UNCLASSIFIED

MASTER

UNITED STATES ATOMIC ENERGY COMMISSION

(NYO-4602(DEL.))

THE TRANSPORT OF ATOMIC DEBRIS FROM OPERATION
UPSHOT-KNOTHOLE

By
Robert J. List

Photostat Price \$ 30.30

Microfilm Price \$ 8.70

Available from the
Office of Technical Services
Department of Commerce
Washington 25, D. C.

June 25, 1954

Weather Bureau
Washington, D. C.

Technical Information Service Extension, Oak Ridge, Tenn.

DELETED VERSION
Classification changed to UNCLASSIFIED
by authority of Jack Kahan / 4-22-59
by Hugh Kahan date 10/16/09
and Chris Davenport date 10/16/09

This document is
PUBLICLY RELEASABLE

H. Kahan
Authorizing Official
Date: 10/20/09

UNCLASSIFIED

DISCLAIMER

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

DISCLAIMER

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

PREFACE

IMPORTANT NOTE

Subsequent to the Upshot-Knothole test series, the automatic counting equipment of the New York Operations Office was recalibrated using a newly agreed upon radioactive standard. The results indicated that all previous values of radioactivity obtained from the automatic counting equipment were too low by a factor of about three. This correction, which has been applied to the present data, is also applicable to data previously reported for the Tumbler-Snapper (2) and Ivy (12) tests. Since not all samples were counted on the automatic counters, it is not possible to correct the results in the earlier reports simply by multiplying all values by three. About 1 to 2% of the samples processed (samples with high activity, in general) were measured on non-automatic equipment.

In the present report, all values given in the body of the report (including references to previous tests) have been corrected to the new standard.

ACKNOWLEDGEMENTS

The work reported on here was done under the direction of Dr. Lester Machta, Chief of the Special Projects Section, Scientific Services Division, U. S. Weather Bureau. The radiological data was provided by the Health and Safety Laboratory, New York Operations Office, Atomic Energy Commission, Merril Eisenbud, Director. Particular acknowledgement is given to Mr. Daniel E. Lynch of the Health and Safety Laboratory for his efforts in coordinating the activities of the Weather Bureau and the New York Operations Office in connection with the investigation. Many helpful suggestions were received from the author's colleagues in the Special Projects Section, D. Lee Harris, Lester F. Hubert, Kenneth M. Nagler, and Francis Pooler, Jr. The laborious and painstaking plotting of data, preparation of finished drawings and typing of the manuscript was done by the staff of the Special Projects Section.

CONTENTS

	Page
PREFACE	iii
ACKNOWLEDGEMENTS.	iii
ILLUSTRATIONS	vi
TABLES.	viii
ABSTRACT.	ix
CHAPTER 1 FALLOUT MONITORING.	1
1.1 The Upshot-Knothole Monitoring Network	1
1.2 Extrapolation to Sampling Day.	1
1.3 Pre-Test Background of Radioactivity	4
CHAPTER 2 THE UPSHOT KNOTHOLE TESTS	6
2.1 List of Bursts	6
2.2 Highest Observed Activity.	7
2.3 Discussion of Individual Bursts.	16
CHAPTER 3 TOTAL FALLOUT FROM THE UPSHOT-KNOTHOLE TESTS.	46
3.1 Introduction	46
3.2 Fallout in the Vicinity of the Test Site	46
3.3 Fallout in the Continental United States	46
3.4 World-Wide Fallout	51
CHAPTER 4 THE DESIGN OF A FALLOUT MONITORING NETWORK.	56
4.1 Spatial Variability of Fallout	56
4.2 Physical Processes	58
4.3 Intense Fallout at Albany, N. Y.	63
4.4 Other Implications of the Albany Fallout	65
4.5 Other Possible Cases of Intense Fallout.	71
CHAPTER 5 PREFERRED MONTHS FOR NEVADA TESTS	72
5.1 Factors Studied.	72
5.2 Probability of Favorable Weather at the Test Site.	72
5.3 Probability of Intense Local Fallout away from the Test Site	74
5.4 Reducing Total Fallout in the United States	75
5.5 Minimizing Adverse Public Reaction	80
CHAPTER 6 SPECIAL OBSERVATIONS.	82
6.1 Types of Observations.	82
6.2 Results.	82

	Page
CHAPTER 7 CONCLUSIONS AND RECOMMENDATIONS.	
7.1 Interim Network	85
7.2 Total Fallout	85
7.3 Fallout from Air and Tower Bursts	86
7.4 Location of Stations.	86
7.5 Prediction of Fallout Areas	86
7.6 Intense Local Fallout	86
7.7 Optimum Season for Nevada Tests	87
APPENDIX A MAPS OF DAILY FALLOUT IN THE UNITED STATES AND CANADA	88
APPENDIX B PREDICTED AND OBSERVED AREAS OF FALLOUT.	179
REFERENCES	191

ILLUSTRATIONS

	Page
1.1 Location of Daily Fallout Monitoring Stations.....	2
1.2 Location of Weekly Fallout Monitoring Stations.....	3
2.1 Highest Observed Gunned Film Activity on Days Without Precipitation as a Function of Distance from the Test Site.....	14
2.2 Upper Air Observation at Mercury, Nevada, 1200 G.C.T., March 17, 1953.....	17
2.3 Meteorological Trajectories from the First Burst.....	19
2.4 Upper Air Observation at Mercury, Nevada, 1100 G.C.T., March 24, 1953.....	20
2.5 Meteorological Trajectories from the Second Burst.....	21
2.6 Upper Air Observation at Mercury, Nevada, 1200 G.C.T., March 31, 1953.....	22
2.7 Meteorological Trajectories from the Third Burst.....	24
2.8 Upper Air Observation at Mercury, Nevada, 1600 G.C.T., April 6, 1953.....	25
2.9 Meteorological Trajectories from the Fourth Burst.....	26
2.10 Upper Air Observation at Mercury, Nevada, 1300 G.C.T., April 11, 1953.....	28
2.11 Meteorological Trajectories from the Fifth Burst.....	29
2.12 Upper Air Observation at Mercury, Nevada, 1200 G.C.T., April 18, 1953.....	30
2.13 Meteorological Trajectories from the Sixth Burst.....	31
2.14 Upper Air Observation at Mercury, Nevada, 1100 G.C.T., April 25, 1953.....	33
2.15 Meteorological Trajectories from the Seventh Burst.....	34
2.16 Upper Air Observation at Mercury, Nevada, 1500 G.C.T., May 8, 1953.....	35
2.17 Meteorological Trajectories from the Eighth Burst.....	36
2.18 Upper Air Observation at Mercury, Nevada, 1200 G.C.T., May 19, 1953.....	38
2.19 Meteorological Trajectories from the Ninth Burst.....	39
2.20 Upper Air Observation at Mercury, Nevada, 1500 G.C.T., May 25, 1953.....	41

	Page
2.21 Meteorological Trajectories from the Tenth Burst.....	42
2.22 Upper Air Observation at Mercury, Nevada, 1200 G.C.T., June 4, 1953.....	43
2.23 Meteorological Trajectories from the Eleventh Burst....	45
3.1 Regions Used in Computing Total Fallout in the United States (Figures indicate percent of total area of the United States included in each region).....	48
3.2 Total Fallout in the Northern Hemisphere, March 17 to June 14, 1953, (d/m/ft ² , decayed to July 1, 1953)....	52
4.1 Difference in Activity Collected on Gunned Films Exposed Simultaneously in the Same City. Upshot- Knothole Tests.....	57
4.2 Difference in Activity Collected on Simultaneously- Exposed Gunned Films as a Function of Distance Between Stations, Upshot-Knothole Tests.....	59
4.3 Difference in Average Activity Collected on Simul- taneously-Exposed Gunned Papers as a Function of Distance Between Stations, Tumbler-Snapper Tests.....	60
4.4 Fallout in Northeastern United States, April 26, 1953, and Results of Aerial Survey on May 1, 1953.....	64
4.5 Precipitation in Northeastern United States, 2200 G.C.T., to 2300 G.C.T., April 26, 1953.....	66
4.6 Precipitation in Northeastern United States, 2300 G.C.T., to 2400 G.C.T., April 26, 1953.....	67
4.7 Precipitation in Northeastern United States, 0000 G.C.T., to 0100 G.C.T., April 27, 1953.....	68
4.8 Precipitation in Northeastern United States, 0100 G.C.T., to 0200 G.C.T., April 27, 1953.....	69
4.9 Precipitation in Northeastern United States, 0200 G.C.T., to 0300 G.C.T., April 27, 1953.....	70
A.1 - A.90 Radioactive Fallout in the 24-hour Periods Beginning 1230 G.C.T., 17 March 1953 through 14 June 1953.....	89-178
B.1 - B.11 Predicted and Observed Areas of Fallout, Bursts 1 through 11.....	180-190

TABLES

	Page
2.1 Upshot-Knothole Bursts.....	6
2.2 Maximum Gummed Film Activity at Each Station for Day with Precipitation and without Precipitation.....	8
2.3 Maximum High Volume Air Filter Activity at Each Station.	15
3.1 Total Fallout (d/m/ft ²) as of June 14, 1953, in the Continental United States, by Regions and Bursts, Extrapolated to July 1, 1953. (Excluding the Test Site Area).....	47
3.2 Total Fallout in the Continental United States.....	49
3.3 Percent of Total Observed Activity Collected on Each Day Following Each Burst, Continental United States. (Excluding Test Site Area).....	51
3.4 Total Fallout from the Upshot-Knothole Series as of June 14, 1953.....	53
4.1 Concentration of Debris as a Function of Distance From the Center of a Cloud After 36 Hours, Assuming a Coefficient of Horizontal Eddy Diffusion of 10 ⁸ cm ² sec ⁻¹	62
5.1 Mean Monthly Distribution of Precipitation, Cloudiness and Thunderstorms at Las Vegas, Nevada.....	73
5.2 Percentage Frequency of Favorable Wind Directions Over Las Vegas.....	74
5.3 Percentage Frequency of Winds of 75 Knots or More from Favorable Directions at Las Vegas.....	75
5.4 Mean Number of Days Per Month with Thunderstorms.....	76
5.5 Mean Annual Precipitation in the United States and the Percent Occurring in Each Month.....	78
5.6 Average Number of Tornadoes by Months (1916-1950).....	80
6.1 Results of St. Louis Observations.....	83

ABSTRACT

In connection with the Upshot-Knothole atomic test series in Nevada in the spring of 1953, the New York Operations Office established a gummed film monitoring network consisting of 95 stations in the United States and 26 stations outside the continental United States. Eleven atomic devices were detonated, ranging in yield from 0.2 to 60 KT. Higher activity was found at most continental stations following these bursts than had been experienced from any previous test series. Considerably more fallout followed tower bursts as compared with air bursts, both near the test site and elsewhere in the United States. The highest single gummed film activity occurred on April 26, 1953, at Albany, N. Y., 16,000,000 d/m/ft²/day, associated with a severe thunderstorm.

An integration of the total fallout from this series as of June 14, 1953, indicated roughly that 9.3% of the total fission product beta activity produced fell in the test site area, 2.8% was accounted for by the gummed film network in the United States, and 13.1% in the rest of the world, for a total of 25.2%. It is concluded that the gummed film network fails to detect a substantial portion of the deposited debris.

Information relating to the optimum spacing of stations in a gummed film network and the probability of missing local areas of intense fallout is discussed. Intense local fallout at distances greater than 600 miles from the test site is dependent upon the following combination of circumstances: a high-yield tower burst to inject large amounts of radioactive debris into the atmosphere, a fast-moving atomic cloud to bring high concentrations of debris into the area, and the occurrence of showers or thundershowers to bring fresh debris to the ground. It is estimated that a chance combination of circumstances could result in fallout of the order of 10^9 to 10^{11} d/m/ft²/day at distances greater than 600 miles from the test site.

A consideration of several meteorological factors indicates that the months of October and November would be more suitable for conducting test series at the Nevada Proving Grounds than the spring months used in the last two series. A series of special observations with gummed films exposed in normal and inverted positions showed that on days with no rain about an order of magnitude less debris is deposited on the inverted film. Maps of daily fallout values in the United States and Canada and maps showing a comparison of predicted and observed areas of fallout are appended.

CHAPTER 1

FALLOUT MONITORING

1.1 THE UPSHOT-KNOTHOLE MONITORING NETWORK

In connection with the Upshot-Knothole series of atomic tests at the Nevada Proving Ground in the Spring of 1953, the New York Operations Office of the Atomic Energy Commission again sponsored a world-wide network of fallout monitoring stations to collect samples of radioactive debris near the ground. The principal collecting device was a one-foot square sheet of gummed cellulose acetate film mounted horizontally on a three-foot stand. In addition, 14 stations in the western United States also made daily observations of the concentration of atomic debris in the air by means of high volume air filtering devices. Both techniques have been described in an earlier report (1).

Daily gummed film collections (two simultaneously exposed films in most cases) were made at 95 Weather Bureau stations in the United States, at nine stations of the Canadian Meteorological Service, at the Canadian Atomic Energy Installation, and at three stations of the Air Weather Service in Newfoundland, Bermuda, and the Canal Zone. The locations of the daily sampling stations are shown in Figure 1.1.

In an attempt to get more information concerning the world-wide aspects of the fallout problem, thirteen overseas stations (Figure 1.2) of the Weather Bureau, the Air Weather Service, the State Department, and the Atomic Bomb Casualty Commission were designated to collect duplicate gummed film samples. Overseas collections were made on a weekly rather than a daily basis.

As in previous tests, the radioactivity found on the gummed film is reported in units of disintegration per minute per square foot per day ($d/m/ft^2/day$), that on the air filter in units of disintegration per minute per cubic meter of air ($d/m/M^3$).

