EFFECTS OF RAINFALL AND DROP SIZE SPECTRA ON THE STANDARD AND MODIFIED MTSQ M564 FUZE

FINAL REPORT

ON

U. S. Army Contract
DAAG 11-69-C-0178

Prepared by

E. A. Mueller and A. L. Sims

June 1969

ILLINOIS STATE WATER SURVEY
at the
UNIVERSITY OF ILLINOIS

for

U. S. Army
Frankford Arsenal
Philadelphia, Pennsylvania

DISTRIBUTION STATEMENT

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ABSTRACT

The results of an experiment at Port Sherman, Panama Canal Zone, are reported. This experiment consisted of determining the reliability of a modified MTSQ M564 fuze to penetrate natural rain. The rainfall parameters, rainfall rate and drop size spectra, were used to determine the number and size of the raindrops encountered by the projectile. The modified fuze penetrated the rain successfully in all cases when fired from the 105-mm weapon. Eight premature detonations of the standard M564 fuze were recorded and tend to verify the model derived from the earlier work under Contract No. DAAG 11-68-C-1342 for rainfall rates greater than 25 mm/hr. For lower rates the model overestimates the number of premature detonations.

The raindrop size spectra obtained for tropical rains are valuable not only for this work but in other areas such as communication, environmental testing, and in artificial rainfall simulation for testing purposes.

FOREWORD

This report summarizes work performed in the Panama Canal Zone by Dr. E. A. Mueller and Messrs. A. L. Sims and E. Brieschke of the Illinois State Water Survey at the University of Illinois for the U. S. Army Frankford Arsenal, under Contract No. DAAG 11-69-C-0178, which was under the technical surveillance of Messrs. David Askin, John Sikra, and Donald Lenton of Frankford Arsenal.

The authors desire to acknowledge the U. S. Army Tropical Test Center in the Panama Canal Zone for providing facilities and aid in the data collection. In particular the direct aid afforded by Sgt. Ramon Colon-Pomales was greatly appreciated. The raingages were serviced by the U. S. Army Meteorological Team. In addition we are grateful to Capt. Michael Hudlow and his radar team of the U. S. Army Electronics Command for their cooperation in providing the radar data used in this report.

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INTRODUCTION

An experiment was conducted in Panama from October 24, 1968 to November 25, 1968 to determine the rainfall conditions in existence at the time of firings of a modified MTSQ M564 artillery fuze. Primary interest was to determine the rainfall rates through which these fuzes were passing and to deduce therefrom the number and diameters of the raindrops encountered. Previous work under Contract DAAG 11-68-C-1342 had indicated a model for the premature detonations of the standard MTSQ M564 fuze, and this model was to be tested over longer firing ranges.

A second goal of the project was to obtain a sufficient number of drop size spectra to permit statistical evaluations of tropical rainfall. Information on rainfall rates and drop size spectra from tropical regions has been and is in demand for a number of purposes. Previously data have been obtained in Bogor, Indonesia, and Miami, Florida, with Army Electronics Command support. These two locations were the nearest climatic regions to a tropical regime. The inclusion of the large number of spectra obtained in Panama permits a much better interpretation of the rainfall in tropical areas. Some of the other areas where this data will be utilized include radar meteorology, radio communications, and cloud physics. Additionally, the spectra will permit better interpretation of the validity of artificial rain fields in testing of rain effects on fuzes and other projectiles.

Since a large portion of the gun range was over water, an MPS-34 radar furnished by the Army Electronics Command at Port Monmouth, New Jersey, was very useful in obtaining rainfall rate information. In addition the University of Illinois furnished six modified weighing bucket raingages, which along with four gages supplied by the Meteorological Support Team, provided rainfall rate data along the first portion of the trajectory. All of these gages were operated with 6-hour gears and 12-inch collectors.

A raindrop camera was installed and operated at the gun site to determine the raindrop size spectra. This raindrop camera was the same one that was left in Panama after the conclusion of work on Contract DAAG 11-68-C-1342 (operated by the meteorological team personnel of the Army at Battery Mackenzie). The combined drop size data obtained from the July 1968 tests, Battery Mackenzie, and the November 1968 tests consist of 336l one cubic meter raindrop spectra. This is considered to be an excellent sample of rainfall. The November tests resulted in 1394 spectra collected between November 6 and November 21.

RAINFALL RATE ANALYSIS

Raingage Results

During the tests 10 weighing bucket raingages were installed along the gun range. These gages were placed in clearings in the jungle of at least 100-ft diameters. The gages were 200 m apart. Pig. 1 shows the gage locations. Raingage no. 8 was on the west bank of the Chagres River and gage no. 9 on the east bank. The distance between these two gages was not accurately known, and the assumption was made that they were 300 m apart. The results are not greatly affected by this assumption since only average rates to the point of impact or to the bursting point were required.

Considerable difficulty with the gages was experienced in the early part of the experiment due to continual clock stoppages. When Mr. Eberhard Brieschke of the University of Illinois arrived in Panama, he recognized that the clips used for attaching the recording charts to the drum of the raingage were of an incorrect length. These extra long clips were mechanically dragging and causing clock stoppages. Apparently clips from either a different style of gage or from different instruments had been substituted for the original clips. After shortening the clips, considerably less difficulty with clock stoppages was experienced.

Tables 1 to 10 show the rains which were recorded at the various raingages. As indicated the records are frequently incomplete, particularly near the early part of the experiment. Only

19 hours of rain occurred at the gun site in November instead of 63 hours in July, and only a portion of this time could be utilized in actual firing.

At the gun site only 7.65 inches of rain were recorded between November 7 and November 21. At Shelter Point there were 8.48 inches and at Skunk Hollow there were 6.92 inches. Thus, at least for this two-week period, there was not as much areal variability as in the July tests. This is substantiated by analysis of the radar film which showed no preference for areas of precipitation and that the storms were large and moved with a speed of 10-15 miles/hour. In July the storms were more isolated and slower moving.

Remote Recording Raingage

In an attempt to provide better knowledge of the rainfall downrange in real time for use by the project leader in determining firing times, a remote recording raingage was installed on the shores of the Carribean Sea. This raingage was a copy of the raingage produced by R. A. Semplak[1] of the Bell Telephone Laboratories. This raingage measures rate of rainfall by capacitively sensing the amount of water running through a tilted trough. The electrical capacity is used to frequency modulate an oscillator, and the signal is then brought to a remote location over a telephone line. The choice of the ocean site was made so that a measure of rate at the most distant range could be made. This proved to be a very poor choice. The gage operated successfully when installed and through the first rain (before the gun was ready). On the second day the zero-rain frequency continually drifted in a direction of more rain. It was determined that this was the effect of salt deposits forming on the trough of the gage. It was hoped that these deposits would be washed off by the next rain. Before the next rain, salt had also deposited in the electronics of the gage and the circuits became inoperable. Attempts to correct the damage to the electronic package were unsuccessful and further data with the gage were not gathered.

Table 1. Raingage storm summaries from gage number 1.

Date	Time began	Time end	Total amount, inches	Max., 5-min. amount	Max. rate	Dur., hours
11/ 7	0656	0818	0.87	0.19	3.00	1.4
11/ 7	2150	0808	0.45	0.07	1.20	10.3
11/ 8	0819	1130	0.33	0.05	0.90	3.2
11/ 9	1343	2023	0.23	0.02	0.60	6.7
11/12	0016	0140	0.12	0.06	0.60	1.4
11/12	0401	0703	0.77	0.35	6.00	3.0
11/12	0816	0826	0.06	0.04	0.60	0.2
11/12	1626	1901	0.06	0.02	0.60	2.6
11/12	2120	2247	0.03	0.01	0.30	1.5
11/13	1359	1424	0.02	0.01	0.09	0.4
11/13	2004	0001	0.26	0.07	1.05	4.0
11/14	0224	0646	0.20	0.08	2.40	4.4
11/14	1110	1205	0.24	0.20	2.40	0.9
11/14	1605	1633	0.05	0.03	0.30	0.5
11/14	2316	2354	0.20	0.13	2.40	0.6
11/15	2204	0159	1.67	0.41	3.00	3.9
11/16	0524	0719	0.81	0.19	2.40	1.9
11/17	1755	1830	0.15	0.04	0.60	0.6
11/20	1538	0038	0.94	0.14	3.60	9.0
11/21	0828	1104	0.19	0.08	1.80	2.6

Table 2. Raingage storm summaries from gage number 2.

Date	Time began	Time end	Total amount, inches	Max., 5-min. amount	Max. rate	Dur., hours
11/ 7	2250	0041	0.15	0.03	0.60	1.9
11/ 8	0825	1042	0.27	0.05	1.80	2.3
11/12	1622	1902	0.08	0.03	1.20	2.7
11/12	2121	2233	0.02	0.01	0.30	1.2
11/14	1111	1150	0.29	0.23	4.80	0.7
11/14	1605	1645	0.05	0.02	0.60	0.7
11/14	2313	2359	0.28	0.14	3.00	0.8
11/15	2203	0716	2.21	0.36	6.60	9.2
11/17	1757	1827	0.12	0.03	0.60	0.5

Table 3. Raingage storm summaries from gage number 3.

Date	Time began	Time end	Total amount, inches	Max., 5-min. amount	Max. rate	Dur., hours
11/14	1113	1206	0.16	0.08	0.90	0.9
11/14	2315	0013	0.28	0.11	1.50	1.0
11/15	2205	0201	1.63	0.43	5.40	3.9
11/16	0557	0741	0.55	0.24	2.40	1.7
11/17	1800	1819	0.09	0.03	0.60	0.3

Table 4. Raingage storm summaries from gage number 4.

Date	Time began	Time end	Total amount, inches	Max., 5-min. amount	Max. rate	Dur., hours
11/ 8	0852	1158	0.26	0.08	1.20	3.1
11/ 9	1215	1930	0.25	0.02	0.60	7.3
11/12	0017	0045	0.08	0.04	0.60	0.5
11/12	0402	0653	0.84	0.39	5.40	2.9
11/12	0816	0832	0.05	0.04	0.60	0.3
11/12	1619	1856	0.06	0.02	0.60	2.6
11/12	2119	2231	0.02	0.01	0.30	1.2
11/13	0811	0818	0.07	0.06	1.20	0.1
11/13	1403	1451	0.01	0.01	0.09	0.8
11/13	2007	2241	0.31	0.05	1.80	2.6
11/14	0228	0712	0.18	0.09	3.00	4.7
11/14	1114	1151	0.15	0.10	1.80	0.6
11/14	2313	2358	0.20	0.07	1.20	0.8
11/15	2201	0211	1.73	0.35	4.80	4.2
11/16	0549	0737	0.49	0.11	2.40	1.8
11/17	1800	1821	0.10	0.04	1.20	0.4

Table 5. Raingage storm summaries from gage number 5.

Date	Time began	Time end	Total amount, inches	Max., 5-min. amount	Max. rate	Dur., hours
11/ 8	0932	1139	0.22	0.06	1.20	2.1
11/12	0013	0039	0.08	0.04	1.20	0.4
11/12	0354	0641	0.84	0.32	4.80	2.8
11/12	0806	0820	0.06	0.04	1.20	0.2
11/14	1113	1141	0.14	0.07	2.40	0.5
11/14	2316	0039	0.35	0.09	2.40	1.4
11/17	1801	2022	0.11	0.03	0.60	2.4

Table 6. Raingage storm summaries from gage number 6.

Date	Time began	Time end	Total amount, inches	Max. 5-min. amount	Max. rate	Dur., hours
11/14	1113	1204	0.21	0.12	1.80	0.9
11/17	1804	2021	0.06	0.01	0.19	2.3

Table 7. Raingage storm summaries from gage number 7.

Date	Time began	Time end	Total amount, inches	Max., 5-min. amount	Max. rate	Dur., hours
11/ 8	0927	1138	0.19	0.04	0.60	2.2
11/ 9	1203	1939	0.20	0.03	0.39	7.6
11/12	0025	0128	0.09	0.03	1.20	1.1
11/12	1932	1944	0.01	0.01	0.19	0.2
11/12	2236	2244	0.02	0.02	0.60	0.1
11/13	1401	1453	0.02	0.01	0.09	0.9
11/13	2005	2239	0.39	0.10	1.80	2.6
11/14	1113	1146	0.18	0.12	2.40	0.6
11/14	2315	2349	0.16	0.10	1.50	0.6
11/15	2200	0709	2.46	0.27	5.40	9.2
11/17	1815	2015	0.05	0.02	0.30	2.0

Table 8. Raingage storm summaries from gage number 8.

