DDT LARVICIDES DISPERSED BY SPRAY AND THERMAL AEROSOL PLANES FOR THE CONTROL OF *AEDES DORSALIS* (MEIGEN) AND *AEDES NIGROMACULIS* (LUDLOW).[1]

HARVEY I. MAGY, Vector Control Specialist; ARVE H. DAHL, Chief, Bureau of Vector Control; ARTHUR F. GEIB, Manager, Kern Mosquito Abatement District; SETH J. KIRKWOOD, Vector Control Officer, Grade II.

I. INTRODUCTION

One of the major mosquito breeding areas in the interior of the State of California is the Central Valley which runs north and south for about 400 miles, and averages 40 miles in width. Most of the agricultural practices in the valley are based on irrigation. Millions of acres of natural and planted pastureland and alfalfa are periodically flooded during the spring, summer and fall. There may be as many as ten floodings within one season.

The life cycles of *Aedes dorsalis* (Meigen) and *Aedes nigromaculis* (Ludlow) are suited to this practice of intermittent flooding. Each time a parcel of land is flooded, the larvae of these two species hatch from eggs that have been previously laid on the ground. Within four or five days, under the high temperature conditions prevailing in the valley, the adult mosquitoes emerge in tremendous numbers. The application of larvicides through the use of airplanes is an economical method of controlling these mosquito larvae.

The Bureau of Vector Control, California State Department of Public Health, in cooperation with the Kern Mosquito Abatement District in Kern County evaluated several airplane mosquito larval control techniques from March until September, 1947.

One of the first airplanes equipped with a spray boom with detachable nozzles used for mosquito control was reported by Metcalf, Hess, Smith, Jeffery, and Ludwig (1945). A spray boom was mounted on the trailing edge of the lower wing of a Stearman PT-17 airplane for dispersing solutions for anopheline larval control. Ninety per cent, or better, mortality of *Anopheles quadrimaculatus* Say larvae was obtained when the spray solution was applied at rates of less than 0.03 pound of DDT in Velsicol NR 70 solutions. During the summer of 1946, Geib (1946) in Kern County, California, used a similarly equipped airplane with a spray boom having detachable nozzles. In addition to the spray boom, an engine exhaust venturi was installed on the same plane. It was patterned after the exhaust venturi airplane used by the Tennessee Valley Authority for the control of anopheline mosquitoes as detailed in the report by Krusé and Metcalf (1946). They found that from 0.05 to 0.20 pound of DDT per acre applied by this technique would give adequate control of *A. quadrimaculatus* larvae if the swath width was varied depending upon the density of the vegetation. Geib (1946) used 5% DDT in diesel oil plus 16 ounces of B-1956 as a spreader, applied at rates varying from 0.05 to 0.85 pound DDT with the spray boom on his plane with fair results. One application at the rate of two quarts per acre, with the thermal exhaust aerosol using 20% DDT in light extractives of oil with B-1956 added, gave 100% mortality to fourth instar *Aedes* larvae.

II. OBJECTIVES

The objectives of this study were: (1) to evaluate the use of airplanes for the dispersal of DDT solutions for the control of *A. dorsalis* and *A. nigromaculis*

---

1 This report is one of a series on continuing mosquito control operational and biological studies begun in 1946 by the Bureau of Vector Control, Division of Environmental Sanitation, California State Department of Public Health, in cooperation with various mosquito abatement agencies.

larvae under conditions of a routine operational mosquito control program; (2) to determine if the method of applying DDT solutions by means of an airplane thermal exhaust venturi aerosol generator as used by Krusé and Metcalf (1946) for anopheline larval control in impounded water was adaptable to the control of *A. dorsalis* and *A. nigromaculis* larvae occurring in intermittently flooded pasturelands; (3) to compare an airplane equipped with a thermal exhaust aerosol generator for applying larvicides with an airplane equipped with a spray boom for *A. dorsalis* and *A. nigromaculis* larval control.

III. Procedure, Equipment, and Techniques

These studies were conducted during the active 1947 mosquito control season and under the conditions of a routine control program. Any study that failed to give control entailed additional expense and time for the district in order to eliminate the mosquitoes that survived treatment. For this reason, if any one material failed to give control after a few trials, another material was tried. Untreated plots were not used for controls because mosquitoes in the untreated fields would emerge and create a nuisance problem in the district.