1.2 EXTRAPOLATION TO SAMPLING DAY

All significant activity reported for the United States, Canada, and Bermuda has been extrapolated to the sampling day on the assumption that the decay has been proportional to $t^{-1.2}$, where t is the time since the burst.

FIGURE 11 LOCATION OF DAILY FALLOUT MONITORING STATIONS

FIGURE 12 LOCATION OF WEEKLY FALLOUT MONITORING STATIONS

The difficulties inherent in this procedure have been discussed in a previous report (2). To extrapolate the activity to sampling date it is necessary to know which burst is responsible for the activity measured, and this cannot always be done with certainty. In attempting to assign observed activity to a given burst, consideration must be given to the computed meteorological trajectories, to the low level flow patterns, to the scavenging by precipitation and to the time of arrival of increased activity at the stations. Since the samples are not counted until several days, and in some cases weeks, following exposure, the extrapolation factors for relatively recent debris can be quite large. If minor contamination of the sample occurs in the laboratory, or if debris from an older burst is mixed with the more recent debris, considerable bias towards reporting too high values of activity on sampling date can occur. Such bias also results from the tendency to ascribe debris to the most recent burst when there is doubt as to its origin.

In an attempt to eliminate some of the bias resulting from uncertain extrapolations and to reduce the work-load involved in assigning activity to a specific burst, only those observations which exhibited activity above an arbitrary threshold value on the counting day were considered significant. The activity for these samples was extrapolated to sampling day on the basis of a particular burst.

For the gummed film observations, the level of significance was taken to be either (a) one of the daily duplicate films with an activity of more than $180 \text{ d/m/ft}^2/\text{day}$, or (b) both films with an activity of more than $120 \text{ d/m/ft}^2/\text{day}$ on counting day. For the air filter observations, this threshold of significance was taken as 1200 d/m measured on the filter, which corresponds to approximately 0.9 d/m/M^3 on counting day. However, since activity on the air filters is reported to the nearest whole d/m/M^3 , the values would not be reported unless extrapolation to sampling date resulted in a value greater than 0.5 d/m/M^3 , based on the uncorrected counting procedure (see Preface).

For gummed film samples with less than the threshold activity, the activity on counting day is reported. For air filters, activity below the level of significance is reported as "low".

1.3 PRE-TEST BACKGROUND OF RADIOACTIVITY

The threshold levels of significance given above were chosen with reference to the pre-test background of atmospheric radioactivity as determined from dust samples collected prior to the first burst of the series. Since more than 30 atomic explosions

have been detonated in the past nine years, there is some residual radioactive debris present. In examining the gummed film results for collections made from March 2 through March 16, 1953, prior to the first burst of the series and 3-1/2 to 4 months after the Ivy test series, the large majority showed no activity above the normal counter background. However, at least 100 of the more than 2200 films exposed showed activity greater than 60 d/m/ft²/day on counting day and 19 papers had more than 50 d/m/ft²/day. Of the more than 100 higher-than-average films, about half were exposed on days with precipitation. In comparison, the samples exposed prior to the Tumbler-Snapper series (about 10 months after the Greenhouse test series) in the Spring of 1952 showed only a few papers with over 45 d/m/ft²/day and the highest was 135 d/m/ft²/day. Gummed film observations in the United States and Canada made just prior to Operation Ivy (5 to 5-1/2 months after the Tumbler-Snapper series) in November, 1952, showed similar results, of 272 papers exposed, only 3 had more than 60 d/m/ft²/day and the highest was 78 d/m/ft²/day.

The high volume air filters operated prior to the first burst showed that of the 109 samples collected between March 2 and March 16, 1953, over 100 had activity greater than 0.15 d/m/ft² and 27 had activity greater than 0.3 d/m/ft². Although no similar pre-test air filter data is available for the Tumbler-Snapper series, of the eleven samples collected on the day of the first burst of that series nine had less than 0.15 d/m/ft² and the other two were affected by the burst.

Although both gummed film and air filter samples apparently had higher activity prior to the Upshot-Knothole tests when compared with the activity prior to the Tumbler-Snapper and Ivy series, the increase seems somewhat more marked in the air filter data. This may be indicative of the fact that the particles present were too small to settle on the gummed film although they were capable of being impinged on the air filter.

CHAPTER 2

THE UPSHOT-KNOTHOLE TESTS

2.1 LIST OF BURSTS

The Upshot-Knothole test series consisted of eleven atomic detonations in the Yucca Flat and Frenchmans Flat areas of the Nevada Proving Ground. Table 2.1 summarizes the burst data.

TABLE 2.1

Upshot-Knothole Bursts

Burst	Code Name	Date, 1953	Time (GCT)	Type of Burst	Height of Detonation Above Ground (feet)	Height of Top of Cloud, ISL (feet)	Yield (KT)
1	Annie	Mar. 17	1320	Tower	300	41000	16.3
2	Nancy	Mar. 24	1310	Tower	300	41000	24.5
3	Ruth	Mar. 31	1300	Tower	300	14300	0.21
4	Dixie	Apr. 6	1530	Air	5020	43000	10.8
5	Ray	Apr. 11	1245	Tower	100	14000	0.22
6	Badger	Apr. 18	1235	Tower	300	37200	27.7
7	Simon	Apr. 25	1230	Tower	300	43200	51.5
8	Encore	May 8	1530	Air	2423	40500	20.4
9	Harry	May 19	1205	Tower	300	44200	32.4
10	Grable	May 25	1530	Air	[REDACTED]	[REDACTED]	[REDACTED]
11	Climax	June 4	1115	Air	1334	41700	60.0

Since this series was characterized not only by the large number and high yield of the devices tested as compared with previous continental tests, but also by the preponderance of tower bursts, considerably more fallout was observed than occurred with previous continental tests.

2.2 HIGHEST OBSERVED ACTIVITY

Table 2.2 shows the highest activity (extrapolated to sampling day) reported on any one film at each of the daily gummed film stations for both days with precipitation and dry days. The stations are arranged in accordance with distance from the test site. The sampling day, the burst responsible for the activity, and the amount of precipitation (in accordance with the code in Appendix A) are also given.

Of greatest interest in Table 2.2 is the fact that the highest activity found on any of the papers exposed during this series of tests was at a station located at a distance of 2000 miles from the test site. The fortuitous coincidence of a severe thunderstorm and a fast-moving trajectory of the top of the cloud resulted in a value of 16,000,000 d/m/ft²/day at Albany, N. Y., on April 26. (This case will be discussed in detail in Chapter 4.) At the other extreme, San Diego, Calif., less than 300 miles from the test site, was the only station in the United States and Canada to experience no significant fallout during the entire test series.

On days without precipitation, the highest activity measured on any one film was 15,000,000 d/m/ft²/day on a sample from Salt Lake City, Utah, on March 24. Figure 2.1 shows the highest activity found without precipitation in each 200 nautical miles annulus around the test site, plotted as a function of the distance of the outer edge of the annulus from the test site. The dashed line in Figure 2.1 gives some indication of the maximum dry fallout which may be expected at various distances following bursts of the type and size used in this series. Considerable caution should be exercised in drawing any conclusions from this figure, since the data represent a limited sample, and a combination of circumstances not encountered in these tests could easily produce much higher concentrations of debris. Comparison of Figure 2.1 with a similar figure prepared from data obtained following the Tumbler-Snapper test series (2, p. 20) shows considerably higher activity from the present tests, especially in the region 600-1600 nautical miles from the test site, although the figures are not directly comparable since the earlier data represent the average of three gummed papers and the current data show the highest activity found on any individual paper. However, the maximum difference so introduced would be a factor of three; another factor of two would result from the higher yields of the Upshot-Knothole series. The actual difference in the range mentioned is an order of magnitude or more, and is undoubtedly a reflection of the fact that more, and more powerful, tower bursts were detonated.

TABLE 2.2

Maximum Gummed Film Activity at Each Station
For Day With Precipitation and Without Precipitation

Station	<u>No Precipitation</u>			<u>Precipitation</u>			
	Date	Burst	Activity d/m/ft ² /day	Date	Burst	Precip.	Activity d/m/ft ² /day
A: Stations less than 200 naut. miles from the test site							
Las Vegas, Nev.	April 18	6	940,000	April 21	6	2	33,000
Ely, Nev.	March 24	2	2,100,000	May 23	9	5	45,000
Milford, Utah	April 25	2	930,000	May 19	9	4	780,000
Fresno, Calif.	April 22	6	2,100	April 19	6	3	2,600
B: Stations 200-400 naut. miles from test site							
Reno, Nev.	April 28	7	15,000	April 19	6	2	84,000
Elko, Nev.	March 24	2	69,000	May 28	10	5	19,000
Winnemucca, Nev.	April 20	6	2,500	May 28	10	6	63,000
Flagstaff, Ariz.	April 25	7	3,600,000	April 27	7	6	110,000
Phoenix, Ariz.	April 1	3	330,000	April 27	7	2	2,600
Yuma, Ariz.	April 12	5	450,000	April 21	6	2	2,300
Los Angeles, Calif.	April 22	6	900	April 25	6	2	11,000
San Diego, Calif.	May 21		140	April 20		4	110
Sacramento, Calif.	April 20	6	4,500	May 18	8	3	1,300
San Francisco, Calif.	May 11	8	11,000	April 20	6	2	12,000
Salt Lake City, Utah	March 24	2	15,000,000	May 19	9	6	66,000

TABLE 2.2 (Cont'd)

Station	<u>No Precipitation</u>			<u>Precipitation</u>			
	Date	Burst	Act.	Date	Burst	Precip.	Act.
Tucson, Ariz.	April 2	3	28,000	May 27	10	2	3,000
Grand Junction, Col.	April 26	7	2,900,000	May 19	9	2	11,000,000
Boise, Idaho	May 6	7	3,000	May 26	10	4	230,000
Pocatello, Idaho	May 26	10	66,000	May 27	10	3	16,000
C: Stations 400-600 naut. miles from the test site							
Eureka, Calif.	March 26		69	May 24	9	5	1,300
Medford, Oregon	May 10		81	April 25	6	3	1,300
Rock Springs, Wyo.	March 24	2	60,000	June 5	11	5	230,000
Albuquerque, N. M.	May 19	9	7,800,000	May 27	10	3	45,000
Portland, Oregon	April 1		30	April 4	2	4	45,000
Butte, Montana	May 9	8	90,000	March 25	2	2	16,000
Denver, Col.	May 21	9	160,000	June 5	11	6	180,000
Pueblo, Col.	May 19	9	550,000	June 5	11	3	180,000
Raton, N. M.	May 19	9	2,000,000	April 6	4	3	180,000
Colorado Springs, Col.	April 27	7	190,000	June 5	11	3	84,000
Cheyenne, Wyo.	April 26	7	130,000	June 5	11	5	160,000
Roswell, N. M.	April 20	7	13,000,000	April 28	7	3	780,000
Casper, Wyo.	March 24	2	2,100,000	April 28	7	4	120,000
Helena, Montana	May 27	10	3,600	May 31	10	3	7,200
D: Stations 600-800 naut. miles from the test site							
Billings, Montana	May 31	10	26,000	May 9	8	3	420,000
Spokane, Wash.	May 28	10	1,300	May 26	10	3	480,000

TABLE 2.2 (Cont'd)

Station	<u>No Precipitation</u>			<u>Precipitation</u>			
	Date	Burst	Act.	Date	Burst	Precip.	Act.
Scottsbluff, Nebr.	April 27	7	36,000	May 22	9	4	110,000
Amarillo, Texas	May 19	9	1,600,000	April 4	3	0	36,000
Goodland, Kans.	May 20	9	700,000	April 28	7	5	50,000
Rapid City, S. D.	March 25	2	680,000	April 28	7	6	105,000
Kalispell, Montana	April 1		48	May 26	10	5	420,000
Seattle, Wash.	May 25	9	1,200	May 26	10	5	48,000

10
-
E: Stations 800-1000 naut. miles from the test site

Williston, N. D.	March 25	2	1,000,000	May 8	8	6	1,200,000
Abilene, Texas	April 26	7	360,000	April 28	7	5	33,000
Del Rio, Texas	May 22	9	39,000	April 22	6	2	5,700
Concordia, Kans.	April 27	7	190,000	May 20	9	3	1,100,000
Wichita, Kans.	May 20	9	560,000	April 6	4	3	72,000
Huron, S. D.	March 25	2	63,000	April 28	7	6	105,000
Ft. Worth & Dallas, Texas	March 18	1	1,000,000	April 28	7	2	24,000
Regina, Sask.	June 6	11	4,200	May 9	8	6	60,000
Port Hardy, B. C.	April 8	3	540	March 29	2	5	1,400

F: Stations 1000-1200 naut. miles from the test site

Edmonton, Alberta	May 27	8	150	May 20	10	2	19,000
Fargo, N. D.	March 26	2	60,000	April 29	7	5	63,000
Kansas City, Kans.	March 26	2	230,000	May 20	9	2	510,000
Ft. Smith, Ark.	May 20	9	120,000	March 17	1	6	30,000
Corpus Christi, Texas	April 19	6	78,000	April 27	7	3	2,200

ex

TABLE 2.2 (Cont'd)

No Precipitation.Precipitation

Station

Texarkana, Ark.
Des Moines, Iowa
Minneapolis, Minn.
Winnipeg, Man.
Prince George, B. C.
Port Arthur, Texas

Date	Burst	Act.
March 18	1	210,000
March 26	2	28,000
May 23	9	6,900
May 8	8	2,400
April 2		160
April 19	6	1,500,000

Date	Burst	Precip.	Act.
April 28	7	7	24,000
May 20	9	5	1,500,000
May 20	9	6	480,000
March 26	2	2	290,000
May 20	8	4	3,000
April 28	7	2	54,000

G: Stations 1200-1400 naut. miles from the test site

St. Louis, Mo.
Memphis, Tenn.
Jackson, Miss.
Chicago, Ill.
Milwaukee, Wis.
Green Bay, Wis.
Marquette, Mich.
New Orleans, La.

