P.F.T.R. No.610

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PORTON FIELD TRIAL REPORT No.610

THE PENETRATION OF BUILT-UP AREAS BY AEROSOLS AT NIGHT

CHEMICAL DEFENCE EXPERIMENTAL ESTABLISHMENT

PORTON DOWN, WILTS.

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The Penetration of Built-up Areas by Aerosols at Night

Programme No 2/63 Trial 1 — Carried out 28th March, 1963

INTRODUCTION

1. When an aerosol cloud is generated in the atmosphere above the stable layer associated with a night-time temperature inversion, it diffuses downward only slowly, and may therefore be expected to drift for great distances without penetrating to the ground to an appreciable extent. It has been suggested however, that in the vicinity of a large town the inversion could be destroyed by the heat emitted from industrial and domestic services etc., and that sufficient turbulence may be set up for aerosol material to be brought to ground level locally in larger concentrations than in the open country far outside the town.

2. An attempt was made to verify this hypothesis by trials in and around Salisbury, but the results were inconclusive: the smallness of the town and the unevenness of the surrounding country were such that any effect of the type sought was masked by topographical effects. It was proposed therefore to repeat the experiments in a larger town which is a more powerful heat source and which is situated in an area as free as possible from topographical irregularities; the City of Norwich was selected for this purpose.

3. The trial herein reported was the first of the series and was carried out on 28th March, 1963.

GENERAL ARRANGEMENTS

4. A quantity of fine powder (zinc cadmium sulphide fluorescent pigment (F.P.) was emitted from an aircraft flying at 500 ft. a.m.s.l. along a line perpendicular to the forecast wind direction and about 62 mi. in length. The centre of the line was about 24 mi. upwind of Norwich.

5. Sampling of the aerosol was carried out in the city at 30 stations (mostly in the yards adjoining police buildings and in the gardens of private houses) and in the country at 10 roadside positions lying approximately along a line parallel to the flight path, passing through the centre of the city.

SOURCE

6. The F.P. was emitted from a mechanical-feed dispenser to design C.D.6415(1) mounted in a Devon aircraft. The F.P. used was Derby Luminescents Ltd., grade 1318/10, silicone-treated by the manufacturers to improve its flow characteristics, and the total quantity dispersed was 150 lb.

7. The relevant flight data are recorded in Appendix I.

8. The source strength for the first 4 to 5 min of emission was rather variable and averaged 3.1 lb/mi. This variability was due mainly to the flow characteristics of the powder and has been observed on previous occasions (1). The last 19 min of the emission was much more uniform, and the output rate for this period was 2.25 lb/mi. The average output rate for the whole line was 2.4 lb/mi.

SAMPLING

(a) Inside the City

9. The 30 stations were located at the positions shown in Fig.1. The inlets to all samplers were 5 ft above ground level and the samplers were aspirated by means of T.1 pumps powered by two 12V 100 A.H. batteries connected in parallel. At each point there was a set of millipore filters, type AA, with critical orifice, giving a nominal flow rate of 10 l/min. At each of four stations (Nos. T3, T4, T5 and T6 in Fig. 1) there was in addition a drum impactor operated at a flow rate of 10 l/min. A monitor unit was located at station No. T2, by means of which the arrival, build-up and clearance of the cloud could be observed.

(b) In open country

10. The location of the 10 sampling stations outside the City is shown in Fig.2. The two stations nearest the built-up area were 3 miles from the centre of the City and the other positions were 2 miles apart on each side. The ten stations formed a line as nearly parallel to the flight path of the source-laying aircraft as easy access by road allowed. Millipore filters were operated at each station in the same manner as described above and at the centre position on each side a drum impactor was also operated.

TIMING

(a) Source

11. Zero was taken as the time at which the source-laying operation commenced, i.e. 1745 G.M.T. It was decided at noon on the day of the trial on the basis of the forecast time of evening cross-over, which was 1715 G.M.T.

(b) Sampling

12. All sampling apparatus was set in operation at Z - 2 hr. The millipore filters were changed at approximately two-hourly intervals, the exact times of the changes being recorded, and the drum impactor sampling surfaces were changed every 15 min throughout the sampling period. The purpose of taking samples before the cloud reached the sampling line was to obtain some indication of the concentration of "spurious" particles, if any, so that allowance might be made for these in the evaluation of the results. The sampling period ended 1 hr after the monitor operator had reported that the cloud had passed.

METEOROLOGICAL OBSERVATIONS

13. The mean wind profile and direction from ground level to 1000 ft were measured at 2-hourly intervals by pilot balloon ascents from St. James' Hill (map ref. TG 243 093). The mean temperature profile from ground level to 1000 ft was taken from radio-sonde ascents made at Hemsby, about 18 miles E.N.E. of Norwich, on the coast.