Date	Time began	Time end	Total amount, inches	Max., 5-min. amount	Max. rate	Dur., hours
11/ 7	1521	1545	0.07	0.03	0.90	0.4
11/ 8	0057	1123	0.50	0.11	1.50	10.4
11/ 9	1212	1931	0.24	0.02	0.60	7.3
11/12	0022	0127	0.09	0.04	1.20	1.1
11/12	0401	0652	0.86	0.39	4.80	2.9
11/12	0817	0825	0.02	0.01	0.60	0.1
11/13	1959	2315	0.48	0.11	1.80	3.3
11/14	0225	0651	0.07	0.02	0.60	4.4
11/14	1114	1145	0.08	0.05	1.20	0.5
11/14	1713	1841	0.22	0.10	1.80	1.5
11/15	2203	0718	2.65	0.29	6.60	9.3
11/17	1816	2025	0.09	0.03	0.60	2.2

Table 9. Raingage storm summaries from gage number 9.

Date	Time began	Time end	Total amount, inches	Max., 5-min. amount	Max. rate	Dur., hours
11/15	2355	0252	1.37	0.22	4.20	3.0
11/16	0540	0745	0.73	0.20	3.00	2.1
11/17	1824	2023	0.12	0.03	1.20	2.0

Table 10. Raingage storm summaries from gage number 10.

Date	Time began	Time end	Total amount, inches	Max., 5-min. amount	Max. rate	Dur., hours
11/ 5	1626	0604	0.60	0.08	1.20	13.6
11/12	0023	0123	0.06	0.04	1.20	1.0
11/12	0402	0651	0.81	0.37	5.40	2.8
11/12	0818	0828	0.01	0.01	0.30	0.2
11/13	2001	2243	0.66	0.16	3.60	2.7
11/14	0230	0241	0.01	0.01	0.30	0.2
11/14	0424	0651	0.08	0.03	1.20	2.5
11/14	1117	1149	0.13	0.09	1.80	0.5
11/14	2309	0009	0.25	0.09	1.80	1.0
11/15	2208	0259	2.15	0.35	3.60	4.9
11/16	0544	0811	0.96	0.25	2.40	2.5
11/17	2004	2021	0.06	0.02	0.30	0.3

Radar Raingaging

An MPS-34 radar was operated by personnel from the U. S. Army Electronics Command, Port Monmouth, in support of this project. The most important function of this radar was to provide means of assessing rainfall rates throughout the gun range. Since only about 2200 m of the range was over land and since the total range was to be 7000 m, the rainfall rate over the final 5000 m could not be measured by raingages. The second usage of the radar was to provide operational short time forecasts of the occurrence of rain in the gun range. In addition some insight into the meteorological conditions affecting the rainfall patterns in the area was obtained from viewing the time lapse pictures of the plan position indicator.

Radar Determination of Rainfall Rate

An attempt was made to verify rainfall conditions along the trajectory beyond the gages by using the radar. For this purpose, photographs were taken of the radar "A" scope. This display consists of a rectangular display where the abscissa represents the range and the ordinate is a function of the radar return power (see fig. 2). The radar used in Panama was not calibrated absolutely so that the precise function of the ordinate value to the **power** return **was** not known. Since the radar observed the area over the raingages as well as the region beyond, the values of raingage rates could be used in attaching a scale to the ordinate. This method, in fact, is usually considered to be more accurate than absolute calibration in terms of radar parameters.

The "A" scope pictures were digitized by a semi-automatic chart reader. **The** total length **of** the abscissa **was** 20 statute miles, and it **was** assumed that **the origin** of the trace **was** at zero range. Since this zero range setting **was** under operator control, some errors could be made. **In a few cases which were discarded,** it **is apparent that** the **operator did not have the range set to zero.** The radar was 3 miles behind the **guns and very nearly in line with** the firing range. **This alignment is absolutely necessary in order** to use the **"A" scope as the data recording scope.**

The radar extrapolated rain rates are useful in assessing the conditions downrange, but unfortunately at the times when the data would be most useful, the number of photographs is small. In particular at the time of the premature rounds, no close time data are available. Of course, it is always easier to recognize after the fact when data should have been taken. Nevertheless, the radar was a most useful adjunct to the analysis.

Rain rate data from the radar were calculated for the November 15 and 16 cases. Pig. 2 is an "A" scope trace and table 11 is the resultant rainfall information extracted from this trace. The computer program that was developed for this project obtained rainfall rates every ¼ mile from the radar to 10 miles from the radar. The rates from 3 to 4½ miles (corresponding to 0 to 1½ miles from the gun) were averaged and equated with the raingage average over the gaged part of the range. The resultant scale factor was then applied to the radar values from 4½ miles to 7¼ miles range from the radar to obtain the average rate for the portion of the gun trajectory over the ocean.

Table 11 represents the time that 105-mm round number 120 and 121 both prematured. These rounds were standard M564 fuzes. It can be noted in demonstrating the usefulness of the radar that the highest rate (5-23 in/hr) was not measured on any raingage. The radar amount at 1 mile from gun was 3.80 in/hr which compares very favorably with the rate of 3.84 in/hr at raingage 8 (see table 14).

Table 11. Rainfall rates as determined from the radar for November 16 at 0043.

Distance from gun, miles	Distance from radar, miles	Rate, in/hr
0	3	0.43
½	3½	0.71
1	4	3.80
1½	4½	5.23
2	5	0.78
2½	5½	0.64
3	6	0.63
3½	6½	0.67
4	7	0.72
4½	7½	0.84

General Radar Observations

The storms in November were different in character than the July storms. It was evident from personal observations that the July storms tended to be smaller in areal extent and definitely moved from the east. In November, the radar observations showed that the storms moved in from the north-northeast to northeast. Furthermore, there was much more organization of the storms into lines or groups of echoes. It is our opinion that a part of the higher hourly rainfall amounts found in the November rains in Panama is a result of the more continuous nature of the rain due to agglomeration of these individual storms.

One observation indicates that, on occasion, rain may be generated at two different levels in the atmosphere at the same time. Two rain areas were observed on the radar moving toward each other. One was moving from the northeast while the second one was moving from slightly west of north. These two rain areas intersected and separated again, maintaining their original identity. These rain areas were obviously being steered by winds at different levels in the atmosphere.

A further observation which can be made from the radar is the variation in rainfall rates with height. It is assumed that the highest point in the trajectory is less than 1500 m. Then, in order to evaluate the conditions through which the projectile passed, the changes in radar return in the lower 1500 m can be evaluated. Data from the Range Height Indicator (RHI) were used in this evaluation. Fig. 2b is a reproduction of a typical RHI taken at 0035 on November 16. On this picture the abscissa represents the range from the radar. The lower right corner is 25 miles. The horizontal lines represent height. The lower line represents ground level and the succeeding lines are 7000 feet apart. The receiver has been reduced by 12 decibels on this photograph so that only the higher rainfall rates are presented. The core of this storm extends to about 23,000 feet. Some variation is noticeable in the lower 4500 feet, particularly at the right edge of the echo. In general less change than this was noted near the ground level. In no cases was it deemed necessary to make an adjustment to the rainfall rate data for the height of the trajectory.

DROP SIZE SPECTRA

Average Raindrop Size Distributions

Average distributions have been found useful in showing the general trends of the drop size data. By removing some of the statistical noise and the very rare situations, the general patterns become more apparent. Also, this process reduces the data to a more convenient size for reporting.

To prepare these average distributions, the 1-m^3 sample distributions were divided into groups each having similar rainfall rates as calculated from the distribution. For each group, the number of drops of each size increment was averaged. From the resultant average distributions, the rainfall rate and concentrations appropriate to the average distribution were calculated.

Average distributions have been prepared for the November data, for all the Panama data, and for each of three of the more important rains. These single storm average distributions have been used primarily in the comparison of the drop camera data with the data taken by Geotis of the Massachusetts Institute of Technology (MIT), using the Joss spectrometer reported elsewhere in this report.

The November average distributions are presented in a tabular form in table 12. The parameters R, Z, Q, L, DL, and NT are calculated for each average distribution and are defined in table 13. The NS in the average distribution tabulations indicates the number of 1-m^3 samples in the average. The drop distribution follows NS, begins with the number of 0.5-mm drops, and continues in 0.1-mm increments to 7.9 mm. Drop sizes from 0.5 mm through 1.1 mm are indicated in the first line, 1.2 mm through 2.6 mm in the second line, 2.7 mm through 4.3 mm in the third line, 4.4 mm through 6.6 mm in the fourth line, and 6.7 mm through 7.9 mm in the fifth line. The first two lines are always present; the remaining lines are used only as far as necessary to report all non-zero concentrations.

