one-cubic-foot cage, and the females feed avidly on guinea pigs. The eggs hatch after 5 days, larvae begin to pupate in 5 days, and adults emerge in 2 days. Since adult females escape through the normal screen used in cages (18 x 16 mesh), it is very important to use a much smaller mesh screen. Pupae are unusual because they turn very black shortly after pupation.

ACKNOWLEDGMENTS. The writers wish to acknowledge the valuable contributions made by virtually all workers at the Fresno and Lake Charles laboratories to the success of the colonizations. The list of workers involved is far too long for citation here but the colonization procedures evolved were the work of many hands.

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CAGED INSECT KILLS OF UP TO TWO MILES UTILIZING A NEW LOW-VOLUME AEROSOL GENERATOR[1]

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INTRODUCTION

The method of dispensing high volume low concentrate insecticides which has been the general practice for many years has been to a large extent very limited in its effectiveness. This is because the relatively large size droplets produced would remain air borne for short distances and thus result in a few hundred feet of effective control. Additionally, the equipment generally was heavy, bulky and required large insecticide reservoirs. In some cases, the weight of the dispersal apparatus plus the insecticide amounted to several thousand pounds and could only be transported by special vehicles on well established roads. Permanent mounting of the equipment often limited the transport vehicle for that use only. The new concept in insect control today is the technique involving ultra low volume dispersal of high concentrate insecticides, thereby avoiding the necessity of using heavy, bulky equipment with a large insecticide reservoir.

The need for a compact, light weight apparatus which could be handled by two men and operated from a jeep over rough terrain in combat zones was a prime factor which prompted the development of the ultra low volume aerosol generator.

Several new techniques and procedures in determining droplet size and distribution have been reported recently by other researchers. One such method is the fluorescent particle (FP) spray tracer technique which gives a quantitative measure of spray deposition by suspending a known number of FP's in a known volume of insecticide (Vaughan *et al.,* 1965;

[1] The opinions and assertions contained herein are those of the authors and are not to be construed as official or reflecting the views of the Navy Department or the Naval Service at large.

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Himel, 1969a). Sampling of airborne spray droplets is possible by means of Rotorod impaction type samplers. Determination of droplet size and number is subsequently made by counting the FP's impinged on the rods' collecting arms. This method also makes it possible to identify pesticide droplets by size and number directly on target insects, foliage or other solid substrates.

The importance of spray droplet size and number for insect control was demonstrated by Himel and Moore (1967). Using the FP tracer method they applied an insecticide to a tract of conifer forest for the control of spruce budworm larvae. Examination of 1113 larvae affected by the spray revealed that 93 percent had not been contacted by any droplets larger than 50 microns in diameter. Himel (1969b) stated that the optimum size for insecticide spray droplets is that size which gives maximum control of the target insect with minimum insecticide and minimum ecosystem contamination. Data from tests reported by Himel and Moore (1969) show that the maximum size for efficient insecticide spray droplets is under 50 microns in diameter. Droplets in the range of 50–100 microns are only marginal in efficiency while those larger than 100 microns have a low probability of contacting the target insects (Himel, 1969b).

Tests to determine the influence of air velocity and particle size on the toxicity of DDT to adult mosquitoes were conducted by Latta *et al.* (1947). Analysis of these results indicates the median lethal dose for female mosquitoes is that amount contained in a single droplet of 10 percent DDT 83 microns in diameter, or a droplet of 100 percent DDT 34 microns in diameter. This is equivalent to 0.03 microgram of DDT.