Airplane Equipment. Two converted army PT-17 biplanes flown at 90 miles per hour and equipped with 220 h.p. Continental engines were used for these studies. One was equipped with a venturi thermal exhaust aerosol generator and the other as a spray plane.

The thermal exhaust plane was patterned after the airplane used by Krusé and Metcalf (1946) for the control of anopheline larvae in impounded waters; however, there were several modifications. The plane was equipped with a four-inch O.D. exhaust stack, 13 feet long. One flat cone spray nozzle extended into the venturi throat on either side. Chicago Spraying Systems nozzles Numbers 8006, 8010, and 8015 were used. The plane was equipped with a wind-driven Pesco pump and discharged two to four gallons per minute. A Pittsburgh Tropic-Split Case Type, ⅝ inch flow meter was installed.

The spray plane was equipped with a 30 foot long ¾″ diameter streamlined boom that was mounted 18 inches below and extended the entire length of the under-surface of the lower wing. A wind-driven pump was used. A flow meter which was the same as that used on the aerosol plane was also installed. There were 20 outlets on the boom having two nozzles at each outlet attached by a "T" to the boom. No. 1 Whirljet Chicago Spraying Systems brass nozzles were used. At the end of three months' service the brass nozzles were unserviceable due to scoring and they were replaced by stainless steel nozzles. After six months, a month before the completion of these studies, the original stream-lined boom was replaced with a ⅝″ I.D. steel tube which had 40 openings with one nozzle to each opening.

Materials. The materials used in the thermal aerosol plane were premixed. A General Petroleum solvent designated as PD544C, which is high in aromatics, was the principal solvent used in these studies. DDT was added at the rate of two pounds of DDT to each gallon of solvent. The number of pounds of technical grade DDT per gallon of concentrate was determined to be 1.71 which is equivalent to a 21.4% DDT concentrate when compared with an arbitrary standard of 2.00 pounds per gallon as resulting in a 25% concentrate. Other DDT solutions dispersed with the aerosol plane were DDT in Standard Base Oil WT, in Velsicol NR 70 and AR 60, but these were used to a lesser degree.

In the spray plane studies DDT-Xylene water emulsions were used. The concentrate was obtained from the War Assets Administration.

Vegetation. Natural and planted pastures were the predominant types of fields used in these studies, although some alfalfa fields with poor drainage were also used.

Vegetation in a study area was divided into two types, horizontal and vertical. All broad-leafed vegetation was considered to be horizontal, and all grasses were considered to be vertical. The two types were judged on the basis of their height and density. Density was determined by placing a dipper used in collecting larvae on the ground in the vegetation of the study area, walking back about 10 feet, and determining the area of the dipper handle covered when facing the dipper at right angles to its length. The area of the dipper handle thus obstructed was used as an estimate of the density; e.g., if ⅓ or less of the dipper handle was covered, the vegetation was considered to be of light density; if ⅓-⅔, it was considered to be medium density; ⅔ or more was considered to be heavy density. The percentage of cover over the water surface was estimated to the nearest twenty-five per cent.

Flight Data. The height of flight in an unobstructed field was approximately 15 feet; however, the height was always dependent upon obstructions in the flight path. Numerous studies were flown at 50-foot heights, and several at 75 and 100 feet. The intervals between lines of flight were paced off on the ground by one man at each end of the field, these two men acting as swath markers for the pilot. Fifty, seventy-five and one hundred foot intervals were used in the studies.

Acreage was measured by the pilot while in flight during spray applications, by determining the treatment time with an accumulative time stop watch. The watch was clicked at the beginning and end of each pass of the airplane as the larvicide was turned on or off. Since the plane speed was constant at 90 miles per hour, and the intervals between lines of flight were measured from the ground it was easy to calculate the acreage covered by the plane in any given treatment time and the amount of solution discharged per acre.

Entomological Sampling and Control Evaluation. Following the district's control procedure, the fields for these studies were sprayed in the order of their discovery, irrespective of the larval development. However, fields with pupae were avoided. The larvae were a mixture of *A. dorsalis* and *A. nigromaculis,* the former predominating.