Date	Burst	Act.
March 26	2	120,000
March 18	1	630,000
April 28	7	210,000
May 26	10	19,000
May 26	10	45,000
March 27	2	5,400
May 22	9	4,800
April 19	6	630,000

Date	Burst	Precip.	Act.
April 28	7	3	130,000
April 28	7	2	240,000
April 29	7	8	45,000
May 20	9	5	140,000
May 20	9	5	240,000
May 20	9	6	360,000
May 20	9	6	940,000
April 29	7	4	45,000

H: Stations 1400-1600 naut. miles from the test site

Nashville, Tenn.
Louisville, Ky.
Grand Rapids, Mich.
Mobile, Ala.
Montgomery, Ala.

Date	Burst	Act.
March 19	1	340,000
May 21	9	130,000
May 28	10	3,300
March 26	6	300,000
May 21	9	51,000

Date	Burst	Precip.	Act.
April 29	7	7	42,000
April 27	7	5	66,000
May 20	9	6	100,000
March 20	1	4	8,700
March 26	2	4	21,000

TABLE 2.2 (Cont'd)

Station	<u>No Precipitation</u>			<u>Precipitation</u>			
	Date	Burst	Act.	Date	Burst	Precip.	Act.
Atlanta, Ga.	May 22	9	81,000	March 18	1	6	13,000
Knoxville, Tenn.	May 22	9	120,000	March 18	1	2	1,900,000
Detroit, Mich.	May 20	9	150,000	May 21	9	4	120,000
Alpena, Mich.	May 9	8	3,600	May 20	9	2	360,000
Churchill, Man.	April 1	2	2,800	April 24	6	2	6,900
Fort Simpson, N.W.T.	June 6		45	May 9	7	5	3,000
I: Stations 1600-1800 naut. miles from the test site							
Pittsburgh, Penn.	April 29	7	16,000	May 21	9	6	190,000
Dunkirk, N. Y.	March 21	1	2,200	May 29	10	6	25,000
Buffalo, N. Y.	June 5	10	4,200	May 21	9	6	72,000
North Bay, Ont.	May 10	8	720	May 21	9	6	59,000
Moosonee, Ont.	April 3	2	2,500	March 27	2	6	100,000
Rochester, N. Y.	June 7	11	7,200	June 6	11	2	57,000
Dansville, N. Y.	May 11	8	2,000	May 21	9	3	39,000
Lynchburgh, Va.	April 28	7	29,000	March 18	1	6	9,600
Jacksonville, Fla.	April 8	4	390,000	May 20	9	5	14,000
Charleston, S. C.	May 22	9	81,000	May 20	9	7	6,000
Deep River, Ont.	June 7	11	48,000	March 18	1	5	36,000
J: Stations 1800-2000 naut. miles from the test site							
Watertown, N. Y.	March 18	1	12,000	June 6	11	2	23,000
Syracuse, N. Y.	May 23	9	2,500	May 21	9	3	24,000
Binghamton, N. Y.	May 3	7	390	May 22	9	6	87,000

- TABLE 2.2 (Cont'd)

Stations	<u>No Precipitation</u>			<u>Precipitation</u>			
	Date	Burst	Act.	Date	Burst	Precip.	Act.
Washington, D. C.	April 29	7	24,000	March 18	1	6	130,000
Baltimore, Md.	May 26	10	28,000	March 18	1	6	96,000
Philadelphia, Penn.	May 23	9	0,000	March 18	1	6	560,000
New York, N. Y.	May 23	9	6,000	March 18	1	6	900,000
Albany, N. Y.	May 21	9	21,000	April 26	7	7	16,000,000
Montreal, P. Q.	April 26	7	330,000	May 22	11	5	36,000
New Haven, Conn.	May 11	8	16,000	April 7	7	7	930,000
Miami, Fla.	March 20	2	150,000	May 20	9	7	48,000

K: Stations 2000-2200 naut. miles from the test site

Providence, R. I.	May 11	8	45,000	April 7	9	7	910,000
Boston, Mass.	April 9	4	45,000	April 7	4	6	5,100,000
Caribou, Me.	May 1	7	9,000	April 27	7	6	250,000
East Port, Me.	May 3	7	4,200	April 27	7	3	94,000

L: Stations 2200-2600 naut. miles from the test site

Seven Islands, P. Q.	April 29	7	3,900	April 27	7	6	350,000
Moncton, N. B.	May 2	7	2,700	April 27	7	3	780,000
Bermuda	May 21	9	8,400	May 11	8	5	570,000
Stephenville, Nfld.	May 9	7	1,000	April 20	6	5	530,000

FIGURE 2.1 HIGHEST OBSERVED GUMMED FILM ACTIVITY ON DAYS WITHOUT PRECIPITATION AS A FUNCTION OF DISTANCE FROM THE TEST SITE

No similar plot for precipitation cases is presented for the Upshot-Knothole series, since it is evident from the Albany case that combinations of circumstances may yield even higher concentrations than have been experienced to date (see Chapter 4). This is especially true near the test site, where a strong bias towards low activity with precipitation exists, since no firings take place when precipitation is expected in the area.

The highest activity collected by the high volume air filters at each of the fourteen stations in the western United States where such equipment was operated is given in Table 2.3. The data are not separated by precipitation, since the activity collected by the air filter has not proven to be sensitive to the occurrence of precipitation.

TABLE 2.3

Maximum High Volume Air Filter Activity at Each Station

<u>Station</u>	<u>Date</u>	<u>Burst</u>	<u>Precip. Code</u>	<u>Activity (d/m/M³)</u>
Reno, Nev.	April 19	6	2	621
Elko, Nev.	March 24	2	1	1,980
Winnemucca, Nev.	April 19	6	1	168
Los Angeles, Calif.	March 26	2	1	42
San Francisco, Calif.	May 28	10	2	39
Salt Lake City, Utah	March 24	2	1	9,960
Grand Junction, Col.	May 19	9	2	21,793
Boise, Idaho	April 20		1	24
Pocatello, Idaho	May 25	10	1	472
Denver, Col.	April 27	7	1	1,242
Pueblo, Col.	April 27	7	1	2,249
Casper, Wyo.	March 24	2	1	984
Helena, Montana	May 26	10	2	60
Billings, Montana	May 9	8	3	325

The highest value observed on the air filters was 22,000 d/m/M³ at Grand Junction, Col., on May 19, the same day that had the maximum gummed paper activity at this station of 11,000,000 d/m/ft²/day. Boise, Idaho, had the lowest maximum activity, 24 d/m/M³.

From Tables 2.2 and 2.3, it is evident that the bursts responsible for the highest activity at the majority of the stations were the seventh, ninth, and second, in that order. All three were high-yield tower bursts.

2.3 DISCUSSION OF INDIVIDUAL BURSTS

Data concerning date, time, type of burst, yield, maximum altitude, etc., of the bursts of the Upshot-Knothole series are given in Table 2.1. The results of fallout monitoring from stations making daily observations are shown in Appendix A and comparisons of the areas of fallout predicted from meteorological considerations with the observed fallout patterns are shown in Appendix B. All references to date of sampling in the discussion to follow are to the date the sample was begun. All sampling was for a 24-hour period beginning at 1230 G.C.T. (0730 E.S.T.).

For each burst, a figure has been prepared showing the vertical structure of the atmosphere as given by the rawinsonde observation made at NPG at about burst time. These figures show the temperature (and dewpoint, when available) as a function of height above sea level. The winds at each 5,000-foot level are shown in standard meteorological symbols. The shaft of the wind arrow indicates the direction from which the wind was blowing and the barbs indicate the wind speed (long barb = 10 knots, short barb = 5 knots, triangular flag = 50 knots).

A map showing the trajectories of the debris at various levels in the atmosphere is given for each burst. These trajectories, computed from meteorological considerations, were prepared for the standard meteorological levels, 10,000 feet (700-millibar constant pressure surface), 18,000 feet (500 mb), 30,000 feet (300 mb), and 40,000 feet (200 mb) above mean sea level. Only those levels at which debris was present following the burst are shown. The successive six-hour positions (0000, 0600, 1200, and 1800 G.C.T.) of the cloud are indicated by circles along the trajectory. Each 0000 G.C.T. circle is filled in and the date indicated.

2.3.1 First Burst

The first burst, a tower shot which reached a maximum altitude of 41,000 feet was detonated at 1320 G.C.T., March 17, 1953. The vertical temperature and wind distribution at the time of detonation are shown in Figure 2.2. Westerly winds prevailed at all upper levels and the debris was carried eastward and somewhat northward over the St. Lawrence River Valley. The meteorological

FIGURE 2.2 UPPER AIR OBSERVATION AT MERCURY, NEVADA
1200 G.C.T., MARCH 17, 1953

trajectories of the burst are shown in Figure 2.3. On March 18, surface fallout was found about 200-300 miles farther south in central and eastern United States than had been indicated by the trajectories (see Figure B.1). This was undoubtedly the result of northerly winds in the lowest levels of the atmosphere associated with a well-developed anticyclone that moved through the central United States on this day. An interesting case of high activity occurred in eastern Tennessee on samples started on March 18. Knoxville collected 1,900,000 and 1,400,000 d/m/ft²/day on films exposed on that date, the second highest activity ever reported east of the Mississippi River. This activity was associated with a series of thundershowers that occurred with the passage of a cold front at about the time the 18,000-foot trajectory was in the area. Although the amounts of rain which fell were small, only a trace at Knoxville, there was considerable lightning reported, which indicates that strong vertical motions were present to bring down debris from aloft. Fairly intense dry fallout was experienced in the central United States on March 19, but on succeeding days the fallout was associated principally with rain.

2.3.2 Second Burst

The second burst, also a high yield tower shot, was detonated at 1310 G.C.T., March 24, 1953, and the resulting cloud reached to 41,000 feet. The temperature and wind distribution at the time of detonation is shown in Figure 2.4, and the trajectories of the cloud are shown in Figure 2.5. Southwesterly wind prevailed at most levels, and the trajectory of the debris between about 15,000 feet and 30,000 feet was directly towards Great Salt Lake. This resulted in the highest value for dry fallout recorded by the monitoring network, 15,000,000 d/m/ft²/day, as well as one of the highest air concentrations, 9960 d/m/M³, at Salt Lake City on the day of the burst. Heavy fallout was experienced in the northern plains states on March 25 as expected; however, on March 26 and 27 a band of heavy dry fallout extended from the central Mississippi valley through southern Florida. This fallout was undoubtedly associated with the fallout curtain from fast-moving high-level trajectories at 30,000 and 40,000 feet, which passed over this area on March 25, since the lower level cloud moved much more slowly and well to the north of this area.

2.3.3 Third Burst

The third burst was a very low yield tower shot detonated at 1300 G.C.T., March 31, 1953. The top of the mushroom extended to only 14,300 feet. Figure 2.6 shows the wind and temperature

FIGURE 23 METEOROLOGICAL TRAJECTORIES FROM THE FIRST BURST

FIGURE 2.4 UPPER AIR OBSERVATION AT MERCURY, NEVADA,
1100 G.C.T., MARCH 24, 1953

FIGURE METEOROLOGICAL TRAJECTORIES FROM THE SECOND BURST

FIGURE 2.6 UPPER AIR OBSERVATION AT MERCURY, NEVADA,
1200 G.C.T., MARCH 31, 1953

distribution at burst time and Figure 2.7 the trajectories of the debris at the 10,000 and 14,000-foot levels. All of the debris was carried southward initially. The uppermost part of the cloud moved over Lower California, while the 10,000-foot trajectory indicates that the stem recurved to the east. Except for the first day or two following the burst, when considerable fallout occurred in southern Nevada and in Arizona, there was very little fallout from this cloud, confined mainly to rain areas which coincided with the 10,000-foot trajectory.

2.3.4 Fourth Burst

The fourth burst was a high yield air burst detonated 6020 feet above the ground at 1530 G.C.T., April 6, 1953. The cloud resulting from this burst extended from 32,300 feet to 43,000 feet, with no visible debris below this level. Figure 2.8 shows the temperature and wind at the time of detonation and Figure 2.9 shows the trajectories of the debris at 30,000 and 40,000 feet. The cloud moved eastward extremely rapidly and crossed the east coast within 28 hours of burst time. The only appreciable fallout from this burst occurred in rain areas. On April 7, an area of very high activity was observed in southern New England associated with rain from a storm off the Atlantic Coast. This strong activity was also noted at the Brookhaven National Laboratory in eastern Long Island (C). The meteorological trajectory at 40,000 feet was 200 miles south-east east of this area at about 0000 G.C.T. on April 8. The Brookhaven report states "Although it rained on most of April 7, until 2.00 (0500 G.C.T., April 8), the activity did not arrive until about 2300 (0400 G.C.T., April 8). By then, the rain had subsided appreciably and the activity was deposited on the surface of the ground...Although the activity arrived at 2300, as is indicated by the roof counters, the dust monitors showed an initial increase only after 2400. Presumably, during this last hour of light rain the activity was being washed out of the air by the rain and little or no activity was present near the dust monitor intakes. However, as soon as the rain ceased, further vertical mixing brought the activity down near the surface of the ground where it could be collected by the dust monitors." Although the high activity was noted at Boston, Providence and Hartford, only moderate activity was experienced farther south at New York City, Philadelphia, Baltimore and Washington, and no activity was found inland at Albany or Binghamton. Rain occurred at all of these stations during the period, but had ended at the latter two well before the arrival of debris and had ended at stations south of New York City by 0400 G.C.T., April 8. The rain did continue in the southern New England area for several hours until about 1000 G.C.T.