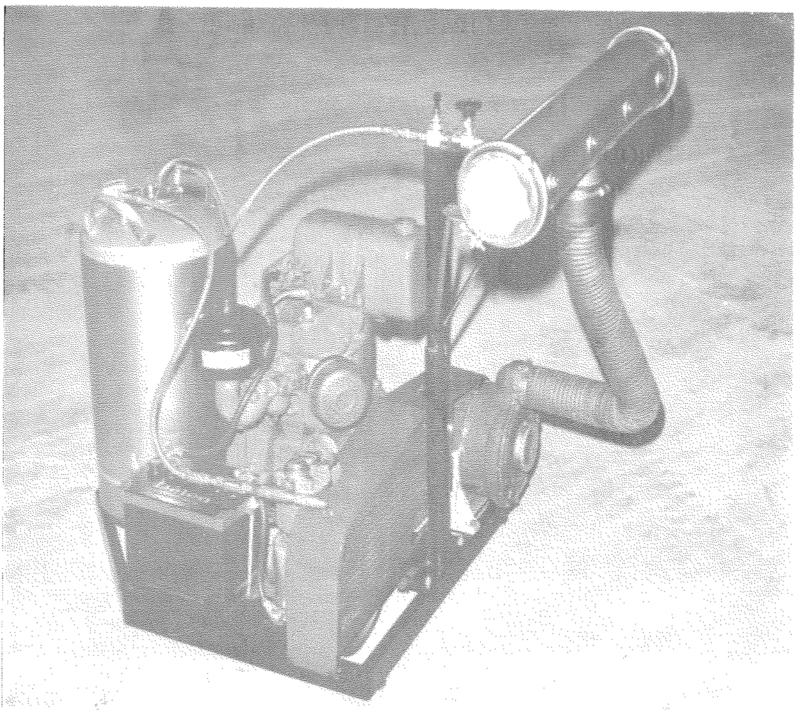

FIG. 1.—Close-up of aerosol generator.

MATERIALS AND METHODS

AEROSOL GENERATOR. This aerosol generator was specifically designed and developed to disperse ultra low volume-high concentrate chemicals. It is powered by a 14-horsepower gasoline engine. Insecticide is drawn from a ten-gallon stainless steel reservoir constantly pressurized at 50–60 psi by a 750 r.p.m. compressor type pump. Droplet breakup occurs in four air-liquid double vortical type nozzles located in the manifold. Air required by the nozzles is produced by a high capacity blower having an output of 500 cfm of air at 4 psi. All parts of the system coming in contact with insecticide are constructed of either stainless steel or teflon to prevent corrosive effects of concentrate pesticides. Net weight of the generator is 350 pounds; light enough for easy handling by two men. The unit is compact (Fig. 1) and can be operated from a vehicle as small as a military type jeep (Fig. 2).

FIELD BIO-ASSESSMENT. All test specimens were from laboratory reared non-resistant colonies. Mosquito species used in the tests were *Culex pipiens* Say and *C. tarsalis* Coquillett. The flies were *Musca domestica* Linnaeus. An arbitrary number ranging from 20 to 50 unsexed adults was transferred to individual cages and transported to the field. The cages were distributed along the test line and suspended 3 feet from the ground on stakes. Control cages were stationed 1 mile upwind from the test site.

Cages utilized in the test were constructed of 16 x 18 mesh screen wire and were 2⅞ inches in diameter by 7 inches long. Cage ends were made from two-piece fruit jar tops in which the lid portion had been replaced by a screen disk. The cages were discarded after each test.

FIG. 2.—Aerosol generator operating from a military jeep.

TEST SITE. The tests were conducted at Skaggs Island, a military reservation in Sonoma County, California. The reservation covers an area of approximately six square miles and has flat terrain of recently harvested grain which was well suited for purposes of these studies. Test lines were laid out in a north-south pattern to take advantage of prevailing winds. The insecticide aerosol was dispersed upwind of the test line and was carried to the caged insects and sampling devices by the wind currents.

In test No. 1 the test line was limited to 5500 feet. Concentrated Dibrom-14 was applied at the rate of 33 ounces per minute for 6 minutes traveling at 440 feet per minute and covering a distance of one-half mile. A 7–8 m.p.h. wind carried the droplets downwind where the specimens and samplers were located. The test line was extended to 10,500 feet in test No. 2. In the latter test Dursban (6) was utilized and was dispersed at a rate of 37.2 ounces per minute. The distance traveled and vehicle speed were the same as in test No. 1. The wind velocity was 6–7 m.p.h., temperatures varied from 70°–80° F.