Table 12. Average raindrop distributions for data taken at Port Sherman, Canal Zone, November 6 to November 21, 1968

```
R=    .2  Z=6.00E 01  Q=   0  L=  .02  DL=1.3  NT=  24.79  NS=168      2.04   1.68   2.43   2.75   3.77   3.19   2.85
              2.14   1.55   1.06    .54    .36    .24    .09    .06    .02    .02    .01    .01    .01    .00    .00

R=    .9  Z=4.00E 02  Q=   3  L=  .05  DL=1.5  NT=  40.44  NS=184       .38    .70   1.15   1.95   3.70   4.40   5.74
              5.53   5.16   3.79   2.54   1.80   1.11    .88    .51    .33    .25    .17    .09    .10    .04    .02
               .02    .02    .01    .03    .01    .00    .01    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00

R=   2.4  Z=1.27E 03  Q=   8  L=  .14  DL=1.6  NT= 104.21  NS=216      1.20   2.93   5.25   7.06   9.09  11.44  12.52
             13.20  11.18   8.84   6.37   4.43   3.18   2.13   1.68   1.08    .76    .46    .37    .28    .19    .12
               .12    .08    .09    .05    .04    .03    .01    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00

R=   4.4  Z=2.43E 03  Q=  14  L=  .24  DL=1.6  NT= 152.94  NS=141       .34   1.44   3.34   6.16   9.09  14.51  18.44
             20.94  20.32  15.82  12.31   8.99   6.37   4.19   3.35   2.21   1.38   1.19    .84    .54    .42    .23
               .17    .09    .08    .03    .03    .03    .00    .03    .01    .01    .02    .00   .01   .01    .00    .01   .01
               .00   .01   .00   .00   .00   .00   .00   .00   .00   .00   .00  .00 .00  .00 .00 .00  .00 .00 .00  .00 .00 .00

R=   7.3  Z=4.57E 03  Q=  24  L=  .39  DL=1.7  NT= 212.85  NS=217      1.01   1.50   3.11   5.52   9.71  16.20  21.77
             26.99  26.16  24.36  20.11  15.40  11.70   8.75   6.36   4.57   3.20   2.23   1.35    .88    .61    .46
               .25    .20    .10    .07    .05    .02    .03    .03    .04    .05    .01    .01    .00    .00    .00    .00    .00

R=  12.0  Z=7.82E 03  Q=  42  L=  .61  DL=1.8  NT= 286.58  NS=132       .83   2.03   5.15   8.68  13.29  18.07  23.80
             28.67  29.47  29.54  27.98  23.16  18.68  15.64  13.14   9.76   6.80   4.71   2.91   2.08   1.46    .83
               .65    .44    .27    .14    .13    .11    .03    .03    .02    .02    .02    .01    .00    .01    .00    .00    .00
               .01   .00   .00   .00   .00   .00   .00   .01   .00   .00   .00  .00 .00  .00 .00 .00  .00 .01 .00  .00 .00 .00

R=  19.8  Z=1.54E 04  Q=  84  L=  .95  DL=2.0  NT= 355.63  NS=113       .45   1.12   3.17   5.27  11.14  17.07  24.25
             30.38  34.31  35.02  33.61  29.47  26.02  22.84  20.26  15.69  11.71   9.20   6.69   5.34   3.57   2.65
              1.95   1.39    .91    .68    .39    .31    .24    .17    .13    .08    .03    .05    .04    .02    .01    .01    .00
               .00   .00   .02   .00   .00   .00   .00   .00   .00   .00   .00  .00 .00  .00 .00 .00  .00 .00 .00  .00 .00 .00

R=  31.4  Z=3.59E 04  Q= 180  L= 1.39  DL=2.2  NT= 378.74  NS= 79       .22    .75   1.50   3.82   8.09  14.87  18.85
             25.24  29.15  31.19  29.90  29.65  26.15  25.78  25.21  20.85  18.92  15.26  12.02   9.43   7.78   5.44
              4.00   3.52   2.49   2.22   1.35   1.07    .83    .71    .66    .34    .43    .26    .18    .16    .12    .06    .04
               .05   .01   .00   .02   .06   .00   .01   .00   .00   .00   .00  .01 .01  .00 .01 .00  .00 .00 .00  .00 .00 .00 .00

R=  44.8  Z=5.50E 04  Q= 261  L= 1.97  DL=2.2  NT= 539.78  NS= 44       .02    .44   2.20   7.34  20.46  24.74  34.24
             34.90  36.37  38.40  42.79  38.47  36.60  35.69  34.32  30.00  24.43  20.46  15.72  14.22   9.52   8.62
              6.86   5.27   3.88   3.70   1.98   1.57   1.46    .82    .71    .75    .53    .31    .37    .31    .13    .13    .11
               .04   .07   .05   .02   .00   .02   .00   .00   .00   .04   .02  .00 .00  .00 .00 .02  .00 .00 .00  .00 .00 .00 .02

R=  68.2  Z=9.56E 04  Q= 451  L= 2.94  DL=2.3  NT= 827.89  NS= 54     11.64  15.57  20.64  25.91  35.56  41.95  49.47
             53.93  58.68  58.52  54.73  54.71  48.65  45.23  40.74  35.48  30.59  26.02  20.80  17.41  15.48  11.52
             11.10   9.18   7.10   5.10   4.44   3.52   3.11   2.12   1.51   1.46   1.15   1.17    .84    .70    .56    .38    .23
               .43   .22   .05   .09   .02   .07   .04   .04   .04   .00   .00  .00 .00  .00 .00 .00  .00 .00 .00  .02 .00 .00 .00

R=117.9  Z=2.29E 05  Q= 957  L= 4.69  DL=2.7  NT= 860.48  NS= 32     10.09   7.61  10.43  15.10  28.80  37.10  40.32
             42.01  43.06  42.23  46.86  45.44  44.32  45.86  46.65  42.86  41.92  36.89  33.56  28.80  26.07  21.58
             19.43  16.79 15.88 14.34   9.25   8.52   7.67   5.76   4.67   3.36   2.91   2.39   2.06   1.79   1.15   1.18    .85
               .73   .61   .58   .45   .55   .27   .21   .12   .12   .12   .09  .00 .06  .09 .09 .03  .00 .00 .00  .00 .00 .00 .00

R=194.1  Z=3.95E 05  Q=1675  L= 7.58  DL=2.8  NT=1242.64  NS= 14      8.87  11.85  17.53  24.74  37.59  41.43  49.19
             55.08  61.87  62.84  58.75  63.74  62.57  53.74  69.22  60.49  56.61  56.54  50.16  43.23  41.05  34.02
             29.31  24.18 27.71 21.55 17.18 14.48 14.20  10.46   9.01   8.45   6.79   5.27   5.68   4.16   2.49   2.36  1.46
              1.46  1.04   .83   .55   .49   .21   .28   .14   .28   .21   .07  .07 .00  .00 .14 .07  .07 .00 .00  .00 .00 .00 .00
```

Table 13. Definitions of terms and units used on table 12.

Symbol	Definition	Units
R	Rainfall rate	$\mathrm{mm\ hr^{-1}}$
Z	Radar reflectivity	$\mathrm{mm^6 m^{-3}}$
Q	Attenuation cross section	$\mathrm{mm^2 m^{-3}}$
L	Liquid water content of rain	$\mathrm{g\ m^{-3}}$
DL	Median volume diameter	mm
NT	Total concentration	$\mathrm{m^{-3}}$

Six of these average distributions are shown as a family of curves in fig. 3. These curves show a tendency for more rounded shape than the July data,[2] particularly at the higher rates. The broader more rounded curves are usually associated with greater hydrometeor growth in an ice phase. This observation may have some meteorological significance in the differences in upper air conditions in existence at the time of rain. With respect to the fuze problem, the November rains with high rates tend to have a somewhat larger portion of large drops. At the low rates (e.g., 12 mm/hr or less) the reverse is true. The November rains had a smaller percentage of large drops.

Plots of representative distributions for three separate storms are presented in figs. 4, 5, and 6. These curves illustrate some of the storm-to-storm variabilities of the drop data. The November 15 storm is distinctly different from the two November 16 storms, and there are some differences between the two November 16 storms. Particularly, the 139.9 mm/hr on 0556-0647 LST, November 16 storm (fig. 6) is quite unusual in its great reduction in numbers of drops in the 1-2 mm area.

Drop Camera - Joss Spectrometer Comparisons

During the November tests at Port Sherman, an electronic raindrop spectrometer was operated in the very near vicinity of the drop camera. This spectrometer was designed by Jurg Joss[3] and was operated by Spiros Geotis and Donat Hogl of MIT. Mean distribution curves have been provided the authors of this report by Geotis for the storms of November 15-16.[4] Drop camera mean distributions were prepared for the same storms. Very good agreement was found between the two methods in the measurement of all but the smaller drops. Very large differences are found in the small drop sizes, that is, for diameters less than 1 mm.

Typical illustrations of these comparisons are shown in figs. 7 and 8. Mean distributions were chosen from each of the two methods which nearly matched in the large drop side of the curve. Between these matched distribution curves, the MIT data show up to three orders of magnitude larger numbers of drops than are indicated by the University of Illinois (UI) drop camera. These additional small drops can be important at the lower rates, such as in the case of the November 15 data where a UI rate of 3.8 mm/hr is matched with a MIT rate of 5.6 mm/hr. Geotis claims that the rate calculated from the MIT drop data agrees well with the rate from the tipping bucket gage nearby.

In an attempt to explain the gross differences in the small drops, consideration to the accuracy of both instruments is warranted.

The drop camera has three major problems which might be related to errors in the small diameter classifications. First, the equipment is large and bulky and thus presents an obstacle to smooth flow of air in the vicinity of the sample volume. Any change in the airflow to that of free space would produce aerodynamic sorting of the raindrops. It is considered likely that the effect would be to sweep the small drops around the shelter, and thus a disproportional number of small drops would not be measured. That this effect occurs i3 indisputable and its magnitude is not easily assessed. An attempt was made to determine whether the direction of wind flow and air speed produced noticeable effects in the spectra. These attempts indicated there was no measurable difference except for winds greater than 20 mph in line with the camera axis. Thus, if the effect is of a large magnitude, it is equally important and effective regardless of moderate to low wind speeds and directions. Since intuition would indicate that cross winds should be less effective in drop sorting than along axis winds, it is believed that wind effects are relatively small for the low wind speeds experienced in Panama.

A second possible problem is one of optics and recording on the drop camera. The theoretical optical resolution of the drop camera is ±0.2 mm throughout an 18-inch volume. However, in practice the resultant resolution of ±0.2 mm can only be held to about 14 inches. Thus the hoods which define the sampling volume are placed 14 inches apart. A better resolution is obtained over a shorter distance intermediate to the hood placement. A raindrop which is 0.5 mm in diameter is thus imaged on film as a blur with a diameter slightly greater than twice the size of a theoretical point source. This small blur is difficult to separate unambiguously from background blemishes. However, in a smaller volume (say ±3 inches from best focal plane), the resolution of the optics is much improved so that the image of the 0.5-mm drop, though not larger in size, is sharply defined and thus more easily recognized as a drop. Again, it is difficult to assess the exact importance of these effects. If, indeed, only the smallest drops in the center 6 inches were measured and the others ignored, an error of a factor of 2.5 might be expected. Increasing the number of 0.5-mm drops by a factor of 2.5 still does not bring the two spectra together at the 0.5-mm diameter.

The third problem area, and by far the most difficult to assess, is errors made by the operators of the film measurement equipment. This task is an extremely boring one and, human nature being as it is, a strong tendency to miss the measurements of the small drops exists. However, personal inspection of the film from November 15 would indicate that operator negligence could not account for a factor of 10 in the numbers of small drops. Repeated measurements of the same film by different operators have shown good agreement in numbers in each of the size classes for drops greater than 0.8-mm diameter and usually within a factor of 2 for drops within the 0.5-mm class.

Assessment of the Joss spectrometer can at best be only speculative. Two problem areas might be suggested, one of edge effects and the other of acoustical noise problems.

Directing attention to the acoustical noise problem, considerable design effort was expended in its minimization. Certainly in fair weather conditions these efforts appear to be reasonably effective. The acoustical noise of the generator and of people moving around the sensing head produced negligibly small numbers in the small drop channels. Noise due to the firing of guns was also apparently small or could be corrected. However, there would appear to be one noise that has not been assessed. This is the rain-made noise inside the concrete block well. The amount of this noise and its effect on the instruments is not known and has not as yet been experimentally checked. Undoubtedly, any effect that this has would be most important in the small size classes and further would probably increase proportionately with the rainfall rate.

A second effect which suggests itself is a misinterpretation of drops which impact near the edges of the cone. This effect might be termed as an edge effect. If it exists, one would expect to overmeasure in the small drop categories and underestimate in the large drop categories. The relatively small sampling area of the Joss spectrometer tends to accentuate the edge effects.

It is suspected that the true concentration of drops in the small classes lies somewhere between Geotis' measurements and our measurements. The agreement in the sizes above 1.5-mm diameter is quite good. Of particular interest is the differences between the storms on November 15 and 16. The storm on November 15 exhibits relatively larger numbers of drops greater than 3 mm in diameter by both the MIT and the UI measurements. Furthermore, good agreement with the shapes of the curves on both days is apparent.

Whether the numbers of small drops are important in the mechanism of fuze detonation by rain is a moot question. As is indicated in other sections of this report and as noted by Geotis, little correlation between fuze detonation and presence of large drops can be detected. However., a part of the difficulty is the fact that the numbers of large and small drops can not be independently adjusted. That is to say, at the higher rainfall rates there are larger concentrations of both large and small drops. To properly assess the importance of drop size on the fuze, it would be ideal to shoot through an artificial rain field of a monodispersed distribution of drops. It is our opinion that since the momentum change imparted to the fuze in transversing a rain field varies as the cube of the drop diameter, the effect of small drops is of less importance than the medium sized drops of 1.5 to 2.5 mm.

PREMATURE ROUNDS PROM THE 105-MM WEAPON

There were eight premature rounds with the 105-mm weapon. All of these rounds were the standard M564 fuze. Table 14 indicates the calculated statistics of these eight rounds.

Fig. 9 is a figure showing the relationship between the average rainfall rate and the distance to burst. The lines represent probabilities of premature firing as obtained from the July tests. In the July tests there were more prematures of the standard M564 fuze because more rounds were fired in rain. In November emphasis was placed on firing the modified fuze to determine its effectiveness. A total of 17 standard M564s were fired in rain. Thus, nearly one-half of the standard rounds from the 105-mm weapon were premature. On fig. 9 the X's represent the rounds which did not fire prematurely but successfully detonated at 7 km (the impact area).

Table 14. Rainfall parameters for premature rounds (standard MTSQ M564 fuze).

105-mm round no.	Distance to detonation (m)	Rainfall rate (in/hr) at time of firing at gages indicated* 1	2	3	4	7	8	10	Average rainfall rate to point of detonation	Expected no. of impacts
120	1394	0.51	0.64	0.87	0.63	3.09	3.84		1.91	46
121	2342	1.00	0.65	0.88	0.63	1.94	4.40	3.81	2.15	180
135	585	1.13	2.58	3.69	1.01				2.37	41
146	335	5.10	3.87	2.20					3.11	33
153	2114	0.39	0.35	0.87	0.94	1.93	1.85	1.23	1.22	141
157	2229	0.72	0.79	0.87	0.95	2.12	1.83	2.02	1.50	127
163	4792	0.69	0.53	0.93	0.70	0.42	0.84	2.58	1.00	222
179	5467	0.22	0.11	0.14	0.14	0.09	0.14	0.86	0.24	129

*Gages 5, 6, and 9 are missing.