At least two larvae per dip was considered the minimum number of larvae for a field to have if usable for study purposes. Larval stations were selected in multiples of ten in each study. A metal welding rod was used as the station marker and a ½″ by 4½″ by 10″ wood float for holding slides for collecting droplets was placed at five of these stations. A thermometer was attached to the under surface of the float by inserting it into a ¾″ cork plug which in turn was inserted into a ¾″ hole that was drilled in the center of a ½″ by 2⅝″ by 4½″ piece of wood. This piece of wood was screwed sidewise across the width of the float. The stations were widely dispersed in order to cover the area being treated, but they were placed only where larvae could be found. Three dips were taken around each station for a total of sixty dips for most of the studies, both before and after treatment.

The larvae were separated into two groups: first and second instars, and third and fourth instars. Areas with late fourth instar larvae or pupae were avoided. If the same number of larvae or more larvae were present in the post-treatment count than were found in the pre-treatment count in either of the larval groupings, it was presumed that there was no reduction. If on post-treatment inspection the third and fourth instar larval survivors were more numerous than in the pretreatment count, the excess would be added to the first and second instar survivors and it was therefore assumed that the third and fourth instar had no reduction. In the post-treatment, count pupae that might have appeared were counted separately and added to the third and fourth instar count. The larval count was made preferably one or two hours before treatment and twenty-four hours after treatment. The effectiveness of treatment was based upon the number of survivors after treatment, or as expressed in the result, as "per cent reduction."

Meteorological Data. For each study meteorological data were obtained. Relative humidity was determined by means of a sling psychrometer, and the wind velocity was determined with an anemometer. Converse and inverse air conditions were determined by placing a thermometer at one foot above the ground and another thermometer at six feet above the ground. The difference in temperature would indicate whether the air was rising or falling.

Water and Biological Factors. The temperature of the water was determined by placing a thermometer at the bottom of three of the floats. The average of these three readings was recorded. Water depth was estimated to the nearest 4 inches as the average depth of the water area where the larvae were present. The coverage of algae was noted and estimated to the nearest 25%, whether it was on the surface, sub-surface, bottom or a combination of these levels in the water. The presence or absence of flotage was noted, and estimated to the nearest 25%.

Droplet and Chemical Studies of DDT Recovery. To attempt to correlate the effectiveness of control and droplet penetration through the vegetation, magnesium oxide coated slides were placed on five of the floats in the vegetation. The mean diameter, the mass median diameter, and the number of droplets per square centimeter were determined microscopically. Three clean slides were placed on each of four of the floats, (to give an aggregate area totaling one quarter of a square foot). After the DDT solution was deposited the slides were collected and the clean ones were chemically analyzed for DDT. The results were reported in terms of pounds DDT recovered per acre and the per cent recovery was then determined.

IV. DISCUSSION OF RESULTS

Comparative Toxicity of Spray vs. Aerosol. The results of the reduction of the larval population following treatment for the spray and aerosol studies expressed on an average basis are summarized in Table 1. The studies are grouped in three DDT dosage ranges. The reduction of larvae is further broken down into instar groupings.

Those studies conducted under favorable vegetative conditions are listed separately from those done under adverse vegetative conditions. Favorable vegetative conditions were presumed to prevail when the density of the vegetation was light or medium and 75% or less of the water surface was covered; when the density was heavy and 100% of the water surface area was covered with vegetation, the vegetative conditions were considered to be adverse.

In the DDT-Xylene spray plane studies the solutions were dispersed as water emulsions at rates varying from 0.5 to 1.4 gallons of 2.5% to 5% solutions. The results of these studies are based upon the pounds of DDT dispersed per acre.

In the DDT-Xylene water emulsion spray studies better than 88% control was obtained for all larval stages when more than 0.30 pounds of DDT was applied per acre. At this dosage those studies done under favorable vegetative conditions gave 100% control for first and second instars, and 93% control for third and fourth instar larvae. Those conducted under adverse vegetative conditions involving first and second instar larvae gave 96% control, while third and fourth instar larval studies had 78% control. Below 0.30 of a pound DDT per acre the first and second instar reduction was 81% under favorable vegetative conditions and 55% under adverse vegetative conditions; the third and fourth instar reduction was 36% or less under all vegetative conditions.

In the aerosol studies, however, the dosage of DDT, the vegetative conditions, and the relative susceptibility of the larval groupings were not usually demonstrable.