14. The mean wind speed at 2 m., air and ground temperature and relative humidity were measured at:-

(a) St. James' Hill (TG 243093) - a high point in the City,

(b) the allotments adjacent to Valpy Avenue (TG 215102) - a low point in the City,

(c) the central positions in the two sampling arms outside the City (TG 335037 and TG 119112).

15. The temperature gradient (4 m - 0.5 m) was measured at the Valpy Avenue allotments position and at the centre position in the left arm (TG 335037). The wind direction at 2 m. was also measured at the latter position.

RESULTS

(a) Sampling

16. The numbers of particles collected on the millipore filters inside the City are shown in Fig.3. The results for millipore filters on the sampling arms and drum impactors inside and outside the City are recorded in Appendices II and III respectively. The number of "spurious" particles collected during the 2-hour period before the source was released was small - in fact no more than 6 were found on any filter, usually 0 to 2.

17. As the task of counting the particles on the filters was distributed among several different people, arrangements were made for some filters to be counted by more than one person to obtain some measure of the difference in individual assessments. These results are shown in Appendix IV, wherein it will be seen that, although there is sometimes a considerable difference between individual counts on any one filter, the total numbers of particles on several filters are usually in good agreement. The largest differences are attributable to the presence of particles, often quite large ones, with fluorescence only slightly different in colour or intensity from that normally expected from zinc cadmium sulphide. The occurrence of such particles is more common in samples collected inside a town than in those from the open country.

18. To ascertain whether there had been any separation of the particles of different sizes in the initial cloud, such as would occur as a result of differential gravitational settling, measurements of particle size distribution were undertaken on two of the samples, one from the city on its downwind edge (T18), and one from the open country (R4). If such a separation had occurred, the number median diameters (n.m.d.) of these samples would be larger than that of the initial cloud, i.e. larger than 2.2 - 2.5 μ. Moreover, if the separation had occurred, and at the same time the heat output of the city had caused the downward diffusion of particles to be greater over the city than over the open country, the n.m.d. of the country sample would be greater than that of the city sample.

19. The results are given in Fig.4 and Table 1 below. There is a tendency for the n.m.ds. to be larger than that of the initial cloud, and also the n.m.d. from the country is greater than that from the town, but these differences are too small to be significant by themselves. It cannot therefore be concluded than an appreciable separation of the particles of different sizes occurred.

TABLE 1

Sampling Position	n.m.d. (μ)	I.Q.R. 25% < (μ)	I.Q.R. 75% < (μ)	m.m.d. (μ)	I.Q.R. 25% < (μ)	I.Q.R. 75% < (μ)
T.18	2.5	1.7	4.0	7.0	5.0	9.5
R.4	2.8	2.1	4.0	9.0	5.6	13.0

(b) Meteorological Report

20. A fairly dry SSW'ly airstream gave a fine evening in the Norwich area with little or no cloud. From 1800 GMT there was a gradual increase in very thin cirrostratus cloud with a few patches of shallow altocumulus-altostratus through which the stars remained visible. Surface wind directions and speeds at selected stations in the area in which the trial was carried out are listed in Appendix V. With the advance of a trough over S.W. England during the evening there was a slow backing of the gradient wind. Prior to this the surface wind showed a sudden backing to 130° - 150°, probably due to a fairly rapid early-evening cooling on the ground. Part of the synoptic chart covering the trials area for the time at which the source was released (1800 GMT) is reproduced as Fig. 5, and detailed observations taken inside Norwich and at the centre positions of the sampling "arms" are recorded in Appendix VI.

DISCUSSION

21. It will be observed in Fig.3 that the numbers of particles collected are somewhat higher on the eastern side of the City than on the western side; similarly from Appendix II it will be observed that the numbers collected along the eastern arm (at stations L1 to L5) are somewhat higher than the others. This is probably due to the fact that the wind backed considerably whilst the emission was taking place, so that the part of the cloud which passed over these areas tended to have originated more from the beginning of the source line, where the rate of emission per unit length of the line was greater (see para 8.).

22. The times of arrival of the cloud median* are in good agreement at the four positions in the city where drum impactors were operated (see Appendix III). The mean time of arrival of the cloud median corresponds to a speed of travel of the cloud of about 11 mi/hr; this is much higher than the surface windspeed measured in the vicinity inland (see Appendix V), and is higher than the mean windspeed over the range 0 to 1000 ft above ground level, measured in Norwich itself (see Appendix VI, Table VI.5). However at Gorleston, near the coast, a windspeed as high as 13 mi/hr was recorded at 1800 GMT; hence the rapid transit of the cloud is a further indication that that part of it which passed over the area in which sampling took place, came from near the beginning of the source line.