At average rainfall rates greater than 25 mm/hr, the model proposed from the July data appears to be representative of the data from the November tests. Above this rate only one standard round successfully penetrated the entire 7-km path. Seven rounds fired prematurely and, considering the small sample, distribute around the expected curves very well.

Below 25 mm/hr there was a disproportionately large number of successful penetrations to the full range. At least three hypotheses may be advanced to explain this discrepancy. First, the effect producing premature rounds is not truly one of number of drops alone. Secondly, it may be that the total effect of collisions with two or more drops is dependent on the time between the collisions. The third possibility is that drop collisions with the fuze at the longer distances are less damaging to the fuze.

If the first hypothesis is true, that the total number of drops is not the most important parameter of the drop size spectra, an alternative parameter must be chosen. In the November tests, the number of premature rounds is so small that attempts to repeat the analyses of the July tests are doomed to failure. In the July tests, it was felt that there was no critical drop size which produced premature firing. However, there may indeed be some critical size below which little damage to the fuze is obtained. The sensitivity of the statistical tests available are not high because there are no means in nature of having rains of just large drops or small drops. From the physics of the rain erosion process, some size effects must exist. If such a critical size exists for this fuze at 105-mm velocities, it is apparently below 2.5-mm diameter.

The second hypothesis is conjectured on the possibility that the fuze may be mechanically distorted by a first drop impact, and before it springs back to near its original position, a second impact occurs. If this is the case, the extrapolation for range beyond 2 km from the July tests is doubtful. The extrapolation is made just considering the total number of impacts, and if the range is increased, the expected time between impacts is reduced, and one would predict greater probability of successful penetration.

This indeed appears to be the case, for there were eight rounds which traveled 7 km in rates from 4 to 23 mm/hr without premature detonation, and only one round which was premature in this same rate interval at 6 km.

The third hypothesis could equally well explain the discrepancy if the ballistics of the round indicate differences in the velocity of the round. In the November tests, the gun was elevated so that a portion of the initial muzzle velocity is a vertical velocity and thus subjected to the negative acceleration of gravity. The elevation angle of the gun was about 17°; thus, ignoring any air drag on the projectile, the velocity at one-half the total range would be about 5% less than muzzle velocity. It would appear that this change may not be sufficient to produce such a great difference. Aerodynamic drag effects on the projectile may be much more important and should be investigated further. The amount of momentum transfer reduces as the relative velocity between the round and drop decreases. As the round is slowed at the longer ranges, the effects of the collisions with drops should be less.

It is interesting to note that if the 17 rounds of standard M564 fuzes had been fired in the same rain on the July gun range, only three prematures would have been logged. However, it should be recognized that the average rates over the first 1850 m would also have been different. Three premature rounds out of 17 are a smaller percentage than the 25 out of 74 obtained in July. Again, the purpose of the November test was to shoot the modified fuze more frequently, and during the heavier parts of the rain the modified fuze was used and successfully penetrated the much longer range.

MODIFIED M564 FUZE - 105-MM WEAPON

Fig. 10 is the cumulative frequency of the average rainfall rates through which the modified M564 rounds were fired. There were 11 rounds fired through average rainfall rates greater than 3 in/hr.

At rain rates above 1 in/hr, there were eight rounds of the standard M564 fuze fired, and seven rounds fired prematurely. There were 40 rounds with the steel tipped urethane cap (STU) fired at rain rates above 1 in/hr and none of these detonated prematurely.

The total number of rounds with the modified fuze was higher in November than in July, but the largest average rainfall intensity was less. This is due in part to the necessity of averaging the rate over much longer distances in November and in part due to lower peak rainfall rates. The highest November rainfall rate measured at a point was 9.5 in/hr which occurred on November 16 at 0100. Round 142 was fired at this time with an average rate through the range of 3.84 in/hr. The high rate rain area moved downrange through the following few minutes. The average rates over the range for rounds 143 through 146 were 3.97, 3.67, 3.67. and 3.87, respectively. Round 146 was a standard M564 fuze and prematured 335 m downrange. Over this first 335 m the average rain for round 146 was 2.62 in/hr. Thus, four modified rounds penetrated the heaviest rain for the entire 7-km range while a standard round, fired after the peak rain had already moved downrange, detonated prematurely in 335 m.

In the combined July and November tests, there were 183 rounds of the modified fuze fired in rain. Not one of these detonated prematurely. This would appear to completely justify the use of the modified steel tipped urethane cap in rain when used in the 105-mm weapon.

ROUNDS WITH THE 90-MM WEAPON

There was a total of 13 rounds fired from the 90-mm gun during measurable rainfall. Of these 13 rounds, 11 rounds were fired with average rainfall rates less than 0.25 in/hr. There were two rounds (ll and 12) fired 2 minutes apart through approximately the same average rainfall rate (1.06 and 1.32 in/hr). Both of these rounds had steel tipped urethane cap fuzes. One round prematured at 2800 m downrange, and the other successfully penetrated to the impact area. It is possible that the one premature firing was a result of something besides rain (such as a sea gull?) but on the basis of this data, it would appear that considerably more testing of the fuze in this higher velocity weapon is desirable.

Considering just the one case of premature detonation, the expected total number of drop collisions is 127. Prom the 105-mm weapon, there were over 100 rounds with the modified fuze with expected number of collisions in excess of 130. Thus, it is likely that either the higher muzzle velocity of the 90-mm weapon produces a much greater rain effect, or that this one case was a faulty fuze, or that some other object was responsible for the detonation.

It is unfortunate that more 90-mm data could not have been obtained. The lack of 90-mm data was because of problems in keeping the weapon anchored and aimed appropriately. Thus, the data gathered for the 90-mm weapon is quite limited and inconclusive.

CONCLUSIONS AND RECOMMENDATIONS

The main purpose of this experiment was to determine the effectiveness of the modified fuze when fired in rain. Using the 105-mm weapon the modified fuze was a complete success. It successfully penetrated all rains through which it was fired. During the July and November tests, a total of 183 rounds of the modified fuze was fired in natural rains with the average rainfall rate up to 4.8 in/hr. Not one of these rounds failed. Unquestionably the modification of the fuze is successful for the 105-mm weapon.

There was a single failure of the modified fuze when fired at the higher velocites of the 90-mm weapon. It is difficult to assess on the basis of this one failure whether the modifcation is successful at these higher velocities. No great differences in the rain conditions could be found when this round was fired. It appears that the best conclusion on the fuze in the 90-mm weapon is that more testing is warranted.

The model for premature firing of the standard M564 fuze was verified for the higher rainfall rates in the November tests. However, at lower rates and longer distances the model overestimates the number of premature detonations. The most reasonable cause for this discrepancy is that there is a mutual effect when the fuze impacts with two drops in a short time interval. Two other hypotheses have been advanced but appear to be less likely. This effect may be a limiting factor in accelerated testing in artificial rain fields where the raindrop concentrations are unnaturally large.

The tests were handicapped by a poor firing range which restricted the raingage network to a short distance. Ideally raingages should have been arranged along the entire trajectory. The radar did permit extrapolation of the rainfall rates to the greater ranges, but only for the limited number of times that recorded data were available and only with an increase in the uncertainty due to the lack of exact correlation between radar echoes and rainfall rates. Further, the lack of complete freedom in range clearance produced some rains in which no firing data could be collected. Furthermore, the early periods of the experiment resulted in poor raingage records due to the incorrect chart clips. More experienced personnel for the raingaging would be preferable if ever the experiment is repeated.

It is strongly recommended that further work in determining the mechanism of premature fuze detonation be accomplished. In order to more easily test fuzes, an artificial rain field, through which test firings could be made, allows less expensive and repeatable results to be obtained. However, in order for work in artificial fields to be valid a correspondence between parameters of the natural rain to the artificial field must be made. The exact parameter to be modeled is not at present known. Experiments to determine the presence of mutual effect between fuze impacts with raindrops in short periods of time are recommended. Experiments to determine whether a critical drop diameter exists and to determine this size are important. Knowledge of the number of impacts required to premature a round as a function of drop diameter would be valuable in assessing the appropriateness of the artificial rain field in testing this or any other fuze.

Even if detailed answers to the above experiments are not available, continued work in determining the correspondence between the natural rain and artificial rain should be accomplished. The correspondences can be based on the total concentration criteria, the liquid water content, and a measure of the relative number of large drops. The first step in this procedure is to determine the drop size spectra in the artificial rain field.

Further research will be needed to properly evaluate the effects of the velocity of the round on its tendency to detonate premature in rain. The number of 90-mm rounds fired in these tests was not sufficient to make firm conclusions on this subject.

The raindrop spectra data obtained in Panama are unique and will be useful in many other applications. The 336l drop size spectra obtained represent a quite large sample of tropical rain. Furthermore, short period rainfall rate statistics obtained (even though over a short time period) are proving very valuable. To our knowledge these represent the only short time rainfall rate data from a truly tropical climte. Other than the companion data obtained by MIT on this project and a small sample by Diem, the spectra obtained represent the only drop size spectra obtained in tropical areas.

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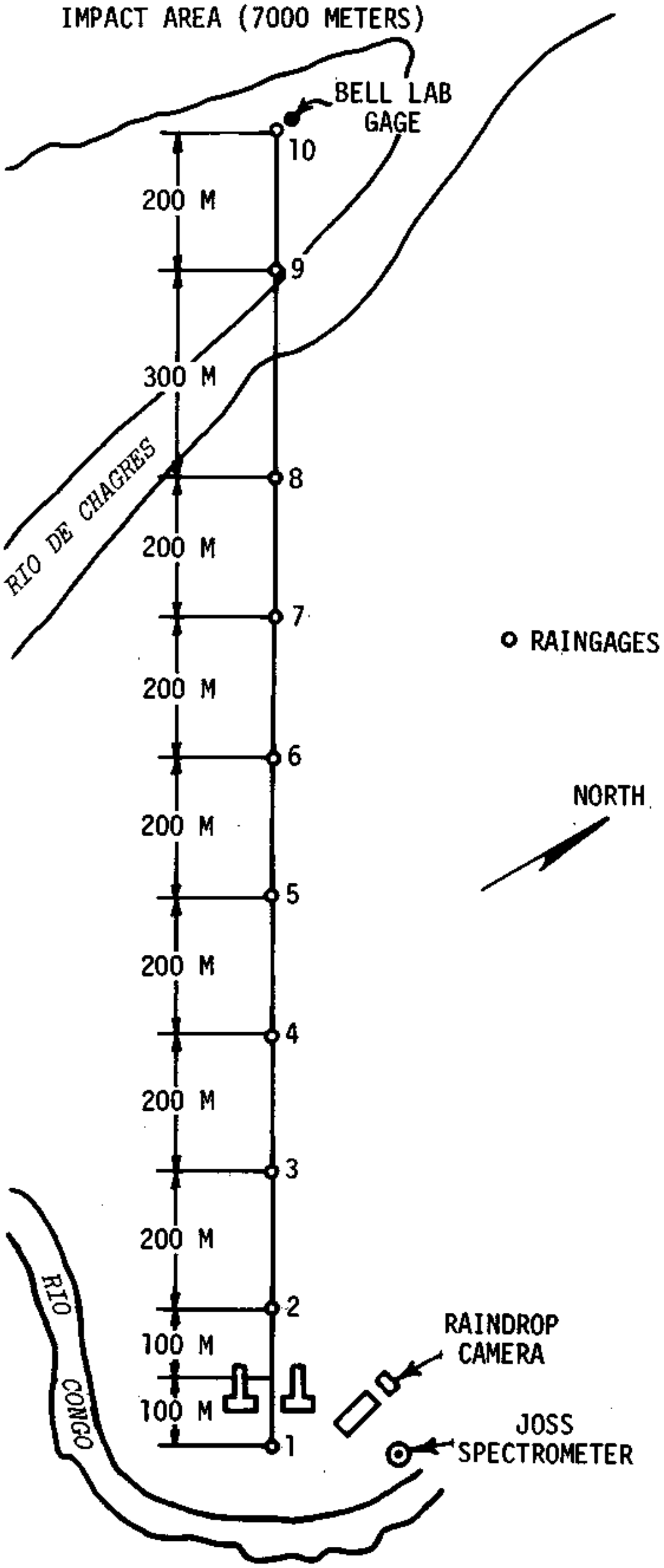
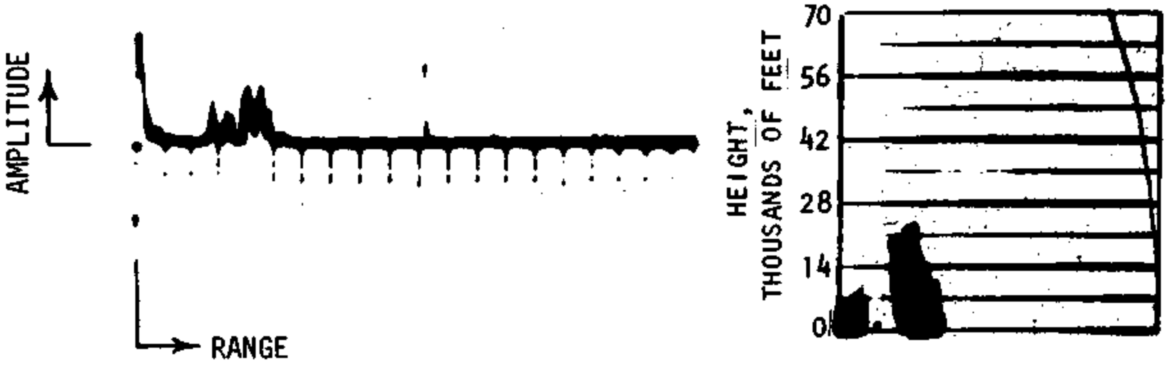