FIGURE 27 METEOROLOGICAL TRAJECTORIES FROM THE THIRD BURST

FIGURE 2.8 UPPER AIR OBSERVATION AT MERCURY, NEVADA,
1600 G.C.T., APRIL 6, 1953

546 034

FIGURE 29 METEOROLOGICAL TRAJECTORIES FROM THE FOURTH BURST

It is probable that even higher activity would have been measured in the Atlantic Ocean 200-300 miles east of New York if observations had been available. The rain area from the storm under discussion included only Boston on the following day, and the only high activity reported was at this station. Little activity from this burst was evident on succeeding days.

2.3.5 Fifth Burst

The fifth burst was another very low yield tower burst, detonated at 1245 G.C.T., April 11, 1953. The atomic cloud attained a maximum altitude of 14,000 feet. The vertical temperature and wind distribution are shown in Figure 2.10 and the meteorological trajectories at 10,000 and 14,000 feet are given in Figure 2.11. The debris moved southward initially, but rapidly curved towards the east and moved across the southern tier of states. Except for the vicinity of the test site, debris from this burst resulted in only moderate activity and it is possible that some of the debris assigned to the fifth burst was actually residual debris from earlier bursts.

2.3.6 Sixth Burst

The sixth burst, a high yield tower shot, was detonated at 1235 G.C.T., April 18, 1953. The top of the mushroom reached 37,200 feet. The vertical structure of the atmosphere and the trajectories of the cloud are shown in Figures 2.12 and 2.13, respectively. As can be seen, there was very little directional shear in the winds above 10,000 feet, and most of the debris was carried eastward over the southern states. There was almost no precipitation associated with the trajectories from this burst. Considerable dry fallout occurred east of the test site, extending over New Mexico, Texas and Louisiana on April 19 and to southern Florida on the 20th. The surface deposition was somewhat south of the computed meteorological trajectories, probably as a result of the northerly surface winds behind a dry cold front which moved through the area on April 18 and 19, reaching southern Florida on the 20th. This burst accounted for the highest dry fallout observed at stations 1000-1400 nautical miles from the test site.

2.3.7 Seventh Burst

The seventh burst was the most powerful detonated in the United States up to that time and the most powerful tower burst

FIGURE 2.10 UPPER AIR OBSERVATION AT MERCURY, NEVADA,
1300 G.C.T., APRIL 11, 1953

346 037

FIGURE 2.11 METEOROLOGICAL TRAJECTORIES FROM THE FIFTH BURST

FIGURE 2.12 UPPER AIR OBSERVATION AT MERCURY, NEVADA
1200 G.C.T., APRIL 18, 1953

FIGURE 2.13 METEOROLOGICAL TRAJECTORIES FROM THE SIXTH BURST

ever attempted at NPG. It was detonated at 1230 G.C.T., April 25, 1953, and the cloud reached to 43,200 feet. Figure 2.14 shows the vertical structure of the atmosphere at burst time and Figure 2.15 shows the meteorological trajectories of the atomic debris. Although debris at all upper levels moved to the east-southeast initially, there were shears in both direction and speed which resulted in a rapid spread of the cloud after it passed the 95th meridian. The 40,000-foot trajectory, which was representative of the movement of the bulk of the mushroom, moved very rapidly to the northeast after passing through a pressure trough in the Mississippi Valley, reaching speeds of over 100 knots. This brought a heavy concentration of debris over Albany, N. Y., on April 26 at the time a thunderstorm was in progress, resulting in the highest surface activity ever recorded by the monitoring network. On the same day, dry fallout from lower levels resulted in very high activities in Utah, New Mexico (13,000,000 d/m/ft²/day at Roswell), and northern Texas. By April 27, most of the central part of the country was covered by dry fallout and in the extreme northeast considerable activity came down in rain. Debris from this burst covered most of the country east of the Rockies on April 28. Scattered patches of debris from this or previous bursts were evident for the next several days. By May 4, only very slight activity was noted in the United States. However, on May 6, increased activity was noted in the northwest and by May 7 light activity was found generally over the Rocky Mountain and Plateau region. This debris was in excellent agreement with the 40,000-foot trajectory from this burst, which passed completely around the hemisphere.

2.3.8 Eighth Burst

The eighth burst of the series was a high yield air burst detonated at 1530 G.C.T., May 8, 1953. The cloud top reached to 40,500 feet and the bottom of the mushroom was estimated to be at 33,000 feet, with a very thin trailing dust cloud to about 10,000 feet. The vertical structure of the atmosphere at the time of detonation is shown in Figure 2.16 and the trajectories of the debris are shown in Figure 2.17. The bulk of the debris from this burst moved initially to the northeast. Rain in the northern plains states resulted in the deposition of considerable activity on the day of the burst as far north as Williston, N. D. The debris reported on this day in New Mexico may either be the result of low level flow patterns or, quite possibly, the result of erroneously attributing debris to the eighth burst which in reality is from the seventh (see above). By May 9, debris covered most of the region from the Mississippi to the Rockies and extended into southern Canada. Again, on this date, it is possible that some debris from the seventh burst has been erroneously included

FIGURE 2.11, UPPER AIR OBSERVATION AT MERCURY, NEVADA
1100 G.C.T., APRIL 25, 1953

FIGURE 2 15 METEOROLOGICAL TRAJEC TORIES FROM THE SEVENTH BURST

FIGURE 2.16 UPPER AIR OBSERVATION AT MERCURY, NEVADA
1500 G.C.T., MAY 8, 1953

FIGURE 2.11 METEOROLOGICAL TRAJECTORIES FROM THE EIGHTH BURST

in the area ascribed to the eighth burst. Light fallout from this burst, principally in rain areas, continued for several days.

2.3.9 Ninth Burst

The ninth burst, the second most powerful tower shot of the series, was detonated at 1205 G.C.T., May 19, 1953. The top of the mushroom reached to 44,200 feet and the base was estimated at 28,000 feet, with a thick stem reaching to the surface. Figures 2.18 and 2.19 show the vertical soundings and the meteorological trajectories of this burst, respectively. The upper part of this cloud was carried to the southeast and over the Gulf of Mexico while the lower parts moved eastward and then northeastward over the Great Lakes. The position of the 40,000-foot trajectory has been independently verified by the observed track of a constant-pressure balloon released from Vernalis AFB by project Moby Dick. This balloon, which was within 50 miles of NPG at shot time, floated at about 40,000 feet and was tracked to a point 150 miles east of Jacksonville, Fla. Although fallout from the mushroom was evident over New Mexico on May 19, this portion of the cloud moved beyond the reporting network by May 20. However, heavy dry fallout from the stem, associated with the 10,000-foot and 18,000-foot trajectories was observed over Colorado and Kansas, while precipitation over the upper Midwest resulted in the highest values reported in that region for the series.

On May 21, fallout from this burst covered most of the country east of the Rockies. The activity found in the southern states on this date is probably fallout from the upper part of the cloud which was swept northward by the strong southerly winds coming off the Gulf of Mexico in the lower levels. A reexamination of the flow pattern between 25,000 and 30,000 feet in the Gulf of Mexico area indicates that a high pressure area with very light winds was centered over the Gulf on May 21 and persisted for several days, so that the debris at these levels remained in this region. Moderate fallout from the ninth burst was widespread over the country until at least May 25, when the next test occurred.

2.3.10 Tenth Burst

The tenth burst, fired at 1530 G.C.T., May 25, 1953,

FIGURE 2.18 UPPER AIR OBSERVATION AT MERCURY, NEVADA
1200 G.C.T., MAY 19, 1953

FIGURE 2.19 METEOROLOGICAL TRAJECTORIES FROM THE NINTH BURST

The vertical sounding at shot time (Figure 2.20) indicates that southwest winds prevailed at all levels, reaching a maximum of 120 knots at the top of the mushroom. The trajectories are shown in Figure 2.21. A low pressure area over California resulted in the movement of debris in the lowest levels to Washington and Oregon. A detailed account of the observed fallout in this area is contained in a report from the Hanford Atomic Products Operation (4). The debris at higher levels moved extremely rapidly to the east and the 30,000-foot trajectory crossed the New England coast 24 hours after detonation. Since fallout from the ninth burst persisted over most of the country until after the detonation of the tenth burst, it is extremely difficult to differentiate between the two. The burst assignment, and consequently the extrapolation to sampling day, must be considered questionable at many stations on May 25 and for several days thereafter.

At about the time the rapidly moving upper cloud from the tenth burst was over the east coast, a violent hailstorm occurred at Washington, D. C. A detailed analysis of the activity in the large hailstones occurring in this storm was made by the Naval Research Laboratory (5). The activity in the hailstones ranged from 0.5 to 3.2×10^{-10} curie/ml, corrected to the time of collection on the afternoon of May 26. Although a high concentration of activity was found in the air near the ground, undoubtedly associated with the violent vertical currents present in a hailstorm, the melting of successive layers of the stones revealed most of the activity was concentrated near the core of the hailstone, indicating that the greatest amount of activity was collected in the upper air where the hail first formed.

Moderate amounts of fallout persisted over most of the country for several days following the tenth burst.

2.3.11 Eleventh Burst

The eleventh, and final, burst of the Upshot-Knothole series was the most powerful device ever tested in the continental United States, an air burst detonated at 1115 G.C.T., June 4, 1953. The mushroom from this burst extended from 35,000 feet to a top of 41,700 feet, with a visible dust cloud below. As shown in Figure 2.22, the winds at burst time were the lightest encountered during the test series. The light winds prevailed at most levels

FIGURE 2.20 UPPER AIR OBSERVATION AT MERCURY, NEVADA
1500 G.C.T., MAY 25, 1953

FIGURE 2.21 METEOROLOGICAL TRAJECTORIES FROM THE TENTH BURST

FIGURE 2.22 UPPER AIR OBSERVATION AT MERCURY, NEVADA
1200 G.C.T., JUNE 4, 1953

for several days, as indicated by the meteorological trajectories (Figure 2.23) and carried the debris generally to the northeast. Again, with the eleventh burst, it was not always possible to distinguish between debris from this and the previous burst. Precipitation was rather widespread following the eleventh burst, and most fallout occurred in rain areas.

FIGURE 2.23 METEOROLOGICAL TRAJECTORIES FROM THE ELEVENTH BURST

CHAPTER 3

TOTAL FALLOUT FROM THE UPSHOT-KNOTHOLE TESTS

3.1 INTRODUCTION

A knowledge of what fraction of the radioactive debris released in the detonation of an atomic device is accounted for by the monitoring network has practical importance not only in evaluating the performance of the network, but also in related projects (e.g., Project Sunshine (6)). Estimates of the total beta activity in the fission products as a function of weapon yield can be made (7, p. 251), and these can be compared with the beta activity collected by the monitoring network. For convenience in making the calculations, all activity discussed in this chapter has been referred to a common date, July 1, 1953. Extrapolations to this date were made on the basis of the $t^{-1.2}$ law (Section 1.2). It should be noted that some of the factors which tend to bias the extrapolation to sampling date towards high values (such as ascribing debris to a too recent burst), tend to bias the extrapolation to July 1 toward low values.

A study of the total fallout from the detonation of the Upshot-Knothole series can be divided into three phases: 1) fallout in the vicinity of the test site; 2) fallout in the continental United States; and, 3) fallout in the rest of the world.

3.2 FALLOUT IN THE VICINITY OF THE TEST SITE

The relatively small areas of intense fallout in the region within 200 miles of the Proving Ground have been subjected to an extensive and careful analysis by Lulejian (8). He has estimated the total fallout from each of the Upshot-Knothole detonations for the period immediately following the shot and expressed the result as a percentage of the total fission product activity. The results are shown in Table 3.2. Only those shots in which the fireball intersected the ground produced any significant activity in the test site area.

3.3 FALLOUT IN THE CONTINENTAL UNITED STATES

For the purpose of investigating the total fallout from each burst in the continental United States, and its geographical

TABLE 3.1

Total Fallout (d/m/ft²) as of June 14, 1953, in the Continental United States,
by Regions and Bursts, Extrapolated to July 1, 1953. (Excluding the Test Site Area).

Burst	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	Mean
	Wash. Ore.	Mon. Ida. Wyo.	N.D. S.D. Neb.	Minn. Wis. Ohio Ky.	Mich. Ind. Ohio Ky.	N.Y. Pa. N.J.	Me. N.H. Vt. Mass. R.I. Conn.	Cal.	Nev. Utah Ariz.	Col. N.M.	Kan. Okla.	Iowa Ill. Mo.	Va. W.Va. Md. Del. D.C.	Tex.	Ark. La.	Tenn. Ala. Miss.	N.C. S.C. Ga. Fla.	U.S.
1	0	22	83	153	161	539	429	0	11	678	325	403	319	830	353	3725	113	415
2	449	1191	2217	72	347	63	406	0	8065	95	125	1072	83	31	266	1987	653	1404
3	6	11	24	0	46	25	0	0	333	104	2	8	112	183	248	151	109	91
4	0	6	26	46	37	28	5887	0	44	183	256	31	87	0	19	20	571	211
5	19	7	13	36	49	45	199	4	396	93	67	168	154	39	356	103	71	104
6	57	165	66	71	171	179	193	165	1023	3099	360	177	113	2014	1362	156	160	667
7	187	1269	2737	3893	3794	7229	1859	32	3868	25946	5453	3433	1235	4608	3082	3363	1057	4623
8	150	1031	2157	30	168	509	392	149	131	539	297	184	409	402	662	706	270	519
9	48	2474	2336	7078	7168	3254	513	27	2327	39856	11902	7482	2253	6561	1873	4597	4596	6773
10	2268	3062	2305	2263	3046	1812	338	58	1878	2643	2651	1862	1858	1646	574	1665	1473	2022
11	88	1849	667	252	801	1197	580	0	844	3981	2338	2958	265	229	156	230	165	1101
Total	3272	11087	12631	13894	15788	14880	10796	435	18920	77217	23776	17778	6888	16543	8951	16703	9238	17930

FIGURE 3.1 REGIONS USED IN COMPUTING TOTAL FALLOUT IN THE UNITED STATES (FIGURES INDICATE PERCENT OF TOTAL AREA OF THE UNITED STATES INCLUDED IN EACH REGION)

distribution, the United States was divided into seventeen regions. The regions, and their percentage of the total area of the United States are shown in Figure 3.1. The average gummed film activity of all stations in each region attributable to a specific burst (See Section 1.2) was found for every day of sampling from March 17 to June 14, 1953 (the last day on which daily samples were collected). The average activity so determined was assumed to be representative of the region. Table 3.1 gives the results of this study. The average activity (d/m/ft²) extrapolated to July 1, 1953 in each region from each burst is shown, together with the totals for the series (excluding the test site area in all cases).