TABLE 1—Comparative toxicity of DDT in xylene emulsion spray and in thermal aerosols to *Aedes* spp. larvae under favorable and adverse vegetative conditions. Kern Mosquito Abatement District, 1947.

		0.20 – 0.29 Lbs. DDT/Acre				0.30 – 0.39 Lbs. DDT/Acre				0.40 – 0.49 Lbs. DDT/Acre			
		1 & 2 Instar		3 & 4 Instar		1 & 2 Instar		3 & 4 Instar		1 & 2 Instar		3 & 4 Instar	
Materials	Vegetative Conditions	No. of stud.	Av. % reduct.	No. of stud.	Av. % reduct.	No. of stud.	Av. % reduct.	No. of stud.	Av. % reduct.	No. of stud.	Av. % reduct.	No. of stud.	Av. % reduct.
DDT-xylene water	Favorable	5	81	4	36	8	100	7	93	7	100	3	100
emulsion spray	Adverse	5	55	5	10	3	96	4	78	3	100	4	96
	Total	10	67	9	22	11	99	11	88	10	100	7	98
PD544C + 16 oz.	Favorable	–	–	–	–	1	62	1	0	2	4	1	0
B-1956 per 100 gal.	Adverse	–	–	–	–	–	–	–	–	–	–	–	–
aerosol	Total	–	–	–	–	1	62	1	0	2	4	1	0
+5% emulsifying	Favorable	–	–	2	50	2	97	4	54	–	–	–	–
agents *	Adverse	1	100	1	95	1	100	–	–	–	–	–	–
aerosol	Total	1	100	3	65	3	98	4	54	–	–	–	–
Standard base	Favorable	–	–	–	–	1	100	–	–	2	71	1	100
oil WT aerosol	Adverse	–	–	–	–	–	–	–	–	1	100	–	–
	Total	–	–	–	–	1	–	–	–	3	81	1	100

* 1½% B-1956, 3½% Igepol.

Solutions of DDT in PD 544C gave very erratic results. With 16 ounces of B-1956 per 100 gallons added as a spreading agent, poor results were obtained. Upon the addition of 5% of an emulsifying agent, containing 1½% B-1956 and 3½% Igepol, the relative susceptibility of the early instars compared to the later instars was demonstrable, but the effect of increased dosage of DDT was not. This latter solution when diluted with water or diesel oil failed to give control in several experimental trials.

Three studies with DDT in Standard Base Oil WT applied as an aerosol generally gave 100% control and two studies gave an average of 71% control, but the relative susceptibility of the earlier larval stages compared to the later stages and the effect of adverse vegetative conditions upon control were not demonstrable. More trials with this material were planned, but the season ended before they could be attempted. Velsicol NR 70 and AR 60-DDT aerosol solutions were tried several times but with very erratic results. These materials were too expensive, due to high shipping costs, to be used economically in California. Additional studies with aerosol solutions are advisable before definite conclusions can be drawn.

DDT-Xylene Water Emulsion Toxicity Curves

Two experimental toxicity curves were obtained when the pounds of DDT per acre applied as DDT-Xylene water emulsion sprays under adverse and favorable vegetative conditions were plotted against the percentage of reduction of third and fourth instar larvae, as presented in Figure 1.

To obtain a dosage of 0.40 of a pound DDT per acre, one gallon of 5% solution was used; for 0.30 of a pound, three quarts of a 5% solution were used; for

0.20 of a pound, two quarts of a 5% solution or one gallon of a 2.5% solution were used; and for 0.10 pound per acre, two quarts of a 2.5% solution were used. For intermediate dosages, intermediate volumes other than those given above were used.