Figure 1. Raingage locations along firing range



2a. "A" scope taken at 0043 LST

2b. "RHI" scope taken at 0035 LST

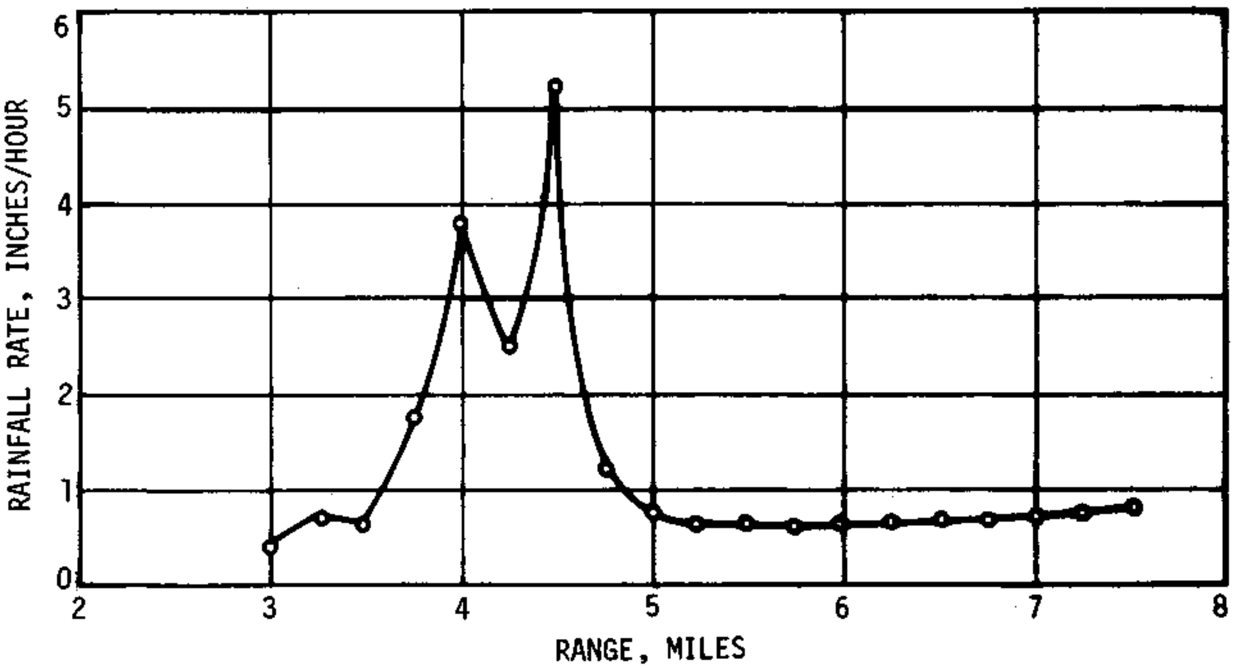


Figure 2. Sample of radar photographs and interpretation for November 16, 1968

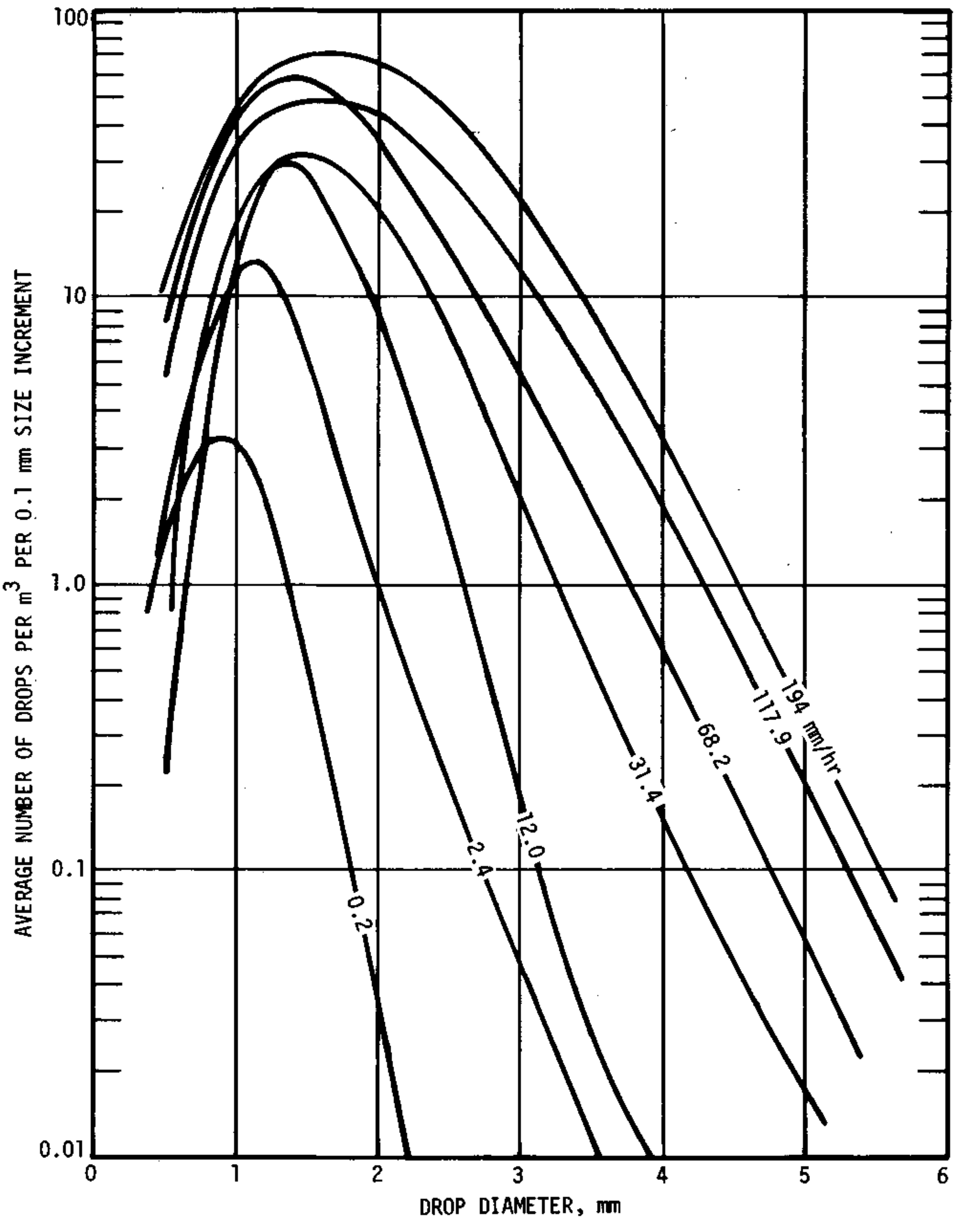


Figure 3. Average raindrop distributions for data taken at Ft. Sherman, Canal Zone, November 6 to November 21, 1968