From the data in Table 3.1, the total fallout in the United States was computed by multiplying the mean activity for each burst by the total area of the United States and converting to megacuries by the relationship: 1 megacurie = 2.22×10^{18} d/m. A comparison of the total beta activity produced with the amount accounted for by the continental monitoring programs is shown in Table 3.2.

TABLE 3.2

Total Fallout in the Continental United States

Burst No.	Total Produced (megacuries*)	Collected in United States, Exclusive of Test Site (megacuries*) (%)	Estimated Fallout near Test Site† (megacuries) (%)	Total Fallout in the United States (megacuries*) (%)
1		0.016	0.202	0.218
2		0.053	0.173	0.226
3		0.0034	-	0.003
4		0.0080	-	0.008
5		0.0039	0.023	0.027
6		0.025	0.424	0.449
7		0.175	0.904	1.079
8		0.020	-	0.020
9		0.257	0.532	0.789
10		0.077	-	0.077
11		0.042	-	0.042
All bursts	24.2	0.680 2.8	2.26 9.3	2.94 12.1

* β -activity, decayed to July 1, 1953.

† From Lulejian (8), dash signifies <1% of the activity produced was deposited in the test site area.

It is evident from Table 3.2 that only a small fraction of the radioactive debris produced in an atomic detonation is deposited on a horizontal surface and can be accounted for by the nationwide fallout monitoring network.

It is of some interest to determine the fraction of the debris which fell on the United States on successive days following each burst. Table 3.3 shows the percentage of the total observed fallout from each burst, exclusive of the test site area, which was observed by the monitoring network on the day of the burst and on each succeeding day until no debris could be attributed to the burst. For comparison purposes, all data for each burst were decayed to a common date, July 1, 1953.

There are many factors which influence the day-by-day deposition of debris: the distribution and intensity of precipitation associated with the trajectories, the speed with which the debris moves beyond the continental monitoring network and the path of the debris with respect to individual stations. The values for more than a few days following each burst are, of course, further affected by the frequency of tests, since a fresh burst will mask any fallout which may still be present from earlier bursts.

TABLE 3.3

Percent of Total Observed Activity Collected on Each Day Following Each Burst, Continental United States (Excluding Test Site Area).

Burst No.	Days After Burst												
	0	1	2	3	4	5	6	7	8	9	10	11	12
	%	%	%	%	%	%	%	%	%	%	%	%	%
1	4	48	29	9	4	3	-	-	2	-	-	-	-
2	59	11	9	4	2	2	5	4	-	1	-	2	-
3	2	22	10	2	27	19	18	-	-	-	-	-	-
4	11	57	24	3	1	2	1	-	-	-	-	-	-
5	1	24	11	24	12	5	13	9	2	-	-	-	-
6	23	42	11	6	6	4	4	4	-	-	-	-	-
7	6	37	21	19	7	5	1	-	1	-	-	-	1
8	30	17	7	10	7	3	3	4	3	2	5	7	1
9	38	19	13	10	9	7	3	1	-	-	-	-	-
10	3	15	14	16	11	0	6	7	5	5	7	2	3
11	11	41	16	12	4	3	2	3	4	2	3	-	-
Average, All Bursts	17	30	15	10	8	5	5	3	2	1	1	1	-

3.4 WORLD-WIDE FALLOUT

It is impossible to determine the world-wide fallout from each burst, because of the difficulty of assigning observed fallout to a particular burst, especially in the case of weekly samples. However, it is possible to estimate the total deposition of debris from the entire series. For this purpose, the activity collected at each of the daily sampling stations outside the continental United States (with the exception of Albrook AFB) was extrapolated to July 1, 1953, on the basis of the assigned burst shown in Appendix A. For the weekly stations, and for the daily values at Albrook AFB, extrapolation was on the basis of an arbitrarily assigned burst determined from the average time of travel of debris to the various stations. For the continental United States stations, the total fallout in each of the seventeen regions mentioned above was determined. The results of these calculations for the northern hemisphere stations are shown in Figure 3.2. (The totals for the two southern hemisphere stations, Lima, Peru, and Pretoria, Union of South Africa, were low, 36 d/m/ft² at Lima and no measurable activity at Pretoria. All values are the total fallout from the period March 17 to June 14, 1953, extrapolated to July 1, 1953,

FIGURE 2.3 TOTAL FALLOUT IN THE NORTHERN HEMISPHERE, MARCH 17
TO JUNE 14, 1953, ($\mu\text{Ci}/\text{m}^2$ DECAYED TO JULY 1, 1953)

expressed in disintegrations per minute per square foot. Isolines of constant activity are shown, and the average activity in the northern hemisphere determined by graphical integration. An average value for the southern hemisphere was also estimated, and the total world-wide fallout was computed. The results are shown in Table 3.4.

TABLE 3.4

Total Fallout From the Upshot-Knothole Series as of June 14, 1953

	d/m/ft ² *	megacuries*	% of Total Produced
United States			
(Excluding Test Site)	17900	0.68	2.8
Northern Hemisphere			
(Excluding Test Site)	3000	3.71	15.3
Southern Hemisphere	120	0.15	0.6
Test Site	-	2.24	9.3
Total for World	-	6.10	25.2

* β -activity, decayed to July 1, 1953.

The results shown above are open to considerable uncertainty. They are based only upon the activity collected by a small horizontal gummed surface exposed at widely scattered points. It may well be that debris is collected much more efficiently by the relatively huge surfaces presented by foliage, which are randomly oriented, or by buildings, mountains, etc., which tend to be more vertical. The efficiency of the gummed surface is likewise not known, especially in the case of rain. Perhaps the increase in activity noted in rain is indicative of a much larger true increase, and that a large part of the activity is lost in water that splatters or runs off the gummed film stands. The water surfaces of the globe, which represent about three-quarters of the total area of the earth may also be much more efficient collectors than the gummed films.

Another uncertainty arises from the distribution of stations. Although an attempt was made to use meteorological consideration in drawing the isolines in Figure 3.2, the absence of stations representative of the more rainy portions of the globe introduces considerable uncertainty. The two Southern Hemisphere stations were located in particularly dry climates, and it was necessary to make a very doubtful estimate of the average activity over that

half of the world. In addition, the extrapolation to July 1, 1953, was done on an arbitrary basis for the weekly sampling stations, and may have resulted in an underestimate of the total fallout because of the tendency to use a too recent burst in extrapolating activity of mixed origin.

Since the monitoring programs are able to account for only 25% of the fission product activity produced by the Upshot-Knothole series, as of June 14, 1953, the question arises as to the disposition of the remaining 75% of the debris.¹ It is difficult to assess the probable error involved in the various monitoring programs, but as pointed out above, the possibility of considerable error exists in attempting to estimate the total fallout from a relatively few gummed film monitoring stations. If it is assumed that the test site results are in error by no more than a factor of two, that the gummed film data are also within a factor of two of being correct, and that both errors operate to make the totals too low, it would still be impossible to account for about 50% of the debris as of June 14.

One possible explanation is that considerable debris is still present in the atmosphere in the form of very small particles, the smallest of which are in virtual colloidal suspension in the air, and the slightly larger particles continue to settle out at a slow rate for a considerable period.

Subsequent to June 14, 1953, weekly sampling was continued at about 14 overseas stations in the Northern Hemisphere and a similar number in the United States. Most stations continued to report small amounts of activity, averaging from 100 to 300 d/m/ft² for a week's exposure. The counting procedure used is not suitable for measuring low levels of activity, so that the results are uncertain. However, if an average fallout of 30 d/m/ft²/day occurs over the Northern Hemisphere and continues for an extended period, say three months, about 3 megacuries will be deposited, which is less than 12% of the total produced. This means that the continued deposition of small particles will not serve to explain the difference between the activity produced and that accounted for by the monitoring programs unless such deposition were to continue for a period of a year or more.

¹The Rand Corporation (9) found similar results following the Tumbler-Snapper series. They report 13.7% of the total fission product activity accounted for by the monitoring programs. However, it is estimated that the correction due to the recalibration of the automatic counting equipment (see Preface) will raise this figure to about 25%.

It is possible that a considerable amount of debris remains airborne. If it is assumed that the activity is uniformly distributed (by weight) in the troposphere, below the 150 millibar level, then an average activity on July 1 of 7.8 d/m/per cubic meter of air at NTP would be required to account for 12 megacuries (50% of the activity produced). No such activities are observed. Although air filter operations were stopped shortly after the conclusion of the Upshot-Knothole tests, an examination of the air filter data following the last Tumbler-Snapper series showed that air concentrations averaged less than 3 d/m/M³ within two weeks of the last burst.

From the foregoing computations, it seems likely that the explanation of the difference between monitored fallout and the activity produced lies in the failure of the monitoring network to measure all the debris which comes to earth.

CHAPTER 4

THE DESIGN OF A FALLOUT MONITORING NETWORK

4.1 SPATIAL VARIABILITY OF FALLOUT

In the design of a gummed film fallout monitoring network, the proper spacing of stations is a function of the spatial variability of the deposited debris, of the allowable tolerance in missing small areas of high fallout, and of the duration of the sampling period. It should be noted that the allowable tolerance may be variable from region to region depending on the importance of radioactive contamination to the industrial or other activities of the region.

For the twenty-four hour sampling period used in the continental United States during the Upshot-Knothole series, the variability of deposited activity from station to station can be studied as a function of the spacing of observation points. To estimate the greatest possible accuracy in locating areas of high concentration of debris, using a hypothetical network of stations spaced at six-foot intervals, a study was made of the difference in activity found on the two gummed film stands spaced six feet apart at seven stations in the eastern United States, and at three stations in the western United States close to the test site (Ely, Nev., Milford, Utah, and Salt Lake City, Utah). For stations somewhat farther apart, but still too close to be operationally feasible, a similar comparison was made for gummed films exposed at Weather Bureau City Offices and Airport Stations in the same city, a spacing of about ten miles, on the average.

In these studies, data are included for only those cases in which at least one sample of the pair had an activity on counting day of $300 \text{ d/m/ft}^2/\text{day}$ or more. For each such pair, the number of orders of magnitude by which the activity on one sample differed from that on the other was tabulated (i.e., if the activity on one sample was less than 10 times larger than the other, they were considered to be of the same order of magnitude; if one was 10 times larger than the other or more, but less than 100 times larger, they were considered to differ by one order of magnitude, etc.) The results of this study are shown in Figure 4.1. It is evident that about 90% of the time, the pairs of samples differed by less than one order of magnitude and that over 97% of the pairs differed by less than a factor of 100. In no case was a difference of three orders of magnitude or more found in the more than 500 pairs with significant activity included in the study.

FIGURE 4.1 DIFFERENCE IN ACTIVITY COLLECTED ON GUMMED FILMS EXPOSED SIMULTANEOUSLY IN THE SAME CITY, UPSHOT-KNOTHOLE TESTS

The results just cited would indicate the maximum possible accuracy to be obtained from hypothetical networks of stations spaced at six-foot and at 10-mile intervals. A similar study has been made using separate stations in the Upshot-Knothole network. For the study, three base stations were selected, Rochester, N. Y., Montgomery, Ala., and Concordia, Kan., and the activity at each base station was compared with the activity on the same day at all surrounding stations up to a distance of 600 miles from the base station. Comparisons in every case involved the activity on the gummed film exposed on only one stand (stand number 1) at each station. The data were grouped according to distance from the base station, 0-100 miles, 100-200 miles, etc. No significant differences were found among the three base stations and a composite tabulation was prepared combining the results from all three. The results are shown in Figure 4.2. From this figure, it is possible to make certain deductions concerning the appropriate spacing of stations. For example, if it is desired that no fallout of three orders of magnitude or more different from that at a sampling station go undetected at least 95% of the time, then stations should be spaced no more than 300 miles apart, assuming a 24-hour sampling period and one gummed film exposed at each station.

For comparison with the Tumbler-Snapper tests, a similar study using the same base stations was made for data from that series. However, the differences between stations were computed from the average activity of the three gummed papers exposed at each station rather than from one paper at each station. The results are shown in Figure 4.3. It is evident that smaller differences between stations appear to exist in the Tumbler-Snapper series as compared with the Upshot-Knothole series. However, much of the difference is undoubtedly a result of the fact that the average of three papers was used in the former case and one film in the latter. Other factors which may have influenced the result are the greater number of tower shots and the higher yield of the devices tested in the Upshot-Knothole series, resulting in higher concentration of debris, and the somewhat different weather regimes. The Spring of 1953 had generally more showery weather in the eastern half of the country.

4.2 PHYSICAL PROCESSES

To utilize the data given above in the design of a monitoring network, it is also necessary to consider the physical processes which lead to small areas of unusually high concentration of fallout. The location of areas of intense fallout within 200 miles of the test site has been a subject of intensive study elsewhere (8) and will not be discussed here.

