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UNITED STATES ATOMIC ENERGY COMMISSION

NYO-4552(DEL.)

RADIOACTIVE DEBRIS FROM OPERATIONS UPSHOT AND KNOTHOLE

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Chapter 1

INTRODUCTION

The monitoring survey described in this report is one of a series coordinated by the Health and Safety Division of the New York Operations Office beginning with the weapons tests early in 1951. These surveys have been made for health monitoring and to provide information useful to the photographic industry and others whose operations are interfered with by small amounts of radioactive contamination. Such operations include low-level radiation measurements for estimating the age of geological and archeological specimens, for locating uranium mines and oil fields, and for other purposes.

The report covers the activities of the National Monitoring System for the period March 1st to June 15th, 1953, during which eleven nuclear devices were fired at the Nevada Proving Grounds.

This survey is similar in plan to the monitoring program for the Spring 1952 weapons tests[1]. References 2, 4 and 5 are reports of monitoring operations conducted during other test series.

The program employed a world-wide network of 125 sampling locations with its greatest density in the United States. It had the cooperation of the Division of Biology and Medicine, the Test Organization, the Weather Bureau, the Department of Defense, the Canadian Weather Service, the Atomic Bomb Casualty Commission and the Civil Aeronautics Administration.

All but the first two in this list of agencies provided sampling stations and personnel. The Civil Aeronautics Administration and the Test Organization extended courtesies to our mobile teams. The Department of Defense provided the personnel for the teams and two aircraft, with crews, for their transportation.

The Special Projects Section of the U. S. Weather Bureau furnished cloud trajectory information and forecasts. Scientists of this section are preparing a report in which the fallout data will be presented in the form of daily maps and analyzed in its relation to meteorology.

Chapter 2

METHODS

2.1 DESIGN OF THE PROGRAM

To estimate the activity settling out of the atmosphere, Weather Bureau personnel at 96 cities in the United States collected daily samples by exposing one foot squares of gummed cellulose acetate film. At a portion of the network, in the northeast quadrant of a circle about 2000 miles in diameter, centered at the Proving Grounds, another type of sample, intended to furnish estimates of radioactive suspended matter in the air, was also collected. The second type of sample was a circle of filter paper through which a measured volume of air had been drawn by a suction pump.

Within about 500 miles of the test site the dust cloud from a nuclear explosion may be concentrated in a small space. A fixed network in this region cannot economically be made dense enough. To improve the coverage, eight mobile teams of two men each were deployed after each burst with the center team under the expected trajectory of the cloud. The teams made radiation measurements and collected special samples for particle size studies in addition to the two principal types collected at the fixed stations.

All samples were mailed to the Health and Safety Division laboratory, New York Operations Office where their beta activity was measured, usually from three to ten days after collection.

2.2 SAMPLING PERIODS

The standard sampling period for fixed stations was twenty-four hours beginning 12:30 GCT. This period applied to settled dust samples and filtered samples. The mobile teams collected settled dust samples for twenty-four hours or less depending on the movements of the teams. They collected filtered dust for twenty minute periods when the readings of their survey instruments indicated that the radioactive cloud was passing. At other times they collected this type of sample for two-hour periods. The usual period for aerotec samples was twenty-four hours and for cascade impactor samples the period was twelve hours. The periods for the last samples of each series were cut short by the ending of the series, when collections were discontinued until after the next burst.

2.3 SAMPLING PROCEDURE

Each fixed station collected settled dust samples in duplicate. One foot squares of gummed cellulose acetate film were held in a horizontal position, gummed side up, by a frame elevated three feet above the ground or roof of the weather station. In most cases the duplicate frames were placed six feet apart but in some cities one frame was set up at each of two weather stations, usually at a suburban airport and in the city.

Filtered dust samples were collected by pumping air through a filter paper circle at the rate of approximately one cubic meter per minute. The flow rate was read from a rotameter attached to the air pump.

Aerotec and cascade impactor samples (collected only by the mobile teams) served the purpose of providing estimates of particle size. The aerotec device is an attachment to the high volume sampler. By imparting a rotary motion to the air entering the sampler it brings about centrifugal separation of the dust into two fractions. The large particles drop out of the air stream and are collected in a bottle partly filled with water. The small particles are collected on the filter of the high volume sampler.

The cascade impactor divides the dust of an air sample into five fractions. The velocity of the air stream is varied in four stages by means of orifices and dust is collected at each stage by impingement on a slide coated with silicone. Dust of a fifth stage containing the smallest particles is collected on a paper filter.

Two of the mobile teams operated automatic dust samplers. Each sampler includes a pump which draws air through a filter paper tape. Every twenty minutes a fresh part of the tape is moved into position for filtering. Design air flow is approximately 2 c.f.m.; thus each twenty minute sample represents 40 cubic feet or 1 cubic meter in round numbers. Radioactivity of the sample is automatically measured and recorded during the last five minutes of each twenty minute period.

2.4 MOBILE TEAM OPERATIONS

Personnel loaned by the Army were organized as a force of eight two-man teams under the direction of a representative of the Health and Safety Division, stationed at the Proving Grounds.

After each burst the teams were deployed in a pattern designed to include the point of maximum airborne concentration and over a large enough area so that the data would show the diminution in activity from this point outward. The pattern was based on meteorological analyses made by Weather Bureau personnel at the Proving Grounds.

While waiting for assignments, the teams were stationed at Hill Air Force Base, Ogden, Utah. Rapid transportation in two C-47 aircraft loaned by the Air Force usually made it possible for them to take up their positions and begin sampling within a few hours after the burst.

They collected settled and filtered dust samples and used survey instruments to measure radiation from the ground and from the filter paper used to collect the filtered samples. The principal purpose of the radiation measurements was to detect the passage of the radioactive cloud. On the basis of these readings the teams increased or decreased the length of the sampling period for the filtered sample. When meteorological information and the radiation readings indicated that the cloud had passed and that no further significant fallout or airborne activity was to be expected, the sampling was discontinued and the teams returned to their base at Ogden. The time for discontinuing sampling was usually about 1½ or 2 days after the burst.

In addition to the standard filtered and settled dust samples, which were collected in the same manner as at the fixed stations but for different sampling periods (see section 3.2), two of the teams collected aerotec and cascade impactor samples and operated automatic recording air dust samplers.

Chapter 3

FINDINGS

The relationships among the several kinds of data make it impractical to discuss each kind as it is introduced. For this reason the results of the survey are presented in this chapter with little comment and discussed in Chapter 4.

3.1 CUMULATIVE FALLOUT

Figures 3.1 to 3.11 are maps of the United States showing fall-out occurring between bursts extrapolated to January 1, 1954. Bursts #7 and #9 were evidently responsible for much greater fallout than any of the others. Because of this fact the arbitrary procedure of attributing all activity to the most recent burst may have caused considerable error in the mapped totals for bursts #8 and #10.

Figure 3.12 is a map showing total fallout for the series extrapolated to January 1, 1954.

3.2 RADIOACTIVE DUST IN AIR

Airborne activity, at locations where analysis of mobile team filtered samples demonstrated the presence of radioactive suspended matter, is plotted against time in figures 3.13 to 3.32. The findings are discussed in Chapter 4 in relation to the fallout pattern.

Observers at fixed stations in Nevada, Idaho, Montana, Utah, Wyoming, Colorado and California collected filtered dust for 24 hour sampling periods beginning at 12:30 GCT. The purpose was to detect any excessive activity in the region where, on account of the expected wind patterns, significant concentrations of suspended radioactive material were believed most likely to occur.

Data for the five stations where the concentrations occasionally exceeded 10 $d/m/M^3$ are plotted against time in figures 3.33 to 3.37. Where data are missing the graphs are shown as dashed lines.

3.3 PARTICLE SIZE

Some of the mobile stations were provided with cascade impactors for separating airborne dust into five fractions according to particle size. The particles of each fraction have a characteristic mass median diameter. Assuming activity to be proportional to mass, the mass median diameter of a sample can be computed from the percentages of the sample activity in the several fractions. The procedure is to plot the cumulative distribution curve on logarithmic probability paper and read the mass median diameter by linear interpolation from the graph. Table 3.1 presents the mass median diameters of samples having more activity than 100 d/m/M^3.

Particle size classification was also effected with the aerotec attachment to the "Hi Volume" sampler, the pump used for collecting the unfractionated air dust samples. The aerotec imparts to the air a rotary motion which causes centrifugal separation of large particles from the stream before it passes through the paper filter of the "Hi Volume" sampler.

The aerotec sample activities and their distribution expressed as the percentage of small particles are listed in Table 3.2. The borderline particle size between the two fractions is estimated at 5 microns. The activities of the individual fractions are also included in the table.

3.4 DECAY DATA

Values of the exponent, X, read from logarithmic graphs of decay data are shown in Table 3.3. Results are listed for all the samples which were counted for decay except those not clearly attributable to a definite burst and therefore of unknown age.

The mean is 1.30. Only a portion of the samples from the first and last bursts tend to confirm the figure, 1.2, which is customarily used.

Since the observed decay rates differ from those calculated from the Way-Wigner formula, using the exponent 1.2, it is desirable to estimate the error which the use of the formula may have introduced into our summaries. Figures 3.38 and 3.39, semilogarithmic graphs, on different time scales, of the activity falling out at Albany on April 26 and counted four days later, compare the effects of extrapolating the activity on the basis of two different exponents.

Of the three curves shown, two are based on attributing the activity to burst 7. The error due to using the exponent 1.2, if 1.35 is the correct value, is indicated by the separation of the two curves and measured by the ratio of activities read from them. The ratio of activities at the time of sampling is 0.8. By day 85, four weeks after the burst, the ratio has increased to 1.2. By day 1000 it has become 1.8 and it increases slowly thereafter.

3.5 EFFECT OF ERROR IN ESTIMATE OF AGE

Figures 3.38 and 3.39 also illustrate the effect of attributing activity to the wrong burst. The error is indicated by the separation of the two curves identified by the exponent 1.2. The activity of the sample was generated by burst 7 and the ratios of corresponding ordinates read from the two curves measures the error which would be committed by attributing it to burst 6.

The mistaken burst assignment results in an estimated activity only one-third of the true value at the time of sampling. In extrapolating to the future the error is in the direction of high values and by day 85, four weeks after burst 7, the exaggeration will be in the ratio 2:1. The ratio reaches 2.7 on day 1000 and 3.0 on day 4000.

Figure 3.40 shows a similar pair of curves based on a 24 hour sample collected at Salt Lake City on the day of burst 2. The most probable time of occurrence of the fallout was 12 hours after burst since this was the time of arrival of the maximum air concentration at Ogden (see Fig. 3.15) and an estimate of activity at this time based on a misassignment to burst 1 will be only one-twelfth of the true value. The same mistake will produce an estimate exaggerated by a factor of 2 on day 300.

The samples used for illustration were collected shortly after the bursts which they represent and they possessed exceptionally high activities. They were chosen to show the greatest possible effect of an erroneous burst assignment on the cumulative totals. However, it is in just such cases that the burst assignments are most reliable, and it is probable that this type of error has been confined to older and less active samples which influence the totals relatively little.

3.6 COMPARISON OF AIR CONCENTRATIONS WITH FALLOUT

Settled dust samples were collected by the mobile teams shortly after each burst and for periods of twenty-four hours except when cut short by the order to discontinue. Estimates of the activity of these samples when fallout occurred are especially subject to some of the errors discussed above.

The best estimate of fallout time is believed to be the time of maximum airborne concentration. In Table 3.4 these maxima, taken from Figures 3.13 to 3.32, are compared with settled dust activity extrapolated to the times of occurrence of the peak concentrations.

To obtain other comparisons of the two types of data, the graphs of air activity at fixed stations, Figures 3.33 to 3.37, are accompanied by parallel graphs of fallout. These graphs show simultaneous sharp peaks. Occasionally, however, a peak in air concentration is not accompanied by any corresponding rise in fallout and vice versa; also, the peaks in the paired graphs, even when they do seem to correspond, are not accurately synchronized. These facts complicate the problem of correlating the two types of data. They limit us to the qualitative inferences that (1) either significant fallout or a significant air concentration may occur without the other and (2) more often they will occur together and when they do the fallout per square foot per day is likely to exceed the airborne concentration per cubic meter by a factor in the hundreds.

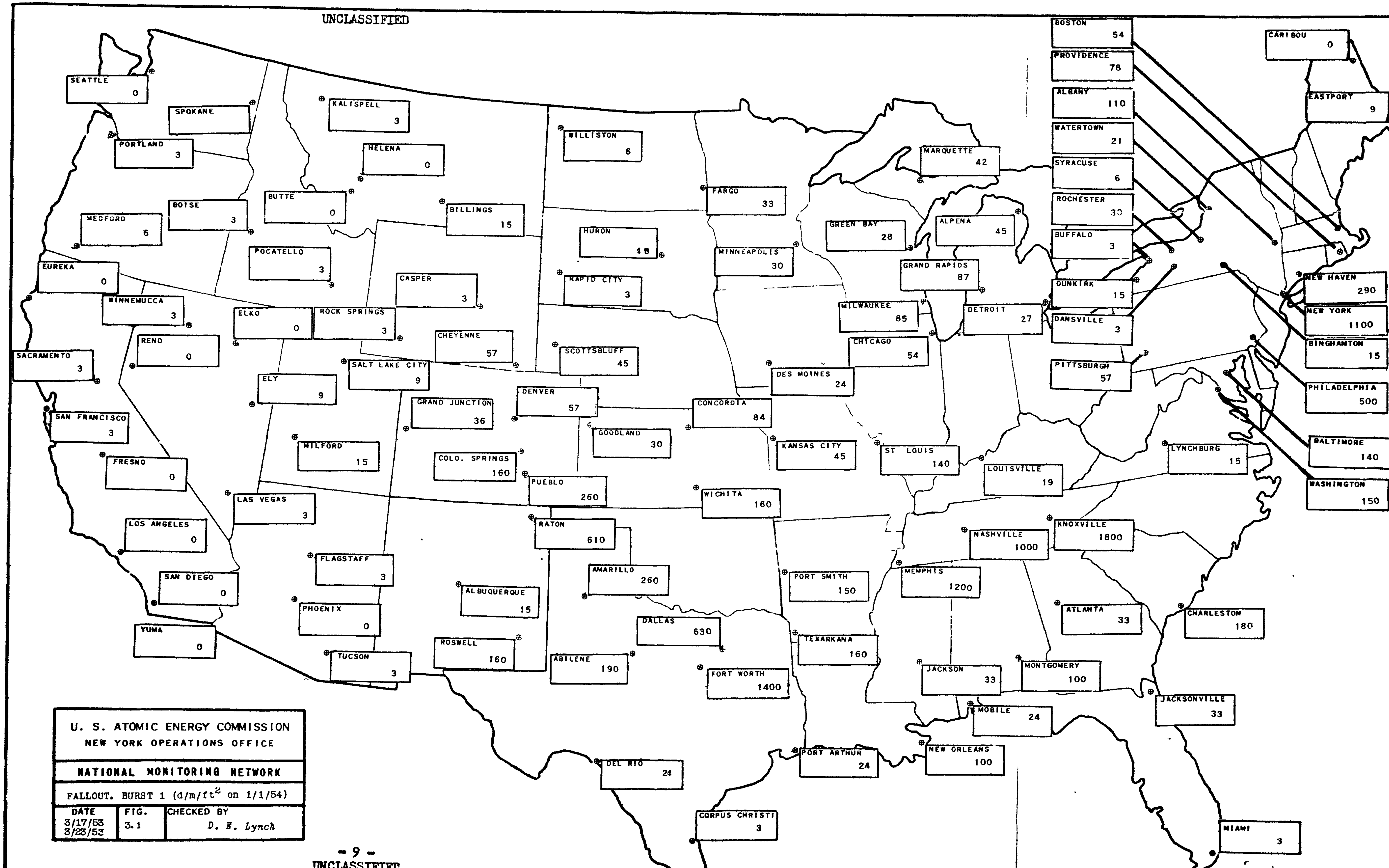
3.7 COMPARISON OF AREA GAMMA WITH FALLOUT

The measurements with survey instruments mady by the mobile teams included gamma readings taken three feet above the ground. If the radiation is due to fallout it should be proportional to the amount of radioactive dust on the ground surface at the time the reading is made. In the absence of disturbing factors such as rainfall and radioactive decay one would expect the fallout, as estimated from the gummed film sample, to be proportional to the difference in the gamma readings at the end and the beginning of the sampling period. To reduce the effects of these disturbing factors the maximum 24 hour gummed film result for each mobile team operation was chosen for study and it was compared with the maximum gamma reading of the 24 hour period, rather than with the difference between the final and initial readings.

Figure 3.41 is a scatter diagram showing the results of this comparison. The equation of the fitted line is:

$$Y = 0.9 + 3.1\,X$$

where Y is fallout in millions of $d/m/ft^2$ and X is gamma radiation in mr/hr.



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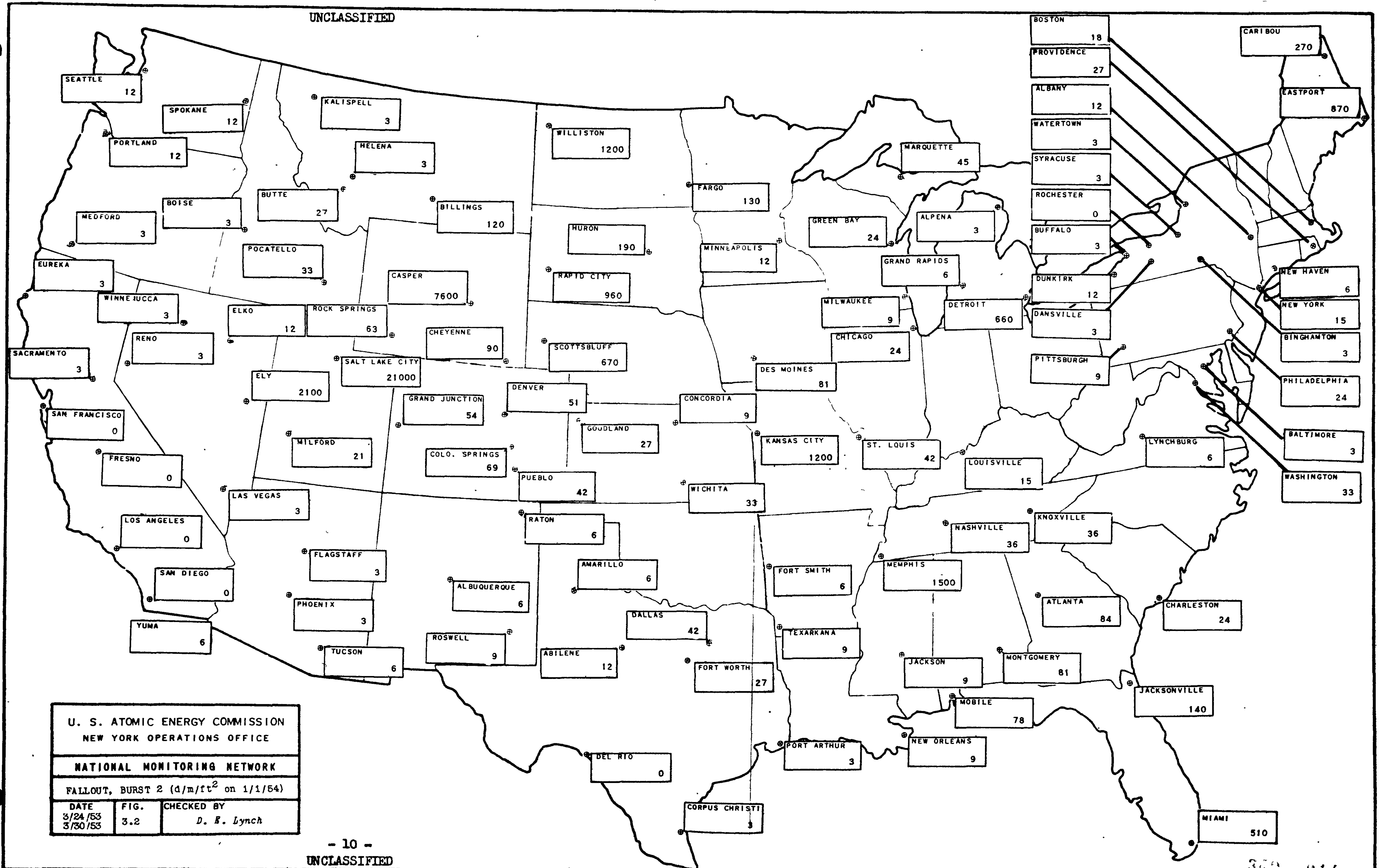
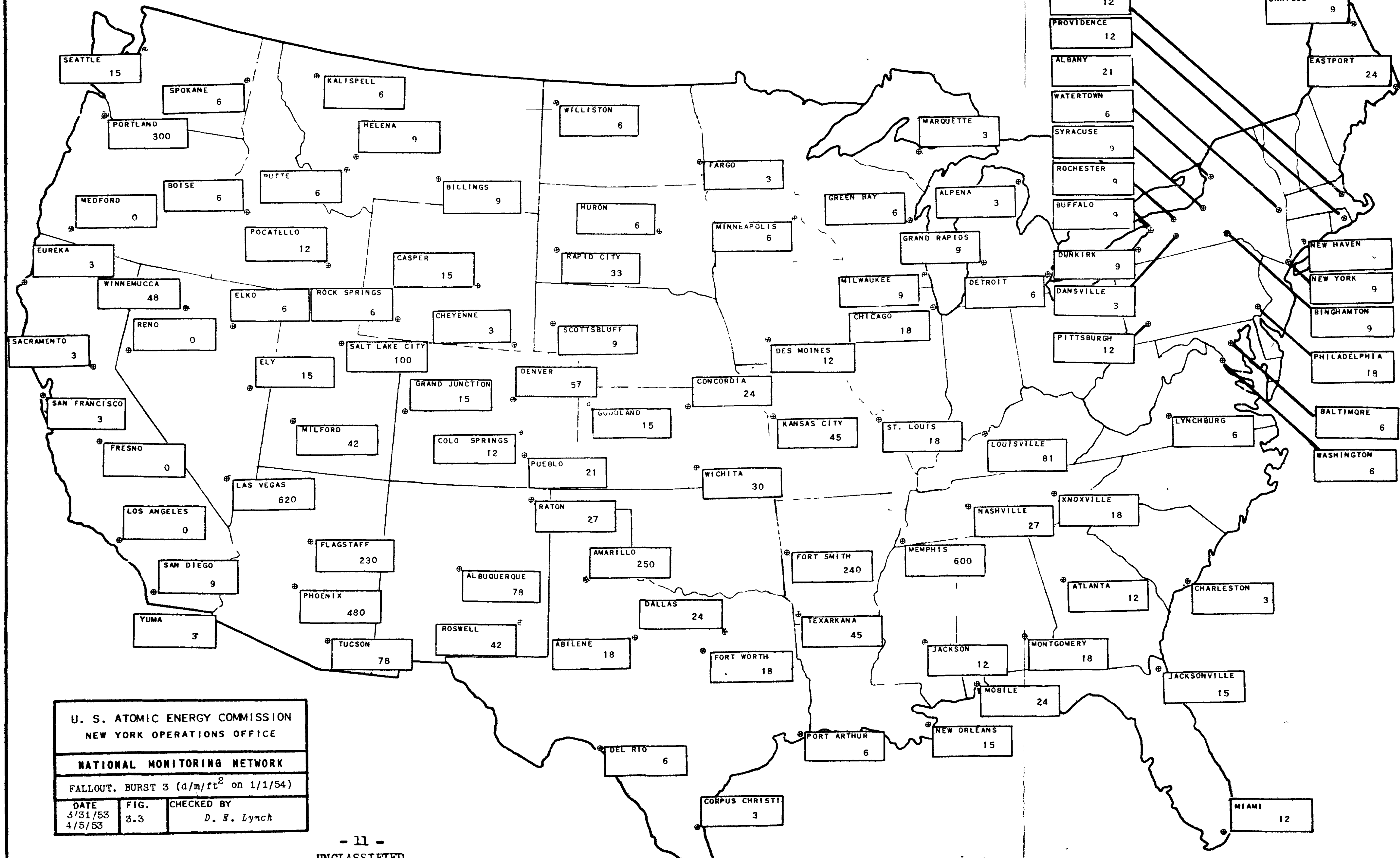
NATIONAL MONITORING NETWORK