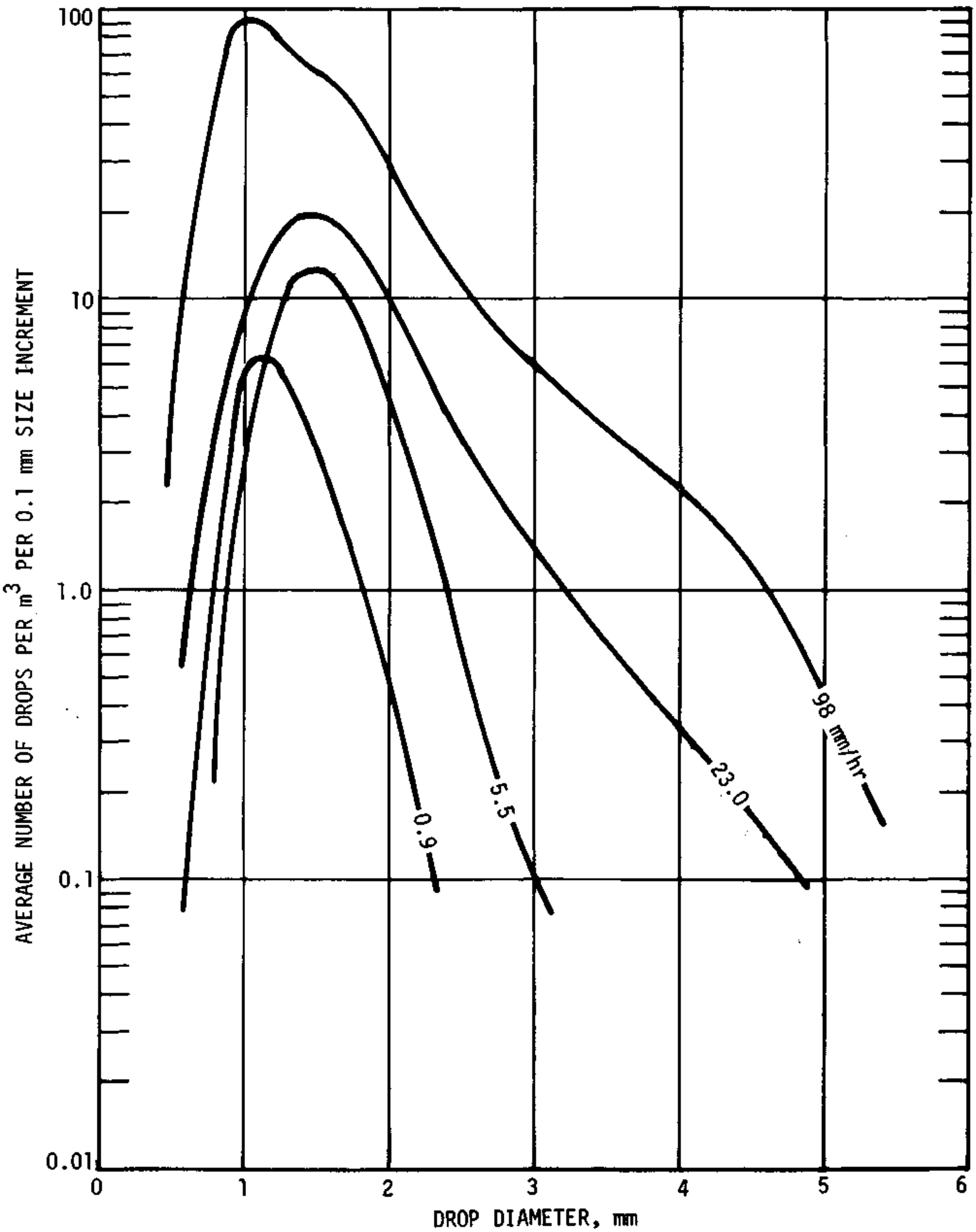


Figure 4. Average raindrop distributions for 2203-2240 LST, November 15, 1968

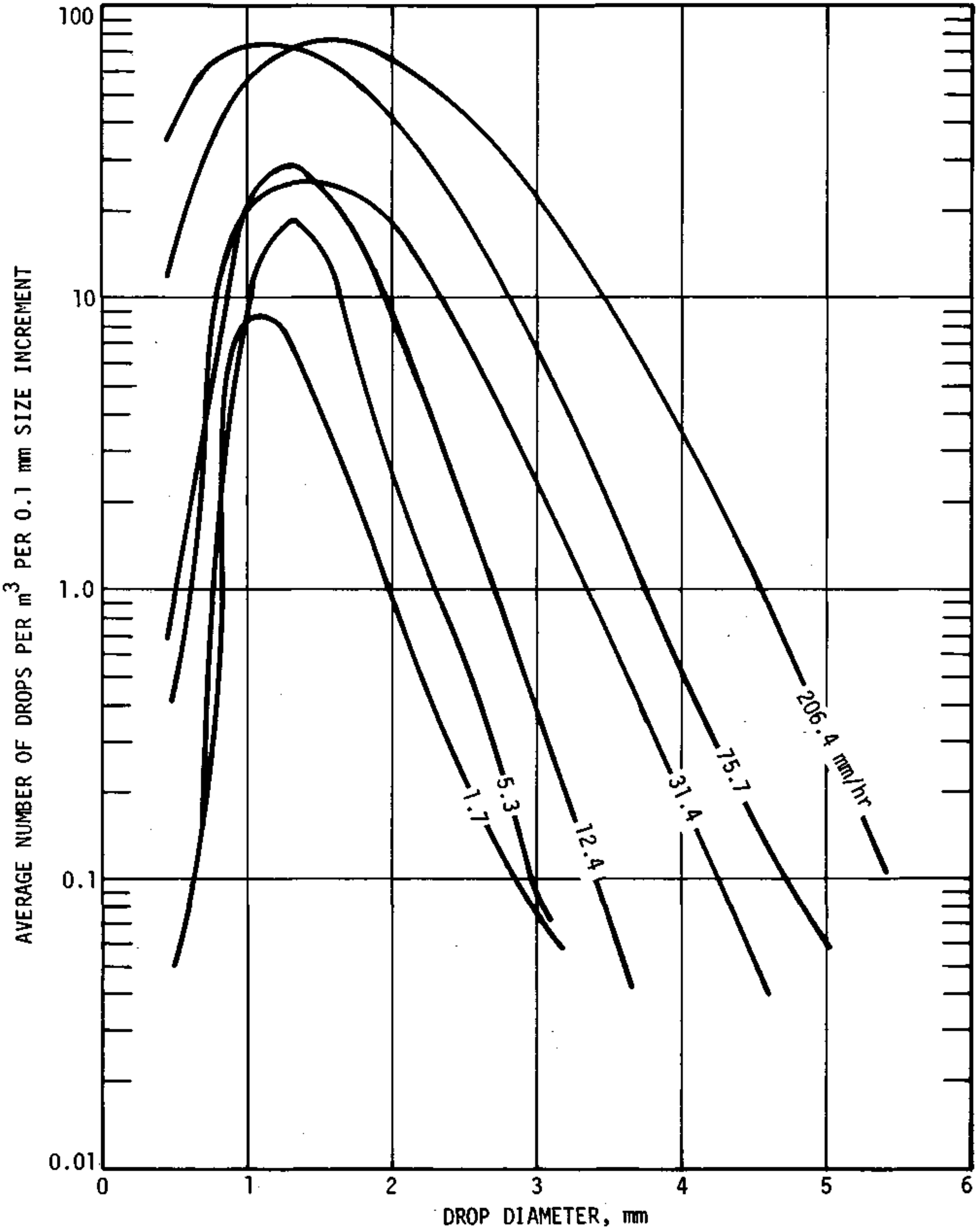


Figure 5. Average raindrop distributions for 0036-0124 LST, November 16, 1968

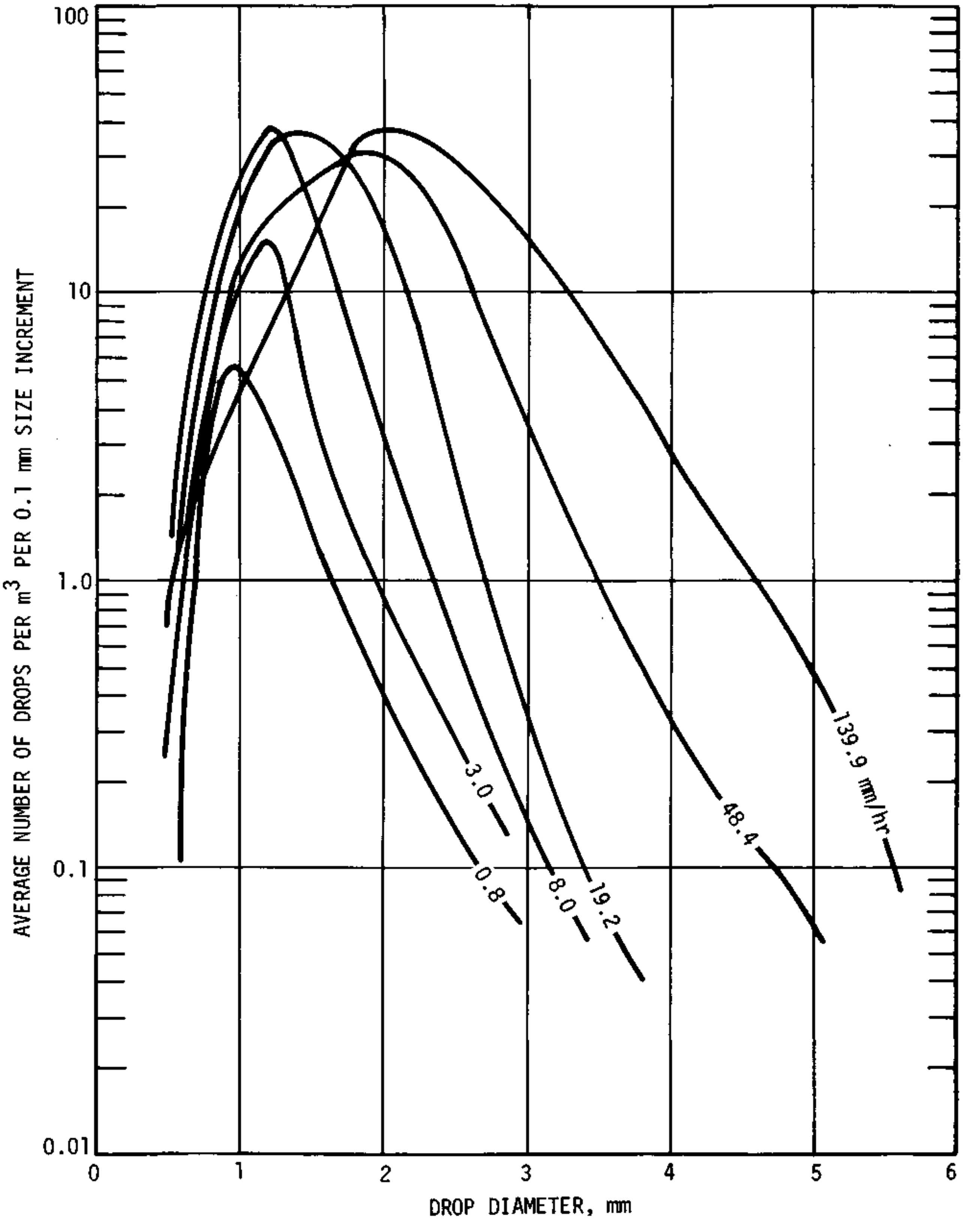


Figure 6. Average raindrop distributions for 0556-0647 LST, November 16, 1968

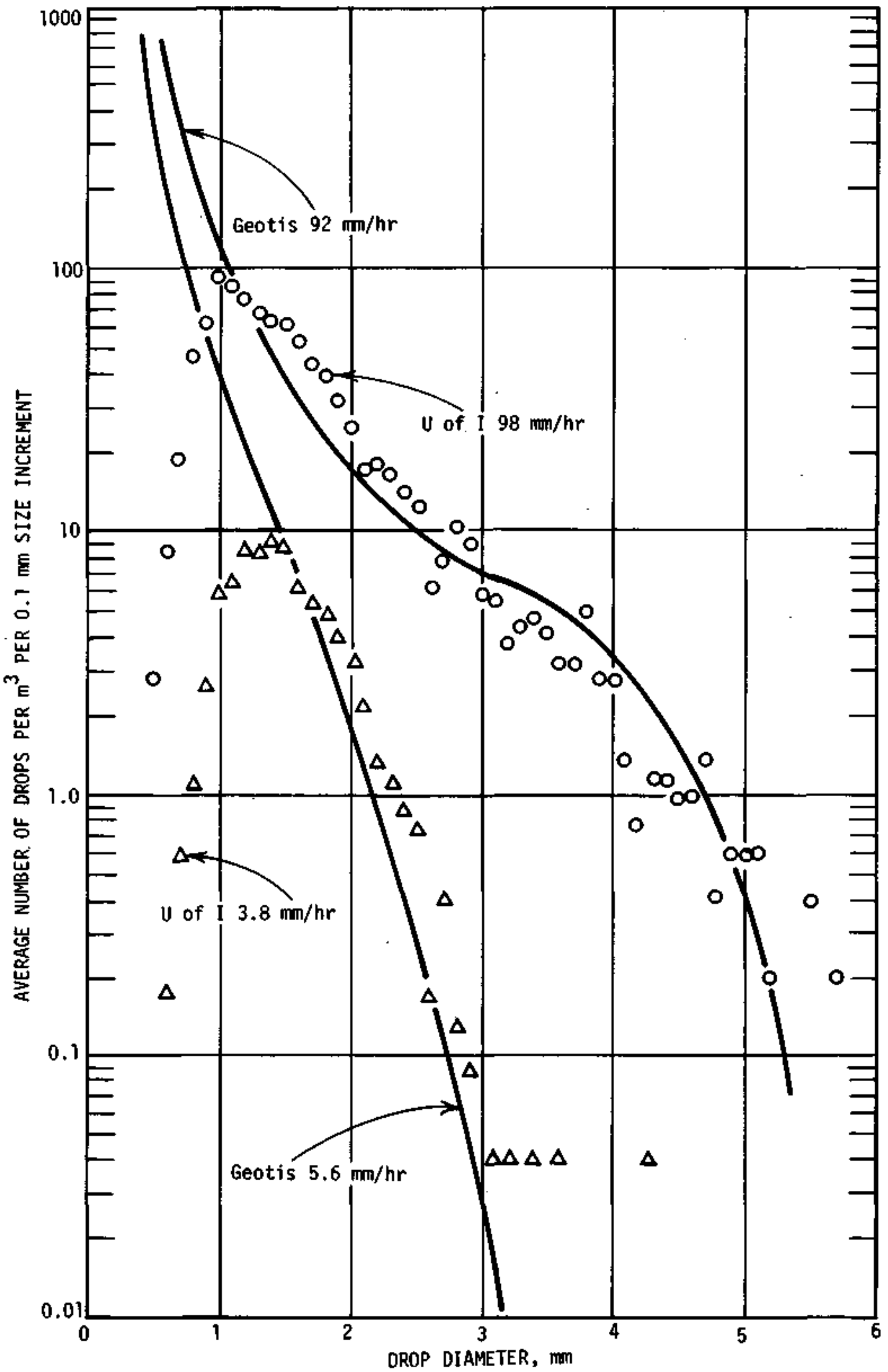


Figure 7. Two average distributions for 2203-2240 LST, November 15, 1968 with corresponding distributions from Geotis ' data for the same rain