23. The mean particle collections, corrected to a sampling rate of 10 l/min, inside and outside the City of Norwich were 292 and 377 respectively. The significance of the difference has been tested statistically by Student's "t" test and the results are significant at the 5% level. If turbulence created by the heat output of the City had been sufficient to break-up the inversion and cause the mixing necessary for the cloud to diffuse down to ground level, one would have expected the higher figure to have been obtained inside the City.

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*The time of arrival of the cloud median at a point is the time at which the dosage at that point reaches half its final value.

24. In view of the small degree of inversion experienced on the day of the trial ($<1^{\circ}$ F temperature difference 4 m - 0.5 m in the open), it is almost certain that there was some mixing of the cloud on route to Norwich. Furthermore, since the part of the F.P. cloud which passed over the sampling array was released very near the coast, it could conceivably have experienced some mixing in crossing the sea-breeze front.

CONCLUSIONS

25. Although the experimental aspects of the trial were completely successful the results were inconclusive. It may be that the effect of the type sought is a small one, in which case it would not have been noticeable under the conditions of this first experiment. Further trials are projected and it is hoped that some of these will be carried out when there is a more marked inversion.

ACKNOWLEDGEMENTS

26. The assistance provided by the Chief Constable and Officers of the Norwich City Police and members of the Home Office Scientific Advisory Branch is gratefully acknowledged. Thanks are also due to C.O., R.A.F., Horsham St. Faith, for accommodation of the trials party.

C.D.E.E.
PORTON DOWN.
JNB/HC.
7.5.64

Superintendent,
Munitions Research Division.

REFERENCES

1. Collins G.F., P.N. 253, 1962.
2. Collins G.F., P.T.P. 858, 1963.

APPENDIX I

FLIGHT DETAILS

Time (G.M.T.)	Position	Notes
1745.5	52°10'N 01°37'E	Start of emission
1747.5	52°12'N 01°29½'E	
1750.5	52°14'N 01°19'E	
1756	52°19'N 01°02'E	
1800.5	52°22'N 00°50'E	
1806	52°29'N 00°32'E	
1808.7	52°33'N 00°19'E	End of emission

Average speed throughout run 145 st. mi/hr.

Height 500 ft. a.m.s.l.

APPENDIX II

Millipore filter results on sampling arms

(Corrected to flow rate of 10 l/min)

Position	Map reference	Nos. of Particles collected
L1	TG.273056	311
L2	TG.308043	368
L3	TG.335037	476
L4	TG.363027	339
L5	TG.385007	646
R1	TG.185098	306
R2	TG.155106	237
R3	TG.119112	286
R4	TG.008127	535
R5	TG.062135	264

Appendix III

Drum Impactor Results

(numbers of particles collected)

Time (G.M.T.)	Counts					
	Station T3	Station T4	Station T5	Station T6	Station L3	Station R3
1545 - 1915	0	0	0	0	0	0
1915 - 1930	2	0	4	0	0	0
1930 - 1945	1	42	48	0	44	0
1945 - 2000	34	51	39	60	166	3
2000 - 2015	40	71	63	77	152	35
2015 - 2030	59	76	67	28	75	104
2030 - 2045	42	25	20	29	28	99
2045 - 2100	19	4	3	10	3	58
2100 - 2115	6	0	0	2	0	26
2115 - 2130	0	0	0	0	0	12
2130 - 2400	0	0	0	0	0	0
Time of arrival of cloud median (GMT)	2021	2009	2007	2008	2002	2034
Ratio* Drum/M.F.	0.73	0.61	0.77	0.73	0.98	1.18

The mean particle collection recorded by the drum impactors in the City was only about 70% of that recorded by millipore filters at the same positions. This may be explained on the basis that some of the particles on the drums were obscured by the soot, etc., collected with the F.P., since the aspiration rate per unit area of collecting surface is very much higher in the case of the drum impactor (2).

Appendix IV

Comparison of particle counts on millipore filters by three different operators

Table IV.1.

Sample	Count			
	Operator A		Operator B	
T.8/2)	114)		120)	
T.8/3)	206)	326	204)	340
T.8/4)	6)		16)	
T.10/2)	78)	382	88)	428
T.10/3)	304)		340)	
T.17/2)	310)	362	305)	367
T.17/3)	52)		62)	
T.18/2)	330)		300)	
T.18/3)	64)	402	94)	404
T.18/4)	8)		10)	
L.5/2)	576)	676	508)	596
L.5/3)	100)		88)	
R.4/2)	42)		88)	
R.4/3)	358)	402	390)	488
R.4/4)	2)		10)	
Total	2550		2623	

Ratio of sums of counts by different operators

$$\frac{B}{A} = 1.03$$

Appendix V

Surface Wind Direction and Speed

In Trials Area

(^{o}True/(mi/hr))