FALLOUT. BURST 1 (d/m/ft^2 on 1/1/54)

DATE	FIG.	CHECKED BY
3/17/53 3/23/53	3.1	*D. E. Lynch*



U. S. ATOMIC ENERGY COMMISSION NEW YORK OPERATIONS OFFICE		
NATIONAL MONITORING NETWORK		
FALLOUT, BURST 2 (d/m/ft^2 on 1/1/54)		
DATE 3/24/53 3/30/53	FIG. 3.2	CHECKED BY *D. E. Lynch*



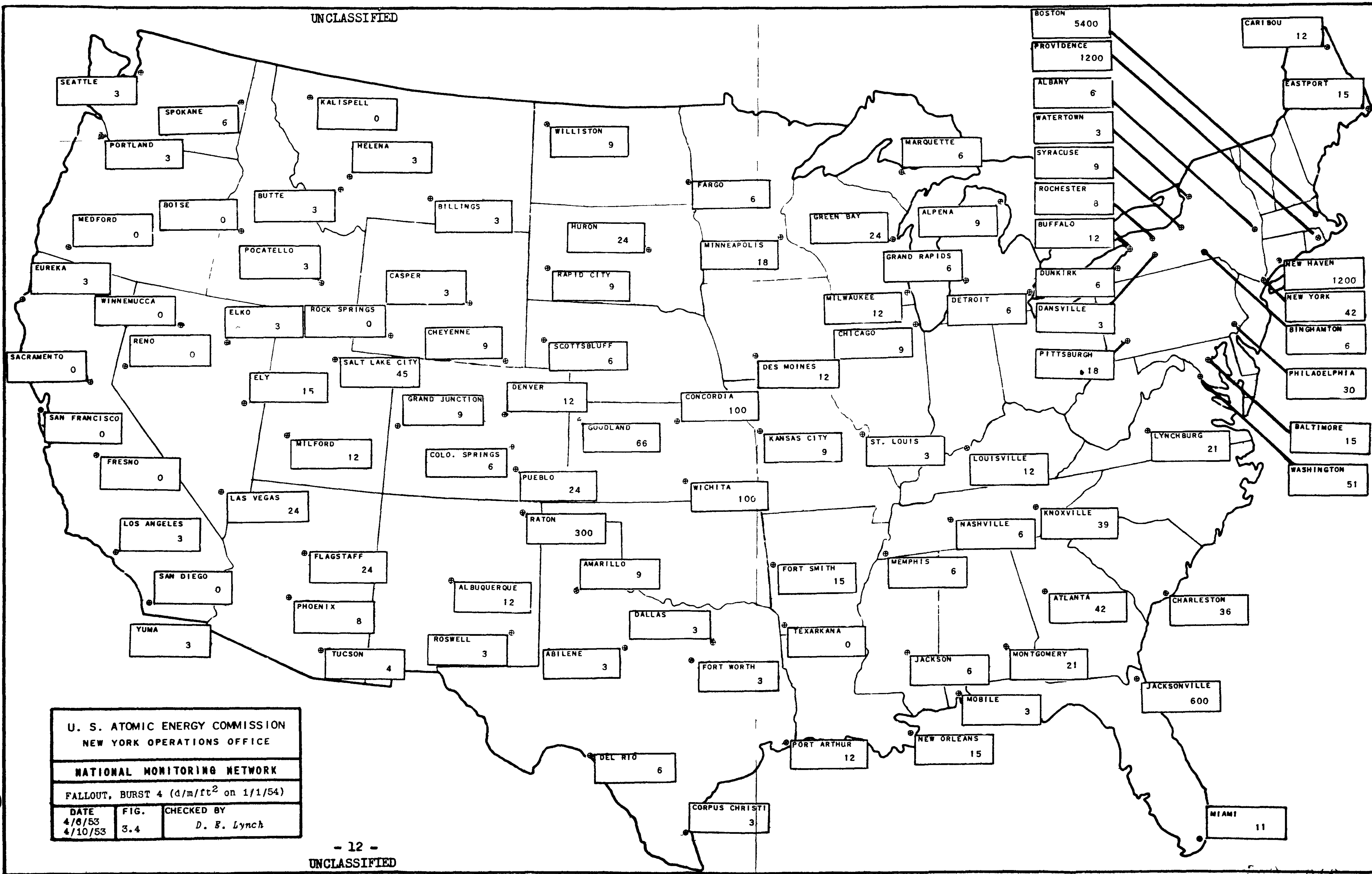
U. S. ATOMIC ENERGY COMMISSION
NEW YORK OPERATIONS OFFICE

NATIONAL MONITORING NETWORK

FALLOUT, BURST 3 (d/m/ft^2 on 1/1/54)

DATE	FIG.	CHECKED BY
3/31/53 4/5/53	3.3	*D. E. Lynch*

349 015



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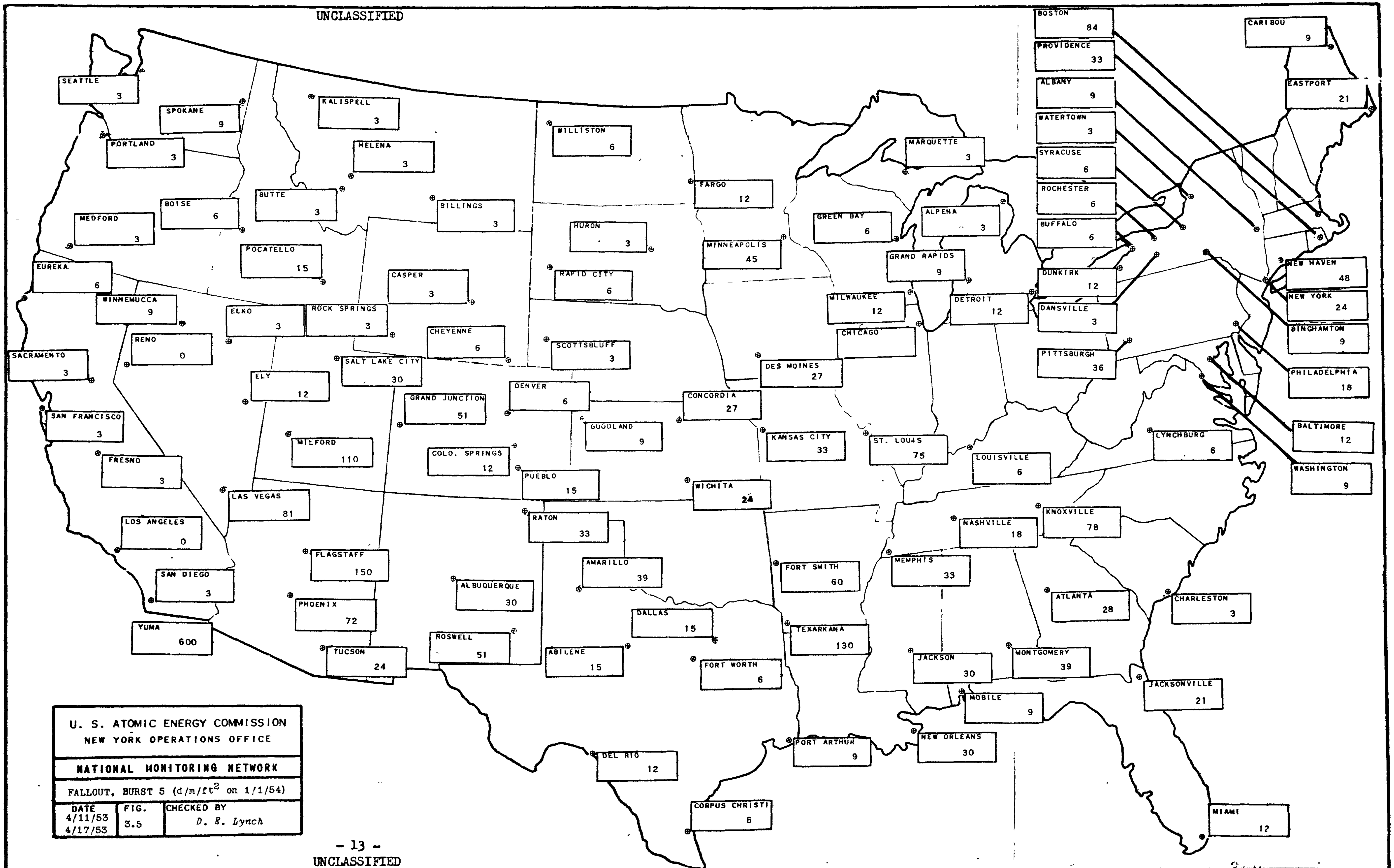
NATIONAL MONITORING NETWORK

FALLOUT, BURST 4 (d/m/ft^2 on 1/1/54)

DATE	FIG.	CHECKED BY
4/6/53 4/10/53	3.4	D. E. Lynch



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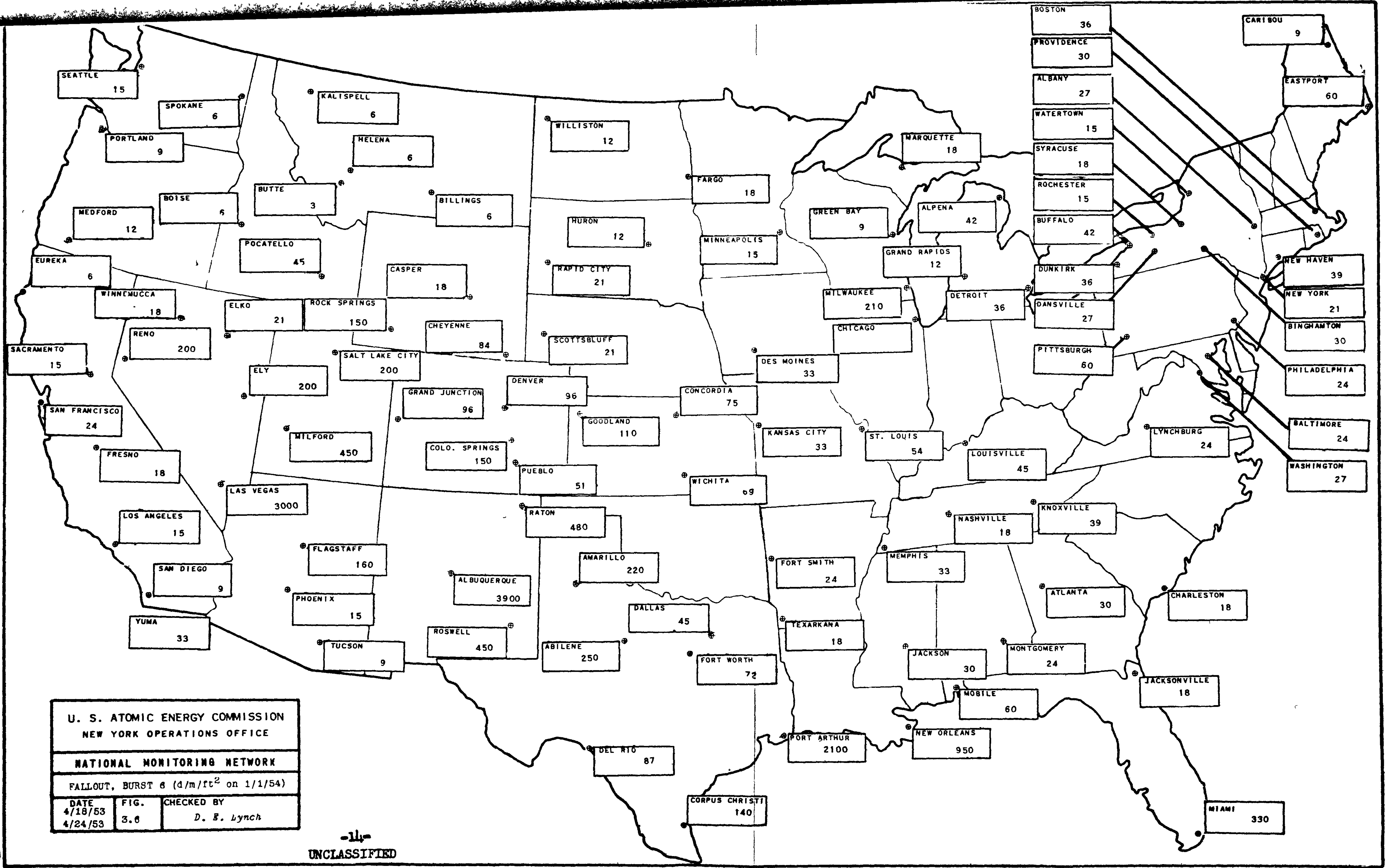
FALLOUT, BURST 5 ($d/m/ft^2$ on 1/1/54)

DATE	FIG.	CHECKED BY
4/11/53 4/17/53	3.5	*D. E. Lynch*



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FALLOUT, BURST 6 (d/m/ft^2 on 1/1/54)

DATE	FIG.	CHECKED BY
4/18/53 4/24/53	3.6	*D. E. Lynch*

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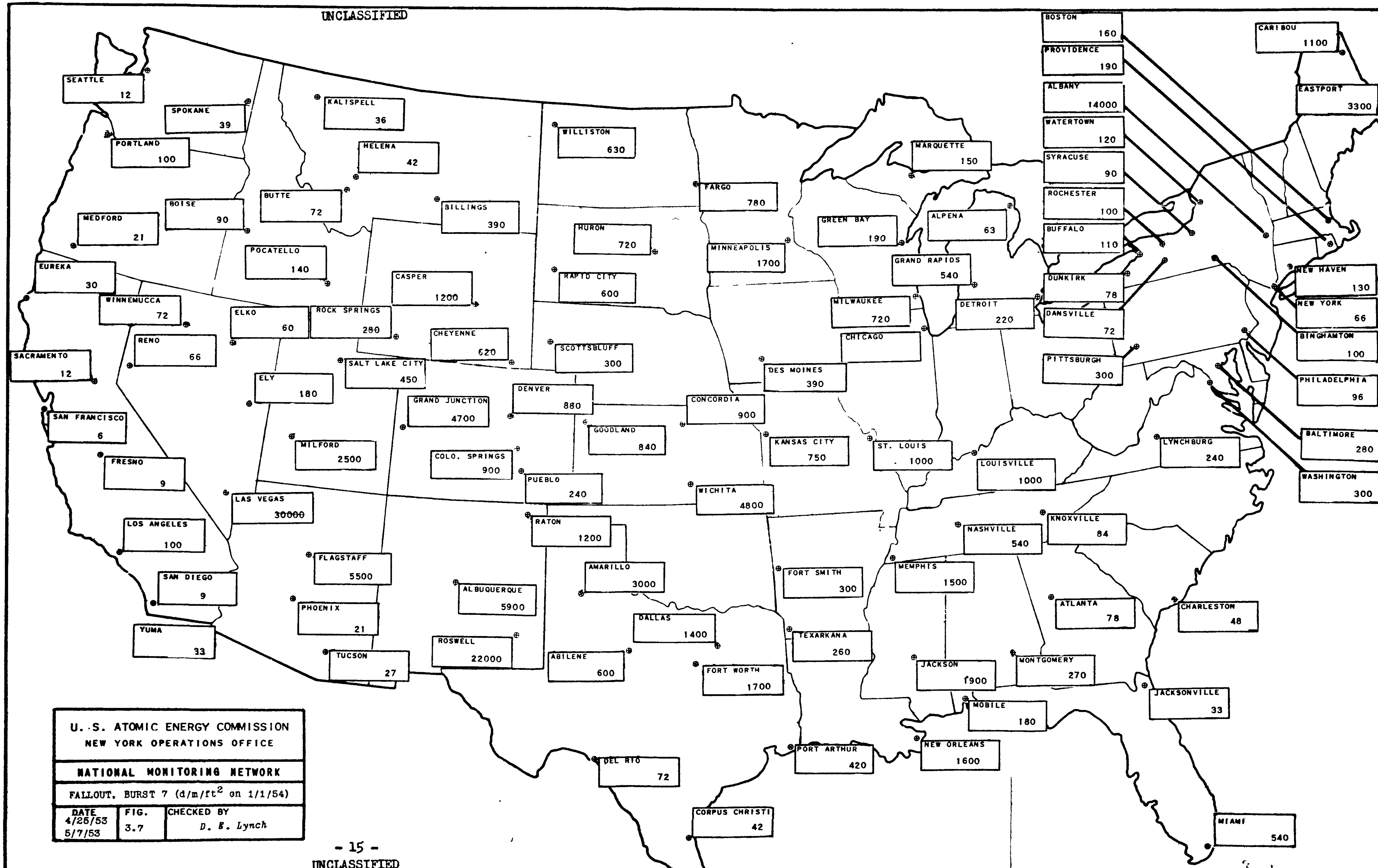

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FALLOUT, BURST 7 (d/m/ft^2 on 1/1/54)

DATE	FIG.	CHECKED BY
4/25/53 5/7/53	3.7	D. E. Lynch

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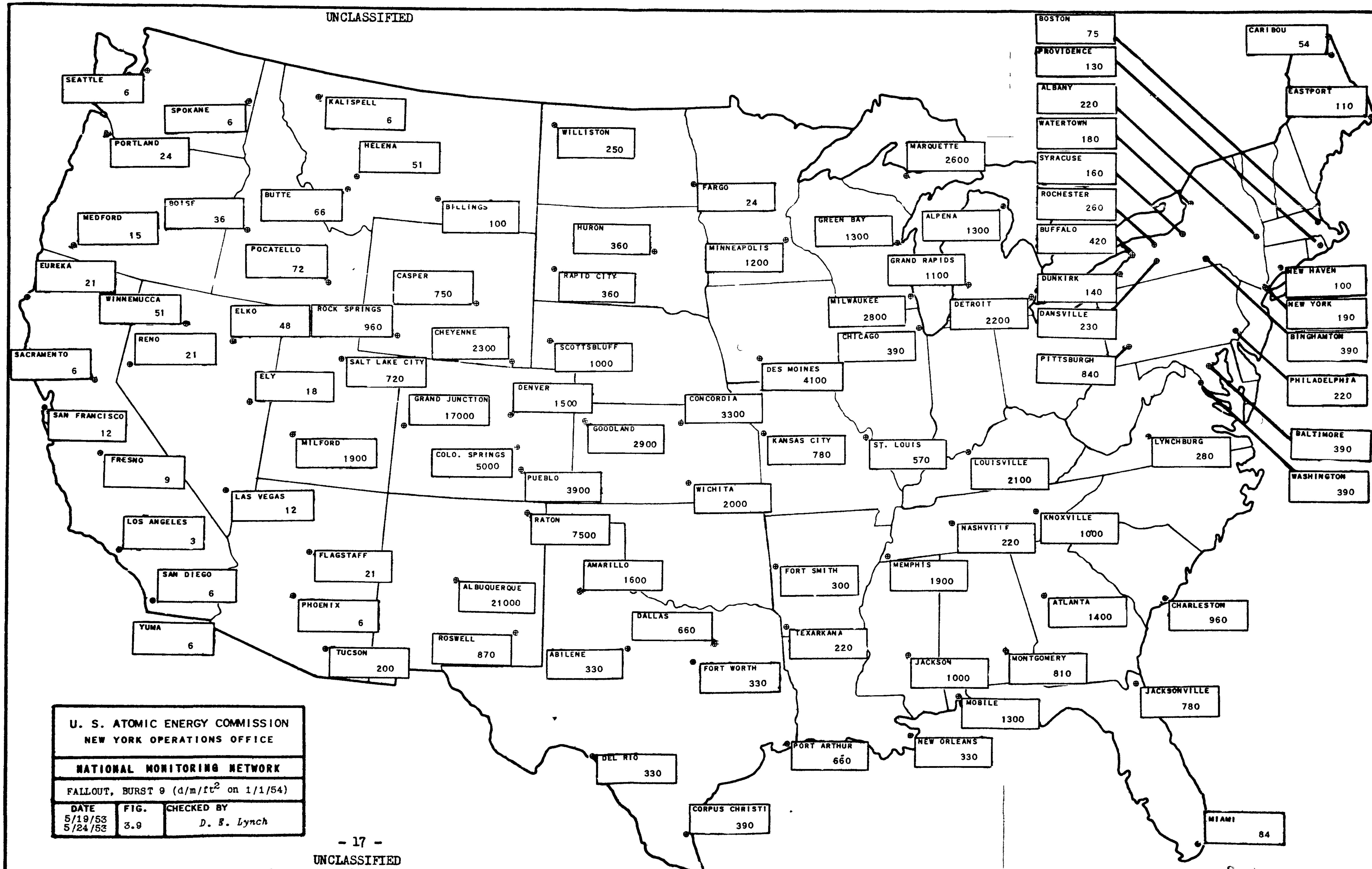
FALLOUT, BURST 8 (d/m/ft^2 on 1/1/54)