FIGURE 4.2 DIFFERENCE IN ACTIVITY COLLECTED ON SIMULTANEOUSLY-EXPOSED GUMMED FILMS AS A FUNCTION OF DISTANCE BETWEEN STATIONS, UPSHOT-KNOTHOLE TESTS

FIGURE 4.3 DIFFERENCE IN AVERAGE ACTIVITY COLLECTED ON SIMULTANEOUSLY-EXPOSED GUMMED PAPERS AS A FUNCTION OF DISTANCE BETWEEN STATIONS, TUMBLER-SNAPPER TESTS

4.2.1 200 to 600 Miles From Test Site

In the region from 200 to 600 miles from the test site, intense ground deposition will (barring accident) result from dry fallout, since no tests are fired if precipitation is expected downwind within 500 miles of NPG. Circumstances which favor intense fallout in this region would include the production of large amounts of debris (high-yield tower burst) and a relatively slow-moving cloud. Lack of wind shear would contribute to a narrow fallout area, but at these close distances, fallout of large particles from a small portion of the cloud may result in localized high activity even in the presence of large shears. An example of intense localized fallout within a few hundred miles of the test site is shown in the fallout map for March 24 (Figure A.8). A narrow band of heavy dry fallout extends from Ely, Nev., north-eastward through Salt Lake City, Utah, to Casper, Wyo., apparently associated with the upper part of the stem and the very lowest part of the mushroom of the cloud. The most active film at Salt Lake City had $15,000,000 \text{ d/m/ft}^2/\text{day}$, while Ely and Casper had $2,100,000 \text{ d/m/ft}^2/\text{day}$. However, no activity was found at Milford, Utah, 100 miles southwest of the line of fallout and only $90,000 \text{ d/m/ft}^2/\text{day}$ was observed at Rock Springs, Wyo., which is less than 20 miles from a line joining Salt Lake City and Casper. Certainly, if Salt Lake City were not included in the network, intensity of the fallout in this area would have been underestimated by at least an order of magnitude, and it is very probable that an even more intense fallout occurred slightly to the north of the stations considered here. Since it would require an impossibly dense network of stations to detect every area of intense fallout within 500 or 600 miles of the test site, especially in the mountainous regions, it appears more feasible to supplement the monitoring in the 200-600 mile annulus with aerial observations. The possible occurrence of unexpected showers in the mountains, which may go undetected by the normal meteorological network, would further indicate the need for supplemental monitoring of some sort in view of the highly erratic nature of the precipitation in this area.

4.2.2 Beyond 600 Miles From Test Site

Beyond about 600 miles from the test site, heavy fallout ($>10^6 \text{ d/m/ft}^2/\text{day}$) is almost invariably associated with precipitation. The conditions which lead to heavy fallout at these distances are:

1. Production of large amounts of debris (high-yield tower burst),

2. The presence of a high concentration of fresh debris aloft (fast-moving mushroom),
3. Precipitation-producing clouds extending to high levels (showers or thundershowers).

In general, all three conditions must be satisfied for heavy fallout to result. The spatial distribution of heavy fallout and the possibility of local areas of intense contamination under these conditions is therefore a function of the distribution of debris aloft and of the distribution of the precipitation which scavenges it.

An estimate of the rate at which the concentration of debris aloft decreases away from the center of the cloud can be made using certain simplifying assumptions. If it is assumed that there is a point source of debris, no wind shear and a coefficient of horizontal eddy diffusivity of $10^8 \text{ cm}^2 \text{ sec}^{-1}$, then after 36 hours the distribution of debris, if projected on a horizontal surface, is as shown in Table 4.1, which gives the activity at various distances from the center of the cloud relative to the peak activity.

TABLE 4.1

Concentration of Debris as a Function of Distance From the Center of a Cloud After 36 Hours, Assuming a Coefficient of Horizontal Eddy Diffusion of $10^8 \text{ cm}^2 \text{ sec}^{-1}$

Distance from Center of Cloud (miles)	Relative Concentration
0	1.0
65	0.1
90	0.01
110	0.001
130	0.0001

Because of the simplifying assumptions employed, Table 4.1 exaggerates the gradients of activity likely to be found in actual cases, principally because of neglecting the effect of wind shear, which, when coupled with vertical diffusion, will cause a more rapid spread and greater dilution of the cloud. It should be noted that Table 4.1 represents an instantaneous view of the cloud, whereas sampling over a 24-hour period integrates the activity over successive positions of the cloud.

Although the distribution of precipitation is known to be very irregular and to have many small-scale features, very little of the voluminous literature on precipitation distribution is directly applicable to the present problem. One study, by Linsley and Kohler (10), of a network of 55 uniformly-spaced rain gages in a rectangular area roughly 10 miles by 20 miles in Ohio, during two thunderstorm seasons showed that in about 2% of the storms, one preassigned station will have less than 0.01 inch of rain while another station in the 200-square mile area will observe over 1.00 inch of rain. If it is assumed that 1.00 inch of rain will scavenge, virtually, all debris in the air above the station, while less than 0.10 inch of rain will be relatively ineffective for scavenging large amounts of debris, it is obvious that large gradients in deposited activity will exist over small areas.

4.3 INTENSE FALLOUT AT ALBANY, N. Y.

An interesting example of a small area of very intense fallout occurred near Albany, N. Y., on April 26, following the seventh burst. On this date, the highest gummed film activity ever observed by the monitoring network, 16,000,000 d/m/ft²/day, occurred on the film exposed at the Albany airport. Although there are six monitoring stations within 150 miles of Albany, the fallout intensity would have been underestimated by about three orders of magnitude in this area had there been no station at Albany. From an analysis of the meteorological data, it appears that the intense activity at Albany was associated with a severe thunderstorm reported at the Albany airport from 2254 G.C.T., April 26 to 0115 G.C.T., April 27.¹ Although the altitude reached by this particular storm is unknown, severe thunderstorms ordinarily extend to the base of the stratosphere, about 40,000 feet. The trajectory of the mushroom of the cloud at 40,000 feet was in this area at the time. Figure 4.4 shows the 40,000-foot trajectory, the location of the monitoring stations in New York and adjoining states, the activity (d/m/ft²/day) measured on the most active or the two papers exposed from 1230 G.C.T., April 26, to 1230 G.C.T., April 27 at each of the stations and the results of measurements made from an aircraft on May 1 by Harley (11). The aerial survey was made with a Scintair gamma instrument at a height of approximately 500 feet above terrain along the Hudson River from Poughkeepsie, where the first appreciable rise in activity took place, northward to the Albany-Troy area. The readings were converted to ground level radiation by multiplying by 10 and are expressed in units of 10⁻²mr/hr.

¹This has been verified by data collected at the Knolls Atomic Power Laboratory, near Schenectady. (Quarterly Report of the Environmental Monitoring Radiological Services Sub-Unit, April, May, June, 1953. Report No. KAPL-1008.)

FIGURE 4.4 FALLOUT IN NORTHEASTERN UNITED STATES, APRIL 26, 1953, AND RESULTS OF AERIAL SURVEY ON MAY 1, 1953

Figures 4.5 to 4.9 show the precipitation recorded during each hour between 2200 G.C.T., April 26, and 0300 G.C.T., April 27, on all available recording rain gages in the area. Areas with measurable amounts of precipitation are shaded; more than 0.30 in/hr is indicated by hatching. The spotty character and large horizontal gradients characteristic of showery precipitation are evident in these maps. Although the areas of heavy rainfall from 2300 to 2400 G.C.T. on April 26 agree well with the location of areas of high activity as determined from the aircraft, it is certainly probable that other areas, not surveyed by air and not containing ground monitoring stations, would have had even higher readings. For example, a very heavy shower occurred in eastern Pennsylvania between 2200 and 2300 G.C.T. Southern Vermont and western Massachusetts had heavy showers from 0200 to 0300 G.C.T. These may well have scavenged more debris than was found near Albany. The reason for the much lower activities found at Binghampton, and other monitoring stations within 150 miles of Albany is evident from the precipitation distribution.

If it is desirable to reduce the probability of intense localized contamination, in the eastern half of the country, which may go undetected by the present monitoring network, tests should be avoided in periods which combine showery precipitation regimes with rapid eastward flow at upper levels. The former are most prevalent in the Spring and Summer months while the latter is most common in the winter half of the year, although each can occur in all seasons.

4.4 OTHER IMPLICATIONS OF THE ALBANY FALLOUT

Because of the many unknowns involved, initial concentration, particle-sized distribution, terminal velocities, scavenging efficiency, eddy diffusion, wind shear, etc., it is impossible to make valid quantitative estimates of the maximum fallout or rainout likely to occur from continental tests. In Chapter 2, the maximum observed fallout at the various station during the Upshot-Knothole series is indicated for dry fallout at distances greater than 600 miles from the test site. However, in view of the Albany case, no conclusions were reached concerning maximum possible rainout and it is very likely that certain combinations of circumstances can bring about surface depositions many times larger than have been heretofore observed from continental tests.

Even if the Albany fallout approaches the maximum likely at distances of 2,000 nautical miles from the test site, and this is by no means certain, what is implied concerning maximum fallout closer to the test site? Assuming no forecasting errors occur, i.e., no rain within 500-600 miles of the test site, it is still

FIGURE 4.5 PRECIPITATION IN NORTHEASTERN UNITED STATES,
2200 G.C.T. to 2300 G.C.T., APRIL 26, 1953

FIGURE 4.6 PRECIPITATION IN NORTHEASTERN UNITED STATES,
2300 G.C.T. to 2400 G.C.T., APRIL 26, 1953

FIGURE 4.7 PRECIPITATION IN NORTHEASTERN UNITED STATES,
0000 G.C.T. to 0100 G.C.T., APRIL 27, 1953

**FIGURE 4.8 PRECIPITATION IN NORTHEASTERN UNITED STATES,
0100 G.C.T. to 0200 G.C.T., APRIL 27, 1953**

**FIGURE 4.9 PRECIPITATION IN NORTHEASTERN UNITED STATES
0200 G.C.T. to 0300 G.C.T., APRIL 27, 1953**

very possible for thundershowers to coincide with a much fresher cloud in the region just beyond the 600-mile limit.

If the activity at Albany is taken to be 10^7 d/m/ft²/day (this value is more nearly the activity at the actual time of fallout, since the debris was 36 hours old rather than one day old as is assumed in the simplified routine extrapolation procedure used), it is possible to estimate the effect of a similar situation in, say, western Kansas, where both diffusion and decay would have had less time to operate. If the fallout occurred within 5 or 6 hours of burst time, the increase in concentration of deposited activity due to the shorter decay time alone would be by a factor of 10. The increase due to the shorter time available for diffusion (and shear) to act would be at least a factor of 6 and could be more than a factor of 100 under certain reasonable assumptions, resulting in activities of the order of 10^9 to 10^{11} d/m/ft² at the time of deposition.

4.5 OTHER POSSIBLE CASES OF INTENSE FALLOUT

It is also of interest to examine the trajectories and precipitation patterns accompanying bursts of this and previous Nevada tests series to see if other potentially serious cases of intense localized fallout could have occurred which were undetected by the monitoring network. Several such situations were found. They are: New York and New England on November 1, 1951, November 3, 1951, and April 7, 1953; Nebraska on May 26, 1952; and Wyoming on May 8, 1952. The latter case appears to be the one most likely to have produced intense local fallout.

CHAPTER 5

PREFERRED MONTHS FOR NEVADA TESTS

5.1 FACTORS STUDIED

Extensive studies have indicated that there is no more satisfactory location in the continental United States at which to conduct atomic tests than the Nevada Proving Grounds, when all factors are considered. Assuming, therefore, that future continental test series will be conducted there, some attention should be given to the problem of selecting the most suitable season for this purpose. The last two continental test series, the only continental tests involving high-yield tower shots, have both been in the spring, and the question arises as to whether this is the best season from a meteorological point of view. Of the factors to be considered, the most important is the probability of favorable weather at the test site. However, several other factors should also be considered. These include the probability of avoiding intense local fallout at some distance from the test site, the possibility of reducing total fallout in the United States and the possibility of minimizing adverse public reaction due to the widespread belief that the atomic tests, in some fashion, cause unusual weather. While the last is not, strictly speaking, a meteorological factor, meteorological considerations can be used.

5.2 PROBABILITY OF FAVORABLE WEATHER AT THE TEST SITE

Since this factor has been considered in detail in various studies on the feasibility of utilizing the Nevada Proving Ground, only a broad outline of the seasonal variation of weather, based on observations at Las Vegas, will be given here. Table 5.1 shows the mean monthly distribution of cloudiness, precipitation, and thunderstorms at Las Vegas, based on a 16-year record.

From Table 5.1, it is seen that rainfall is light in all seasons, May and June having the least rain and the months from December through March having the most. The months from May through November have clear weather on over half the days. Thunderstorms are most prevalent at Las Vegas, and presumably in the area surrounding the test site, in July, August, and September, and are very infrequent in other seasons.

TABLE 5.1

Mean Monthly Distribution of Precipitation, Cloudiness,
and Thunderstorms at Las Vegas, Nevada

Month	J	F	M	A	M	J	J	A	S	O	N	D
Precipitation (inches)	0.58	0.40	0.55	0.28	0.39	0.02	0.43	0.38	0.50	0.24	0.20	0.47
Clear [/] (no. days)	14	11	13	13	17	23	21	21	22	21	16	12
Partly Cloudy [/] (no. days)	6	7	9	9	10	5	7	7	5	5	8	7
Cloudy [/] (no. days)	11	10	9	8	4	2	3	3	3	5	6	12
Precipitation ≥0.01" (no. days)	3	3	3	2	1	*	2	2	2	2	2	3
Thunderstorms (no. days)	*	*	*	1	1	1	5	3	2	1	*	*

*Less than 1/2 day.

[/]Sunrise to sunset.

Source: U. S. Department of Commerce, Weather Bureau, Local
Climatological Data.

Table 5.2 shows the frequency of winds at various levels which are favorable for firing as a function of season. Favorable winds are defined for the purpose as any winds blowing from the WNW, W, from any direction having a southerly component or from the east.

Although the frequencies in Table 5.2 overestimate the number of favorable days, since they do not consider occasions on which winds at one level are favorable, while being unfavorable at another, they indicate the qualitative relationship of one season to another with respect to favorable wind directions. It is evident that the probability of favorable wind directions is higher in the summer than in any other season and that there is little difference among the remaining seasons of the year.