The insects and sampling devices were collected about 30 minutes after exposure. The specimens were then observed and mortality recorded hourly for a designated number of hours thereafter. Percentage mortality was computed and employed in assessing insecticide effectiveness.

TRACER TECHNIQUE. The fluorescent particle (FP)—spray tracing technique was used to measure quantitatively the size distribution and number of droplets in the aerosol cloud at each downwind site at which a bioassay was made. The FP are insoluble, micron-sized crystals which fluoresce brightly when illuminated by ultra-violet light and viewed through a low-power microscope. The FP are readily distinguishable from almost all nat-turally occurring particulates. The earliest application of the FP technique dates back to the late 1940's where the FP were employed as gaseous tracers in air pollution studies. (Leighton *et al.* 1965).

In 1965, Vaughan *et al.* applied the FP technique to tracing insecticide droplets. The particulate tracer has many advantages over the soluble dyes. The insoluble particles are not absorbed by the time quantitative assessment is performed. The FP is stable in sunlight and in corrosive insecticide liquids. But most important, the FP-spray technique permits the quantitative assessment of both droplet size distributions and total sample mass for droplets with MMD to less than 10 microns and total mass sampled to less than 10^{-9} grams. Furthermore, airborne concentration and dosage can be quantitatively sampled and assessed.

The essence of this FP-spray tracing technique is to add a known number of FP to the liquid in the spray tank. The number of FP are then distributed throughout the volume of liquid such that each sub-volume of liquid contains its own representative number of FP. This proportionality between number of FP and volume is maintained when the liquid is sprayed. Thus each droplet, depending on its volume, has its proportional number of FP. On a sampling surface, the presence of the droplet is detected by the presence of the FP, and the number of FP associated with that droplet determines its size. Also, the total number of FP on a sampling surface determines the total volume of insecticide present without having to sum the volume contributed by each droplet on the surface.

For these two tests, an FP concentration of 2×10^9 FP per ml. was used. This concentration yields, on the average, 1 FP in a 10 micron droplet, 8 FP in a 20 micron droplet and 1 FP in one of eight 5 micron droplets. The basic statistical methodology for interpreting the droplet size characteristics when small numbers of FP are present was developed by Vaughan *et al.* In order to maintain uniform concentration of FP throughout the test, the liquid in the spray tank must be agitated. Except for the agitation of the spray tank, the operation of the aerosol generator with the FP is the same as operation without.

The insecticide once aerosolized is carried by the atmospheric movements. A portion of the droplets deposits on the ground and on the foliage, a portion is diffused upward and the bulk of the cloud is carried horizontally downwind. The amount of insecticide deposited is measured directly from the FP counts on fallout plates and foliage. The combined amounts deposited and diffused upward are measured indirectly by observing the reduced amounts of insecticide remaining airborne at subsequent downwind aerosol sampling stations.

The aerosol cloud is sampled by the Rotorod, a small, dry-cell battery powered, rotating rod impactor sampler. The principle of the Rotorod is to drive the collection surface through the air rather than draw an air jet past the impaction surface. The Rotorod is an isokinetic sampler and thus insensitive to problems associated with changes in wind speed and directions. The sampling efficiency of the Rotorod has been calibrated for the size range of droplets encountered in these tests, and this efficiency is nearly constant throughout that range. Therefore, the aerosol samples collected with the Rotorod are representative of both the droplet size distribution and total mass in the ambient cloud.

RESULTS

GENERATOR OUTPUT. Aerosol droplets produced by the generator were very small and had a high degree of uniformity. Utilizing the FP spray tracer technique, it was determined that Dibrom and Dursban had a MMD of 10.4 and 10.9 microns respectively. The mean diameter of all droplets was 7.4 microns for Dibrom, and 8.6 microns for Dursban.

Generator output is specified in terms of ounces dispersed per minute of running time while traveling at a speed of 440 feet per minute (5 m.p.h.). Ounces per acre is an inaccurate designation since no method is known for describing or measuring precisely how many acres were covered by the aerosol cloud. The reason for this is that 100 percent kill of test specimens was observed to the end of the test line and obviously the aerosol remained airborne beyond this point.