DATE	FIG.	CHECKED BY
5/8/53 5/18/53	3.8	D. E. Lynch



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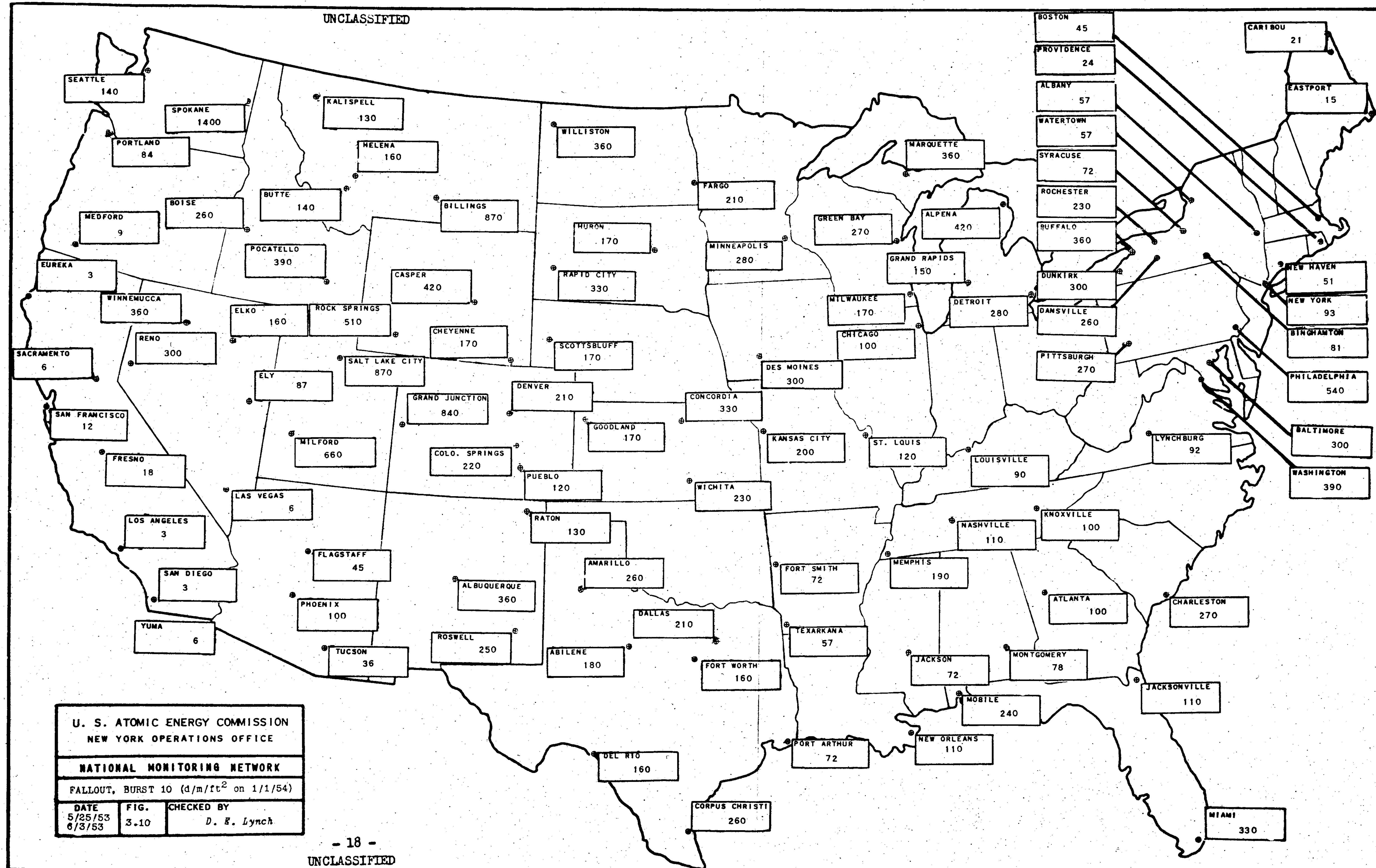
FALLOUT, BURST 9 (d/m/ft^2 on 1/1/54)

DATE	FIG.	CHECKED BY
5/19/53 5/24/53	3.9	D. E. Lynch



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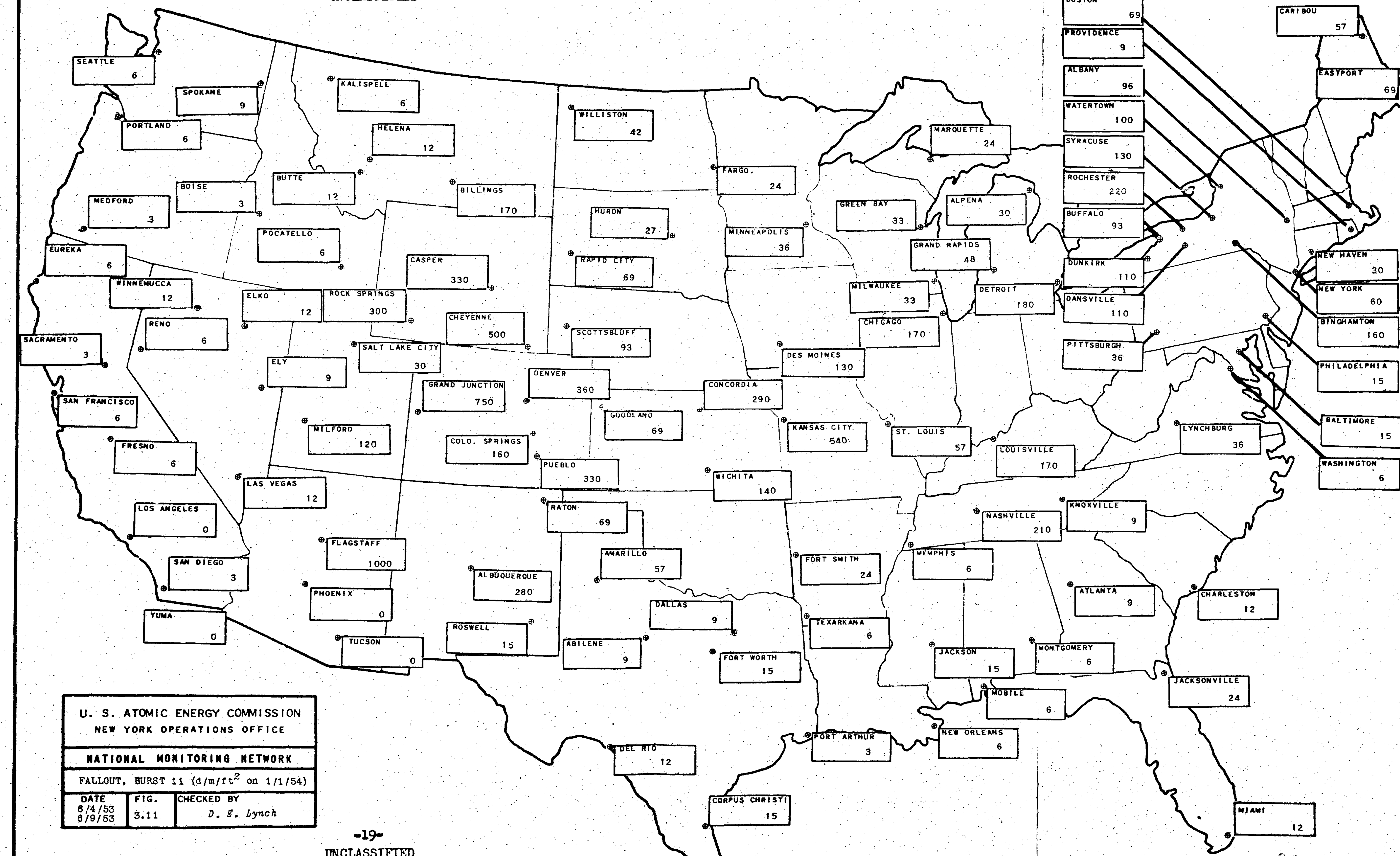
NATIONAL MONITORING NETWORK

FALLOUT, BURST 10 (d/m/ft^2 on 1/1/54)

DATE	FIG.	CHECKED BY
5/25/53 6/3/53	3.10	*D. E. Lynch*

340 022



U. S. ATOMIC ENERGY COMMISSION NEW YORK OPERATIONS OFFICE		
NATIONAL MONITORING NETWORK		
FALLOUT, BURST 11 ($d/m/ft^2$ on 1/1/54)		
DATE 6/4/53 6/9/53	FIG. 3.11	CHECKED BY *D. E. Lynch*

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NATIONAL MONITORING NETWORK

TOTAL FALLOUT (d/m/ft^2 on 1/1/54)

DATE	FIG.	CHECKED BY
3/18/53 6/9/53	3.12	D. E. Lynch

3 024

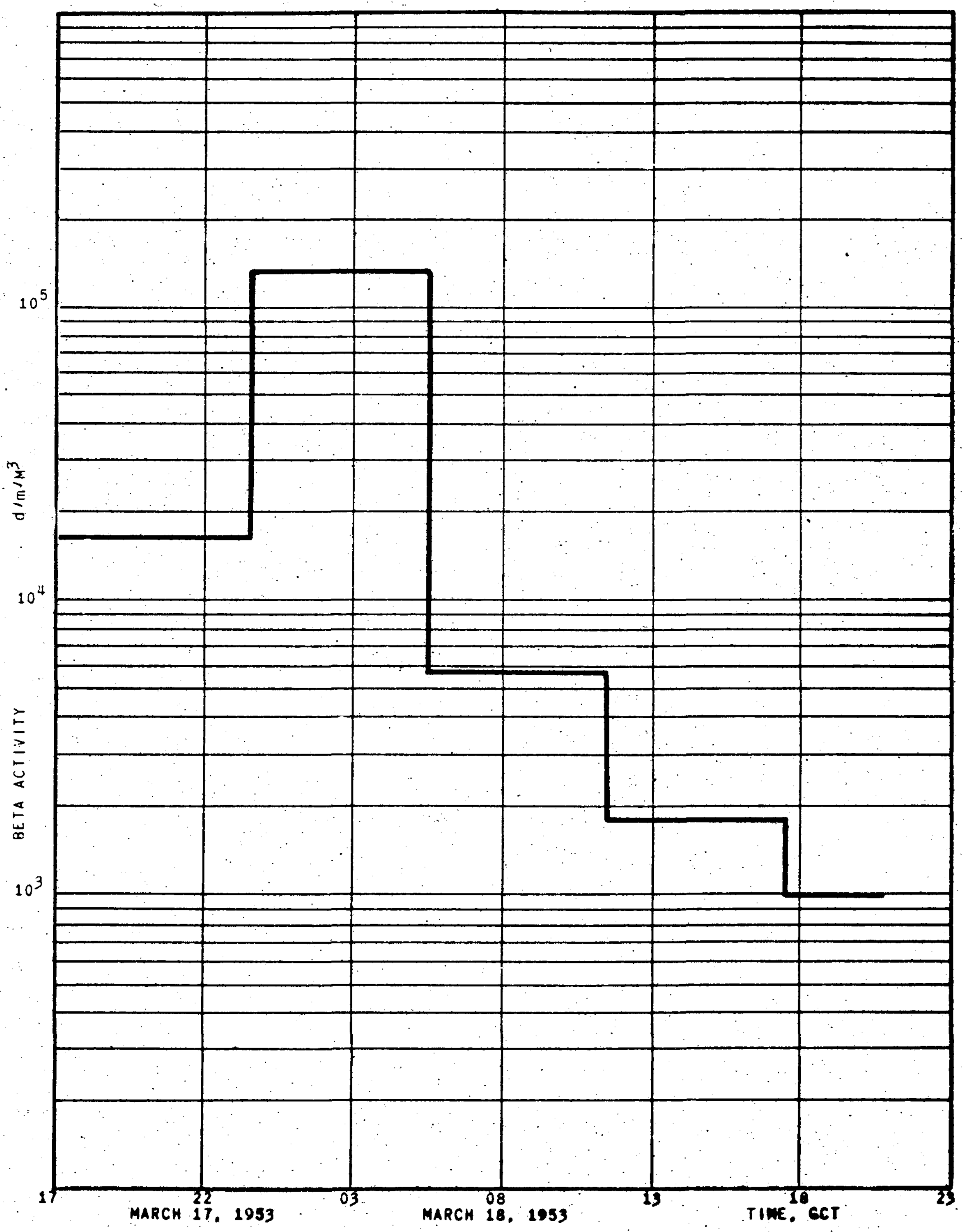

Fig. 3.13 – Active dust in air after burst No. 1, Cortez, Colorado

349 025

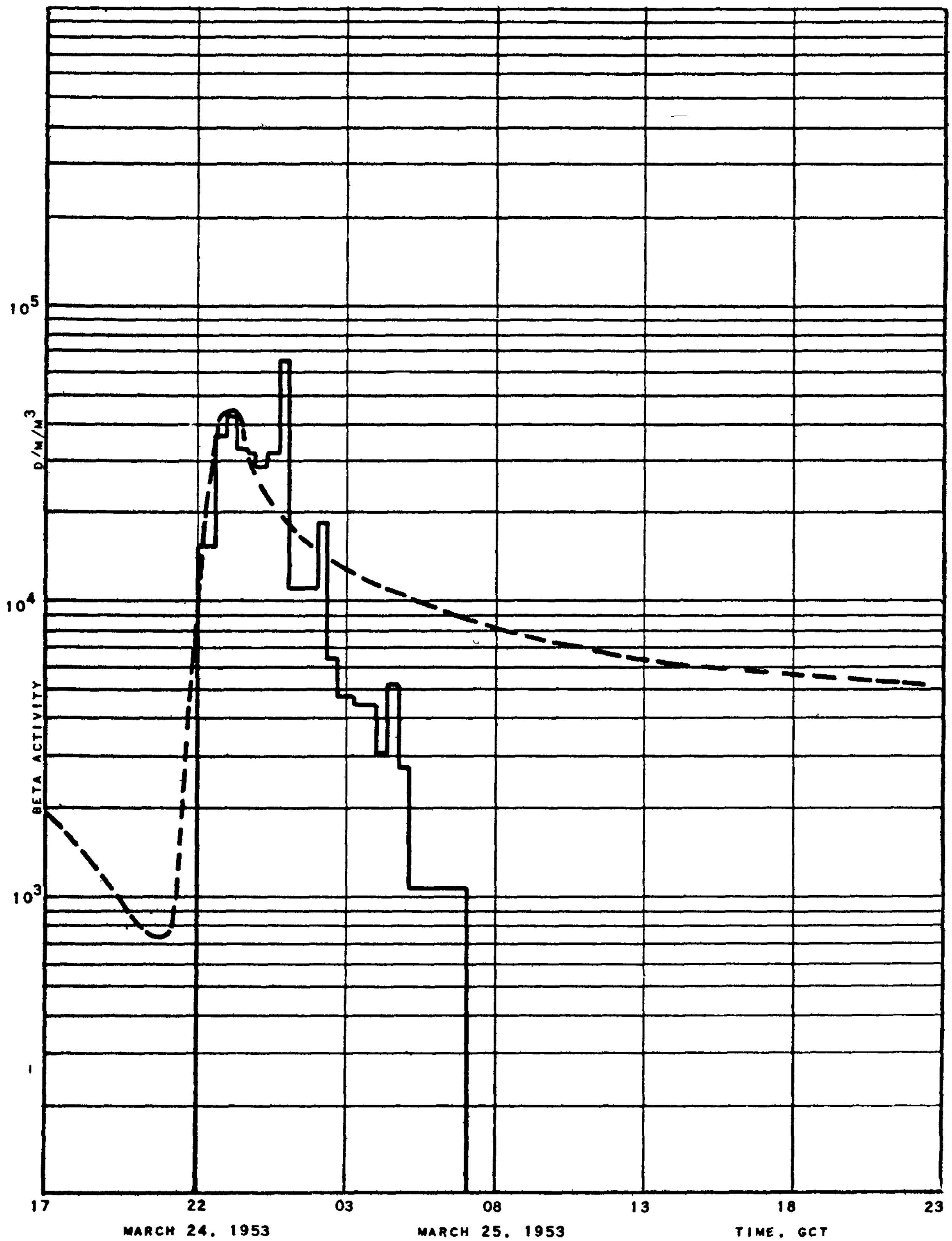

Fig. 3.14 – Active dust in air after burst No. 2, Elko, Nevada (Dotted Curve: Automatic monitor readings, d/m.)

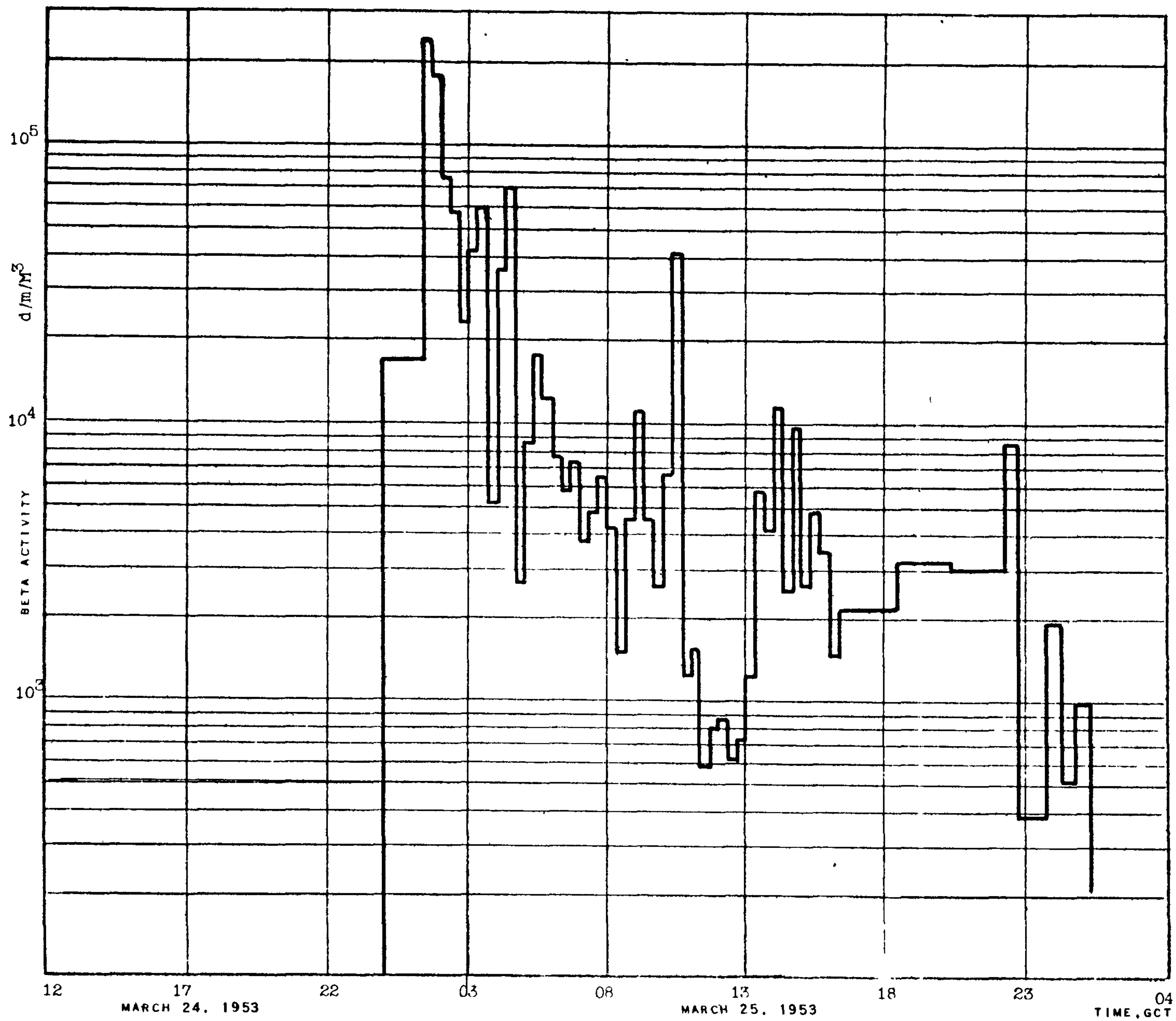

Fig. 3.15 - Active dust in air after burst No. 2, Ogden, Utah

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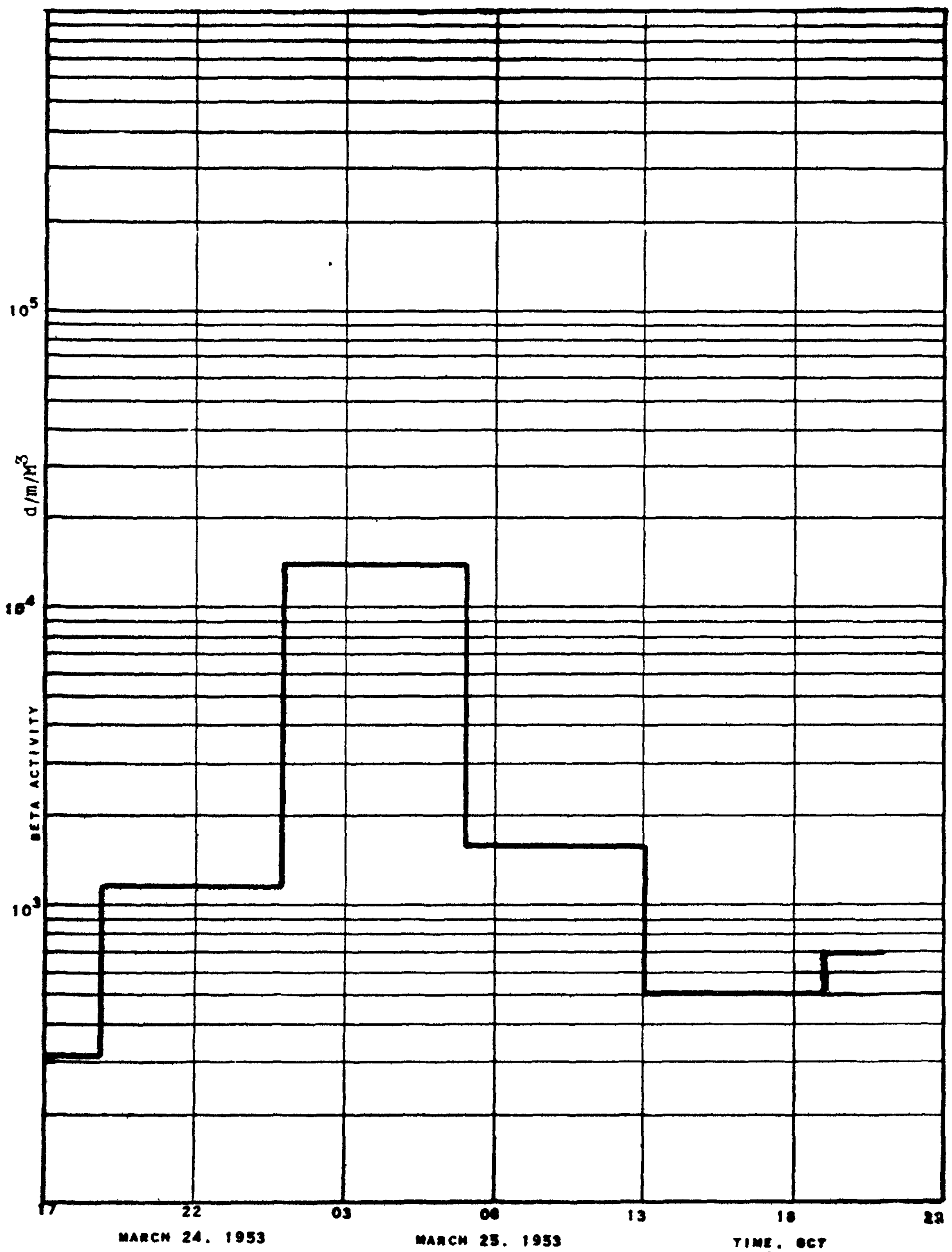