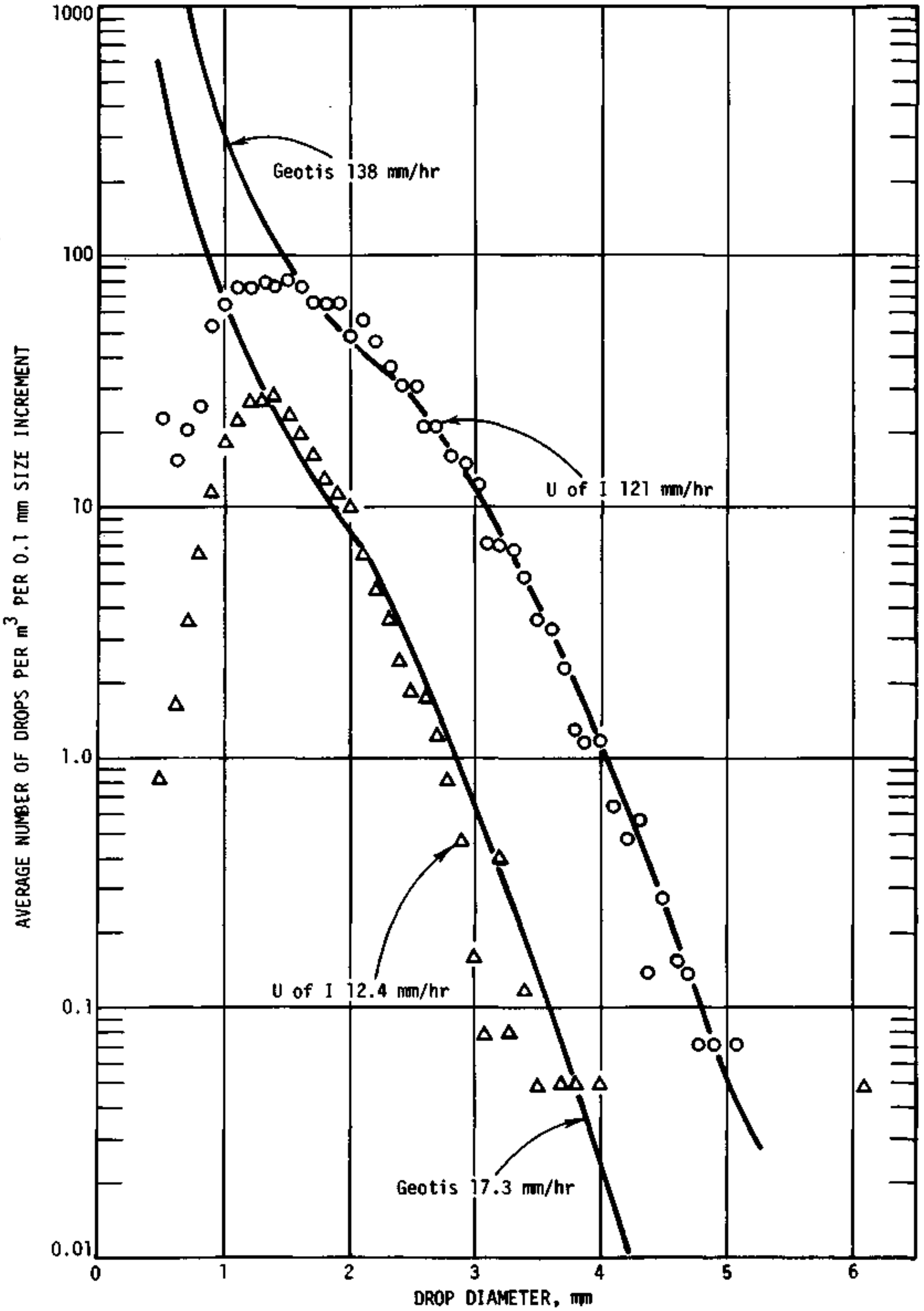


Figure 8. Two average distributions for 0036-0124 LST, November 16, 1968 with corresponding distributions from Geotis data for the same rain

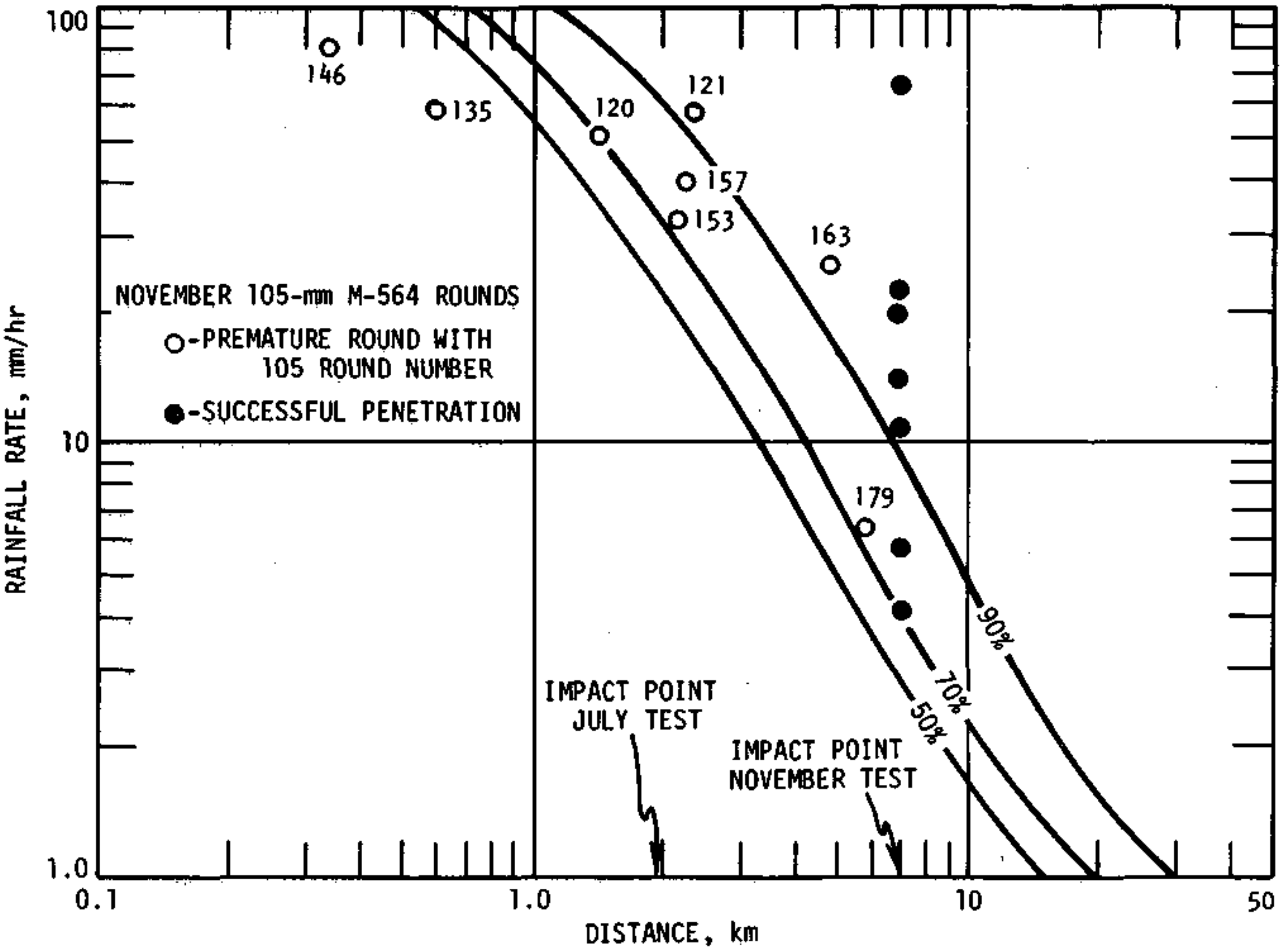


Figure 9. Probable distance to premature detonation as a function of rainfall rate (predicted on total number of drop encounters) for the 105-mm Standard MTSQ M564 rounds as determined from the July test. Points have been added to show the November test data.

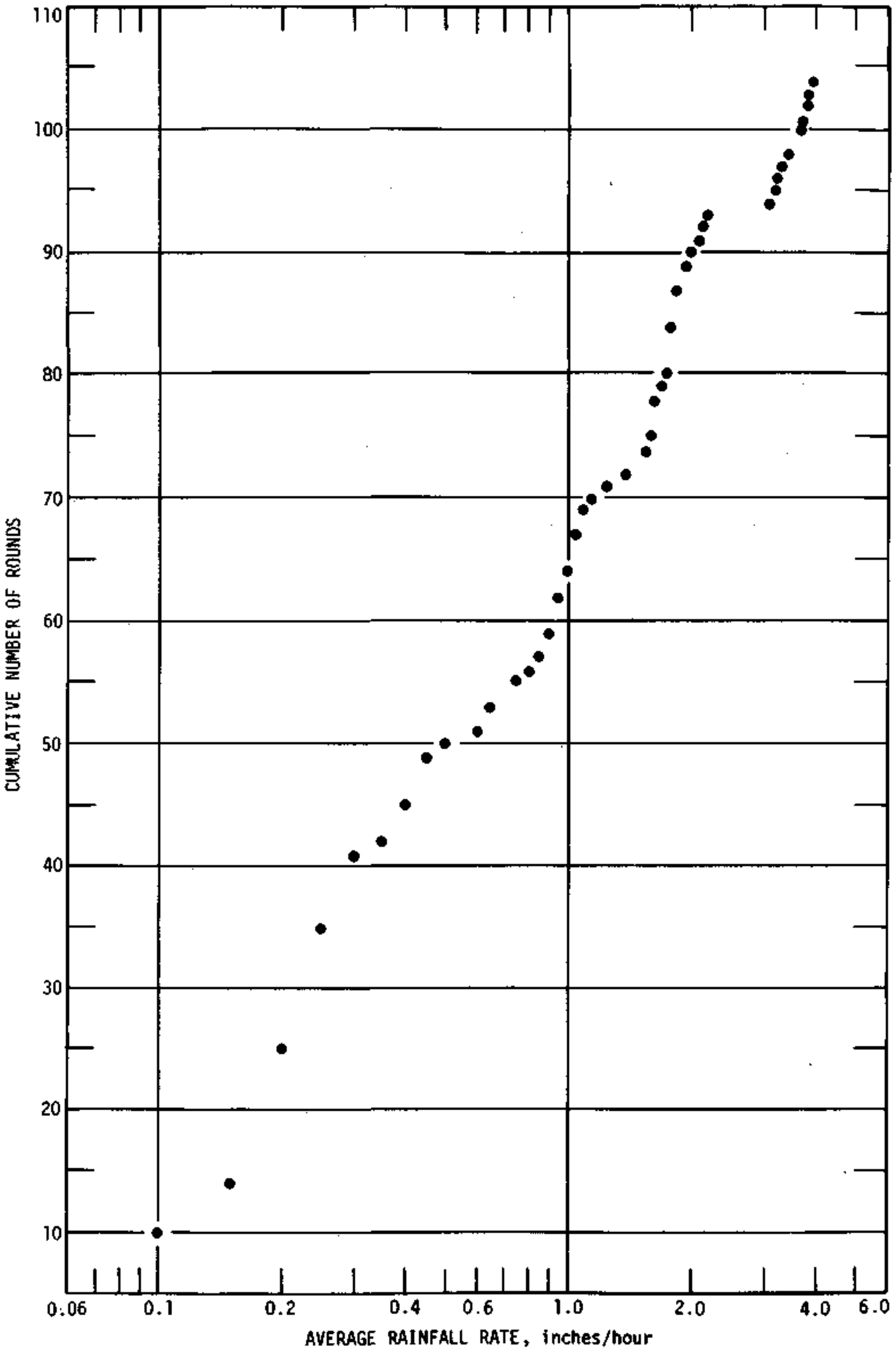


Figure 10. Cumulative frequency of rainfall rates while firing the modified M-564 fuzed 105-mm rounds