TABLE 1.—Percentage mortality to adult *Culex tarsalis*.[a]
Dibrom

Distance (feet)	Hours Following Dispersal				
	2	4	7	10	21
500	100	..	..	..	..
1000	100	..	..	..	..
1500	20	47	73	73	83
2000	100	..	..	..	..
2500	100	..	..	..	..
2750	92	92	100	..	..
3000	100	..	..	..	..
3250	100	..	..	..	..
3500	91	91	91	91	100
3750	100	..	..	..	..
4000	100	..	..	..	..
4250	88	100	..	..	..
4500	88	100	..	..	..
4750	91	100	..	..	..
5000	100	..	..	..	..
5250	63	88	88	100	..
5500	40	60	100	..	..
% Cumulative	76	89	95	95	97
Controls	0	0	0	0	0

[a] Dibrom (14) dispersed perpendicular to a 7–8 m.p.h. wind at the rate of 33 oz/min with the Low Volume Aerosol Generator on 24 September 1968.

Bioassay. In test No. 1, 100 percent mortality was achieved on *Culex tarsalis* adults at a distance of 5500 feet (Table 1). Two hours following application the percent cumulative mortality was 76 percent, and 95 percent after 7 hours. The only mosquitoes remaining alive after 21 hours were those at the 1500 foot station where, for some unknown reason, 83 percent kill was achieved. This same unexplained phenomenon was noted for the house flies (Table 2), and also for test No. 2 results listed on Tables 3 and 4. In Table 5 it can be seen that a decreased amount of fluorescent material was collected indicating the presence of a reduced amount of insecticide. It is presumed that micrometeorological conditions were responsible for these results since no particular topographical difference was noted between this and other sites along the test line.

Table 2 shows the percent kill of adult house flies. Comparative examination reveals that the percent cumulative mortality closely parallels results listed in Table 1. After 7 hours, 100 percent kill was observed at all stations except 1500 and 5000 feet. Again, micrometeorological conditions apparently prevented an even coverage of the entire test area.

In the second test, the line was extended to 10,500 feet. The results show complete mosquito mortality (Table 3) for the entire distance and a correspondingly high kill of house flies (Table 4). *Culex pipiens* adults showed a 60 percent cumulative mortality after 2 hours and 97 percent after 8 hours. All of the mosquitoes exposed to Dursban were dead after 21 hours. House fly adults showed slightly higher tolerance to the insecticide than did mosquitoes (Table 4). It should be noted, however, in comparing the two tables, that a larger percent of house flies were killed in the first 2 hours than mosquitoes. Five percent of the total house fly test population remained alive 33 hours following exposure.

Control specimens showed no mortality for the duration of the observations except for house flies on test No. 2 which had a 4 percent mortality after 21 hours.

Table 2.—Percentage mortality to adult *Musca domestica*.[a]
Dibrom

Distance (feet)	Hours Following Dispersal				
	2	4	7	10	21
250	100	..	..	..	..
500	100	..	..	..	..
750	94	100	..	..	..
1000	100	..	..	..	..
1500	21	35	35	74	74
2000	100	..	..	..	..
2500	100	..	..	..	..
2750	100	..	..	..	..
3000	94	97	100	..	..
3250	75	100	..	..	..
3500	100	..	..	..	..
3750	81	89	100	..	..
4000	86	86	100	..	..
4250	100	..	..	..	..
4500	100	..	..	..	..
4750	83	89	100	..	..
5000	40	67	92	92	92
5250	32	74	100	..	..
5500	53	69	69	100	..
% Cumulative	78	87	94	98	98
Controls	0	0	0	0	0

[a] Dibrom (14) dispersed perpendicular to a 7–8 m.p.h. wind at the rate of 33 oz/min with the Low Volume Aerosol Generator on 24 September 1968.