Fig. 3.16 - Active dust in air after burst No. 2, Wendover, Utah

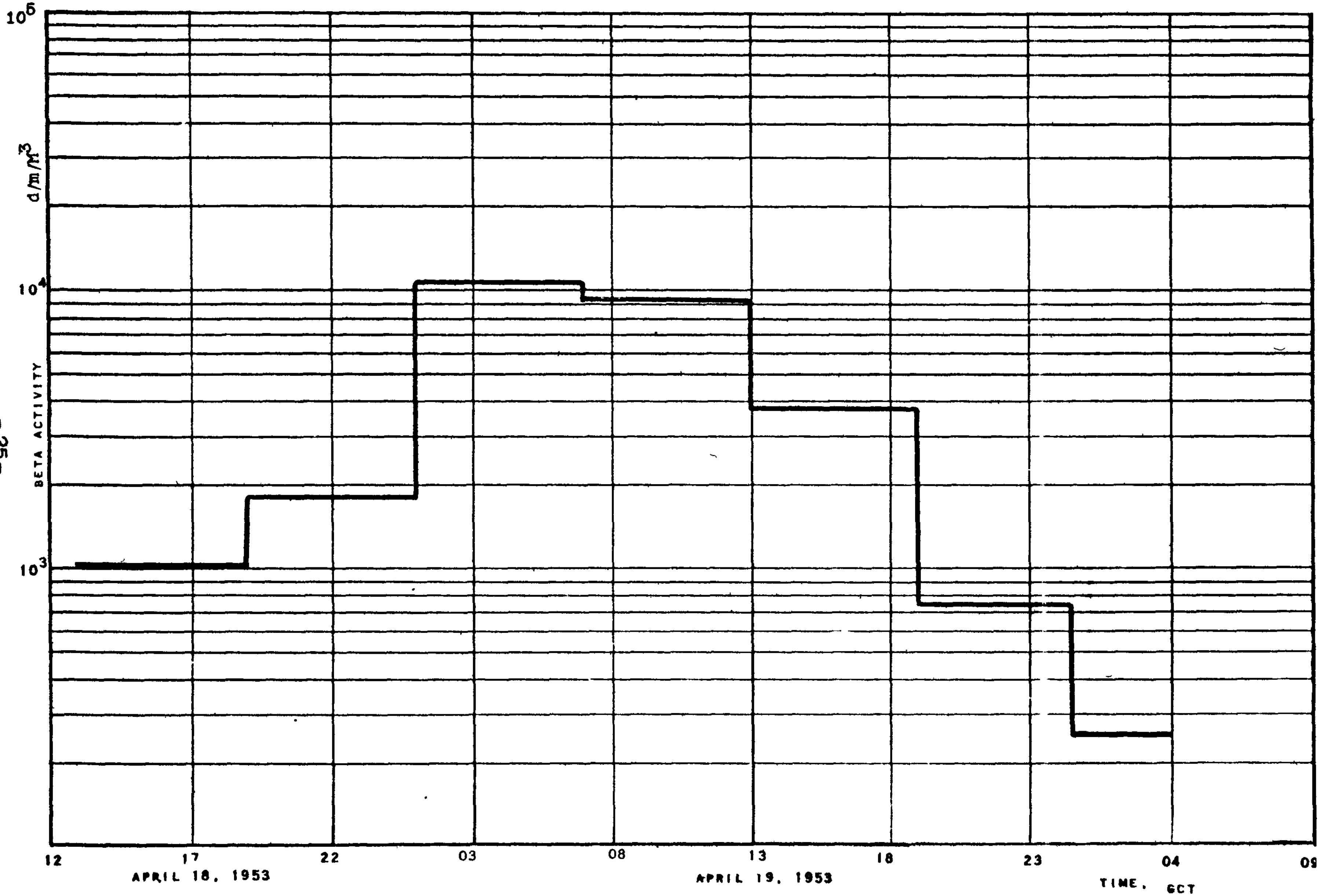

Fig. 3.17 - Active dust in air after burst No. 6, Winslow, Arizona

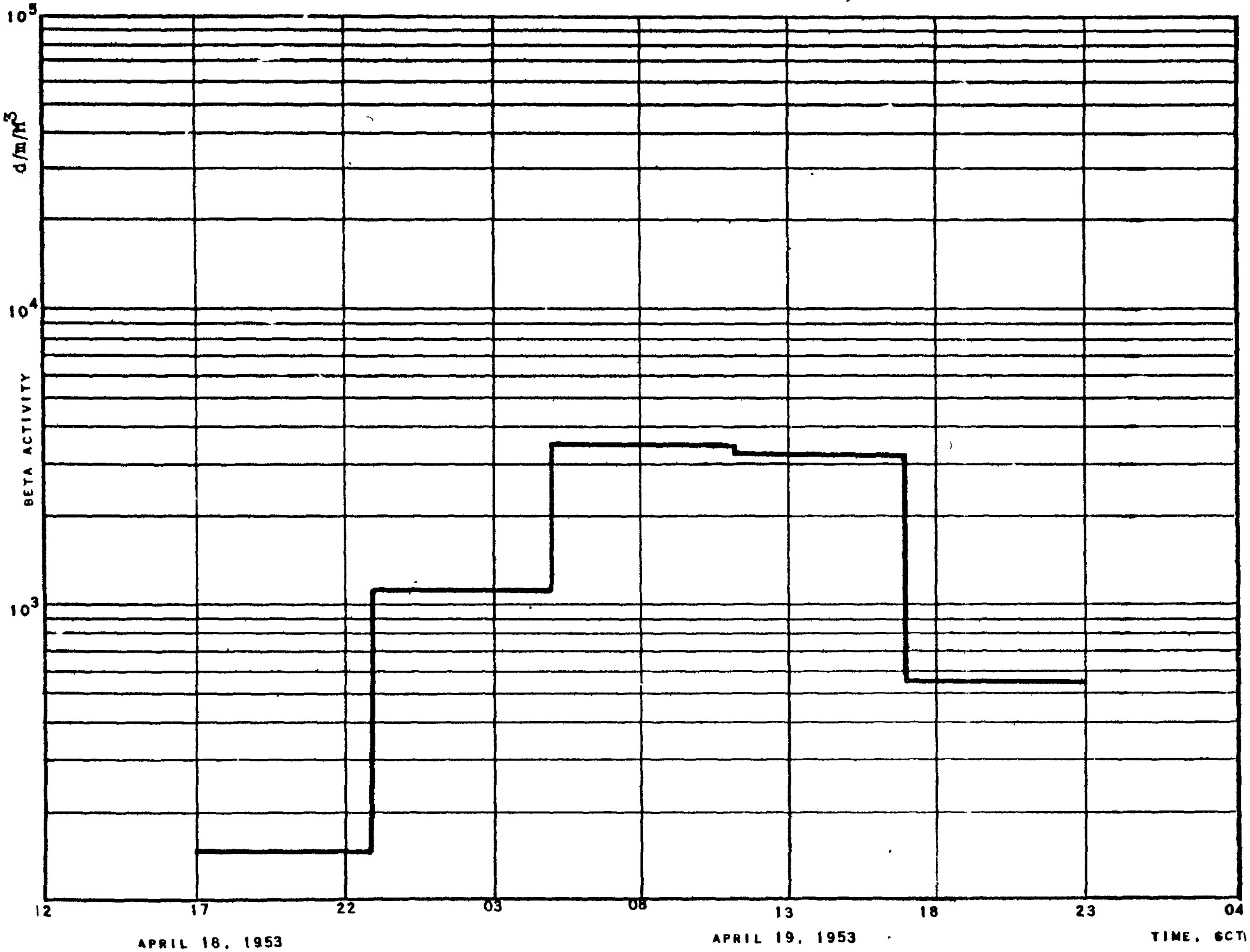

Fig. 3.18 - Active dust in air after burst No. 6, Needles, California

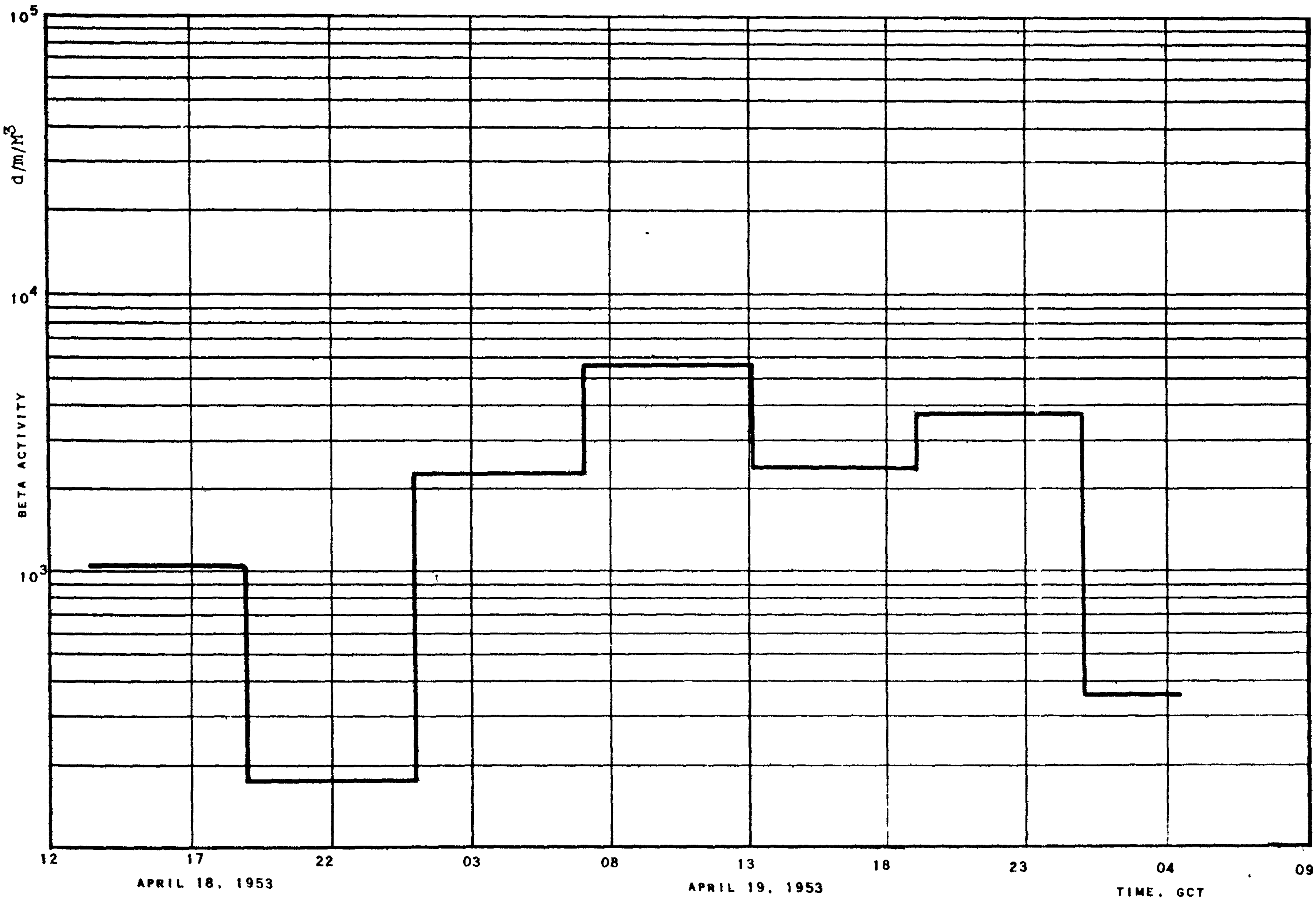

Fig. 3.19 - Active dust in air after burst No. 6, Albuquerque, N. M.

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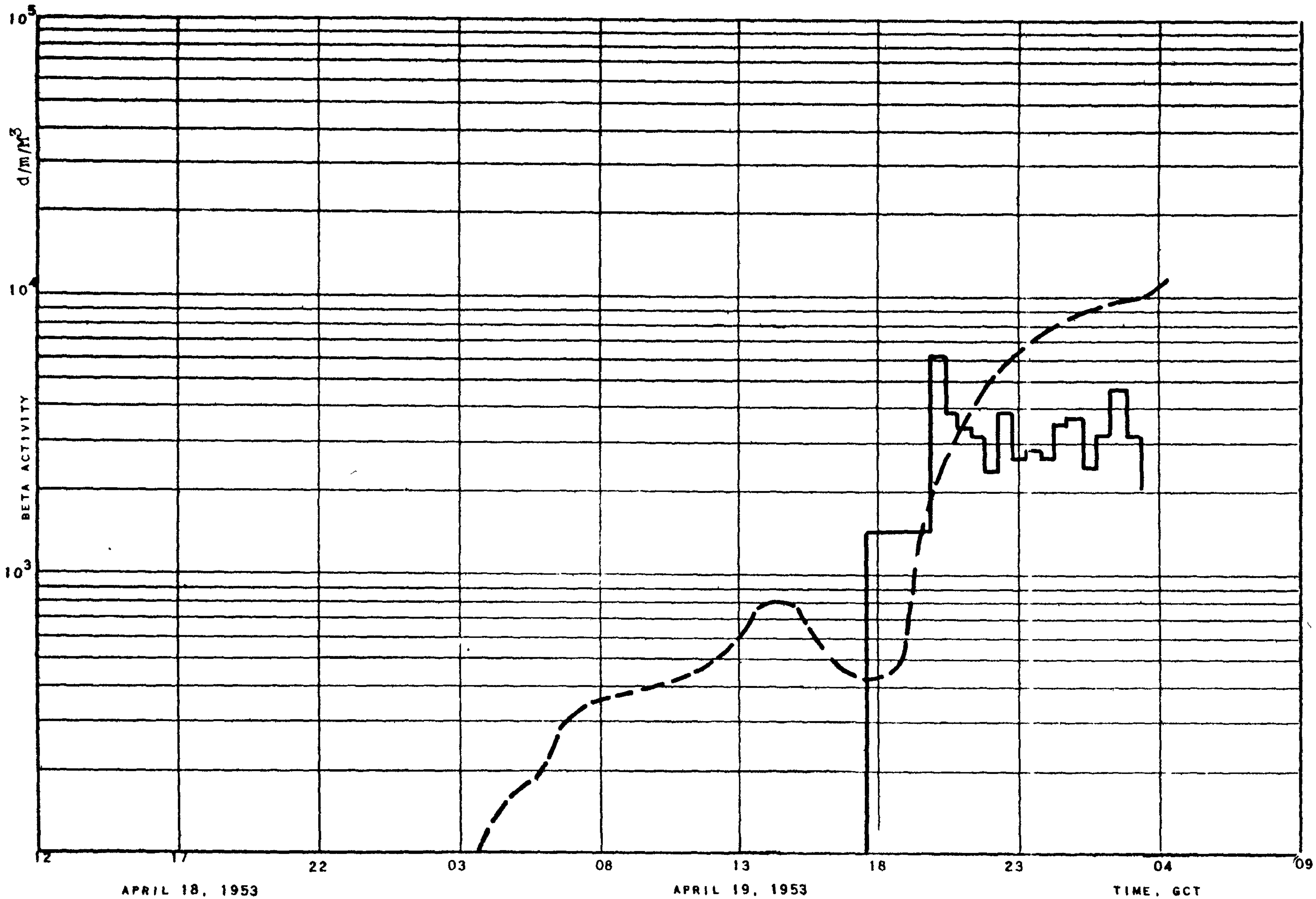

Fig. 3.20 - Active dust in air after burst No. 6, Farmington, N. M.
(Dotted Curve: Automatic monitor readings, d/m.)

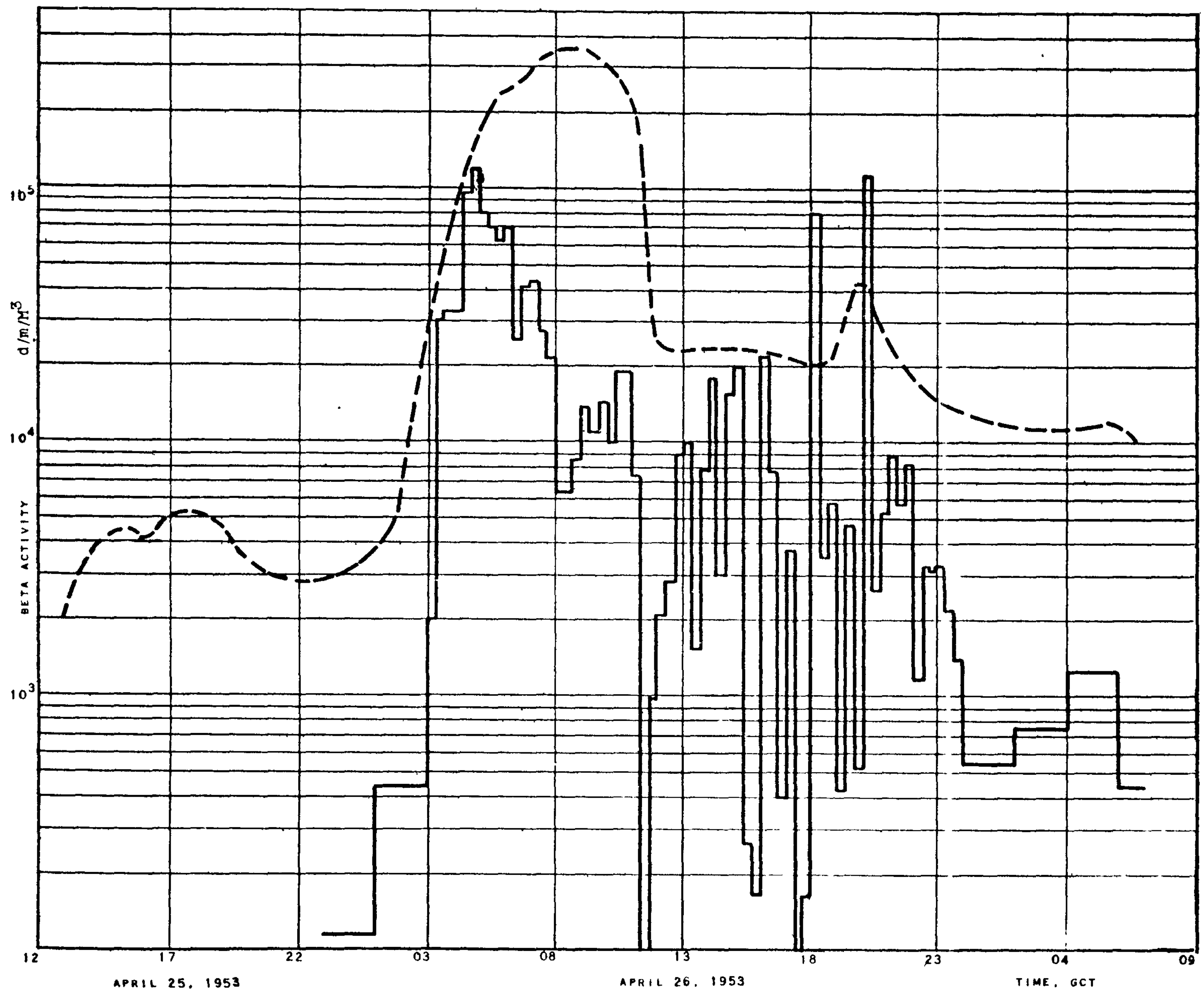

Fig. 3.21 - Active dust in air after burst No. 7, Winslow, Arizona
(Dotted Curve: Automatic monitor readings, d/m.)

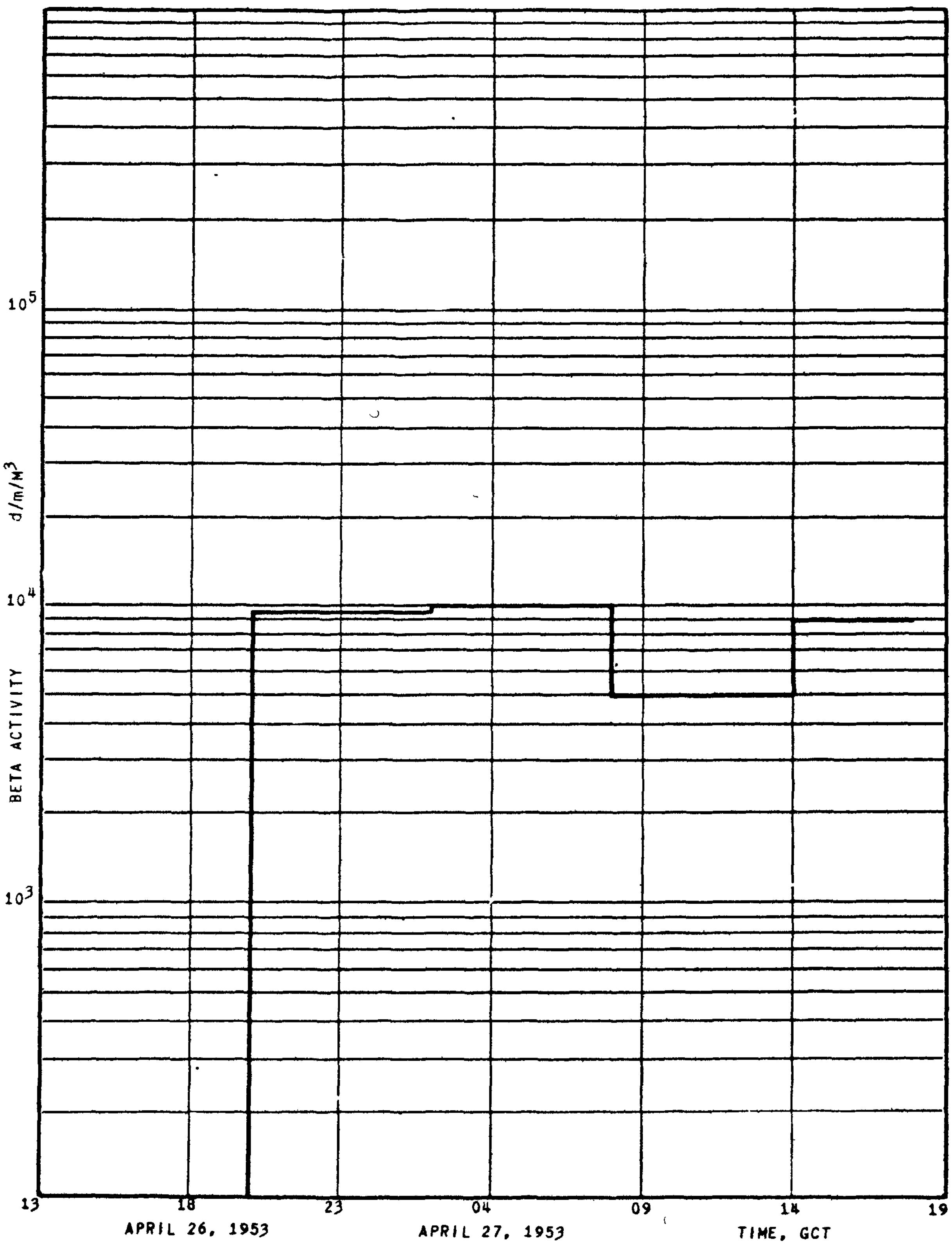

Fig. 3.22 - Active dust in air after burst No. 7, Grand Junction, Colo.