APPENDIX A

1968 date	Time	Total round no.	105-mm round no.	Distance to burst	Fuze type	Avg. rate in/hr	NT/m^3
11/ 6	0441	016	016	I	STU	0.96	370
11/ 6	0443	017	017	I	STU	0.96	370
11/ 6	0445	018	018	I	STU	0.17	135
11/ 6	0446	019	019	I	STU	0.22	155
11/ 6	0448	020	020	Dud	STU	0.36	210
11/ 6	0449	021	021	I	STU	0.45	237
11/ 6	0450	022	022	I	STU	0.76	322
11/ 6	0452	023	023	I	STU	0.49	250
11/ 6	0454	024	024	I	STU	0.50	252
11/ 6	0455	025	025	Dud	STU	0.55	265
11/ 6	0456	026	026	I	STU	0.68	300
11/ 6	0457	027	027	I	STU	0.58	275
11/ 6	0458	028	028	I	STU	0.60	280
11/ 6	0459	029	029	I	STU	0.55	265
11/ 6	0500	030	030	I	STU	0.39	220
11/ 6	0502	031	031	I	STU	0.27	176
11/ 6	0504	032	032	I	STU	0.37	212
11/ 6	0505	033	033	I	STU	0.05	66
11/ 6	0507	034	034	I	STU	0.06	73
11/ 6	0508	035	035	I	STU	0.29	182
11/ 6	0510	036	036	I	STU	0.06	73
11/ 6	0511	037	037	I	STU	0.03	49
11/ 6	0512	038	038	I	STU	0.03	49
11/ 6	0514	039	039	I	STU	0.07	80
11/ 6	0516	040	040	I	STU	0.02	38
11/ 6	0517	041	041	I	STU	0.06	73
11/ 6	0519	042	042	I	STU	0.31	190
11/ 6	0520	043	043	I	STU	0.15	125
11/ 6	0521	044	044	I	STU	0	0
11/ 6	0523	045	045	I	STU	0	0
11/ 6	0524	046	046	I	STU	0	0
11/ 6	0525	047	047	I	STU	0.06	73
11/ 6	0527	048	048	I	STU	0.06	73
11/ 6	0528	049	049	I	STU	0.06	73
11/ 6	0531	050	050	I	STU	0.06	73
11/ 6	0533	051	051	I	STU	0.06	73
11/ 6	0534	052	052	I	STU	0.12	110
11/ 6	0536	053	053	I	STU	0.08	87
11/ 6	0537	054	054	I	STU	0.11	104
11/ 6	0538	055	055	I	STU	0.05	66
11/ 6	0540	056	056	I	STU	0.09	94
11/12	0423	077	064	I	STU	0.12	110
11/12	0425	078	065	I	STU	0.03	49
11/12	0427	079	066	I	STU	0.02	38
11/12	0428	080	067	I	STU	0.02	38
11/12	0429	081	068	I	STU	0.02	38
11/12	0430	082	069	I	STU	0.04	58
11/12	0431	083	070	I	STU	0.04	58
11/12	0432	084	071	Dud	STU	0.04	58
11/12	0643	085	072	I	STU	0.37	210

1968 date	Time	Total round no.	105-mm round no.	Distance to burst	Fuze type	Avg. rate in/hr	NT/m^3
11/12	0644	086	073	I	STU	0.37	210
11/12	0645	087	074	I	STU	0.06	73
11/12	0646	088	075	I	STU	0.07	74
11/12	0647	089	076	I	STU	0.07	74
11/12	0648	090	077	I	STU	0.06	73
11/12	0822	091	078	Dud	STU	0	0
11/12	0824	092	079	I	STU	0	0
11/12	0825	093	080	I	STU	0	0
11/15	2209	094	081	I	STU	0.94	370
11/15	2210	095	082	I	STU	0.36	210
11/15	2210	096	083	I	STU	0.36	210
11/15	2210	097	084	I	STU	0.36	210
11/15	2213	098	085	I	STU	0.63	285
11/15	2214	099	086	I	STU	0.33	200
11/15	2215	100	087	I	STU	0.23	160
11/15	2216	101	088	I	STU	0.23	160
11/15	2217	102	089	I	STU	0.22	157
11/15	2218	103	090	I	STU	0.22	157
11/15	2219	104	091	I	STU	0.24	165
11/15	2220	105	092	I	STU	0.18	140
11/15	2220	106	093	I	STU	0.19	143
11/15	2221	107	094	I	STU	0.18	140
11/15	2222	108	095	I	STU	0.17	135
11/15	2223	109	096	I	STU	0.16	130
11/15	2224	110	097	I	STU	0.16	130
11/15	2225	111	098	?	STU	0.28	180
11/15	2225	112	099	I	STU	0.28	180
11/15	2226	113	100	I	STU	0.28	180
11/15	2227	114	101	I	STU	0.28	180
11/15	2228	115	102	I	STU	0.30	190
11/15	2229	116	103	I	STU	0.29	183
11/15	2230	117	104	I	STU	0.21	151
11/15	2230	118	105	Dud	STU	0.23	160
11/15	2231	119	106	I	STU	0.22	157
11/15	2232	120	107	I	STU	0.21	151
11/15	2233	121	108	I	STU	0.22	157
11/15	2234	122	109	I	STU	0.21	151
11/15	2235	123	110	I	STU	0.08	86
11/15	2235	124	111	I	STU	0.08	86
11/15	2236	125	112	I	STU	0.08	86
11/15	2237	126	113	I	STU	0.08	86
11/15	2243	127	114	I	M564	0.06	73
11/15	2244	128	115	I	M564	0.06	73
11/16	0001	129	116	I	M564	0.10	100
11/16	0002	130	117	I	M564	0.10	100
11/16	0002	131	118	I	M564	0.09	94
11/16	0003	132	119	I	M564	0.09	94
11/16	0043	135	120	1394	M564	2.17	600
11/16	0044	136	121	2342	M564	1.90	560
11/16	0045	137	122	I	STU	1.64	510
11/16	0045	138	123	I	STU	1.65	510

1968 date	Time	Total round no.	105-mm round no.	Distance to burst	Fuze type	Avg. rate in/hr	NT/m^3
11/16	0046	139	124	I	STU	1.65	510
11/16	0047	140	125	I	STU	1.78	530
11/16	0048	141	126	I	STU	1.72	530
11/16	0049	142	127	I	STU	1.82	540
11/16	0050	143	128	I	M564	1.86	550
11/16	0050	144	129	I	STU	1.81	540
11/16	0051	145	130	I	STU	1.76	530
11/16	0051	146	131	I	STU	1.79	530
11/16	0053	147	132	I	STU	1.84	540
11/16	0054	148	133	I	STU	1.99	570
11/16	0055	149	134	I	STU	3.10	730
11/16	0055	150	135	585	M564	2.29	700
11/16	0056	151	136	I	STU	3.74	820
11/16	0056	152	137	I	STU	3.87	840
11/16	0057	153	138	I	STU	3.26	750
11/16	0058	154	139	?	STU	3.21	740
11/16	0058	155	140	Dud	M564	3.12	720
11/16	0059	156	141	I	STU	3.41	770
11/16	0100	157	142	I	STU	3.84	840
11/16	0101	158	143	I	STU	3.97	850
11/16	0102	159	144	I	STU	3.67	810
11/16	0102	160	145	I	STU	3.67	810
11/16	0104	161	146	335	M564	2.62	660
11/16	0105	162	147	I	STU	2.10	580
11/16	0105	163	148	Lost	STU	1.93	550
11/16	0106	164	149	I	STU	1.94	550
11/16	0108	165	150	I	STU	1.54	490
11/16	0109	166	151	I	STU	1.55	490
11/16	0110	167	152	Dud	STU	1.00	380
11/16	0111	168	153	2114	M564	1.08	400
11/16	0112	169	154	I	STU	1.03	380
11/16	0112	170	155	I	STU	1.12	405
11/16	0113	171	156	I	STU	1.08	400
11/16	0114	172	157	2229	M564	1.26	430
11/16	0115	173	158	I	STU	1.39	460
11/16	0115	174	159	I	STU	1.23	430
11/16	0557	175	160	I	STU	0.74	290
11/16	0558	176	161	Dud	STU	0.80	330
11/16	0559	177	162	I	STU	0.71	290
11/16	0600	178	163	4792	M564	0.96	370
11/16	0601	179	164	I	STU	1.03	380
11/16	0602	180	165	I	STU	1.06	390
11/16	0602	181	166	I	STU	0.99	380
11/16	0603	182	167	I	M564	1.01	380
11/16	0604	185	168	I	STU	0.95	370
11/16	0605	184	169	I	STU	0.95	370
11/16	0606	185	170	I	STU	0.84	340
11/16	0607	186	171	I	M564	0.85	340
11/16	0607	187	172	I	STU	0.86	340

1968 date	Time	Total round no.	105-mm round no.	Distance to burst	Fuze type	Avg. rate in/hr	NT/m^3
11/16	0608	188	173	I	STU	0.89	360
11/16	0609	189	174	I	STU	1.02	380
11/16	0610	190	175	I	M564	0.52	260
11/16	0611	191	176	I	STU	0.62	285
11/16	0612	192	177	I	STU	0.45	240
11/16	0612	193	178	I	STU	0.44	240
11/16	0613	194	179	5867	M564	0.242	165
11/16	0614	195	180	I	STU	0.42	230
11/16	0615	196	181	I	STU	0.15	125
11/16	0616	197	182	I	STU	0.14	120
11/16	0617	198	183	I	M564	0.20	150
11/16	0618	199	184	I	STU	0.18	140
11/16	0619	200	185	I	STU	0.14	120
11/16	0619	201	186	I	STU	0.14	120
11/16	0620	202	187	I	M564	0.18	140
11/16	0621	203	188	I	STU	0.16	130
11/16	0622	204	189	I	STU	0.17	135
11/16	0623	205	190	I	M564	0.25	170
11/16	0624	206	191	Lost	STU	0.56	270
11/16	0625	207	192	I	STU	0.48	245
11/16	0625	208	193	I	STU	0.45	240
11/16	0626	209	194	I	M564	0.45	240
11/16	0641	210	195	I	STU	2.16	590
11/16	0642	211	196	I	STU	2.13	590
11/16	0643	212	197	I	STU	1.80	540
11/16	0643	213	198	I	M564	1.72	520
11/16	0644	214	199	I	STU	1.70	520
11/16	0645	215	200	I	STU	0.08	87

1968 date	Time	Total round no.	90-mm round no.	Distance to burst	Fuze type	Avg. rate in/hr	NT/m^3
11/ 9	1552	065	005	I	STU	0.06	74
11/ 9	1737	066	006	I	M564	0.04	58
11/ 9	1739	067	007	I	STU	0.06	74
11/ 9	1847	068	008	I	M564	0.05	66
11/ 9	1905	069	009	I	M564	0.06	74
11/12	0033	070	010	Dud	M564	0.12	110
11/12	0410	071	011	2803	STU	1.32	750
11/12	0412	072	012	I	STU	1.32	750
11/12	0415	073	013	I	STU	0.24	165
11/17	1803	228	027	I	M564	0.14	120
11/17	1805	229	028	I	M564	0.20	150
11/17	1811	230	029	I	M564	0.20	150
11/17	1819	231	030	I	M564	0.10	100

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13. ABSTRACT

The results of an experiment at Fort Sherman, Panama Canal Zone, are reported. This experiment consisted of determining the reliability of a modified MTSQ M564 fuze to penetrate natural rain. The rainfall parameters, rainfall rate and drop size spectra, were used to determine the number and size of the raindrops encountered by the projectile. The modified fuze penetrated the rain successfully in all cases when fired from the 105-mm weapon. Eight premature detonations of the standard M564 fuze were recorded and tend to verify the model derived from the earlier work under Contract No. DAAG 11-68-C-1342 for rainfall rates greater than 25 mm/hr. For lower rates the model overestimates the number of premature detonations.

The raindrop size spectra obtained for tropical rains are valuable not only for this work but in other areas such as communication, environmental testing, and in artificial rainfall simulation for testing purposes.

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Effects of Rain						
MTSQ M564 Fuze						
Sensitivity of Fuzes						

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