The break in toxicity for the studies conducted under favorable conditions is between 0.25 and 0.30 pound, and under

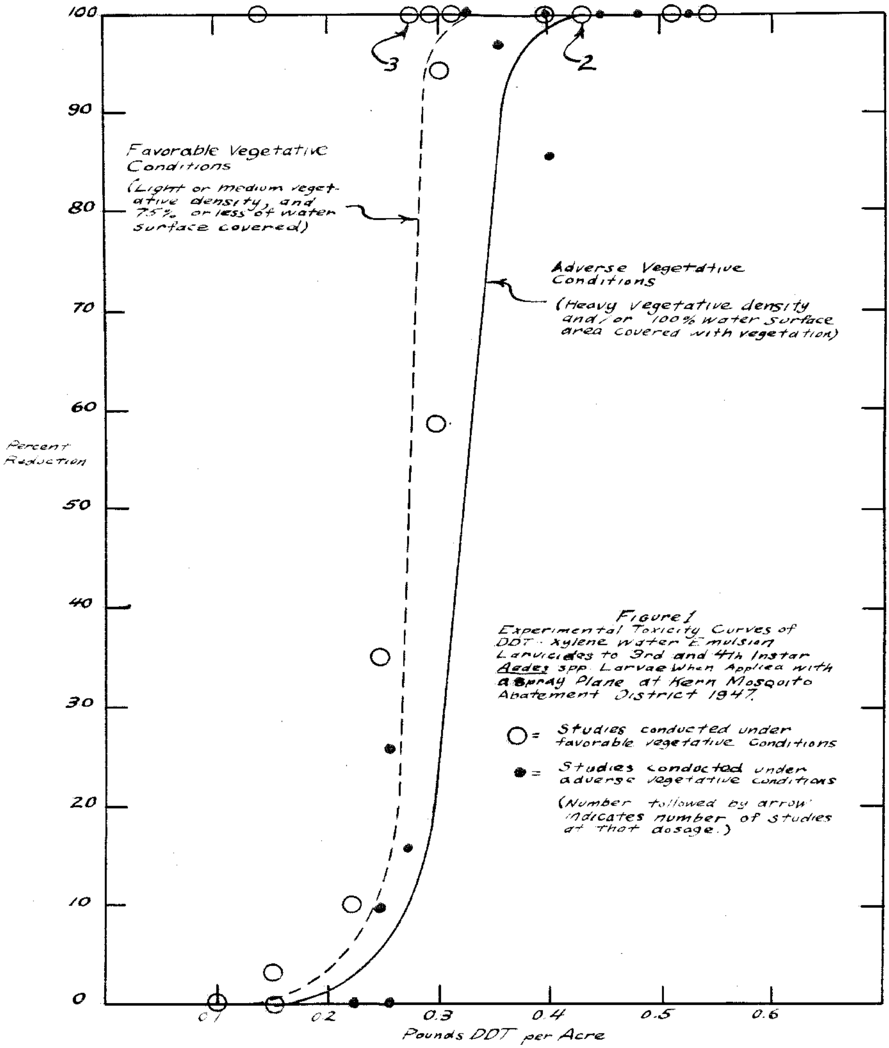

Figure 1
Experimental Toxicity Curves of DDT-xylene water Emulsion Larvicides to 3rd and 4th Instar *Aedes* spp. Larvae When Applied with a Spray Plane at Kern Mosquito Abatement District 1947.

adverse conditions between 0.35 and 0.40 pound of DDT per acre. Larval reduction of 95% was obtained at 0.30 of a pound DDT per acre under favorable vegetative conditions, and under adverse vegetative conditions, 0.40 of a pound had to be applied in order to obtain 95% larval reduction.

The same relationship with first and second instars is shown in Figure 2. The break in toxicity is not so clear-cut but the trend is indicated. It appears that under