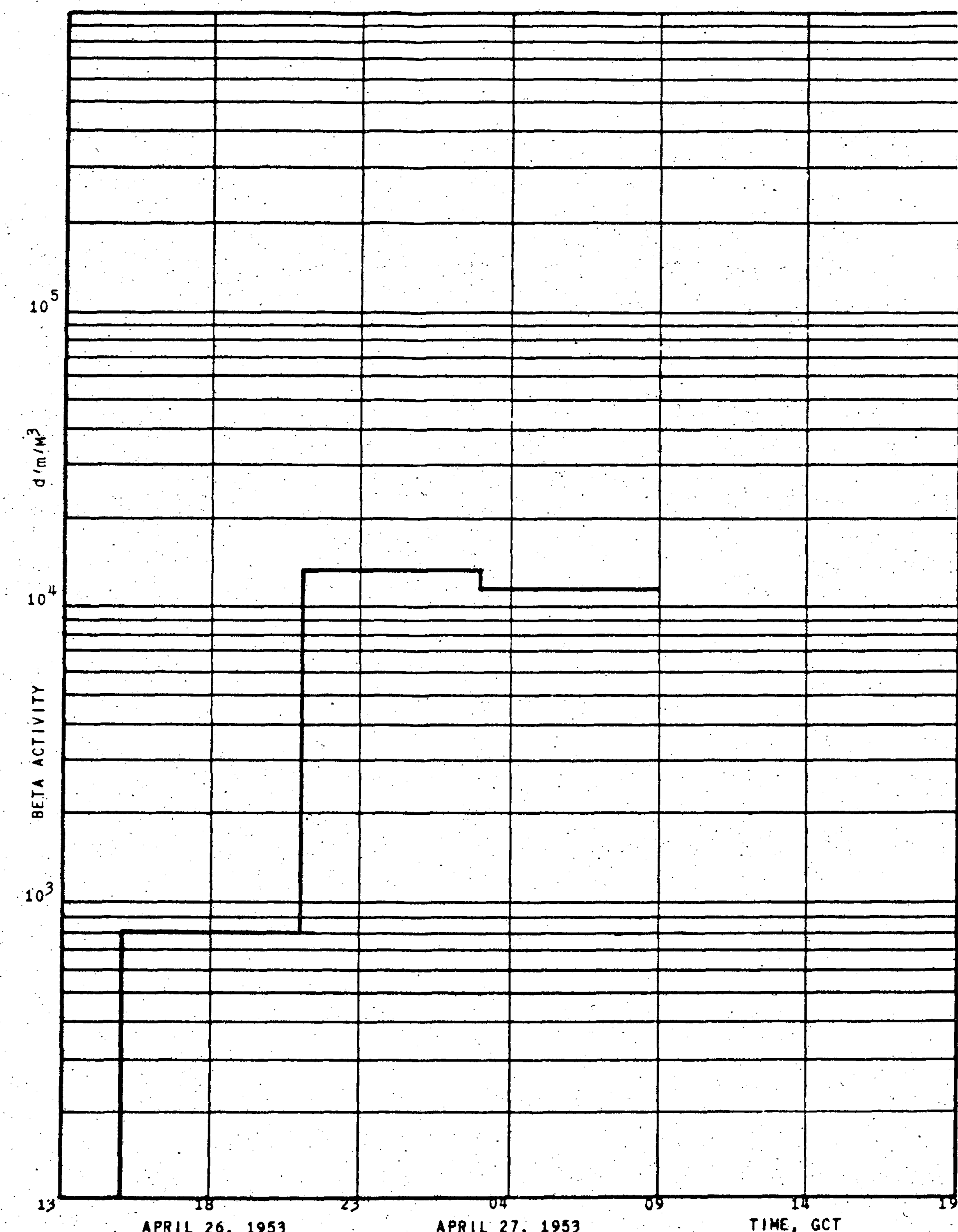

Fig. 3.23 - Active dust in air after burst No. 7, Albuquerque, N. M.

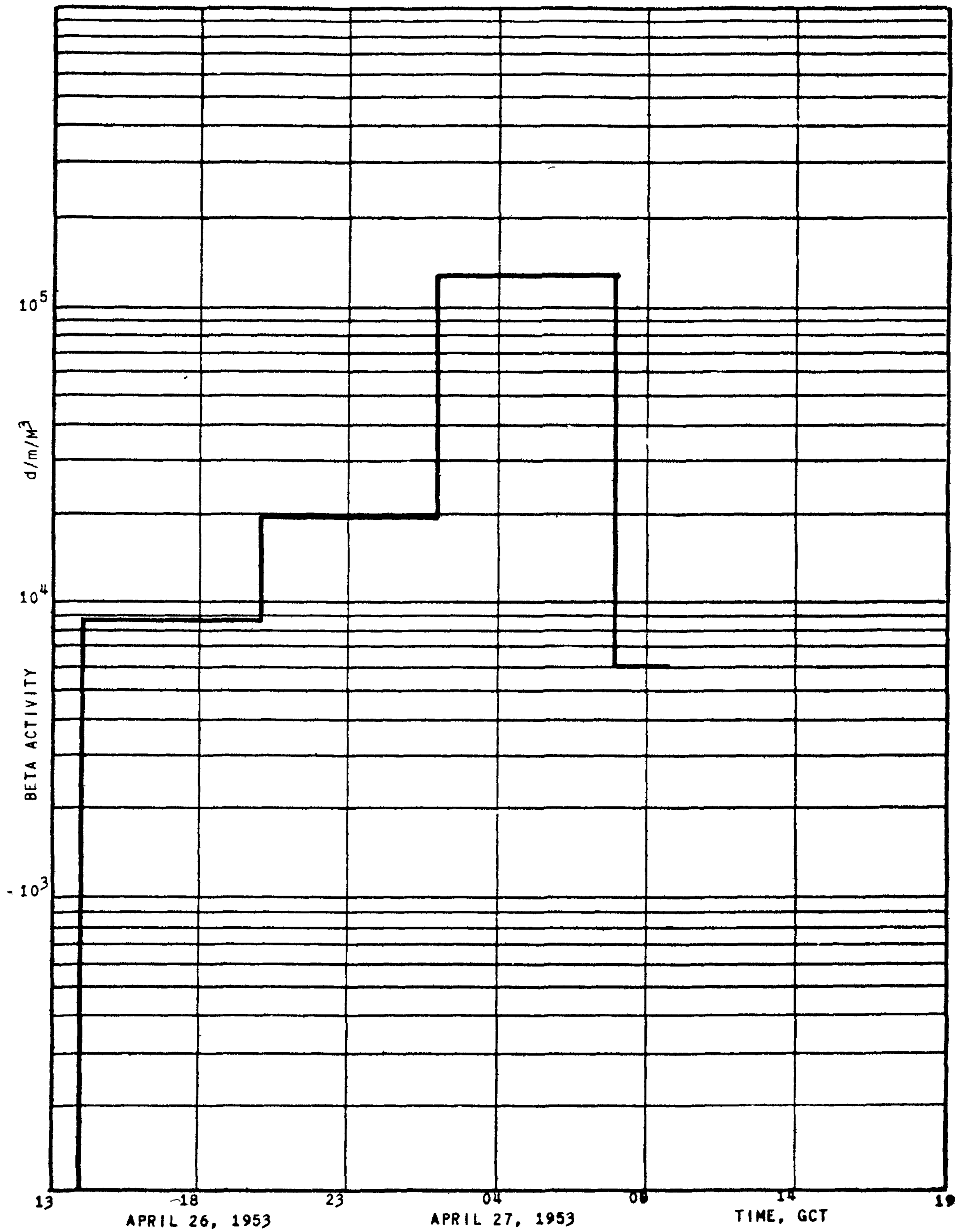

Fig. 3.24 - Active dust in air after burst No. 7, Farmington, N. M.

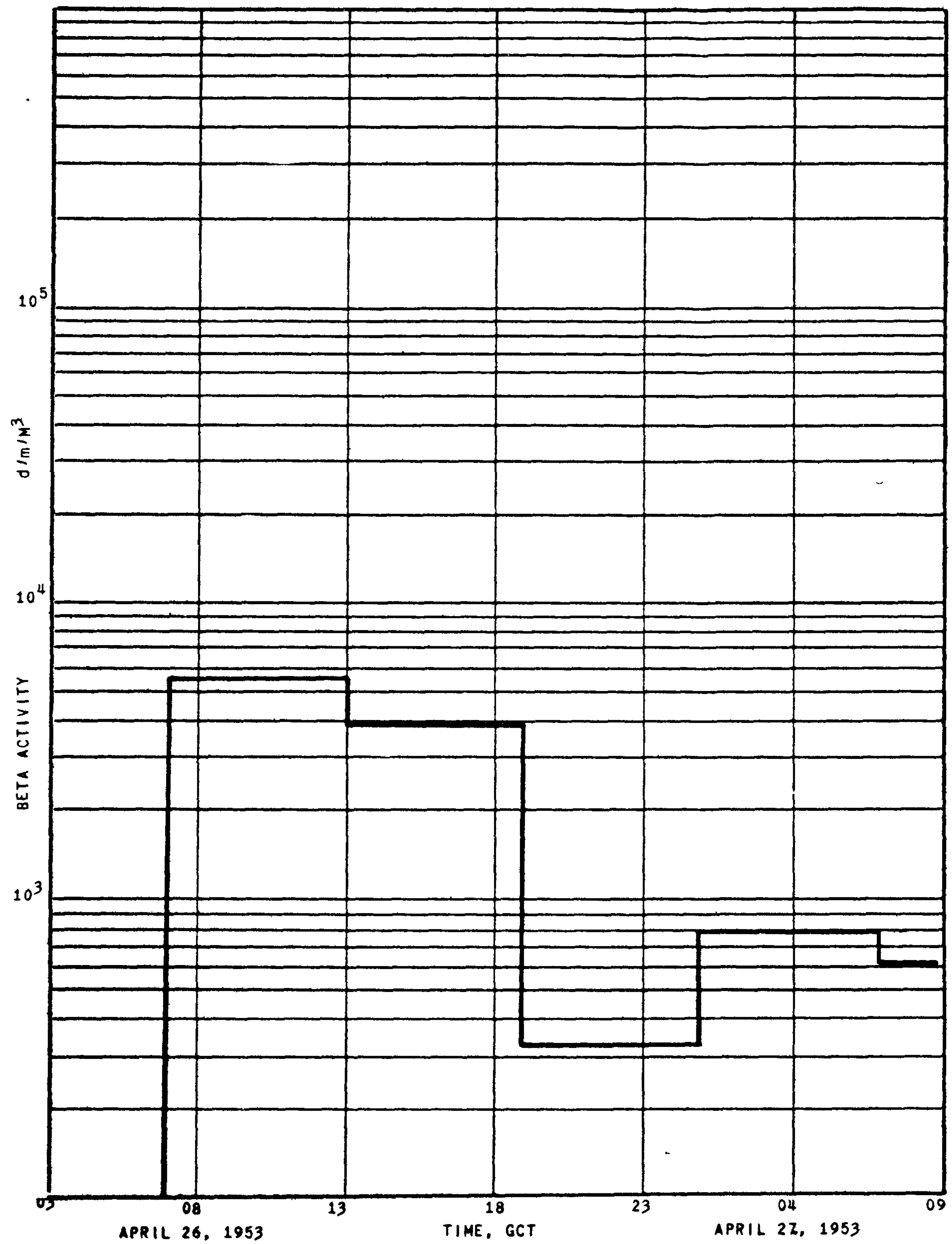

Fig. 3.25 - Active dust in air after burst No. 7, Delta, Utah

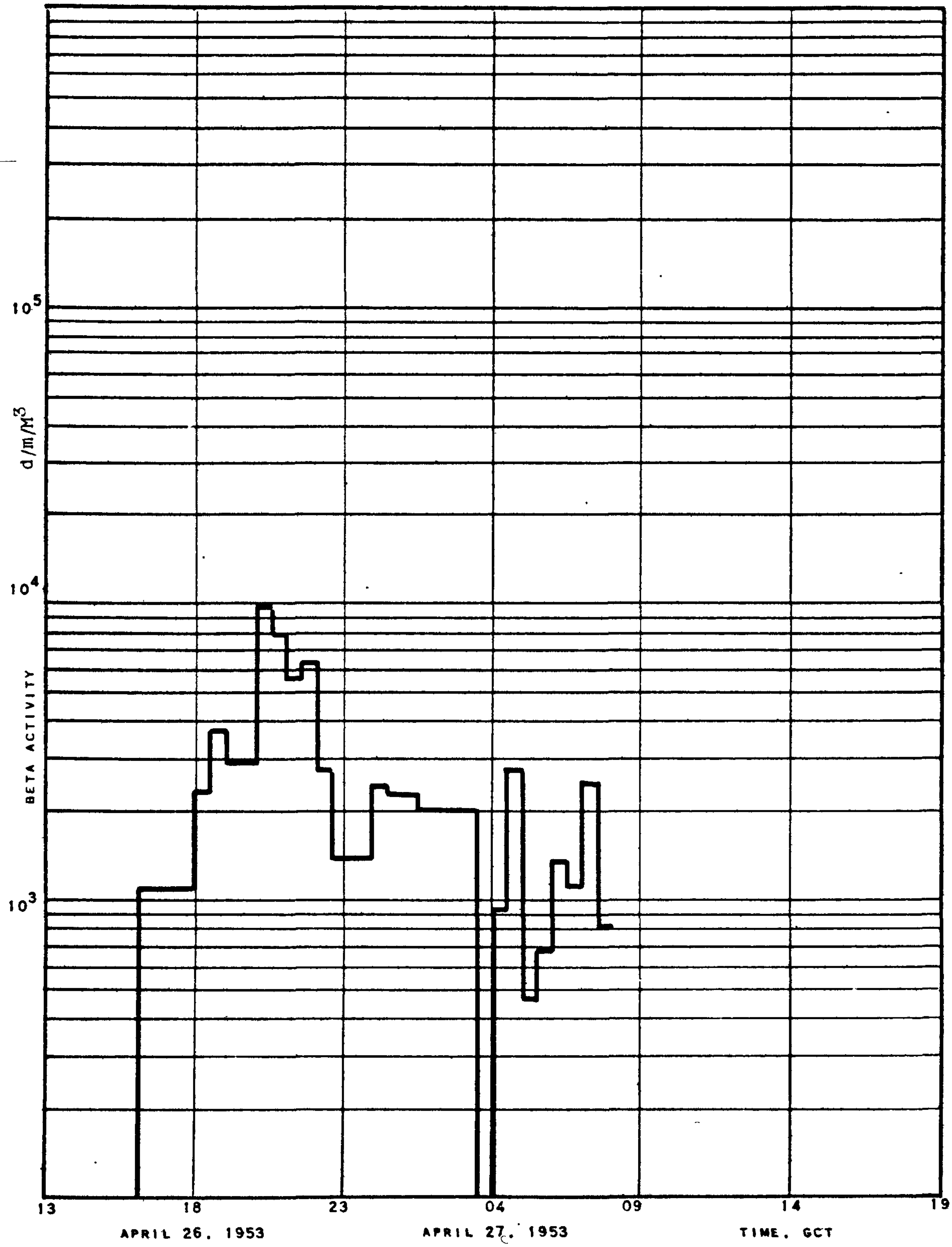

Fig. 3.26 - Active dust in air after burst No. 7, Hanksville, Utah

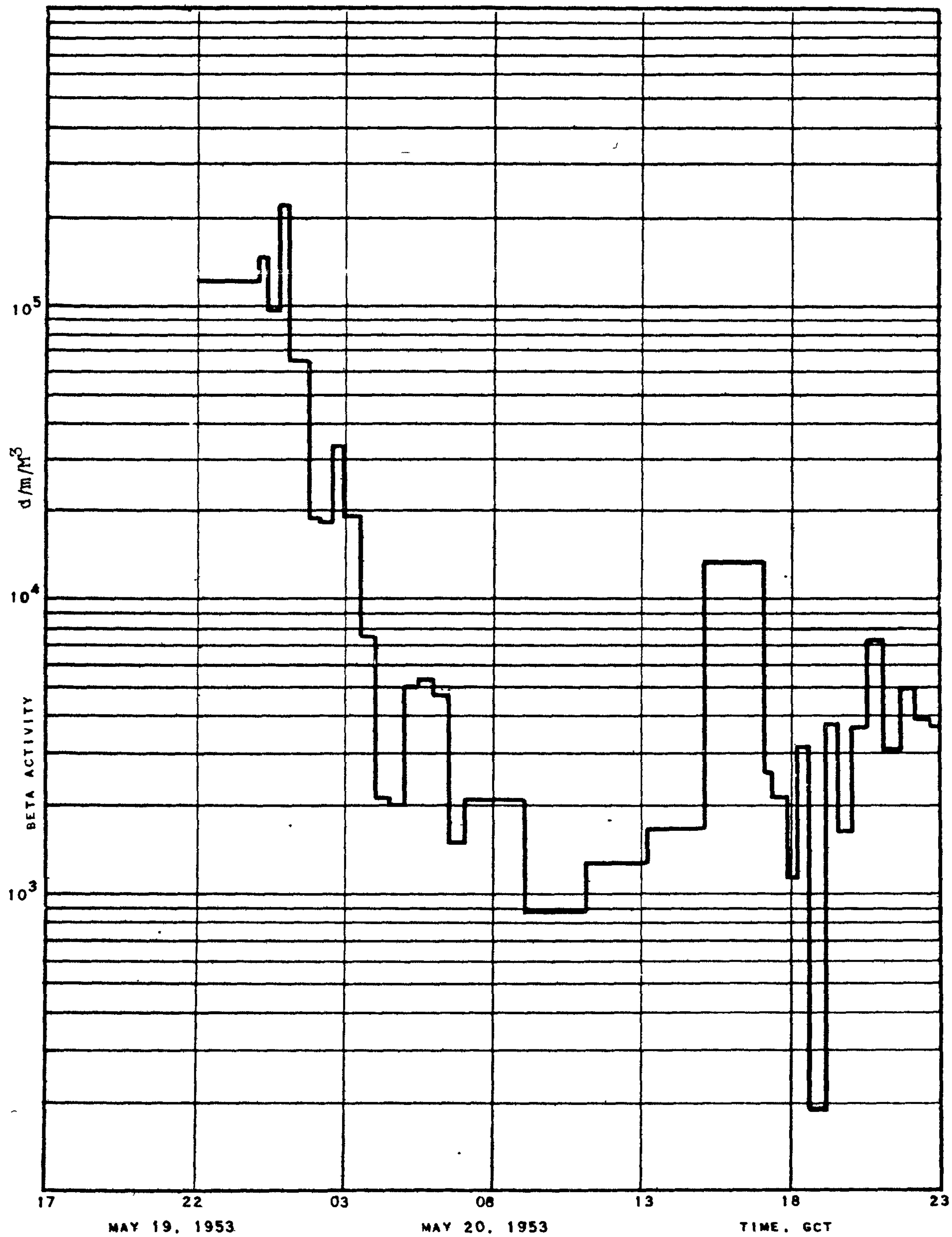

Fig. 3.27 – Active dust in air after burst No. 9, Farmington, N. M.

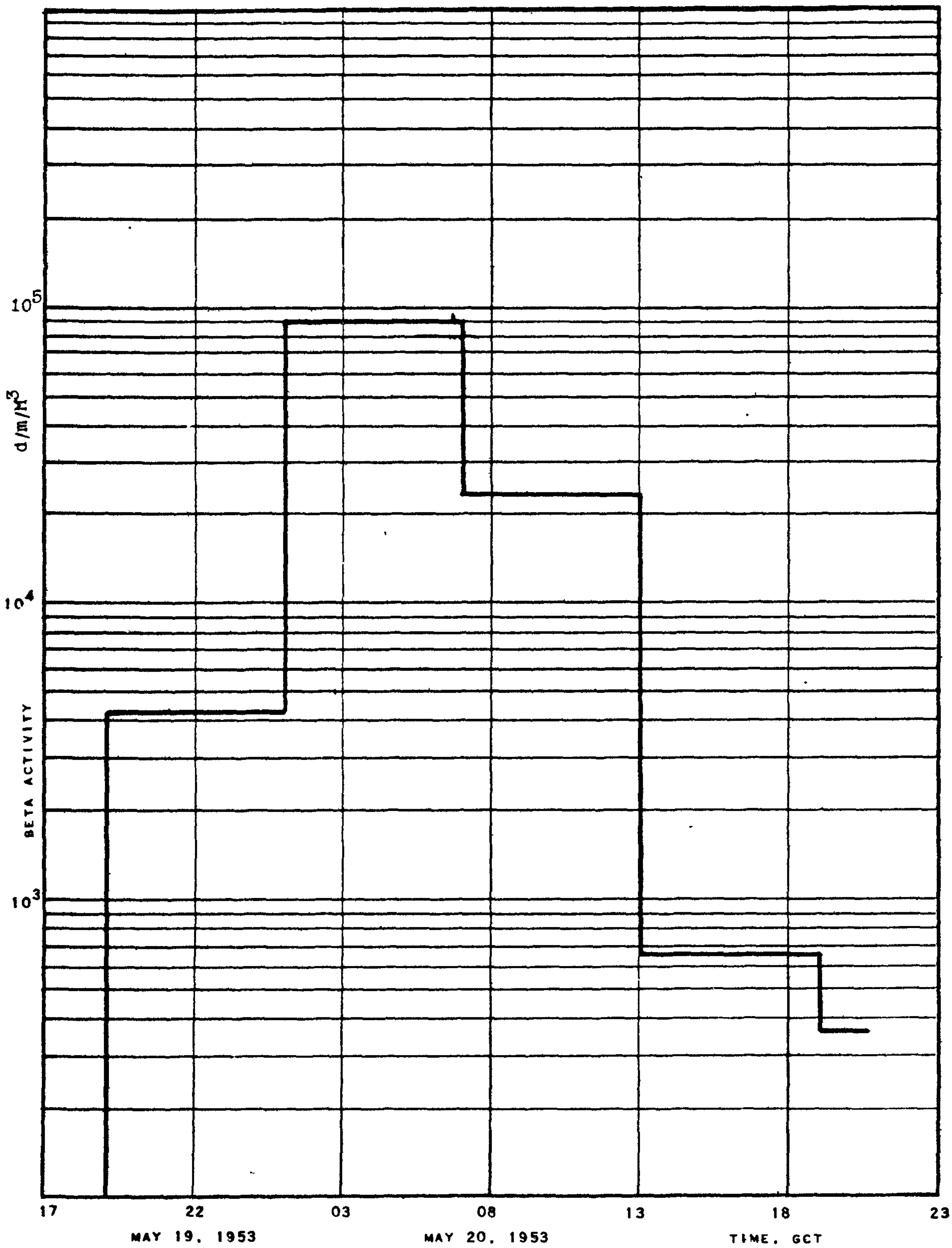

Fig. 3.28 - Active dust in air after burst No. 9, Grand Junction, Colo.

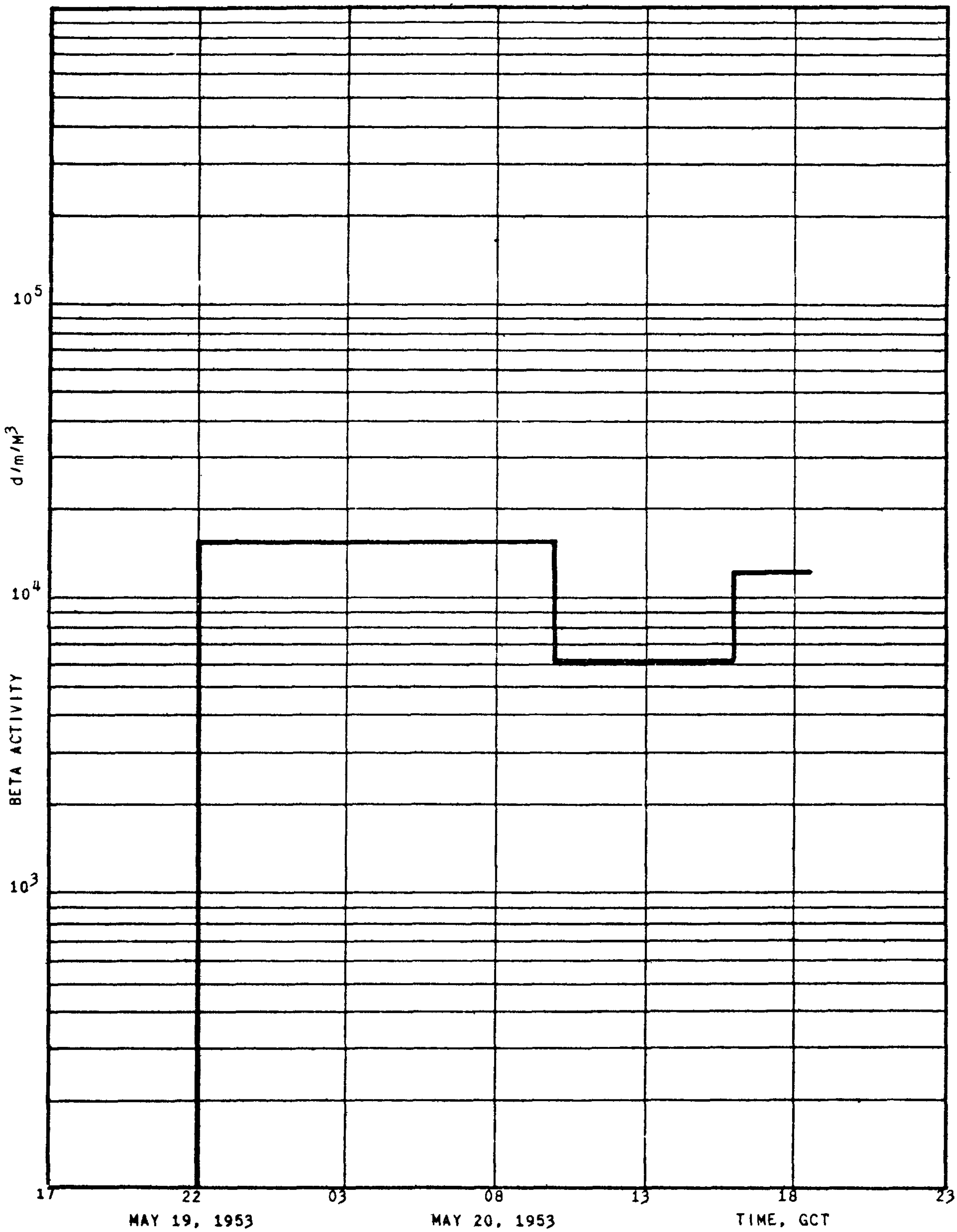

Fig. 3.29 – Active dust in air after burst No. 9, Albuquerque, N. M.