TABLE 5.2

Percentage Frequency of Favorable Wind Directions Over Las Vegas

Altitude	Season									
	Dec-Jan-Feb	Mar-Apr-May	Jun-Jul-Aug	Sept-Oct-Nov						
850 mb. (5,000 ft.)	45	48	74	44						
700 mb. (10,000 ft.)	59	61	92	71						
500 mb. (18,000 ft.)	66	68	90	73						
300 mb. (30,000 ft.)	69	73	90	71						
200 mb. (40,000 ft.)	77	76	91	75						

Source: Reference 13.

With the exception of the higher incidence of thunderstorms in the summer months, this season seems best suited to test operations at Las Vegas. If thunderstorm activity is to be avoided or if tests are not desirable in the heat of the desert summer, fall would be somewhat preferable to spring because of the higher probability of having cloudless days in the fall.

5.3 PROBABILITY OF INTENSE LOCAL FALLOUT AWAY FROM THE TEST SITE

As discussed in Chapter 4, the occurrence of intense local fallout at distances greater than 600 miles from the test site is dependent on the occurrence of showers or thundershowers in a region having a high concentration of debris aloft. The high concentration of debris aloft is, in turn, the result of a high-yield tower shot which injects large amounts of debris into a fast-moving wind stream that serves to carry the debris to great distances before much dilution can occur. The probability of the latter phenomenon can be estimated from the occurrence of very fast winds over Las Vegas. Table 5.3 shows the seasonal frequency of winds of 75 knots or more at 30,000 and 40,000 feet and blowing from a direction favorable for firing.

The average number of thunderstorm days in each month for selected United States stations is given in Table 5.4.

TABLE 5.3

**Percentage Frequency of Winds of 75 Knots or More
From Favorable Directions at Las Vegas**

	Dec-Jan-Feb	Mar-Apr-May	June-July-Aug	Sept-Oct-Nov
30,000 ft.	21	17	2	9
40,000 ft.	28	19	9	13

Source: Reference 13.

From Table 5.4, it is evident that thunderstorm activity is at a minimum from November through February, with a slight increase in number in the southeastern and south-central States in March. This increase continues in April and May, and from June through August thunderstorms are frequent over most of the country, with the exception of the Pacific Coast region. A marked decrease occurs in September, except for the Gulf coast region, and by October thunderstorms are again relatively rare. If situations favorable to intense local fallout at distances greater than 600 miles from the test site are to be avoided, the months of October and November seem to be preferable, since both thunderstorm activity in the United States and fast upper winds over Las Vegas are relatively infrequent in these months.

5.4 REDUCING TOTAL FALLOUT IN THE UNITED STATES

The efficacy of precipitation in bringing debris to the ground is well established, and it follows that the most likely method of reducing total fallout in the United States is to schedule tests for periods when precipitation is least likely. Table 5.5 shows the mean annual precipitation for each state and the percent which falls in each month, on the average.

It can be seen that in the eastern states, although the seasonal variation is not large, precipitation is at a maximum in the summer months and lightest in October and November. In the central states, the seasonal maximum in rainfall occurs somewhat earlier, in May and June and the late fall and winter months have the smallest amounts of precipitation, here the seasonal variation is somewhat more pronounced. In the western states, rainfall is not as significant for the total fallout, since there is a bias toward shooting in periods with little rain in the plateau region and the far western states are ordinarily not affected by direct trajectories from the test site.

TABLE 5.4

Mean Number of Days Per Month With Thunderstorms

	Period of Record	J	F	M	A	M	J	J	A	S	O	N	D
Eastern United States													
Boston	58	*	*	1	1	2	4	5	4	2	*	*	*
Buffalo	62	*	*	1	2	4	5	7	5	3	1	1	*
New York	69	*	*	1	2	4	6	7	6	3	1	*	*
Washington	81	*	*	1	2	5	6	8	6	3	1	*	*
Memphis	72	2	2	4	5	6	8	8	7	4	2	2	1
Montgomery	81	1	2	4	4	6	10	11	9	4	1	1	1
Jacksonville	62	1	2	3	4	8	13	18	16	8	2	1	1
Miami	43	1	1	2	4	8	11	14	13	11	4	1	1
Central United States													
Minneapolis	61	*	*	1	2	6	8	7	7	5	2	1	0
Chicago	74	*	*	2	3	5	7	7	6	4	2	1	*
St. Louis	61	1	1	3	5	7	9	7	7	5	3	1	*
New Orleans	54	2	2	4	5	6	11	15	15	7	2	1	2
Williston	72	0	0	*	1	3	7	7	5	2	*	0	0
Amarillo	62	*	*	1	3	7	7	8	8	4	3	*	*
Corpus Christi	67	1	1	2	3	5	4	4	4	5	2	1	1

TABLE 5.4 (Cont'd)

		Period of Record	J	F	M	A	M	J	J	A	S	O	N	D
Western United States														
Albuquerque	23		*	*	1	2	4	6	13	13	5	3	*	*
Salt Lake City	26		*	1	1	3	4	5	7	8	4	2	*	*
Spokane	72		*	0	*	1	2	3	2	2	1	*	*	0
Phoenix	58		*	1	1	1	1	1	7	9	4	1	1	*
Elko	5		*	0	*	1	4	3	7	5	4	1	*	0
Las Vegas	16		*	*	*	1	1	1	5	3	2	1	*	*
Los Angeles	11		0	1	*	*	0	0	*	*	0	*	1	1
San Francisco	26		*	*	*	*	*	*	*	*	*	*	*	*
Seattle	61		*	*	*	*	1	1	1	1	1	*	*	*
Denver	69		*	*	*	2	6	9	11	10	4	1	*	*
Cheyenne	72		0	*	*	2	7	10	13	10	4	1	*	0

*Less than 1/2 day.

Source: U. S. Department of Commerce, Weather Bureau, Local Climatological Data.

TABLE 5.5

Mean Annual Precipitation in the United States and the Percent Occurring in Each Month

	Mean Annual Precipitation	Monthly Percentages											
		J	F	M	A	M	J	J	A	S	O	N	D
Eastern States													
Alabama	53.61	9	10	11	8	7	8	10	9	6	5	7	9
Delaware	44.08	8	7	9	8	8	9	11	11	8	7	7	8
Florida	53.37	5	6	6	6	7	13	14	13	13	8	4	5
Georgia	50.31	9	10	10	8	7	9	11	10	7	5	6	9
Kentucky	45.27	10	8	10	9	9	9	9	8	6	6	8	8
Maryland	41.87	8	7	8	8	9	10	10	11	8	7	6	8
Mississippi	53.45	10	9	11	9	8	8	9	8	6	5	7	10
N.N. England													
Me., N.H., Vt.	39.78	8	7	8	8	8	9	10	9	9	8	9	8
S.N. England													
Mass., R.I., Conn.	43.91	8	8	9	8	8	8	9	9	9	8	8	8
New Jersey	45.69	8	8	8	8	8	8	10	10	8	8	7	8
New York	39.32	7	7	8	8	9	9	10	9	9	8	8	8
N. Carolina	49.62	8	8	9	7	8	9	12	11	8	7	6	8
Ohio	38.00	8	7	9	9	10	10	10	9	8	7	7	7
Penna.	42.13	7	7	8	8	10	10	10	10	8	8	7	7
S. Carolina	47.91	7	9	8	7	7	10	12	12	9	6	5	8
Tennessee	49.80	10	9	11	9	8	8	9	8	6	6	7	9
Virginia	42.06	8	7	9	8	9	10	11	11	8	7	6	7
West Virginia	43.14	8	7	9	8	9	10	11	9	7	7	6	8

TABLE 5.5 (Cont'd)

	Mean Annual Precipitation	J	F	M	A	Monthly Percentages							
		M	J	J	A	S	O	N	D				
Central States													
Arkansas	48.50	9	7	10	10	10	8	8	7	7	7	8	9
Illinois	36.78	6	5	9	10	11	11	9	9	10	7	7	6
Indiana	39.29	8	6	10	9	10	10	8	8	8	7	8	7
Iowa	31.71	3	3	6	9	13	15	11	11	12	7	5	4
Kansas	27.01	3	4	6	10	14	15	12	12	10	7	5	3
Louisiana	56.49	9	8	9	8	8	8	11	9	7	6	7	9
Michigan	30.46	6	6	7	8	11	10	9	9	10	9	8	7
Minnesota	25.40	3	3	5	8	13	16	13	13	11	7	5	3
Missouri	40.49	6	5	8	10	12	12	9	9	10	7	7	5
N. Dakota	17.12	3	3	5	8	13	21	14	12	9	6	4	3
Nebraska	22.59	2	3	5	11	15	17	14	12	9	6	3	3
Oklahoma	32.92	4	4	7	11	14	12	8	9	10	9	6	5
S. Dakota	19.10	3	3	6	11	15	19	13	11	8	6	3	3
Texas	30.98	6	6	7	10	12	10	9	8	9	8	7	7
Wisconsin	30.53	4	4	6	8	12	14	11	11	12	8	6	4
Western States													
Arizona	13.80	9	9	8	5	2	3	15	17	10	6	7	9
California	23.93	19	19	15	7	4	1	0	0	2	5	10	16
Colorado	16.53	5	6	8	11	11	9	13	12	8	7	5	5
Idaho	18.27	12	10	10	8	9	8	4	3	6	8	11	11
Montana	15.40	6	5	6	7	14	17	9	7	9	7	7	6
Nevada	8.97	13	12	11	9	9	6	4	5	5	7	8	11
N. Mexico	14.48	4	5	5	6	8	9	17	17	12	8	4	5
Oregon	26.43	14	12	10	8	7	5	1	1	5	8	14	15
Utah	13.41	9	10	11	9	9	5	7	8	7	9	7	9
Washington	34.79	14	11	9	7	6	5	2	2	5	9	15	16
Wyoming	14.24	6	5	8	11	15	12	9	8	8	8	5	5

Source: Reference 14.

In general, it appears that total fallout in the United States could be reduced somewhat by scheduling test series in the late fall.

5.5 MINIMIZING ADVERSE PUBLIC REACTION

The spring of 1953 was characterized in several regions of the country by unusual weather conditions: a large number of tornadoes, cool, excessively dry weather in the southwest and greater than normal precipitation in the east. The theory that these events were in some way related to the Upshot-Knothole tests, which took place in the same period, gained widespread public acceptance, although there is as yet, despite intensive study by the Weather Bureau, no scientific evidence to support this contention.

According to F. W. Reichelderfer, Chief of the Weather Bureau, "The usual thing about weather is that it is unusual in some place or other. The strange thing to us is that the public never remembers this. Year after year, there is very unusual weather someplace - heavy rainfall, tornadoes, freezes, frosts...". It follows, therefore, that adverse public reaction can be minimized by scheduling test series for periods when weather is of least importance in everyday activities, if such periods exist, and when catastrophic storms are less likely to occur.

In the United States, the most spectacular and generally feared phenomenon is the tornado, although hurricanes, floods, droughts, blizzards, and freezes also receive widespread attention. It would, of course, be impossible to find a period with no unusual weather, however, certain periods of the year are more likely to be associated with catastrophic meteorological events than others, and it may be advisable to avoid such seasons. Table 5.6 shows the average number of tornadoes by months.

TABLE 5.6

Average Number of Tornadoes by Months (1916-1950)

Month	J	F	M	A	M	J	J	A	S	O	N	D
No. Tornadoes	4.2	4.8	17.4	23.9	32.7	26.0	12.2	7.9	7.4	4.2	4.7	3.3

Source: Reference 15.

It is evident that test series in the months from October through February will be much less likely to be associated with tornadoes than a spring series.

Of course, other phenomena have different seasonal distribution. Hurricanes are most likely in the fall, freezes of greatest significance in the spring, droughts of greatest importance during the growing season, etc., but, with the exception of hurricanes, weather phenomena are probably of least importance to the general public in the fall, after the major crops are harvested.

From the point of view of suitable weather, both at the test site and throughout the country, it appears that the months of October and November would be most satisfactory for test operations.

CHAPTER 6

SPECIAL OBSERVATIONS

6.1 TYPES OF OBSERVATIONS

A special series of gummed film and high-volume air filter observation was made at St. Louis, Mo., during the Upshot-Knothole test series in order to gain more information concerning the processes by which radioactive debris is collected with the monitoring network. Observations were made at the St. Louis University Meteorological Observatory, on the roof of a building near the center of the city, and over a grass surface at Florrisant, a suburb of St. Louis about twelve miles north of the University. At the University, samples were collected by two regular gummed film stands, by a high-volume air filter and by two specially-constructed gummed film stands around which the film was wrapped in a cylindrical shape, with the axis vertical and a rain shield extending over the top. At Florrisant, three gummed films were exposed, one in the normal position three feet above the ground, the second in an inverted position directly below the first, and the third directly on the ground with the gummed side up. Each of the above collections were made for 12-hour periods, beginning at 7:30 a.m. and 7:30 p.m. each day, so that any diurnal effects could be examined. In addition, arrangements were made to make special observations during periods when precipitation coincided with the passage of an atomic cloud over St. Louis. These included gummed film, air filters, and cascade impactor samples, and whole water collections during successive intervals for the duration of the rain. Unfortunately, no storms suitable for study occurred at St. Louis after the program was established.

6.2 RESULTS

The observations at Florrisant revealed no significant differences in the activity collected by the gummed papers mounted in the normal manner and those directly on the ground. Much less activity was collected by the inverted paper. No significant differences between day and night observations was found. It should be noted that the small number of cases with significant activity in the St. Louis area makes it impossible to draw any general conclusions from this data. Table 6.1 shows a summary of the data from Florrisant.