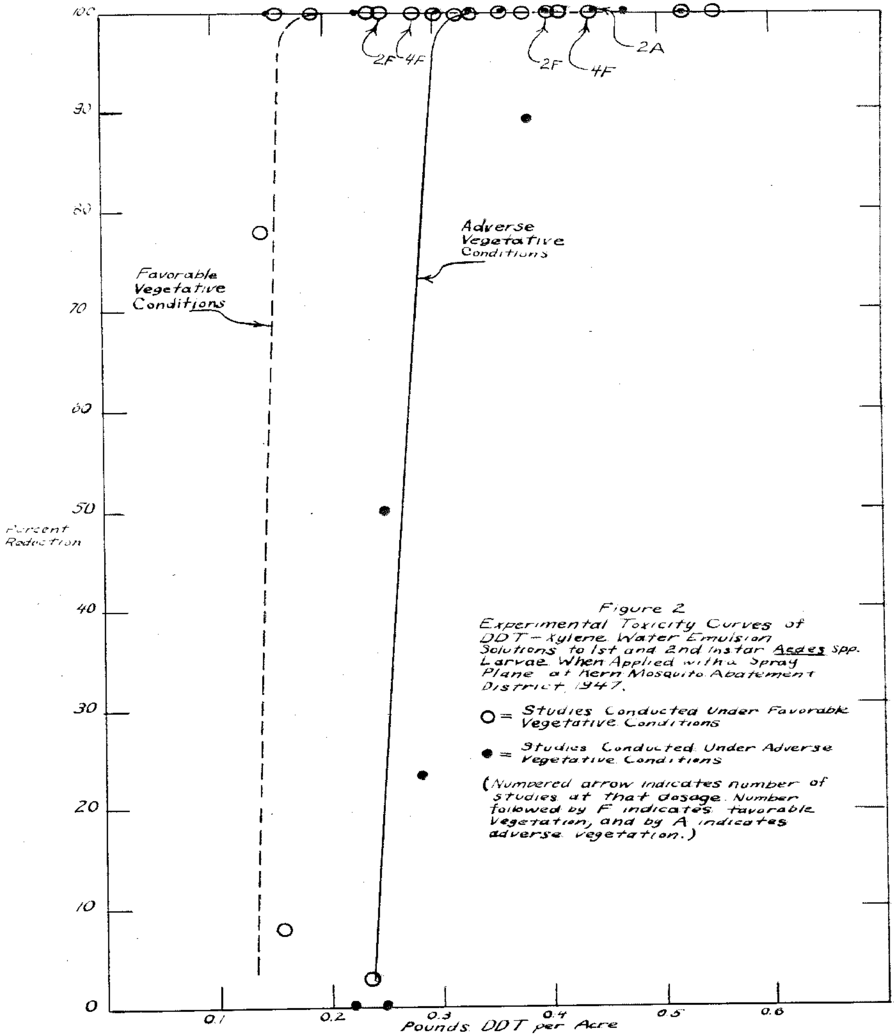

Figure 2
Experimental Toxicity Curves of DDT-Xylene Water Emulsion Solutions to 1st and 2nd Instar *Aedes* Spp. Larvae When Applied with a Spray Plane at Kern Mosquito Abatement District 1947.

favorable vegetative conditions the mortality curve breaks below 0.15 and 0.20 pound of DDT per acre, and under adverse vegetative conditions the break appears to be between 0.25 and 0.35 pound of DDT per acre.

Effective Swath Width for Spray Plane Applications of DDT-Xylene Water Emulsion

Out of eleven studies in which DDT-Xylene water emulsion was applied with a spray plane between 0.30 to 0.40 pound of DDT per acre at various intervals between lines of flight where vegetative conditions were favorable, six of the studies with a resultant 75-foot swath gave an average of 97% control. Four of the studies at 50 foot flight intervals gave an average of 99% control. One flight at 100 foot intervals gave 55% control. Those studies flown at 75 foot flight intervals were almost as effective as those flown at 50 foot flight intervals and were more economical as the plane was able to fly 50% more acreage with the same spray load.

Recovery of DDT and Mortality

An experimental toxicity curve was obtained by plotting the pounds of DDT per acre recovered after spraying with the xylene-water emulsion against per cent of reduction of third and fourth larval instars. This curve was found to correspond roughly with the toxicity curve in figure 1, based on pounds of DDT actually applied.

It would appear from this curve that to obtain a 90% larval reduction, 0.30 pound of DDT would have to be applied, of which 22% or 0.064 pound of DDT could actually be recovered.

Measured Factors

As previously shown there appears to be a correlation of the reduction of larvae following treatment with DDT-Xylene water emulsion with the amount of DDT applied per acre, with the vegetative conditions, and also with the amount of DDT recovered. The other measured factors in the spray studies were not correlative. These included the relative humidity, temperature of water and air, the pH of the water which varied from 6.0 to 8.0, the water depth, and the presence or absence of algae and flotage. In the aerosol studies there were too few studies with each material to enable a correlation of the measured factors.

Other pertinent facts were obtained. In the DDT-Xylene water emulsion spray studies the droplets varied from 10 to 400 microns in size, the bulk of the drops falling between 40 to 150 microns. The mean diameter varied from 30 to 195 microns, the average being 68 microns; the mass median diameter varied from 120 to 260 microns, the average being 198 microns.