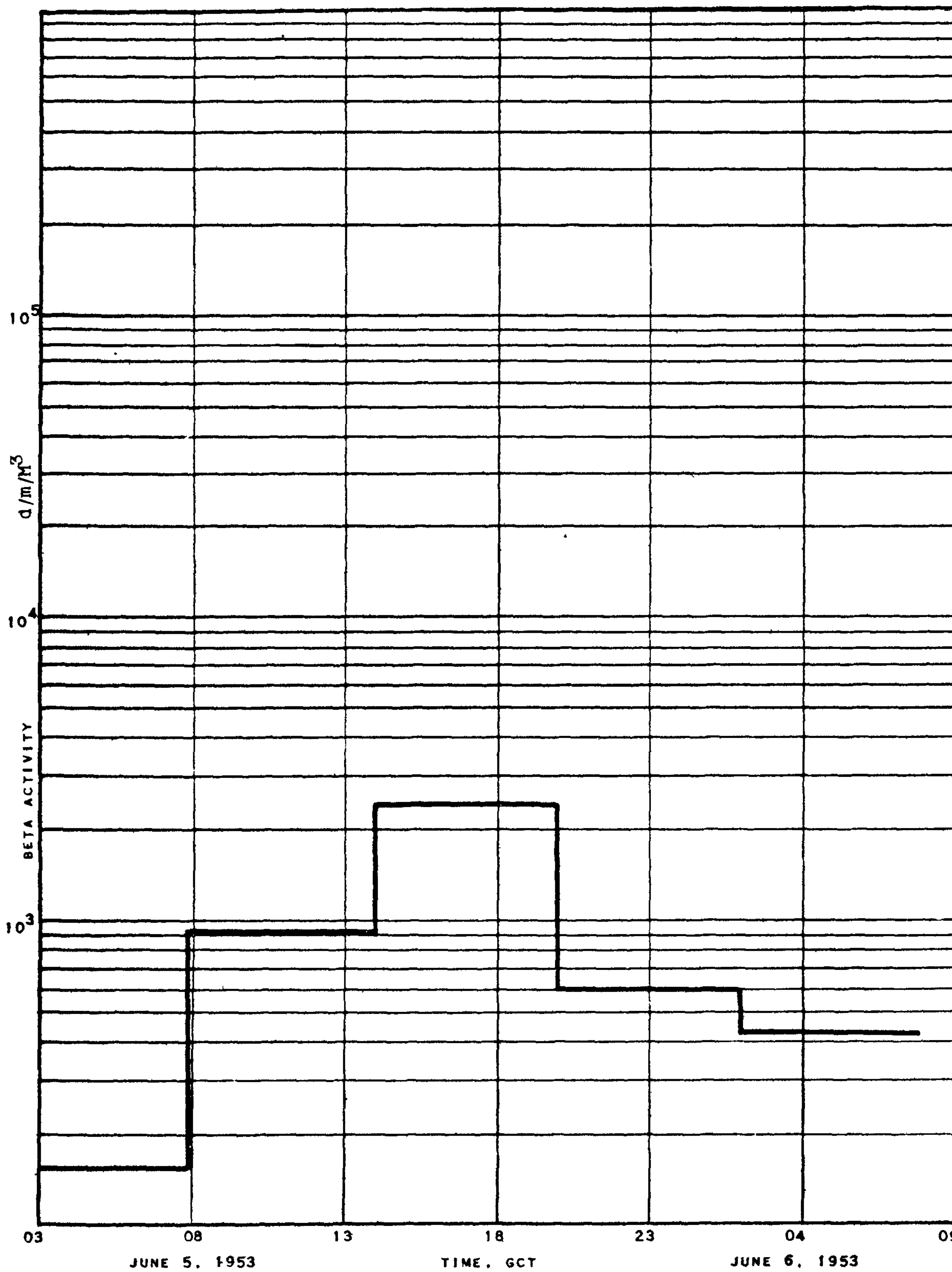

Fig. 3.30 - Active dust in air after burst No. 11, Cortez, Colorado

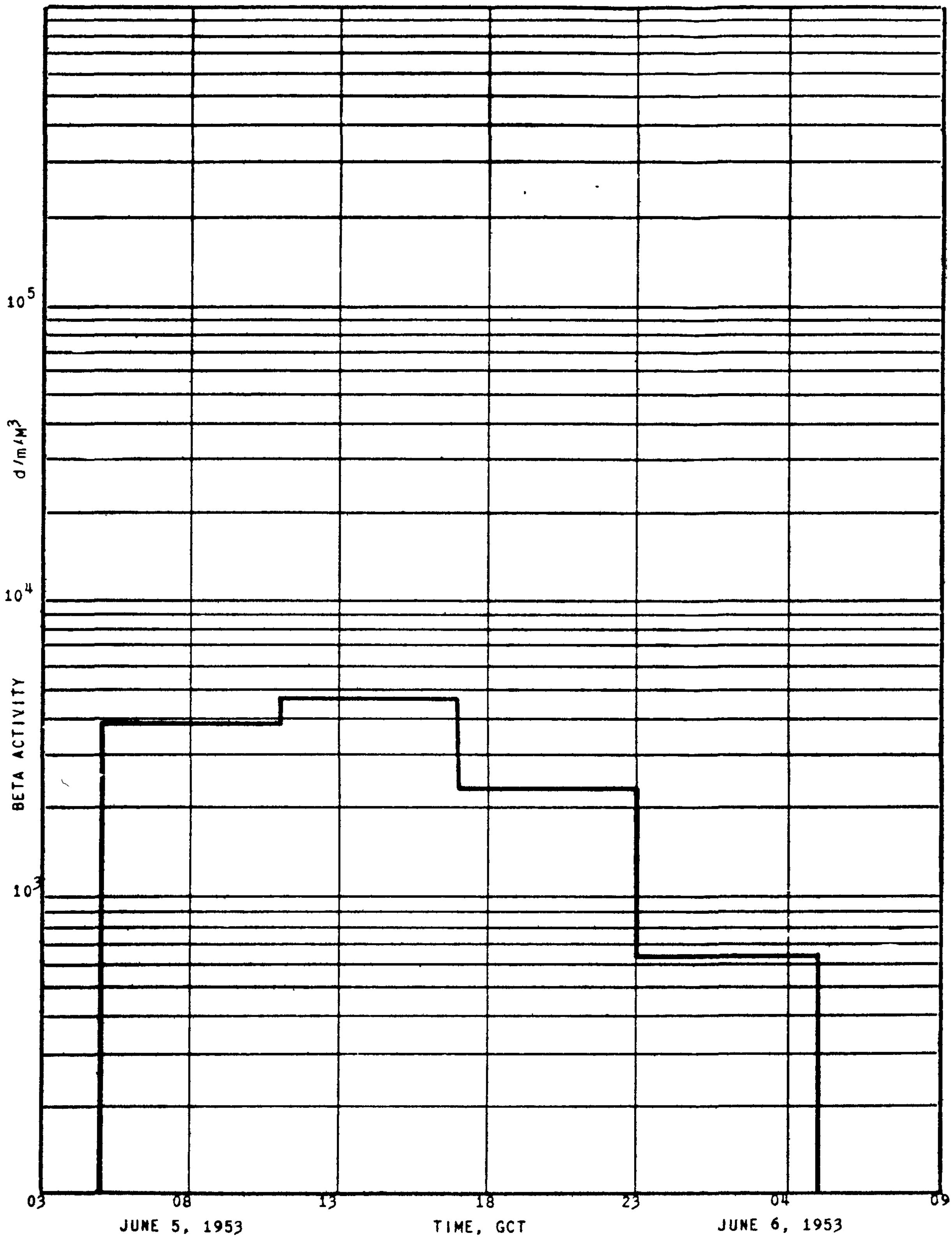

Fig. 3.31 - Active dust in air after burst No. 11, Farmington, N. M.

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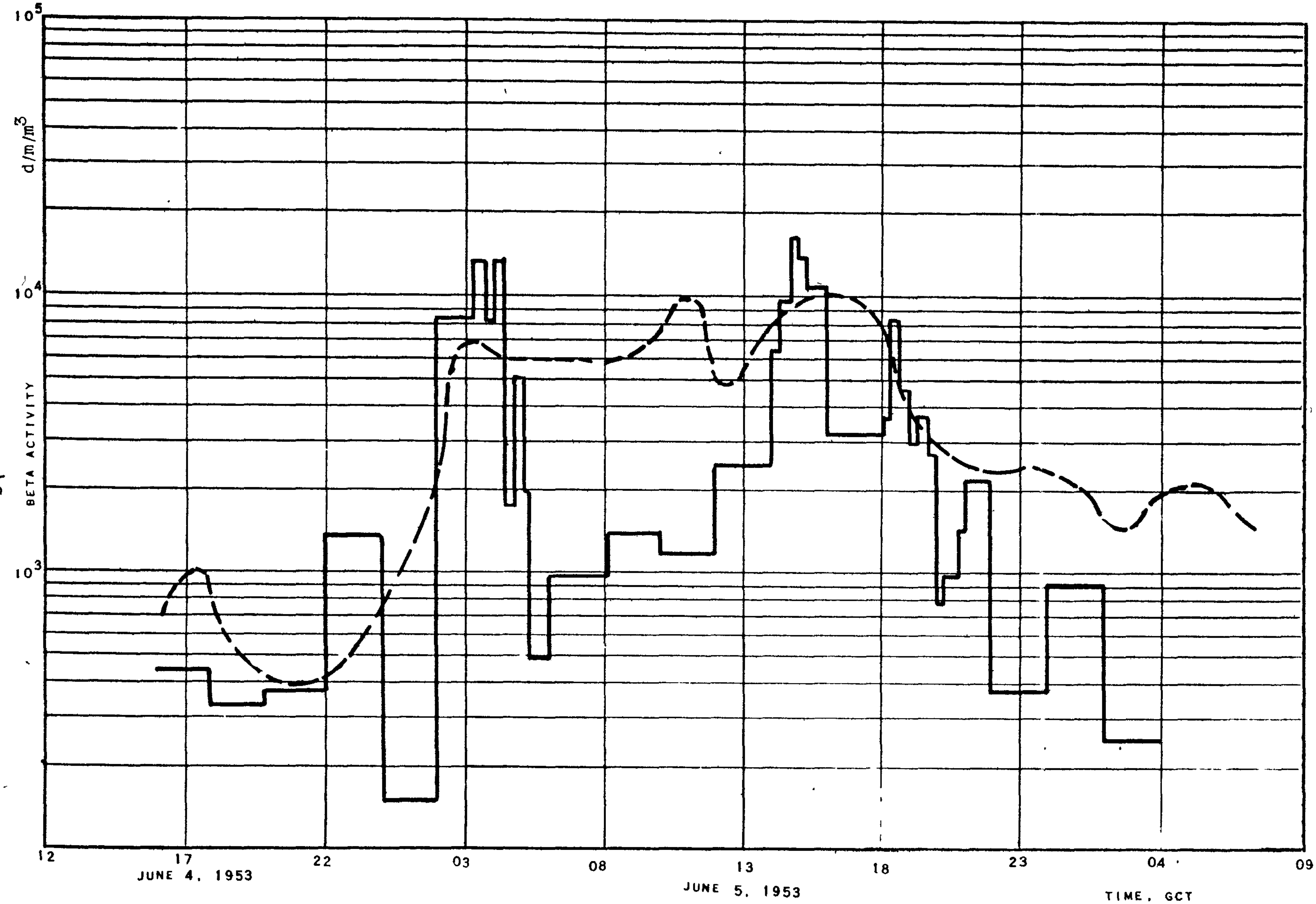

Fig. 3.32 - Active dust in air after burst No. 11, Hanksville, Utah
(Dotted Curve: Automatic monitor readings, d/m.)

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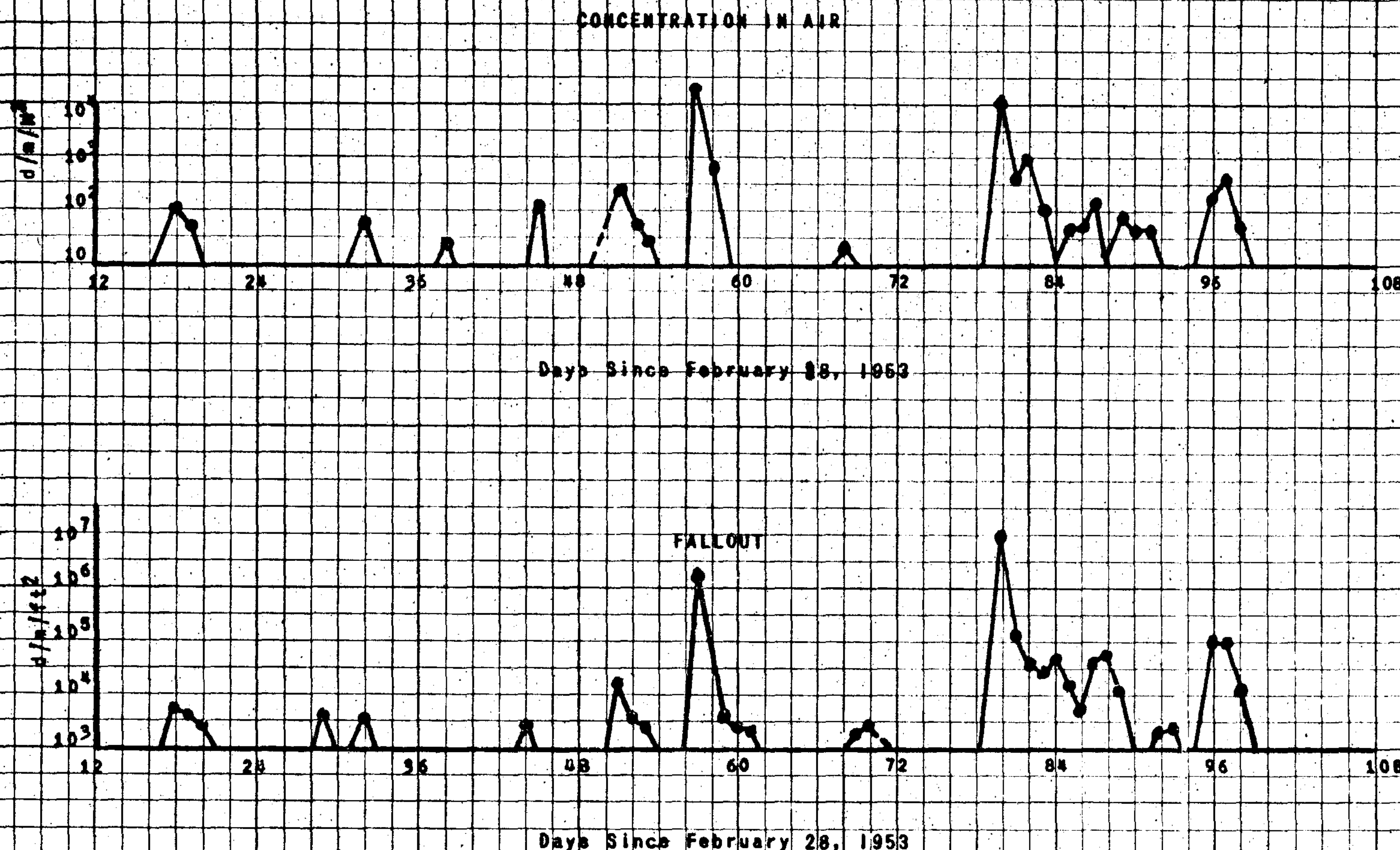

Fig. 3.33 - Radioactivity in airborne dust and in fallout, Grand Junction, Colorado

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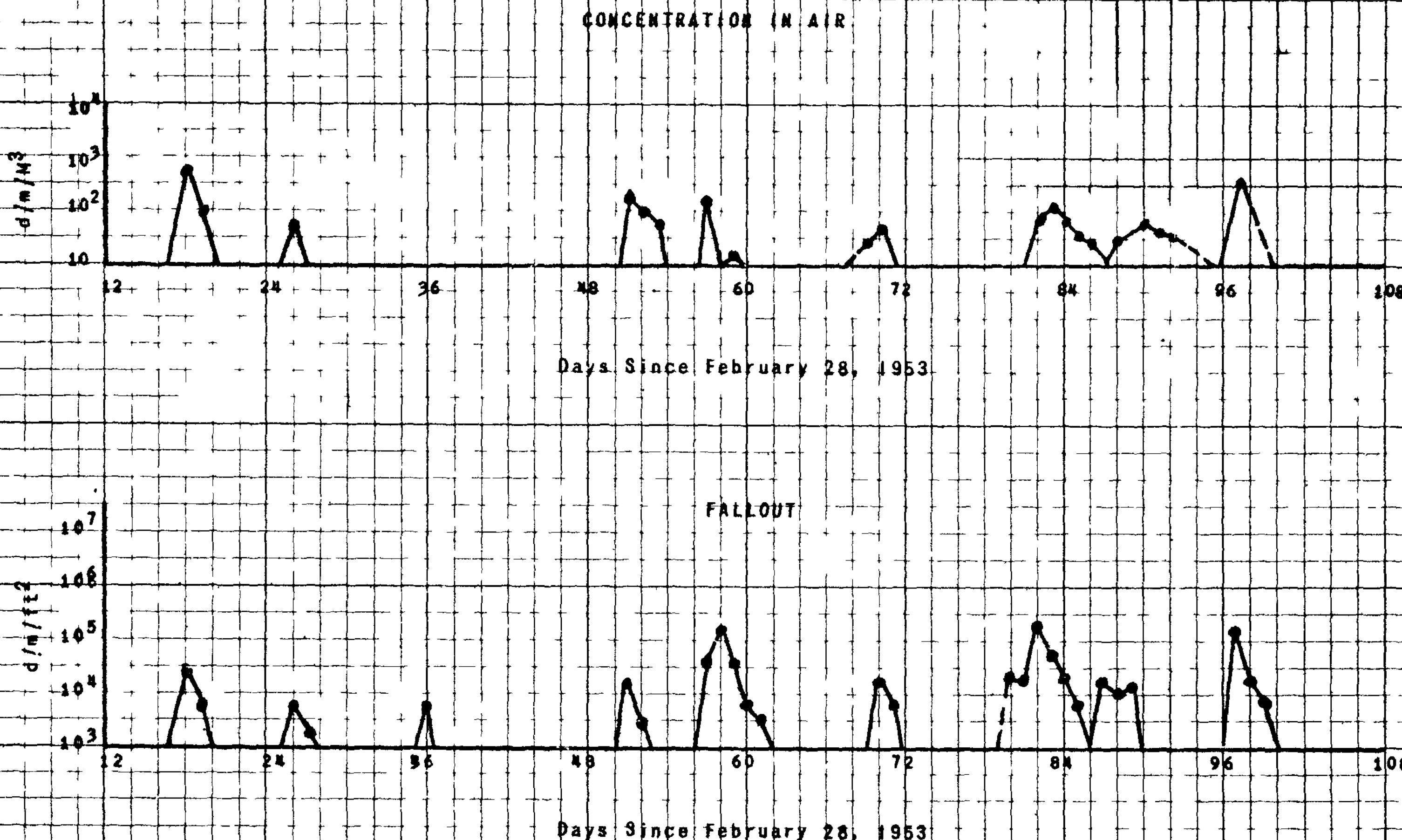

Fig. 3.34 - Radioactivity in airborne dust and in fallout, Denver Colorado

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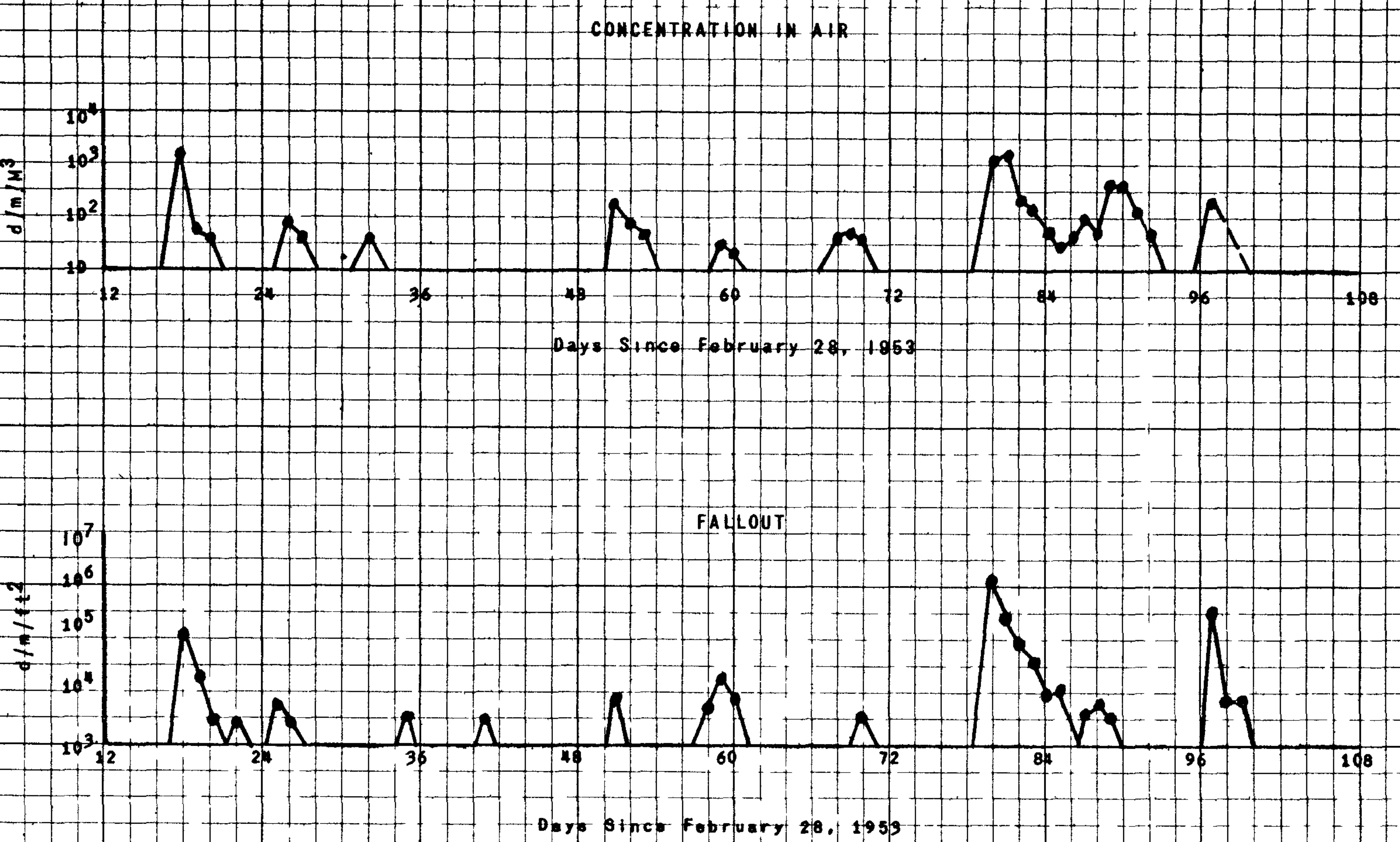