MET. STATION & MAP REF.	TIME G.M.T.						
	1700	1800	1900	2000	2100	2200	2300
MARHAM TF 725 095	190/08	160/06	120/07	120/08	160/09	150/10	150/12
MILDENHALL TL 684 780	210/04	180/02	150/03	190/06	180/06	170/06	170/06
W. RAYNHAM TF 837 248	180/09	180/07	150/07	140/10	150/10	170/11	160/12
COLTISHALL TG 260 247	-	130/10	130/10	130/08	150/09	170/09	130/07
WATTON TF 942 028	210/06	190/04	120/08	130/09	170/08	170/08	160/09
GORLESTON TG 510 054	-	170/13	-	-	200/09	190/09	170/11

Appendix VI

Meteorological Results

Table VI.1.

Station L3 Claxton Manor (TG 335037)

	1600-1800	1800-2000	2000-2200	2200-2400
Average Wind Speed at 2m. (m/s)	2.5	1.7	2.0	1.7
Surface Wind Direction at 2m.	170°	190°	200°	180°
Average Air Temperature (°F)	47	42	40	37
Average Ground Temperature (°F)	48	40	37	34
Average Relative Humidity (%)	72	79	78	86

Table VI.2

Station R3 Honingham Cross Roads (TG 119112)

	1545-1745	1745-1945	1945-2145	2145-2345	2345-2400
Average Wind Speed at 2m. (m/s)	2.3	1.8	1.3	1.5	1.3
Average Air Temperature (°F)	49	44	41	39	37
Average Ground Temperature (°F)	48	42	39	37	37
Average Relative Humidity (%)	59	77	79	78	84

Table VI.3

Valpy Avenue Allotments. (TG 215102)

	1545-1745	1745-1945	1945-2145	2145-2345	2345-0045
Average Air Temperature (°F)	50	46	43	41	39
Average Ground Temperature (°F)	48	43	41	39	37
Average Relative Humidity (%)	56	66	75	86	89

½ minute spot winds at 2m. (m/s)	1645	1745	1845	1945	2045	2145	2245	2345	0045
	1.7	1.6	1.4	1.6	Too low to assess	3.1	1.9	1.2	1.7

Table VI.4

St. James' Hill (TG 243093)

	1545-1745	1745-1945	1945-2145	2145-2345	2345-0030
Average Wind Speed at 2m. (m/s)	4.2	2.3	3.7	3.3	3.3
Average Air Temperature (°F)	49	45	43	41	38
Average Ground Temperature (°F)	50	44	41	39	37
Average Relative Humidity (%)	55	71	67	75	83

Table VI.7.