TABLE 3.—Percentage mortality to adult *Culex pipiens*.[a]
Dursban

Distance (feet)	Hours Following Dispersal				
	2	4	8	11	21
1000	67	100	..	..	..
1500	69	92	100	..	..
2000	83	100	..	..	..
2500	86	100	..	..	..
2750	79	100	..	..	..
3000	80	100	..	..	..
3250	79	100	..	..	..
3500	54	93	100	..	..
3750	100	..	..	..	..
4000	61	100	..	..	..
4250	44	89	89	100	..
4500	62	91	100	..	..
4750	47	82	100	..	..
5000	44	83	94	100	..
5250	46	93	96	96	100
5500	75	100	..	..	..
8000	39	86	92	97	100
10500	43	57	71	93	100
% Cumulative	60	92	97	99	100
Controls	0	0	0	0	0

[a] Dursban (6) dispersed perpendicular to a 6–7 m.p.h. wind at the rate of 37.2 oz/min with the Low Volume Aerosol Generator on 27 September 1968.

TABLE 4.—Percentage mortality to adult *Musca domestica*.[a]
Dursban

Distance (feet)	Hours Following Dispersal				
	2	4	8	11	21
1000	100	..	..	..	..
1500	86	91	100	..	..
2000	100	..	..	..	..
2500	100	..	..	..	..
2750	100	..	..	..	..
3000	94	100	..	..	..
3250	90	100	..	..	..
3500	61	89	100	..	..
3750	95	95	95	100	..
4000	77	100	..	..	..
4250	60	88	94	94	100
4500	47	84	95	95	100
4750	55	85	95	95	95
5000	60	95	95	95	100
5250	37	53	68	68	74
5500	0	38	56	75	75
8000	50	75	90	95	95
10500	45	65	70	70	70
% Cumulative	70	87	93	94	95
Controls	0	0	0	0	4

[a] Dursban (6) dispersed perpendicular to a 6–7 m.p.h. wind at the rate of 37.2 oz/min with the Low Volume Aerosol Generator on 27 September 1968.

FP TRACER RESULTS. At selected downwind sites where caged insects were placed, the aerosol clouds and the ground deposition densities were sampled to determine the degree of exposure to which the insects were subjected. Exposures to the aerosol cloud can be expressed as the number of droplets passing through an "imaginary window" one square inch in size (Table 5). The number of droplets, as determined by the rotating rod samplers, ranged from 15,000 to 125,000. If the "imaginary window" were enlarged to the dimensions of the cage the number of droplets would range from 330,000 to 2,430,000. Ground deposition of Dibrom

TABLE 5.—FP and mortality results of the Dibrom and Dursban Tests.[a]

	Airborne Droplets (thousands)				Percent Mortality (21 hours)				
	Dibrom Test 1		Dursban Test 2		Mosquitoes Test		House Flies Test		Ground Dibrom Deposit[b] ml/acre
Distance (feet)	per in²	per cage	per in²	per cage	1	2	1	2	
500	120	2430	..	..	100	..	100	..	0.230
1000	60	1230	70	1420	100	100	100	100	0.120
1500	40	790	70	1420	83	100	74	100	0.050
2000	70	1430	95	1955	100	100	100	100	0.160
2500	50	985	125	2480	100	100	100	100	0.085
3000	35	740	95	1955	100	100	100	100	0.075
3500	45	895	75	1565	100	100	100	100	0.045
4000	35	690	90	1790	100	100	100	100	0.055
4500	50	985	45	905	100	100	100	100	0.090
5000	40	790	95	1955	100	100	92	100	0.085
5500	15	330	70	1420	100	100	100	75	0.055
8000	..	..	50	1220	..	100	..	95	.....
10500	..	..	65	1305	..	100	..	70	.....

[a] Test 1 included distances from 500 to 5500 feet; test 2 from 1000 to 10500 feet.
[b] Only Dibrom deposit recorded.

TABLE 6.—Measured Droplet Size Distributions Resulting from the Low Volume Aerosol Generator.