Fig. 3.35 - Radioactivity in airborne dust and in fallout, Pueblo, Colorado

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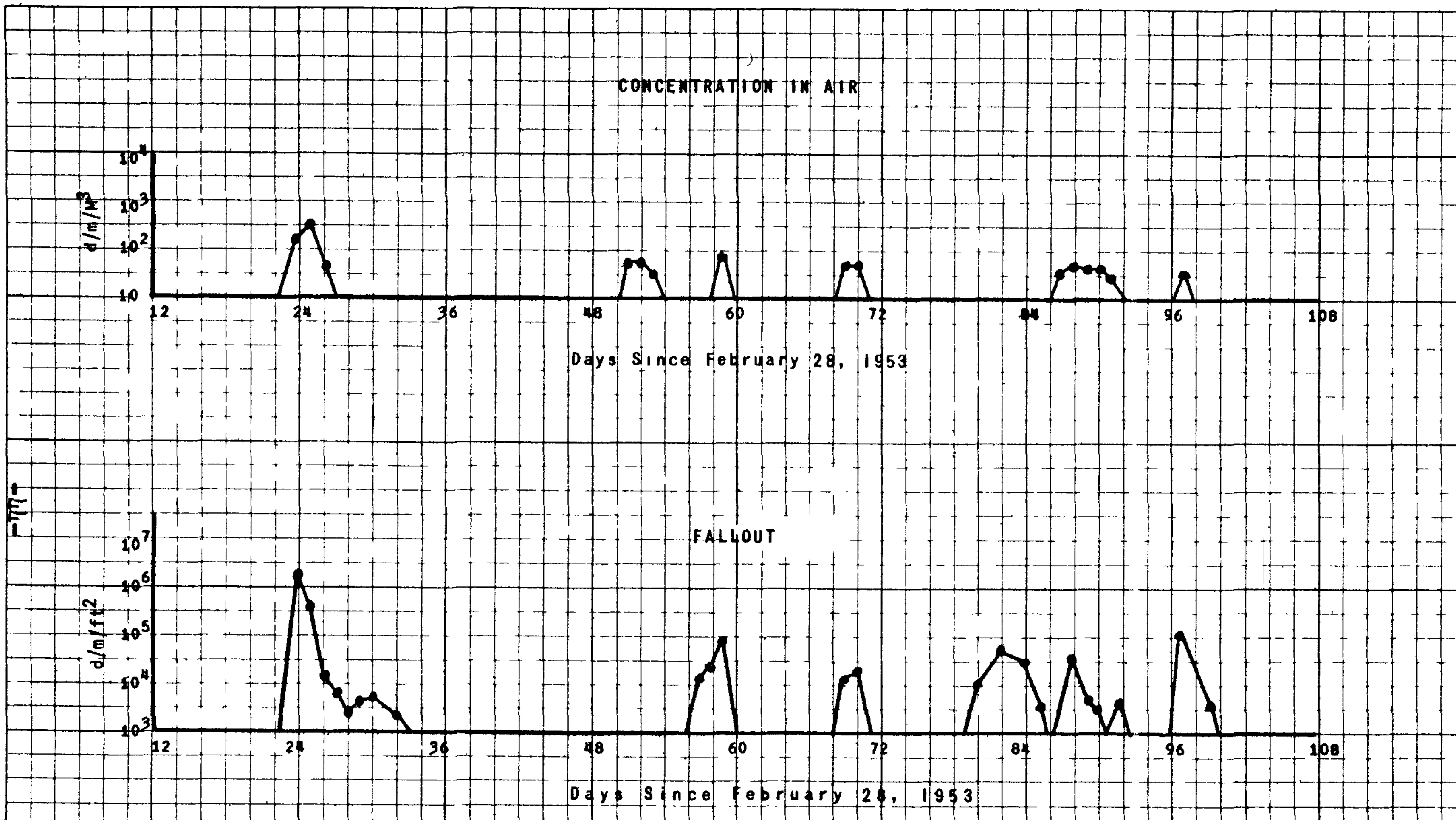

Fig. 3.36 - Radioactivity in airborne dust and in fallout, Casper, Wyoming

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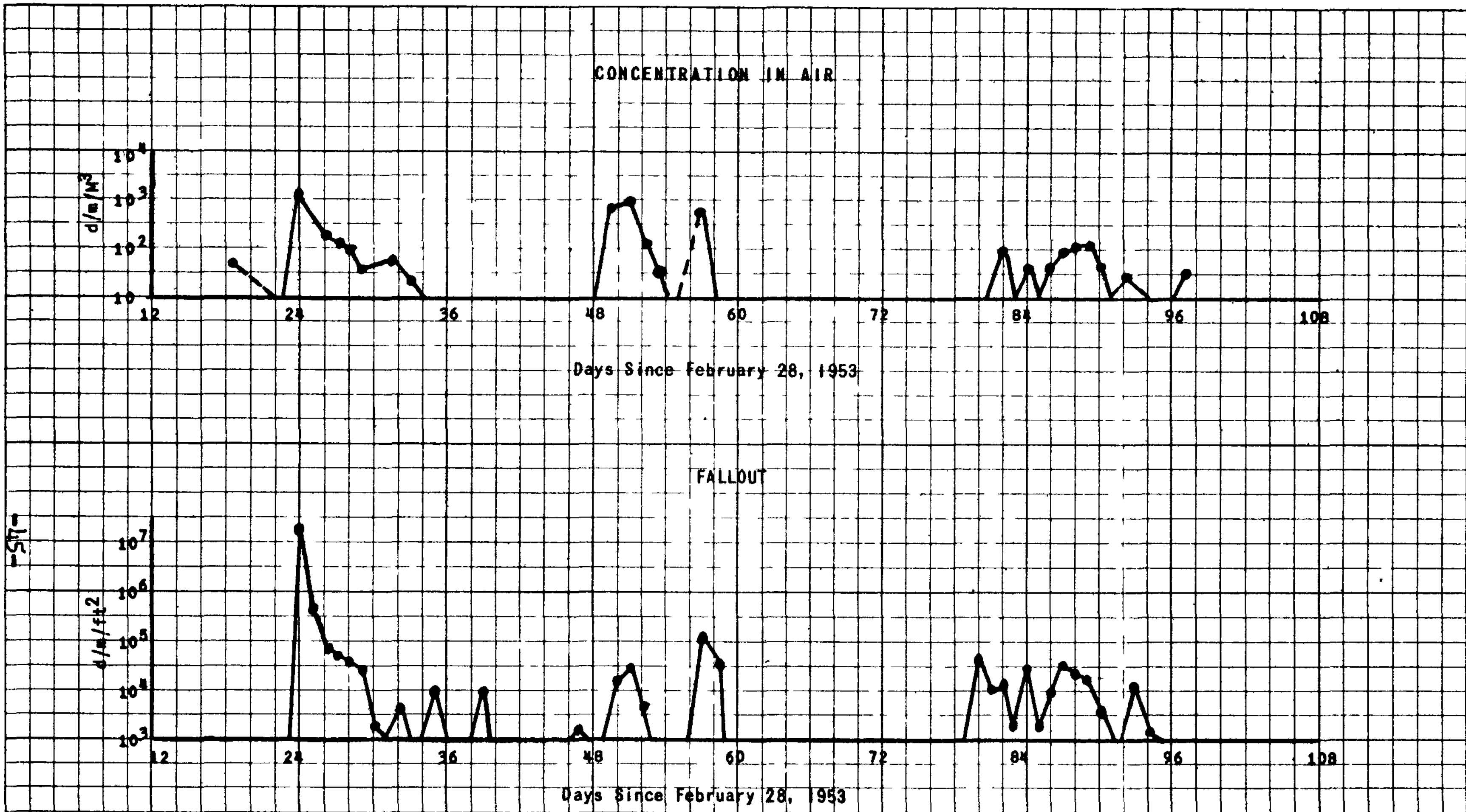

Fig. 3.37 - Radioactivity in airborne dust and in fallout, Salt Lake City, Utah

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Table 3.1 - PARTICLE SIZE OF RADIOACTIVE DUST IN AIR

(12-hour Cascade Impactor Samples)

Burst	Location & Start Time G. C. T.	Beta d/m/M³	Mass Median Diam.	Geometric Standard Deviation	Percent Less Than 5 Microns
1	Ogden, Utah				
	3/17-1410	700	2.6	2.6	82
		100	<0.7	-	100
2	Elko, Nevada				
	3/24-1400	14,000	2.0	1.6	91
		13,000	1.1	2.3	90
	3/25-0200	620	3.7	2.2	66
		840	6.2	1.8	36
	Ogden, Utah				
	3/24-1400	5,000	4.8	2.0	52
		10,000	4.5	2.1	55
	3/25-0200	2,000	5.8	1.9	40
		8,600	6.6	1.8	32
	3/25-1400	11,000	7.5	1.7	20
		7,800	7.8	1.6	15
5	Prescott, Ariz.				
	4/11-1400	300	7.4	2.0	28
6	Farmington, N.M.				
	4/18-1400	150	1.5	3.3	84
	4/19-1400	3,300	2.4	2.0	93
		2,600	1.8	2.0	84
	4/20-0200	2,300	2.2	1.9	96
		1,200	2.2	2.1	90

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Table [illegible] - Continued

Burst	Location & Start Time G. C. T.	Beta $d/m/M^3$	Mass Median Diam.	Geometric Standard Deviation	Percent Less Than 5 Microns
7	Winslow, Ariz.				
	4/26-0100	14,000	6.4	2.2	35
		9,000	1.2	1.6	94
	4/26-1300	7,400	6.5	2.1	35
		3,900	7.0	2.0	31
	4/27-0100	420	5.4	3.0	47
		240	1.0	1.4	100
	Hanksville, Utah				
	4/25-1400	1,200	1.4	2.8	90
	4/26-0200	300	3.8	2.5	59
	4/26-1400	860	2.6	2.1	82
		1,400	1.5	2.3	93
	4/27-0200	330	2.0	2.4	85
		170	2.4	1.7	86
8	Cortez, Colo.				
	5/8-1500	690	1.3	2.8	87
		530	2.4	2.0	85
	5/9-0300	130	5.6	2.5	44
9	Farmington, N.M.				
	5/19-1200	28,000	1.3	2.9	89
		30,000	6.6	1.8	31
	5/20-2400	3,100	4.1	3.9	84
		660	5.8	2.3	40
	5/20-1200	2,000	1.0	3.1	85
		840	1.3	1.3	98

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Table 3.1 - Continued

Burst	Location & Start Time G. C. T.	Beta $d/m/M^3$	Mass Median Diam.	Geometric Standard Deviation	Percent Less Than 5 Microns
11	Hanksville, Utah				
	6/4-1600	190	4.3	4.2	56
		460	5.8	2.2	42
	6/5-0400	150	1.0	1.8	94
		130	0.8	1.5	95
	6/5-1600	850	1.1	3.6	89
		780	1.1	2.8	90
	Provo, Utah				
	6/4-1400	230	5.2	2.5	47

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Table 3.2 - PARTICLE SIZE DISTRIBUTION OF RADIOACTIVE DUST IN AIR
(Aerotec Samples)

Burst No.	Location	Start Date GCT	Start Time GCT	Sampling Period Hrs.	Beta d/m/M³	Per Cent Smaller Than 5 Microns
1	Cortez, Colo.	3/17	1700	24	36,800	68
"	" "	3/18	1700	3.33	400	0.0
"	Elko, Nevada	3/17	1300	24	305	8
2	" "	3/24	1400	24	680	2
"	" "	3/25	1400	8	910	99.2
"	Ogden, Utah	3/24	1400	24	3,246	2.
"	" "	3/25	1400	6	567	58
"	Wendover, Utah	3/24	1300	24	190	100.0
3	Albuquerque, N.M.	4/1	1400	2	105	10
4	El Centro, Calif.	4/6	1400	24	100	50
5	Tucson, Arizona	4/11	1500	24	110	64
"	" "	4/12	1500	6	102	18
6	Winslow, Arizona	4/18	1300	24	4,544	34
"	Needles, Calif.	4/18	1700	24	464	34

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Table 3.2 - Continued

Burst No.	Location	Start Date GCT	Start Time GCT	Sampling Period Hrs.	Beta d/m/M³	Per Cent Smaller Than 5 Microns
6	Albuquerque, N.M.	4/18	1300	24	1,904	33
"	" "	4/19	1300	16 3/4	1,280	61
"	Farmington, N.M.	4/19	1400	14	2,658	67
7	Winslow, Arizona	4/25	1300	24	4,028	42
"	Grand Junction, Colo.	4/26	1400	24	3,940	70
"	Gunnison, Colo.	4/26	1430	18½	155	29
"	Albuquerque, N.M.	4/26	1500	18	4,465	20
"	Farmington, N.M.	4/25	1400	24	208	85
"	" "	4/26	1400	20	3,860	100.0
"	Delta, Utah	4/25	1300	24	1,482	6
"	" "	4/26	1300	20	924	10
"	Hanksville, Utah	4/26	1400	18	370	0.0
"	Ogden, Utah	4/26	1700	16	260	13
8	Cortez, Colo.	5/8	1500	24	784	3
"	Grand Junction, Colo.	5/8	1400	24	312	37

Table 3.2 - Continued

Burst No.	Location	Start Date GCT	Start Time GCT	Sampling Period Hrs.	Beta d/m/M³	Per Cent Smaller Than 5 Microns
8	Grand Junction, Colo.	5/9	1400	15	2,560	44
9	" "	5/19	1245	24	4,326	7
"	" "	5/20	1300	8	1,248	4
"	Albuquerque, N.M.	5/19	1600	24	3,160	7
"	" "	5/20	1600	3	1,752	16
"	Farmington, N.M.	5/19	1200	24	5,650	1.0
"	" "	5/20	1200	12	1,280	10
10	Hanksville, Utah	5/25	1700	24	529	18
"	" "	5/26	1700	2	310	36
"	Wendover, Utah	5/25	1630	24	799	98
"	Rock Springs, Wyo.	5/25	1700	24	128	38
"	" "	5/26	1700	6	1,074	28
11	Cortez, Colo.	6/5	1400	17	224	92
"	Farmington, N.M.	6/4	1700	24	168	34
"	" "	6/5	1700	14	480	65
"	Hanksville, Utah	6/4	1600	24	752	21
"	" "	6/5	1600	15	384	98

Table 3.3 - DECAY EXPONENT, X

Station	Sampling Day	Sample Type	Burst	X
New York, N. Y.	3/18	Settled	1	1.36
Cortez, Colorado	3/18	Aerotec*	1	1.18
Cortez, Colorado	3/18	Aerotec**	1	1.22
Cortez, Colorado	3/18	Filtered	1	1.04
Ogden, Utah	3/24	Settled	2	1.33
Ogden, Utah	3/24	Settled	2	1.33
Salt Lake City, Utah	3/24	Settled	2	1.36
Winslow, Arizona	4/19	Filtered	6	1.35
Winslow, Arizona	4/19	Filtered	6	1.36
Salt Lake City, Utah	4/20	Filtered	6	1.43
Farmington, N. M.	4/26	Filtered	7	1.35
Farmington, N. M.	4/27	Filtered	7	1.33
Albany, New York	4/26	Settled	7	1.47
Billings, Montana	5/9	Filtered	8	1.26
Grand Junction, Colo.	5/20	Filtered	9	1.35
Grand Junction, Colo	5/20	Filtered	9	1.39
Grand Junction, Colo.	5/19	Filtered	9	1.37
Farmington, N. M.	6/5	Filtered	11	1.06
Cortez, Colorado	6/5	Filtered	11	1.21
Grand Junction, Colo.	6/5	Filtered	11	1.31
Mean				1.30

* Large particle aerotec fraction.
** Small particle aerotec fraction.

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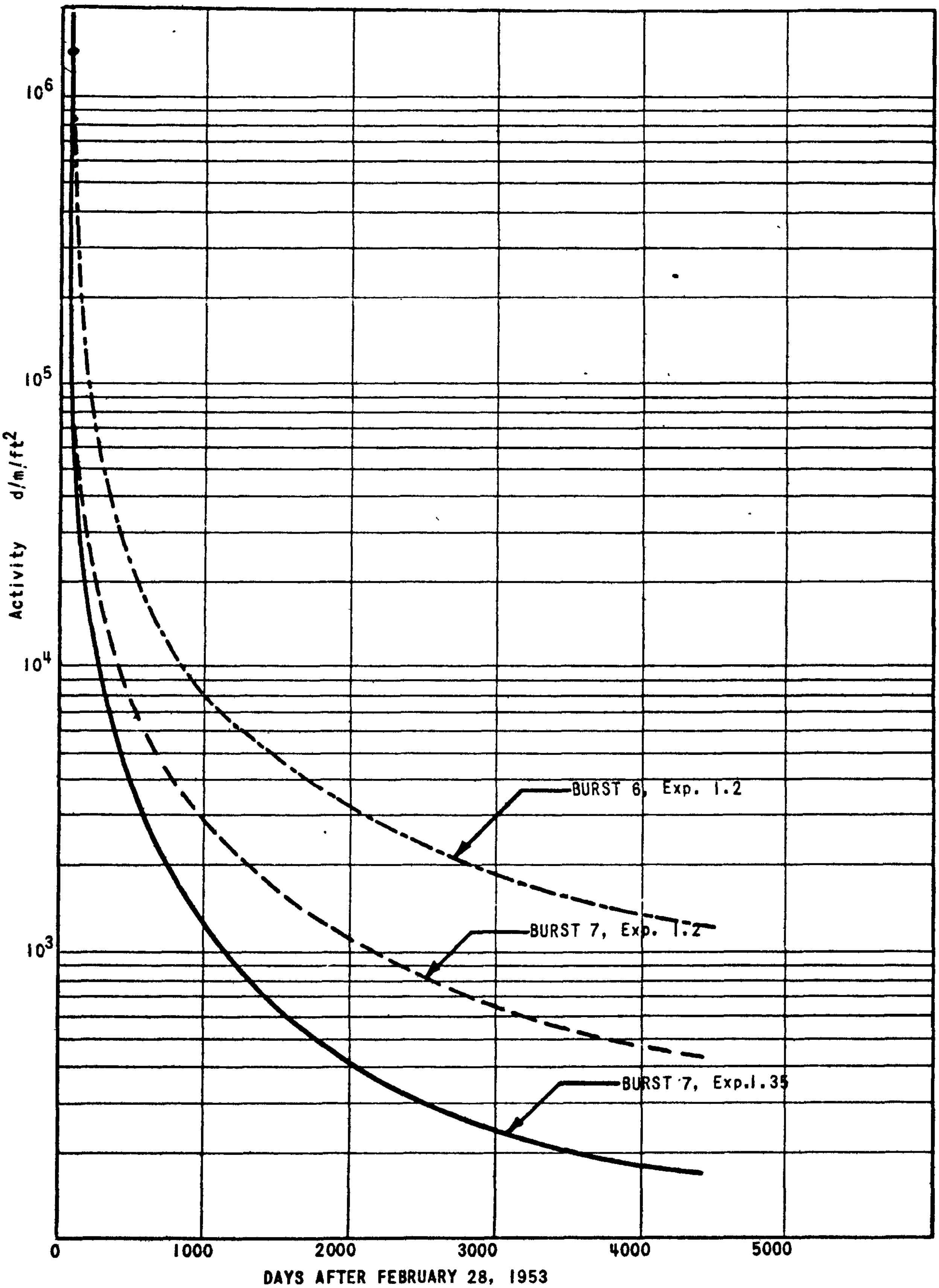

Fig. 3.38 - Albany, N.Y. fallout, April 26, '53, extrapolated from counting day, Apr. 30, on basis of two bursts & two exponents

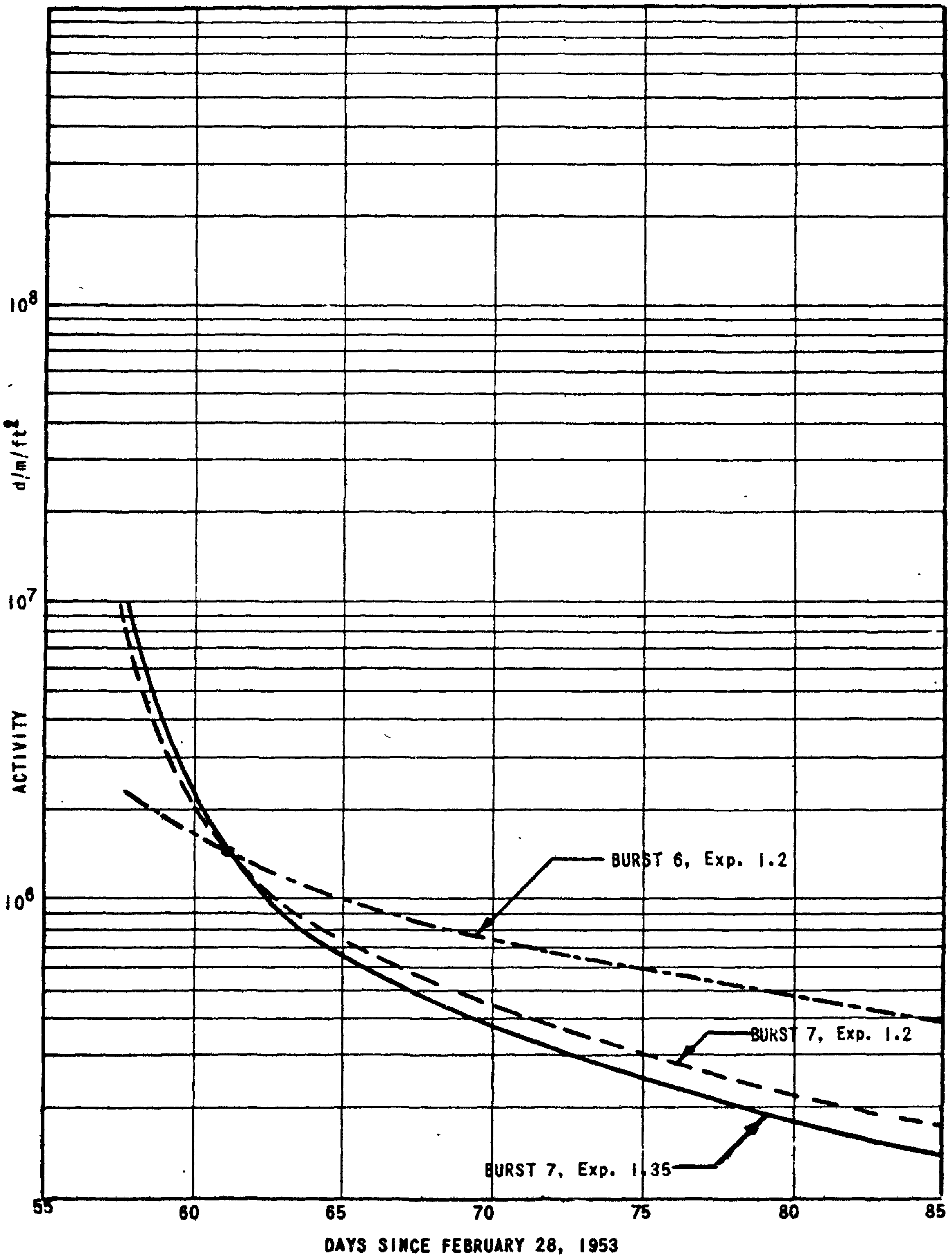

Fig. 3.39 - Albany, N.Y. fallout, April 26, '53, extrapolated from counting day, Apr. 30, on basis of two bursts & two exponents