Upper Air Temperatures

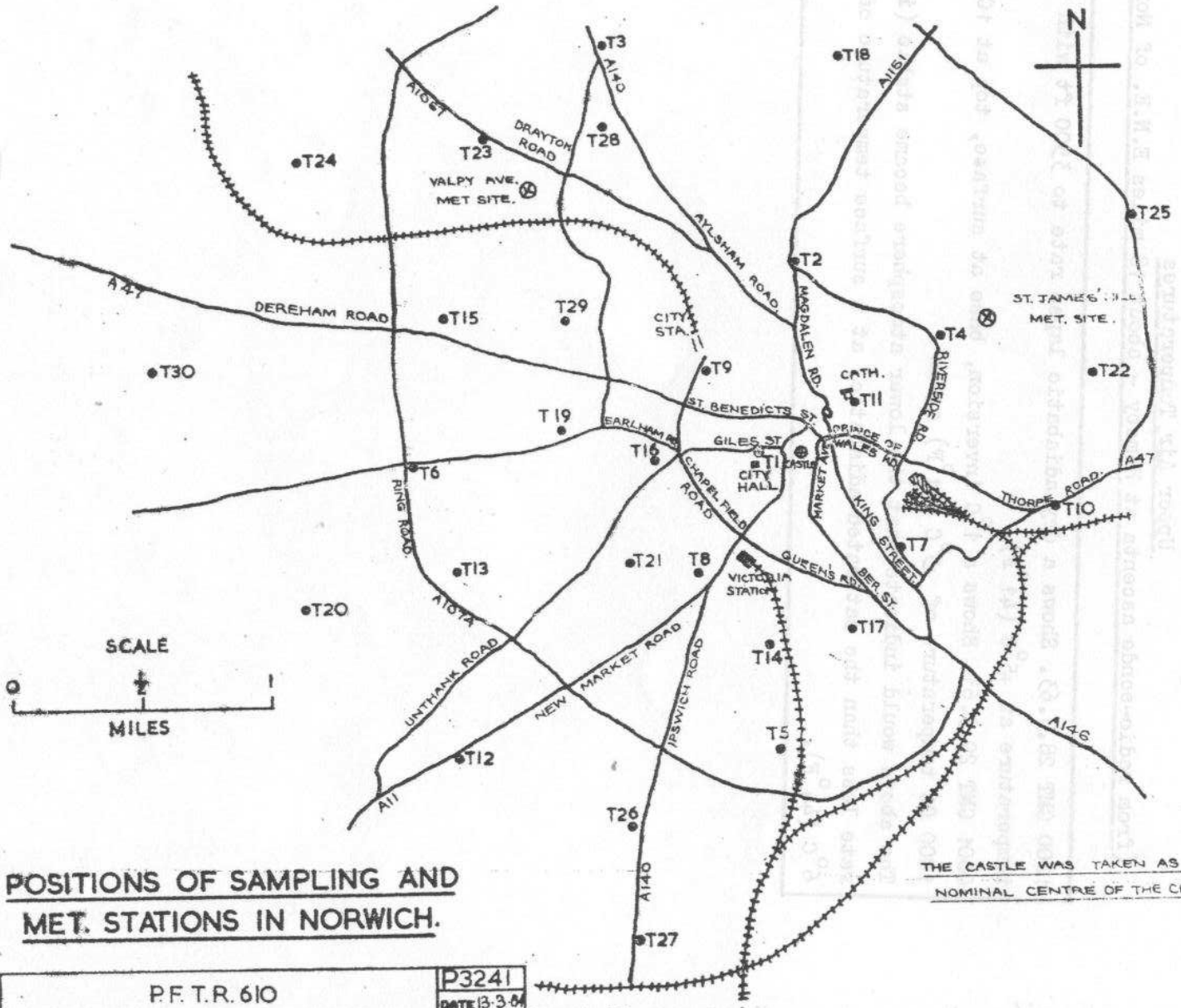
(from radio-sonde ascents at Hemsby - about 18 miles E.N.E. of Norwich)

1200 GMT 28.3.63. Shows a dry adiabatic lapse rate to 3500 ft with the 1000 ft temperature at +5°C (41°F)

0001 GMT 29.3.63. Shows a 1°C inversion, base at surface, top at 1000 ft

1000 ft temperature of +5°C (41°F) again