TABLE 6.1

Results of St. Louis Observations

Type of Observation	Average Activity on Counting Day (d/m/ft ² /12 hrs.)	
	No Rain	Rain
Regular	480	210
Inverted	27	33
Ground	480	450

The results are for 52 periods without rain and 19 periods with rain (a few periods with a trace of rain are omitted from the summary). The relationships in Table 6.1 are essentially unchanged if only periods with heavy fallout are considered. For example, if the two periods with the heaviest fallout are considered (both periods without rain), the average values for the regular, inverted and ground films are 5400, 360, and 5400 d/m/ft²/12 hrs., respectively, on counting day. It is apparent that there is deposition on the inverted film due to eddy motion, but that it amounts to only five to ten percent of the activity deposited on a horizontal surface. If large particles are responsible for the activity, this result is easily understood. However, if the activity found near St. Louis is confined principally to particles of the order of two microns or less, the gravitational settling would be negligible, of the order of 10^{-2} cm sec⁻¹, and would be completely overwhelmed by the normal eddy motion of the atmosphere. If the small-scale eddy motions are essentially isotropic and carry about as many particles upward as downward, a possible explanation of the lack of activity on the inverted paper would be the existence of a very thin boundary layer next to the gummed surface, through which gravitational settling plays an important role. It is also possible that the lack of isotropy near the ground is responsible for the observed results.

The observations at the St. Louis University were designed for several purposes. The vertical cylinders were intended to test the practicability of an inexpensive instrument to measure air concentration of radioactivity. It was thought that the wind blowing past the cylinders would impinge particles on the film, so that the activity collected divided by total air movement past the cylinder would be highly correlated with the air concentration as measured by the high-volume air filter. This did not prove to be the case, even when periods without precipitation were considered separately. The correlation of the air filter with the vertical cylinder was no better than with the regular gummed film observation. On the average, the vertical cylinders collected about 50% as much activity as the

regular gummed films during no rain periods, and about 15% as much during periods with rain. Because of the great variability in the amount of debris present and the small number of active samples obtained, no conclusions could be reached concerning diurnal variability of deposition or the relationship of deposition to other meteorological factors such as wind speed, temperature gradients, etc.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 INTERIM NETWORK

Background gummed film observations of fallout occurring before the first test of the Upshot-Knothole series indicate that the level of activity is somewhat higher than on similar observations made prior to the Ivy and Tumbler-Snapper series. There is no conclusive evidence to show whether this increase is due to downward diffusion from a relatively high concentration of debris injected into the stratosphere as a result of the Ivy shots, or merely to an increased amount of tropospheric debris. In either case, it is considered desirable to maintain an expanded interim network with special emphasis on sampling in the rainier portions of the globe. Since much of the activity detected by such an interim network is of a low order, it would be advisable to revise the counting procedure so that more accurate measurements could be made, presumably by increasing the maximum counting time beyond the twenty minutes now in effect.

7.2 TOTAL FALLOUT

It is suggested in Chapter 3 that the gummed film network is inadequate in accounting for all the deposition of debris which occurs on the surface of the earth, since it seems unlikely that the difference between the activity produced in this test series and that accounted for by the monitoring program can be due to atmospheric storage of debris. It is recommended that an extensive program be undertaken to calibrate the gummed paper in terms of actual natural deposition. For example, simultaneous comparisons of gummed film deposition and that found on the surrounding ground, foliage and buildings should be made. A comparison of the activity in whole water samples with that on the gummed film for various kinds and intensities of precipitation should be made. Also, experiments are needed to better establish the characteristics of the gummed film, such as the adhesive quality in relation to particle size, temperature, humidity, precipitation, orientation, turbulence, etc. More information concerning the characteristics of atomic debris, vertical distribution, particle size, solubility, etc., both near the test site and at various distances is also needed.

7.3 FALLOUT FROM AIR AND TOWER BURSTS

Fallout both in the vicinity of the test site and elsewhere in the country is greater following a burst in which the fireball intersects the ground (tower burst) than following an air burst. Very little fallout is experienced near the test site from air bursts, while tower bursts deposit about 20% of the fission product activity produced in the vicinity of the test site. Likewise, for devices of similar yield, almost five times more debris is deposited elsewhere in the United States following a tower burst when compared to an air burst, which accounts for the fact that the highest activity reported at individual stations was almost invariably associated with a tower burst. It follows that considerably greater caution should be exercised in selecting meteorological criteria for tower bursts.

7.4 LOCATION OF STATIONS

The data in Chapter 4 can be used to evaluate the adequacy of the present continental network in terms of the allowable tolerance in missing areas of intense fallout. To adequately monitor localized areas of intense fallout in the mountainous regions around the test site, supplementary aircrafts monitoring is necessary. Perhaps consideration should be given to a program of mobile monitoring even in the eastern half of the country when the relatively rare combination of circumstances similar to those accompanying the Albany fallout are evident in localized areas between regular monitoring stations. Such a program would depend upon meteorological advice as to when and where special monitoring would be in order.

7.5 PREDICTION OF FALLOUT AREAS

From an examination of the maps in Appendix B, it is evident that there has been little improvement in predicting areas of fallout in the continental United States during this test series when compared with the Tumbler-Snapper series. An examination of the data shows that more consideration should be given to the wind flow in the lowest few thousand feet of the atmosphere in estimating where fallout will occur.

7.6 INTENSE LOCAL FALLOUT

The maximum gummed film activity thus far seen in the monitoring program was 16,000,000 d/m/ft²/day at Albany, N. Y. This value

resulted when heavy thundershowers coincided with the arrival of a fresh, fast-moving cloud from a high-yield tower burst. A similar chance combination of circumstances in the central United States, within five or six hours after the burst, could lead to activities of 10^9 to 10^{11} d/m/ft²/day. Avoidance of such a situation would depend upon a meteorological forecast which takes into consideration the probability of thundershowers coinciding with the arrival of a fresh cloud of debris. The statistical probability of such an occurrence can be reduced by having test series in seasons when it is less likely.

7.7 OPTIMUM SEASON FOR NEVADA TESTS

Meteorological considerations indicate that certain seasons are preferable to others for testing atomic weapons at the Nevada Proving Grounds from the standpoint of weather at the test site, avoidance of intense local fallout at some distance from the site, reduction of total fallout in the United States and minimizing adverse public reaction. A consideration of all these factors points to October and November as being the most suitable months for atomic test series in Nevada. This would also correspond to a season when the absorption of radioactivity by growing plants would be near a minimum.

APPENDIX A

MAPS OF DAILY FALLOUT IN THE UNITED STATES AND CANADA

Figures A.1-A.90 show the data from all fallout-monitoring stations making daily observations from March 17 to June 14, 1953. The radiological and precipitation data is plotted in accordance with the key given on all maps. (Snowfall amounts have been reduced to the water equivalent.) All data refer to the 24-hour period beginning at 1230 G.C.T. (0730 E.S.T.). Significant radioactivity (see Section 1.2) measurements are extrapolated to the sampling day on the basis of the indicated burst.¹ The activity on counting day is reported for samples of low activity and is indicated as "unextrapolated". Where two gummed films were exposed simultaneously, the activities on each are reported, the upper figure refers to stand number 1, the lower to stand number 2. High-volume air filter activity is reported as L (low) if the activity was less than 1.5 d/m/M³.

Dashed lines enclose areas wherein the activity on at least one gummed film at each station exceeds 100 d/m/ft²/day on sampling day. Solid lines enclose areas of more than 30,000 d/m/ft²/day on at least one film. Shading indicates regions with measurable amounts (more than a trace) of precipitation in the 24-hour period. The important role played by precipitation in bringing debris to the ground is evident in the maps to follow and has been pointed out in previous reports (see Reference 12, p. 45).

As indicated on the individual maps, all plotted values of radioactivity, with the exception of those underlined, are too low by a factor of three, and are to be multiplied by three to obtain the real values (see Preface).

¹An exception was made in the case of Albrook AFB, Canal Zone, where the activity on counting day is reported because of the difficulty in assigning a burst at this distance from the test site.

Figure A.1 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 17 March 1953

Figure A.2 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 18 March 1953

Figure A.3 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 19 March 1953

Figure A.4 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 20 March 1953

Figure A.5 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 21 March 1953

Figure A.6 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 22 March 1953

Figure A.7 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 23 March 1953

Figure A.8 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 24 March 1953

Figure A.9 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 25 March 1953

Figure A.10 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 26 March 1953

Figure A.11 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 27 March 1953

Figure A.12 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 28 March 1953

Figure A.14 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 30 March 1953

Figure A.15 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 31 March 1953

Figure A.16 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 1 April 1953

Figure A.17 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 2 April 1953

Figure A.18 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 3 April 1953

Figure A.20 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 5 April 1953

Figure A.21 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 6 April 1953

Figure A.22 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 7 April 1953

Figure A.23 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 8 April 1953

Figure A.25 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 10 April 1953

Figure A.26 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 11 April 1953

Figure A.27 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 12 April 1953

Figure A.28 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 13 April 1953

Figure A.29 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 14 April 1953

Figure A30 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 15 April 1953

Figure A31 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 16 April 1953

Figure A.32 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 17 April 1953

Figure A.33 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 18 April 1953

Figure A.34 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 19 April 1953

Figure A.35 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 20 April 1953

Figure A.36 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 21 April 1953

Figure A.37 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 22 April 1953

Figure A.38 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 23 April 1953

Figure A.39 Radioactive fallout in the 24 hour period beginning 1230 G.C.T., 24 April 1953

Figure A.40 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 25 April 1953

Figure A.41 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 26 April 1953

Figure A.42 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 27 April 1953

Figure A.43 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 28 April 1953

Figure A.44 Radioactive fallout in the 24-hour period beginning 1230 GCT, 29 April 1953

Figure A.46 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 1 May 1953

Figure A.48 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 3 May 1953

Figure A.49 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 4 May 1953

Figure A.50 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 5 May 1953

Figure A.51 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 6 May 1953

Figure A.52 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 7 May 1953

Figure A.54 Radioactive fallout in the 24-hour period beginning 1230 G.C.T, 9 May 1953

Figure A.55 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 10 May 1953

Figure A.56 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 11 May 1953

Figure A.57 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 12 May 1953

Figure A.59 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 14 May 1953

Figure A.60 Radioactive fallout in the 24-hour period beginning 1230 GCT, 15 May 1953

Figure A.61 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 16 May 1953

Figure A.62 Radioactive fallout in the 24-hour period beginning 1230 GCT, 17 May 1953

Figure A.63 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 18 May 1953

Figure A.64 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 19 May 1953

Figure A.65 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 20 May 1953

- 154 -

Figure A.67 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 22 May 1953

Figure A.68 Radioactive fallout in the 24 hour period beginning 1230 G.C.T., 23 May 1953

Figure A.69 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 24 May 1953

Figure A70 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 25 May 1953

Figure A.71 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 26 May 1953

Figure A72 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 27 May 1953

Figure A.73 Radioactive fallout in the 24-hour period beginning 1230 G.C.T, 28 May 1953

Figure A.74 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 29 May 1953

Figure A.76 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 31 May 1953

Figure A.78 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 2 June 1953

346 175

Figure A.79 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 3 June 1953

Figure A.80 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 4 June 1953

Figure A.81 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 5 June 1953

821 058

- 170 -

Figure A.82 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 6 June 1953

Figure A.83 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 7 June 1953

627 958
179

Figure A.84 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 8 June 1953

Figure A.85 Radioactive fallout in the 1-h period beginning 1230 G.C.T., 9 June 1953

Figure A.86 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 10 June 1953

Figure A.87 Radioactive fallout in the 24-hour period beginning 1230 GCT, 11 June 1953

Figure A.88 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 12 June 1953

Figure A.89 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 13 June 1953

Figure A 90 Radioactive fallout in the 24-hour period beginning 1230 G.C.T., 14 June 1953

APPENDIX B

PREDICTED AND OBSERVED AREAS OF FALLOUT

Following each burst of the Upshot-Knothole series, an estimate was made of the areas in the United States likely to have received fallout or rainout from the burst. These estimates were prepared daily for several days following each burst. They were made after the receipt of all pertinent meteorological data, but before any radiological data was available.

Figures B.1-B.11 show the predicted and observed fallout areas for each of the bursts. The hatching indicates the area where debris from the burst was expected to be found on the basis of meteorological considerations. The dashed lines outline areas actually found to contain debris from the burst under consideration (over 300 d/m/ft²/day on at least one gamma film at each station in the area) and the solid line outlines areas with heavy fallout (over 30,000 d/m/ft²/day on at least one gamma film at each station in the area). The solid and dashed lines correspond to those in the figures of Appendix A except in cases where debris from more than one burst was present. The discrepancies between the predicted and observed areas of fallout and the probable reasons, are discussed in Section 2.3.

FIGURE B.1 PREDICTED AND OBSERVED AREAS OF FALLOUT, BURST 1

FIGURE B 2 FREDI 111 1 01 AREAS OF FALLOUT, BURST 2

FIGURE B 3 PREDICTED AND OBSERVED AREAS OF FALLOUT, BURST 3

FIGURE B 4 PREDICTED AND OBSERVED AREAS OF FALLOUT, BURST 4

FIGURE B 5 PREDICTED AND OBSERVED AREAS OF FALLOUT, BURST 5

FIGURE B 6 PREDICTED AND OBSERVED AREAS OF FALLOUT, BURST 6

FIGURE B.7 PREDICTED AND OBSERVED AREAS OF FALLOUT, BURST 7

FIGURE B.8 PREDICTED AND OBSERVED AREAS OF FALLOUT, BURST 8

FIGURE B.9 / PREDICTED AND OBSERVED AREAS OF FALLOUT, BURST 9

FIGURE B.10 PREDICTED AND OBSERVED AREAS OF FALLOUT, BURST 10

FIGURE B.11 PREDICTED AND OBSERVED AREAS OF FALLOUT, BURST 11