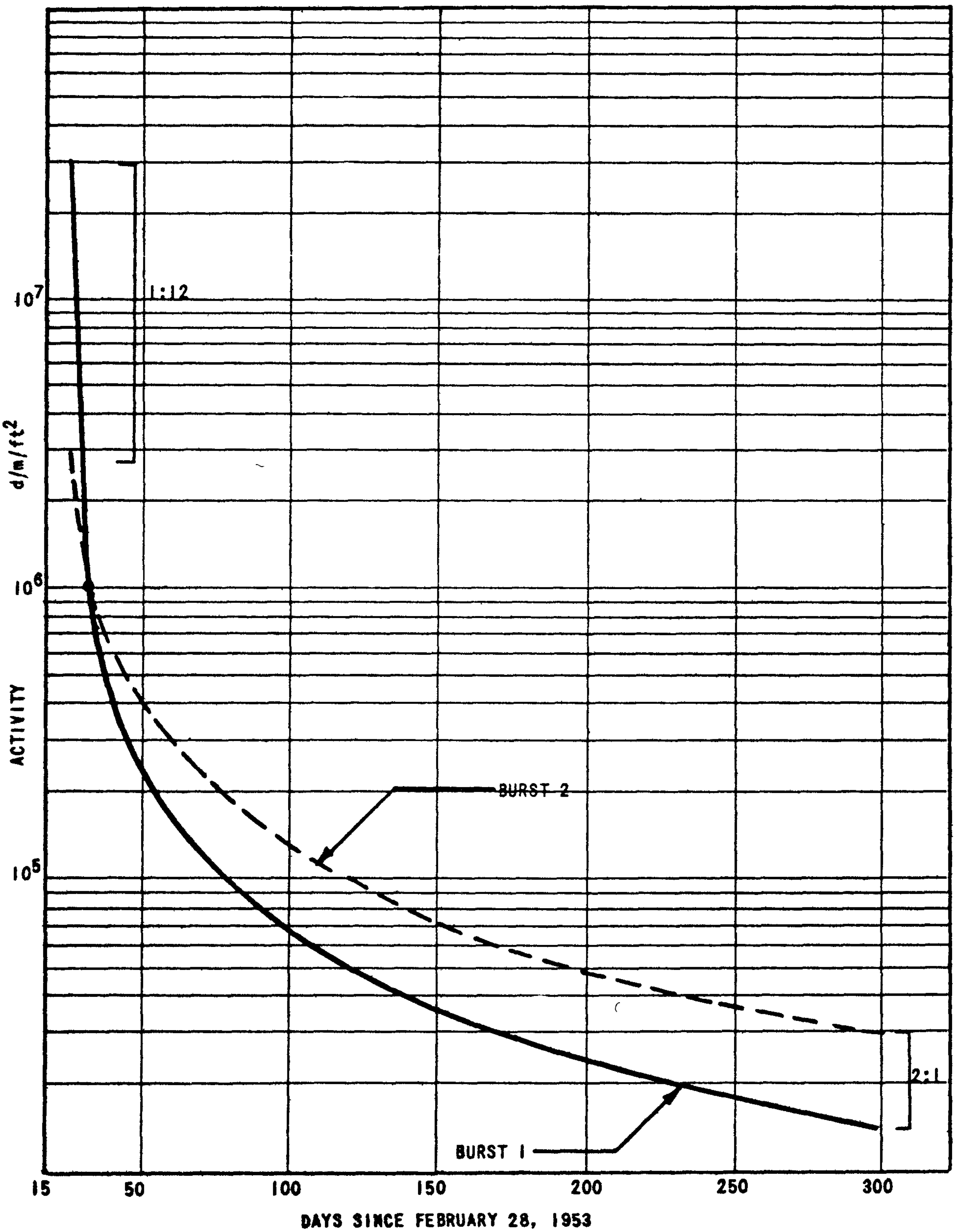

Fig. 3.40 - Salt Lake City fallout, Mar. 24, '53, extrapolated from counting day, Apr. 1, on basis of exponent 1.2 & two bursts

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Table 3.4 - MOBILE TEAM DATA

No.	BURST Date GCT	BURST Time GCT	Location	Max. Air Activity (d/m/ft^2)	Time of Max. Hrs. After Burst	Fallout (d/m/ft^2) Extrapolated to Time of Max.
1	3/17	1320	Cortez, Colorado	1.4×10^5	13	2.3×10^6
2	3/24	1310	Elko, Nevada	4.5×10^4	10	4.7×10^5
"	"	"	Ogden, Utah	2.3×10^5	12	2.5×10^7
"	"	"	Wendover, Utah	1.3×10^4	15	4.8×10^6
6	4/18	1235	Winslow, Arizona	1.1×10^4	16	1.8×10^6
"	"	"	Needles, California	3.6×10^3	20	8.0×10^4
"	"	"	Albuquerque, N. M.	5.4×10^3	22	1.5×10^6
"	"	"	Farmington, N. M.	6.2×10^3	32	3.9×10^4
7	4/25	1230	Winslow, Arizona	1.2×10^5	16	9.0×10^6
"	"	"	Grand Junction, Colo.	1.0×10^4	40	4.0×10^5
"	"	"	Albuquerque, N. M.	1.3×10^4	36	9.6×10^5
"	"	"	Farmington, N. M.	1.3×10^5	40	1.4×10^6
"	"	"	Delta, Utah	5.5×10^3	22	2.4×10^5
"	"	"	Hanksville, Utah	1.0×10^4	32	2.8×10^4

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Table 3.4 - Continued

BURST No.	BURST Date GCT	BURST Time GCT	Location	Max. Air Activity (d/m/ft^2)	Time of Max. Hrs. After Burst	Fallout (d/m/ft^2) Extrapolated to Time of Max.
9	5/19	1205	Farmington, N. M.	2.2×10^5	12	3.7×10^6
"	"	"	Grand Junction, Colo.	9.2×10^4	16	3.0×10^6
"	"	"	Albuquerque, N. M.	1.5×10^4	16	3.6×10^6
11	6/4	1115	Cortez, Colorado	2.5×10^3	30	1.6×10^5
"	"	"	Farmington, N. M.	4.7×10^3	27	6.6×10^5
"	"	"	Hanksville, Utah	1.1×10^4	28	1.7×10^5

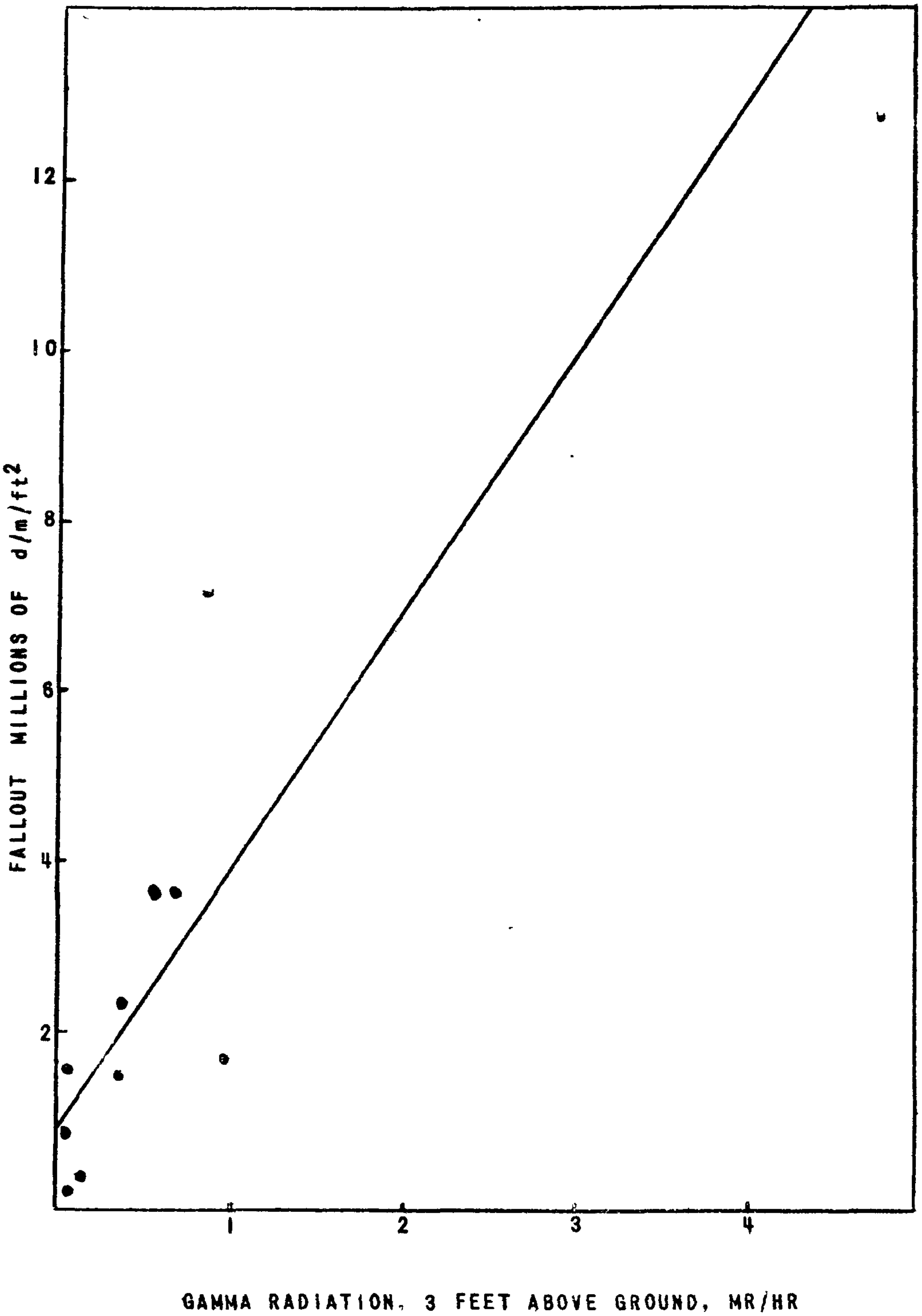

Fig. 3.41 - Fallout compared with Maximum Gamma Radiation during Sampling Period.

Chapter 4

DISCUSSION

The purpose of this chapter is to present a qualitative description of the findings following each burst based on all the pertinent data, which include air concentrations and decay rates as well as fallout activity.

Four of the eleven test explosions were followed by low levels of fallout activity possibly attributable to earlier bursts. Fallout and air concentrations after four other bursts were moderate and formed time and space patterns tending to justify attributing the activity to the latest bursts before sampling. The remaining three explosions, numbers 2, 7 and 9, were clearly responsible for most of the activity shown on their respective maps, Figures 3.2, 3.7 and 3.9, amounting to more than 75% of the total for the series. These inferences depend on both the air concentration and gummed film data and they influence the interpretation of the decay rate results.

4.1 BURSTS 1 THROUGH 5

Only 19% of the total fallout is attributed to the first five explosions. Most of this fraction (11%) occurred between March 24th and 31st, the dates of bursts 2 and 3.

Salt Lake City experienced an especially heavy fallout on the 24th and 25th. Extrapolated to 12 hours after burst the fallout for the day of the explosion amounted to 28,000,000 d/m/ft^2. Ely, Nevada and Casper, Wyoming were also scenes of heavy fallout on that day, ranging from two million to four million d/m/ft^2. Most of the activity following burst 2 settled in a small area which included Salt Lake City (Figure 3.2).

Measurable airborne concentrations were found at Elko, Nevada and Ogden, Utah. These concentrations based on short period samples collected by mobile teams are plotted against time in Figures 3.14 and 3.15. Figure 3.14 has a second graph showing the readings of the automatic air dust monitor, an instrument designed in this laboratory and consisting of a sampler, counter and recorder. The readings are given in disintegrations per minute. At the design flow the volume of one twenty minute sample is about one cubic meter.

The automatic instrument shows high readings at times when the filtered samples have insignificant activity. This is probably due to inclusion in the instrument reading of the gamma background which may be high when weapons test debris is present in the survey area. This source of error is being corrected in newer models of the instrument.

Peak activity arrived at Elko and Ogden about 12 hours after burst and this was the reason for extrapolating Salt Lake City fallout to 12 hour age.

Bursts 1, 3, 4 and 5 accounted for only 8% of the total fallout for the series. During the periods following each of these explosions the mobile teams found significant concentrations of radioactive dust in the air only at Cortez, Colorado (Figure 3.13) after burst 1. The lower levels of activity, not considered significant, at other mobile team locations showed two indications that the material in the samples may have contained residual from earlier bursts. One sign was a steady diminution in the computed concentrations from a maximum at the start of the sampling period and the other sign was a low value of the decay exponent ("X" in Table 3.3). If the activities of samples collected after burst 5 are attributed to burst 4 the decay exponents appear typical and the air concentrations show random fluctuations at a low level. The possibility of the samples containing residual activity makes it unsafe to assume that the maps for bursts 3 and 5 present a true picture of the fallout attributable to those explosions. Some of the activity shown on these maps may have been generated by bursts 2 and 4.

4.2 BURSTS 6 THROUGH 11

Similarly, a considerable part of the activity after bursts 8 and 10 may have been due to numbers 7 and 9. Bursts 8 and 10 are charged respectively with 2% and 6% of the series total. The mobile teams found negligible airborne activity after these explosions and the low values of the decay exponent are consistent with the hypothesis that the samples tested for decay are attributable to earlier bursts. Number 7 accounted for 35% and number 9 for 31% of the total fallout for the series and it would have been reasonable to expect some residual activity in samples collected after May 8th and 25th even if bursts 8 and 10 of those dates had not taken place.

Fairly large amounts of radioactive dust fell out over about half of the United States after burst 7. Activities were low in the Northeastern part of the country except for a flash fallout at Albany, New York during a heavy rain on April 26th. Reports[3] of radiation readings higher than 10 mr/hr obtained at Troy with survey instruments furnished independent confirmation of this heavy fallout.

On May 1st a flight was made to measure radiation levels in the Hudson Valley. Gamma readings at 500 feet altitude converted to ground level radiation showed the first appreciable rise at Poughkeepsie in the flight up the East side of the river and increased to a maximum of 0.22 mr/hr at the town of Rensselaer just South of Troy. During the return flight along the West bank the maximum of 0.25 mr/hr was found near Ravena, South of Albany.

The fallout at Albany for the period between bursts 7 and 8 was 14,000 d/m/ft^2 extrapolated to January 1, 1954. It was exceeded at Las Vegas, Nevada and Roswell, New Mexico, where the cumulative fallout for the same period was 30,000 and 22,000 d/m/ft^2 respectively.

Outside the Albany area bursts 7 and 9 were practically equal as sources of fallout. The dust from number 9 spread throughout the country producing activities over 500 d/m/ft^2 (extrapolated to January 1, 1954) at such widely separated stations as Marquette, Albuquerque and Atlanta. The mobile teams found maximum concentrations of radioactivity in the air at Farmington, New Mexico, and Grand Junction, Colorado, where the levels reached 210,000 and 90,000 d/m/M^3 (see Figures 3.27 and 3.28). There was some activity at Albuquerque, New Mexico (Figure 3.29).

On the map, Figure 3.6, one can trace the path of maximum activity following burst 6 along the Gulf Coast through Las Vegas, Albuquerque, Port Arthur and New Orleans. Total fallout over the nation was moderate. Typical patterns of airborne concentration were exhibited at four of the mobile stations and are shwon in Figures 3.17 to 3.20. The maximum was 10,800 d/m/M^3 at Winslow, Arizona. The maximum fallout, 3,100 d/m/ft^2 (corrected to January 1, 1954) occurred at Albuquerque.

The fallout after the last explosion of the series was 2% of the total. A path of maximum activity is distinguishable through Wyoming, Colorado, Kansas, Missouri, Illinois, Michigan and New York. Air activity concentrations at Cortez, Colorado, Farmington, New Mexico, and Hanksville, Utah are plotted in Figures 3.30 to 3.32.

In summary, it appears that bursts 2, 7 and 9 were responsible for most of the activity found in the gummed film and filtered air samples; that smaller amounts with distinct maxima along paths or at points are attributable to numbers 1, 4,6 and 11 and that the fallout immediately after bursts 3, 5, 8 and 10 is not certainly due to those shots but may have been wholly or partly residual from earlier ones.

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Appendix

WORLD-WIDE MONITORING

This discussion of the world-wide sampling network is presented separately in an appendix in order to avoid unnecessary classification of information on nation wide monitoring.

1 OPERATION OF THE NETWORK

Sampling stations distributed throughout the world, most of them in the Northern hemisphere, were provided by the Weather Bureau, the State Department, the Air Force, the Navy, the Atomic Bomb Casualty Commission, the Canadian Weather Service and the Canadian atomic energy installation at Chalk River.

The stations are listed in Table A-1. As indicated in the table, twenty-four hour fallout samples were collected at some of them and seven day samples at others. Except for the longer sampling period at some localities the world-wide network operated in exactly the same manner as the fixed stations in the United States which collected dust settling on gummed film. This was the only type of sample collected outside the United States.

2 FINDINGS

The activity falling out during the periods between bursts was extrapolated to January 1, 1954 and the results are listed in Table A1. In each case the radioactive dust was assumed to be due to the most recent burst and to have precipitated in the middle of the sampling period.

Outside of the United States only three stations experienced fallout greater than 1000 d/m/ft^2. They were Stephenville, Newfoundland after burst 6, Seven Islands, Quebec after burst 7 and Bermuda after burst 8. Outside of North America only Bermuda, Rhein Main, Hiroshima and Nagasaki were found to have fallout greater than 300 d/m/ft^2.

The activities of 360 d/m/ft^2 at Hiroshima and 450 d/m/ft^2 at Nagasaki tend to confirm each other. Each is the mean of duplicates which agree well. The figures are listed under burst 7 but we have no evidence to justify attributing data from such remote locations to particular bursts.

Eight stations appear to be practically free of free of fallout. They are Anchorage, Port Simpson, Thule, Canal Zone, Lima, Pretoria, Guam and Honolulu.

At foreign stations the fallout was of a lower order than in the United States.

3 DECAY RATES

As in the case of samples from the domestic network the extrapolations were performed on the basis of the formula

$$A = A_c \left(\frac{t_c - t_b}{t - t_b}\right)^X$$

using 1.2 as the value of X. The effect of possible error in this value is discussed in section 3.4 but that discussion can be amplified here by reference to the monitoring of Operation Ivy[3], during which 1.35 appeared to be a better value for the exponent in the decay formula than 1.2. The fifteen days following MIKE shot, the first shot of the Ivy series, made it possible to obtain several samples of relatively high activity attributable, without doubt, to a single explosion. For these reasons the decay rates determined from the samples are probably more than usually reliable.

Olafson and others[6] have found values for the exponent generally larger than 1.2 and ranging from 1.2 to 1.4 for fallout and airborne dust between ten and fifteen miles from ground zero. They also found that samples collected after burst 7 of the Snapper series contained activity attributable to Snapper 6. It was this finding which suggested that activity found at mobile stations in the United States after certain explosions might be residual from previous bursts.

Table A1 - FALLOUT OUTSIDE U. S. FOLLOWING EACH BURST
($d/m/ft^2$ extrapolated to Jan. 1, 1954)

Burst No. : Burst Date:*	1 3/17	2 3/24	3 3/31	4 4/6	5 4/11	6 4/18	7 4/25	8 5/8	9 5/19	10 5/25	11 6/4	TOTAL
Anchorage Alaska	0	3	0	0	6	0	0	3	0	21	0	33
North Bay Ontario	0	3	3	6	0	9	200	15	87	54	27	400
Moosoonee Ontario	0	510	45	18	12	3	33	33	6	0	3	660
Moncton New Brunswick	0	9	3	0	9	480	300	21	21	27	90	960
Montreal Quebec	0	3	3	0	6	6	540	36	290	18	170	1100
Seven Islands Quebec	0	0	0	0	3	9	3600	39	18	21	0	3700
Winnipeg Manitoba	0	1000	3	0	0	3	130	57	78	200	66	1500
Churchill Manitoba	0	18	30	3	0	42	3	0	3	3	3	100
Regina Saskatchewan	0	57	0	0	0	3	240	84	90	54	21	550
Edmonton Alberta	0	3	6	3	0	24	15	0	6	200	12	270

Table A1 - Continued

Burst No.: Burst Date:*	1 3/17	2 3/24	3 3/31	4 4/6	5 4/11	6 4/18	7 4/25	8 5/8	9 5/19	10 5/25	11 6/4	TOTAL
Prestwick Scotland	0	6	0	27	12	9	51	110	0	6	-	220
Rhein Main Germany	15	330	0	93	6	9	39	510	0	36	-	1000
Pretoria South Africa	0	0	0	0	3	0	3	0	0	0	-	6
Dakar Fr. West Africa	6	24	0	0	6	0	180	72	0	18	-	300
Tripoli Tripolitania	0	12	0	27	0	0	120	30	0	36	-	230
Hiroshima Japan	0	36	0	0	9	3	360	36	0	42	-	490
Nagasaki Japan	81	27	0	72	3	15	450	3	0	21	-	670
Anderson A.F.B. Guam	3	3	12	0	0	0	6	18	0	0	-	42
Honolulu Hawaii	0	0	0	6	0	9	9	24	0	6	-	54

* The last column lists total fallout from 3/17 to 6/9. Each other column represents a period from the burst date at the head of the column to the day before the next burst.

Table A1 - Continued

Burst No.: / Burst Dates:*	1 3/17	2 3/24	3 3/31	4 4/6	5 4/11	6 4/18	7 4/25	8 5/8	9 5/19	10 5/25	11 6/4	TOTAL
Port Hardy British Columbia	0	12	12	3	6	12	21	18	6	12	3	100
Prince George British Columbia	0	6	3	3	3	21	30	6	27	15	3	120
Port Simpson Machensen	0	0	0	0	3	12	24	6	6	9	0	60
Deep River Ontario	60	15	3	12	3	30	72	0	0	33	170	400
Stephenville Newfoundland	9	3	3	0	93	4800	100	69	33	27	0	5100
Thule Greenland	3	6	0	3	0	0	3	6	0	3	0	24
Keflavik Iceland	3	3	0	0	51	6	240	66	0	30	0	400
Albrook A.F.B. Canal Zone	3	0	3	0	0	0	6	6	0	18	-	36
Kindley A.F.B. Bermuda	3	390	15	30	15	100	110	3900	220	540	45	5400
Lima Peru	0	0	0	0	0	6	0	0	0	0	-	6