In the aerosol studies the droplets varied from 5 to 300 microns in diameter, while the bulk were less than 100 microns. The mean diameter varied from 15 to 115 microns, the average being 51 microns; the mass median diameter varied from 53 to 260 microns, the average being 132 microns.

The percentage of DDT recovered as determined by chemical analysis varied from 5.0% to 57.9% in the aerosol studies with an average of 20.7%, and for the DDT-Xylene emulsion spray plane studies from 4.6% to 26.0%, with an average of 17.9%.

V. Summary

The method of applying DDT-aerosol solutions by means of an airplane thermal exhaust venturi generator, as developed by Krusé and Metcalf (1946) of the Tennessee Valley Authority for anopheline larval control, was not adaptable for the consistent control of *A. dorsalis* and *A. nigromaculis* larvae occurring in intermittently flooded pastures in the Sacramento-San Joaquin Valley of California. A PT-17 plane modified as a boom-spray plane was adaptable as a means of dispersing DDT larvicides for obtaining satisfactory control of *A. dorsalis* and *A. nigromaculis* larvae.

DDT-Xylene water emulsion dispersed by a spray plane above 0.30 pound of DDT per acre gave 95% and above larval reduction to *A. dorsalis* and *A. nigromaculis* 3rd and 4th instar larvae under favorable vegetative conditions. In areas where the vegetative conditions were adverse, over 0.40 pound of DDT in this solution gave better than 95% larval reduction. For first and second instar larvae of *A. dorsalis* and *A. nigromaculis* 0.20 pound of DDT under favorable vegetative conditions, and 0.30 pound of DDT under unfavorable conditions gave 100% control.

Seventy-five-foot swath intervals flown by the spray plane were almost as effective as 50-foot swath intervals and would be more economical. In the spray plane studies DDT dosage per acre, type of vegetation, and amount of DDT recovered were correlated with mortality. None of these factors were correlated with larval control in the aerosol studies.

ACKNOWLEDGMENTS

The authors wish to thank the following individuals for their helpful assistance on this project: Grafton Campbell and Thor A. Holm, Bureau of Vector Control, California Dept. of Public Health; Gordon F. Smith, Entomologist, and Dale F. Knopf, pilot, Kern Mosquito Abatement District; Dr. R. L. Metcalf, University of California, who was kind enough to visit this project and offer valuable suggestions pertaining to the technical aspects; Dr. W. M. Hoskins, University of California, who gladly offered technical information; T. E. Hillis, chemist, Div. of Laboratories, California Dept. of Public Health; and Miss Geraldine B. Edwards, Senior Public Health Analyst, California Department of Public Health, who generously contributed her help to certain statistical aspects of this project.

Literature Cited

GEIB, A. F. 1946. Dr. Morris Mosquito Abatement District airplane work. Proc. 15th Ann. Conf. *Calif. Mosq. Cont. Assoc.* 125–128.

KRUSÉ, C. W. AND METCALF, R. L. 1946. An analysis of the design and performance of airplane exhaust generators for the production of DDT aerosols for the control of *Anopheles quadrimaculatus*. *U. S. Pub. Hlth. Rpts.* 61 (32):1171–1184.

METCALF, R. L., HESS, A. D., SMITH, G. E. JEFFERY, G. M., LUDWIG, G. W. 1945. Observations on the use of DDT for the control of *Anopheles quadrimaculatus*. *U. S. Pub. Hlth. Rpts.* 60(27):753–774.

JEEP EXHAUST VENTURI AEROSOL

ROBERT W. JONES, III [1] AND JAMES R. HOLTEN [2]

Thermally produced aerosols have come to be rather widely used for mosquito control in California. The limitations imposed by wind, temperature, and humidity are recognized and the aerosols are used within these limitations as an adjunct to basic larval control measures in order to control flights of mosquitoes that do emerge.

The "plumber's nightmare" devised by Raley (1947) and adapted by Crowe (1948) has been most frequently used, because of its low cost as compared to the cost of the large commercial generators. It is a simplified version of the National Defense Research Committee aerosol generator. The venturi aerosol discussed here

[1] Vector Control Specialist, Bureau of Vector Control, California State Dept. Public Health.

[2] Vector Control Officer, Grade I, Bureau of Vector Control, California State Dept. of Public Health.