text{100,000 feet} = 600 \times \left(\frac{760}{8.1}\right)\left(\frac{213}{273}\right) \quad \text{or}$$

$$E = \sqrt{\frac{2\,(2.62 \times 10^{4})}{600 \times \frac{213}{273} \times \frac{760}{8}}} = 1.1 \text{ ESU.}$$

The actual observed voltage divided by the radial distance from wire to cylinder gives a figure agreeing within 20% of the calculated figure which for our purposes is sufficiently good.

For equation (5), the ion density in the charging device is required. This can be calculated by assuming a linear potential distribution as given by Pauthenier for this case.

If $\frac{dv}{dx} = E$ is constant then the velocity of the ions is constant and given by

$$v_i = k_3 \left(\frac{760}{p}\right)\left(\frac{213}{273}\right) E = 5.8 \times 10^{4} \text{ cm/sec}$$

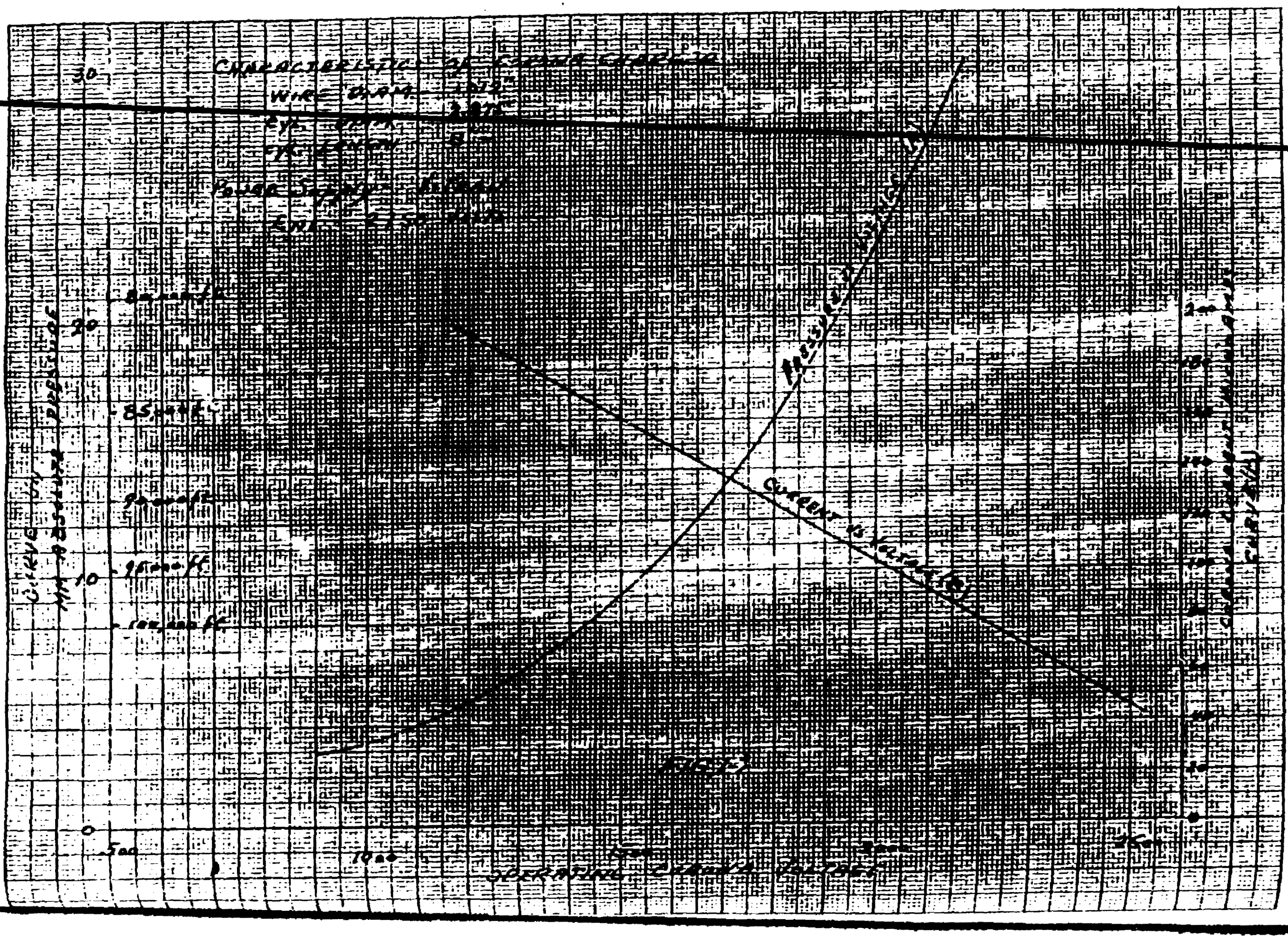
the time to traverse a distance dr from the wire towards the cylinder is then