The above would indicate that the lower atmosphere became stable (i.e. lapse rate less than the saturated adiabatic) at a surface temperature of about 6°C (44°F).



THE CASTLE WAS TAKEN AS THE NOMINAL CENTRE OF THE CITY.

POSITIONS OF SAMPLING AND MET. STATIONS IN NORWICH.

FIG. 1.

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CK. P.J.A.			DATE 13-3-64

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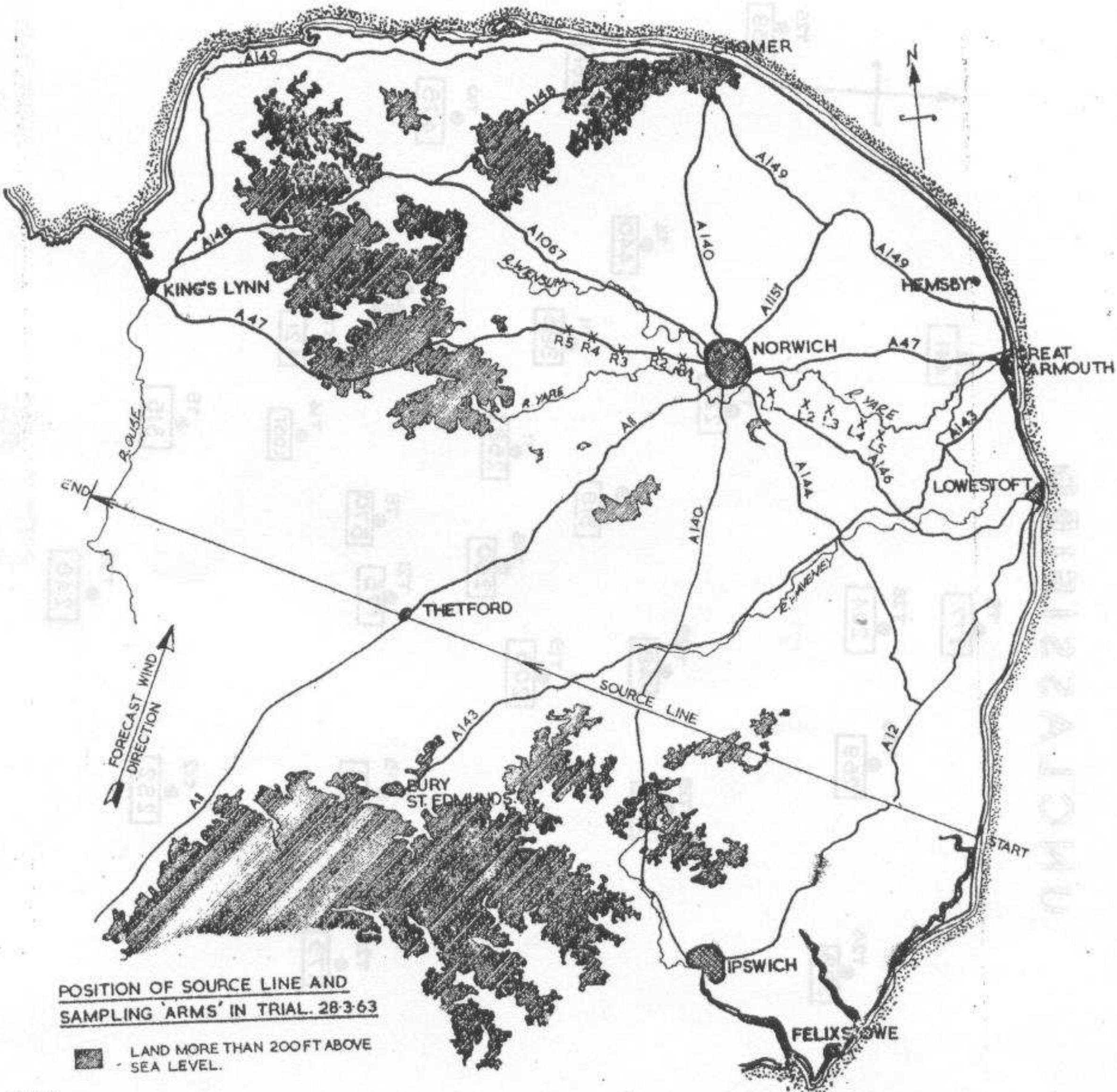