Droplet Size Distribution for Test 1, Dibrom

Diameter	Number		Number	
μ	%	Cumulative %	%	Cumulative %
<5	12.5	12.5	1.4	1.4
5–10	68.5	81.0	44.1	45.5
10–15	17.0	98.0	40.5	86.0
15–20	1.8	99.8	11.3	97.3
>20	0.2	100.0	2.7	100.0

Droplet Size Distributions for Test 2, Dursban

Diameter	Number		Mass	
μ	%	Cumulative %	%	Cumulative %
<5	2.7	2.7	0.3	0.3
5–10	67.3	70.0	37.7	38.0
10–15	27.5	97.5	48.8	86.8
15–20	2.4	99.9	11.6	98.4
>20	0.1	100.0	1.6	100.0

was measured at between 0.045 and 0.23 milliliters per acre and represents a loss of less than one percent of the aerosol cloud during the first mile. This low ground and foliage deposition is in agreement with relatively slight decreases in the numbers of droplets measured at increasing downwind distances as given in Table 5, i.e., both the upward diffusion and the deposition are depleting the near ground level aerosol cloud at a low rate at these tests.

Droplet size distribution is given in Table 6. The percentage of droplets less than 15 microns in diameter was 98 percent for Dibrom and 97.5 percent for Dursban.

Table 7 shows the number of droplets

Table 7.—Number of Droplets per Milliliter.

Diameter (microns)	Droplets
1,000	1,910
100	1,910,000
50	15,278,100
10	1,910,000,000
6	8,849,557,500

per milliliter of liquid spray at specific micron diameter sizes. A tenfold decrease in droplet diameter yields a thousandfold increase in the number of droplets produced. The laws of probability reveal the greater likelihood for droplets contacting the target insect when a given quantity of insecticide spray is dispersed in small droplets as opposed to larger droplet sizes. Also, since the influence of gravity would be reduced, the smaller droplets could normally be expected to travel greater distances horizontally. A meaningful comparison of insect mortality and aerosol cloud density was not possible since threshold exposures were observed at too few stations. One hundred percent mortality occurred at most sampling sites.

SUMMARY

A new ultra low volume aerosol generator ground dispersal unit has been evaluated in the field and found highly effective in producing high mortality of caged mosquitoes and flies. Low volumes of high concentrate Dibrom and Dursban were dispersed in 10-micron MMD size droplets through four double air-liquid vortical type nozzles. These droplets were carried downwind to sites various distances up to 10,500 feet from the aerosol generator where they contacted caged adult mosquitoes and house flies. Up to 100 percent kill was obtained two miles from the point of insecticide release. The rate of flow for each insecticide was calibrated in ounces per minute with the generator traveling at 440 feet per minute (5 m.p.h.).

A modification of the fluorescent particle (FP) tracer technique was used in these studies. This method consisted of suspending a known concentration of FP in the concentrate insecticide and analyzing the airborne aerosol cloud with specialized rotating rod sampling devices. The number of FP's in each impact pattern is a measure of the original droplet volume. Hence, the total mass, size and distribution of aerosol droplets can be determined. The sensitivity and ease of assessment attainable by this technique made it particularly useful in field testing of insecticide dispersal equipment and in determining the effectiveness of dispersal operations.

CONCLUSIONS

Based on observations and an analysis of data obtained from the evaluation of the ultra low volume aerosol generator, it is concluded that:

(1) The generator will produce effective kills of caged house flies and mosquitoes up to 2 miles as compared to similar tests in which thermal and non-thermal fogging devices generally do not produce effective kills beyond 600 feet.

(2) The unusually long range kill produced by the generator is due primarily to the production of comparatively small sized droplets of about 10 microns MMD.

(3) The FP tracer technique is an excellent adjunct to bioassay in determining

droplet size and distribution, and in the evaluation of insecticidal effectiveness.

(4) The dispersal of ultra low volume insecticides from ground control equipment, especially in the small micron size of about 10 MMD, offers a possible means of controlling adult mosquitoes and house flies over much greater distances than heretofore thought possible.

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IMPORTANT NOTE

Beginning with Volume 30, No. 1, the price of reprints will be increased by 6 percent to correspond with the rise in costs of paper, handling, printing and mailing. The last increase in reprint prices was effective with the March, 1966 issue. Since that time both dues and subscriptions have been increased, but the additional cost of processing the reprints has not been met.

A revised "Prices of *Mosquito News* Reprints" will be published on the inside back cover of the March 1970 *Mosquito News*.