$$t = \frac{dr}{v_i}$$

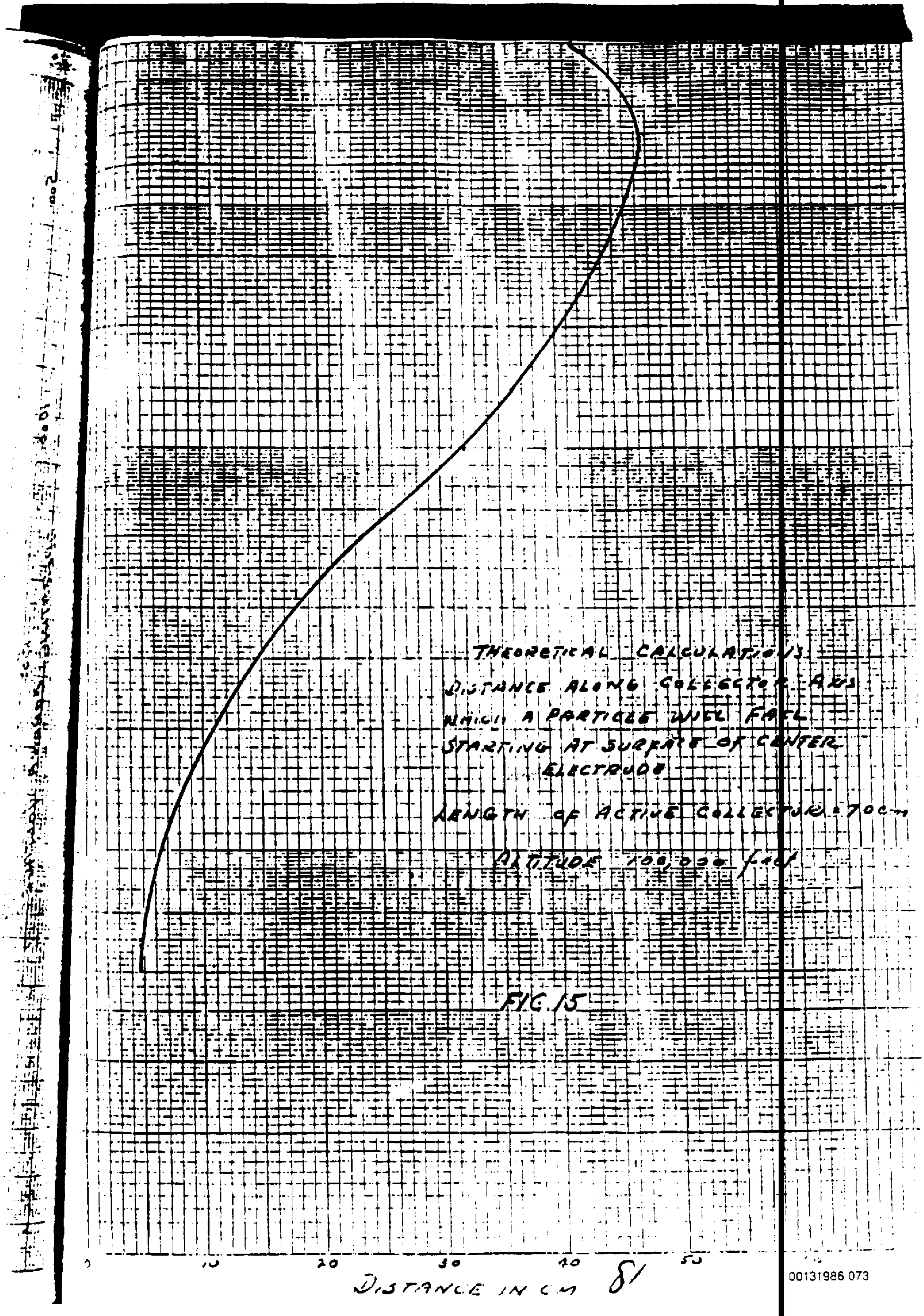
during this time a charge Q = it has filled a 1 cm length of the cylinder dr in radial thickness. The value of the charge density will then be $\frac{Q}{2\pi r\,d r} = \frac{i\,d\,r}{v\,2\pi r\,d\,r} = \frac{i}{2\pi r\,v}$ at a radius r.

Assuming particles entering at 1/2 cm radius, then the ion density No at this radius is

$$N_o = \frac{i}{2\pi E\,k_3 \left(\frac{760}{p}\right)\left(\frac{213}{273}\right) e\,r}$$



CHARACTERISTIC OF [illegible]
WIRE DIAM. .012"
[illegible]
POWER SUPPLY [illegible]
CURVE 24
MM ABSOLUTE PRESSURE
30
20
10
0
80,000 ft
85,000 ft
90,000 ft
95,000 ft
100,000 ft
PRESSURE VS VOLTAGE (a)
CURRENT VS VOLTAGE (b)
FIG 23
500
1000
1500
2000
2500
OPERATING CATHODE VOLTAGE
CATHODE CURRENT MICROAMPS
CURVE 24(b)



THEORETICAL CALCULATIONS
DISTANCE ALONG COLLECTOR AXIS
WHICH A PARTICLE WILL FALL
STARTING AT SURFACE OF CENTER
ELECTRODE

LENGTH OF ACTIVE COLLECTOR = 70cm

ALTITUDE 100,000 feet

FIG. 15

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