FIG. 2.

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CK. PJA			DATE 13·3·64

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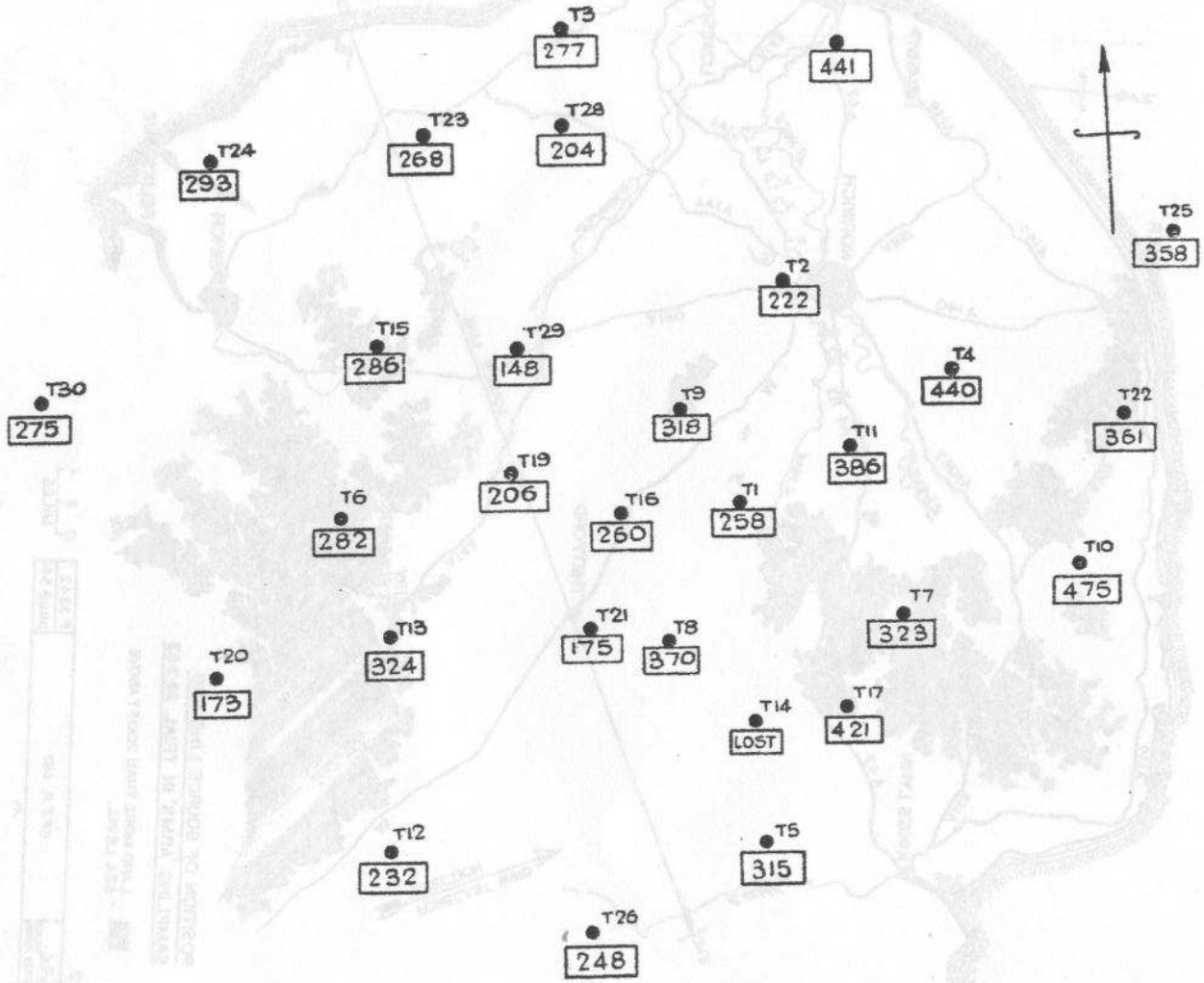

SCALE 0 ½ 1 MILES

FIG. 3.

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TOTAL NUMBER OF PARTICLES COLLECTED AT SAMPLING STATIONS IN NORWICH. (CORRECTED TO SAMPLING RATE OF 10 ℓ/MIN)

PARTICLE SIZE DISTRIBUTION IN AEROSOL CLOUD.

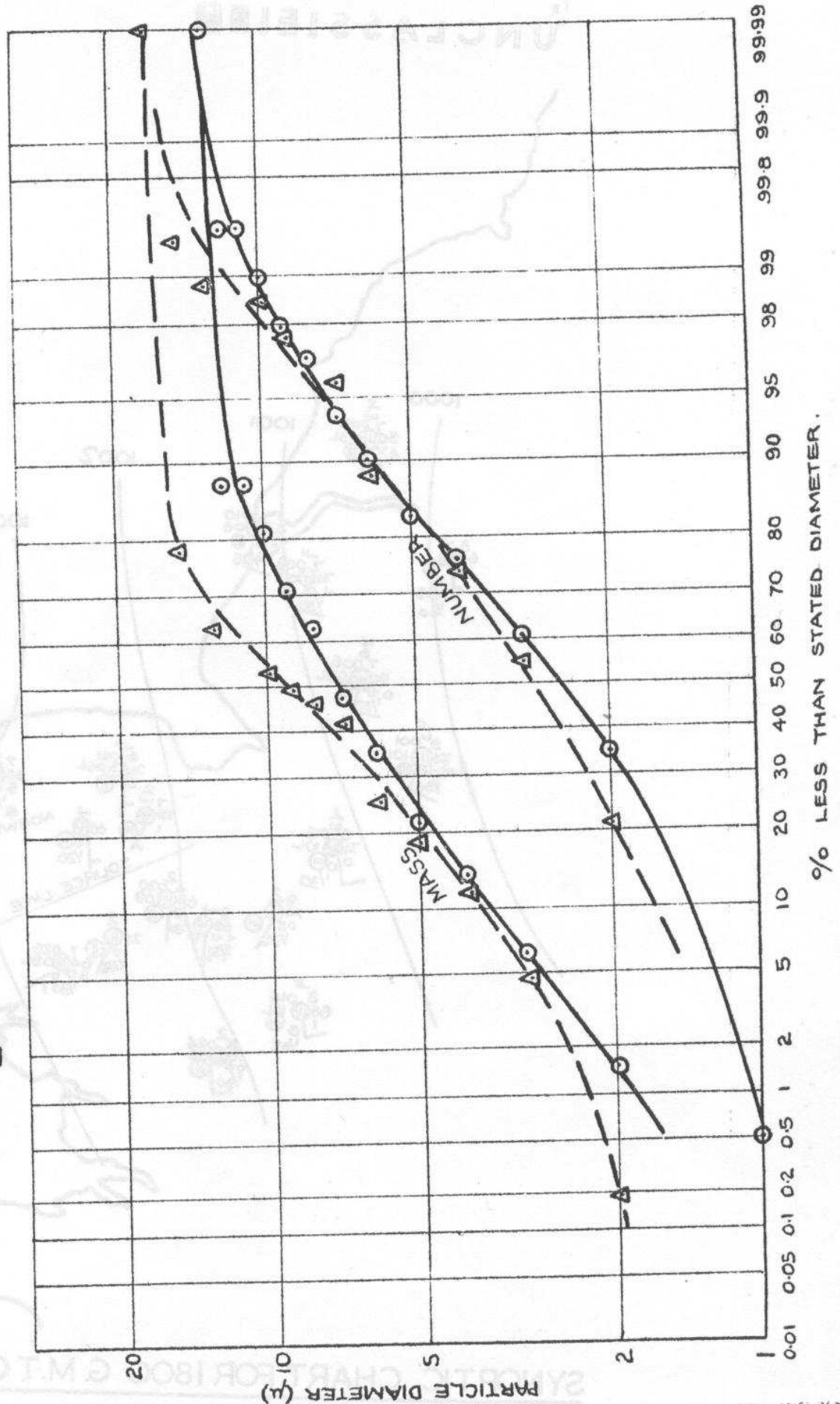
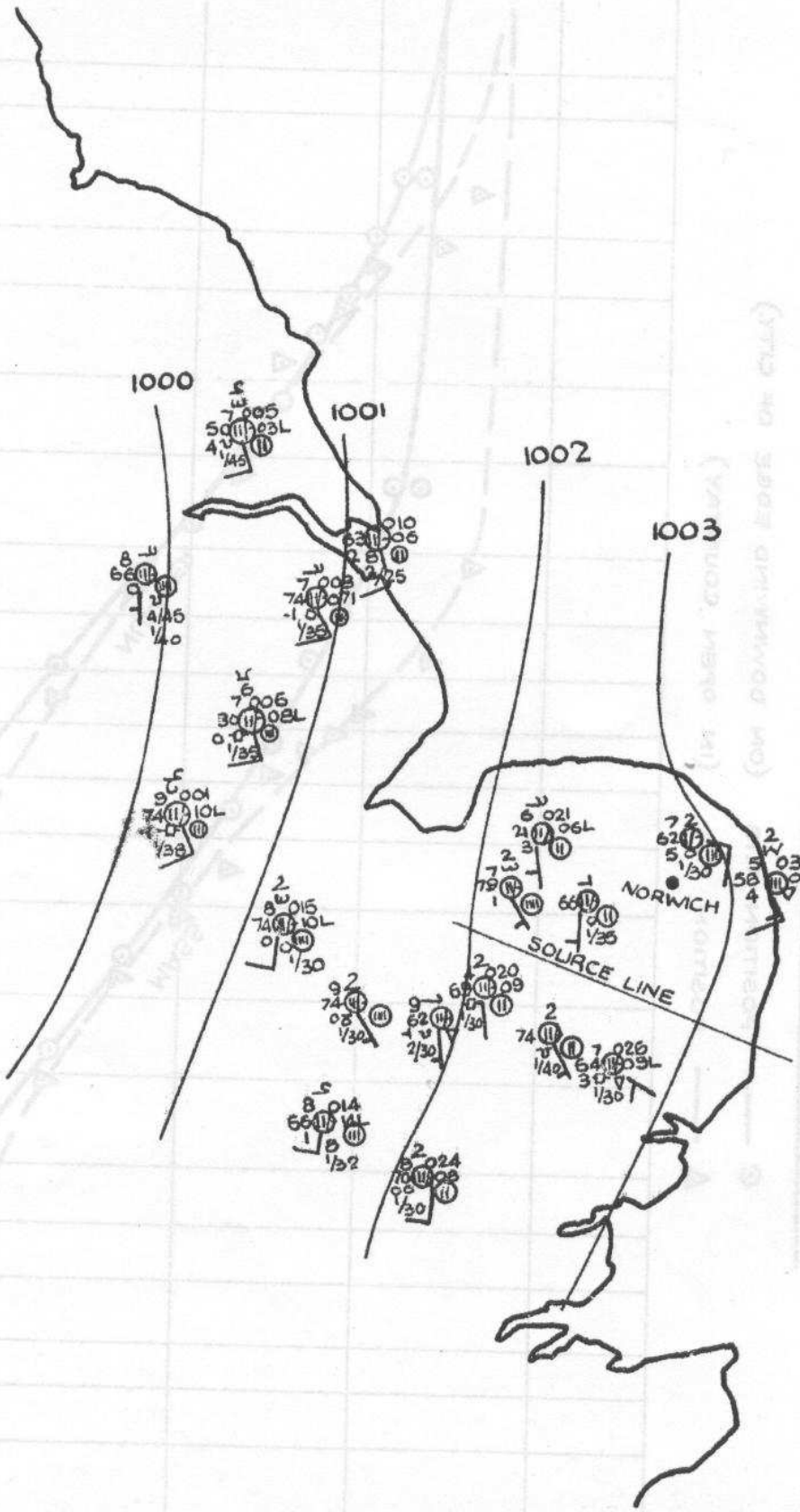


FIG. 4.

T469



SYNOPTIC CHART FOR 1800 G.M.T. ON 28·3·63

FIG. 5.