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DOSE AND CYCLE OF INSECTICIDE APPLICATIONS IN THE CONTROL OF MALARIA

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SYNOPSIS

The authors first review the doses and cycles of application normally recommended in different parts of the world for DDT, BHC, and dieldrin in controlling malaria, and then discuss the experimental evidence concerning their actual efficacy in the field. The irritant effect of the various insecticides is compared, DDT being found the most irritant and dieldrin the least. BHC appears to be highly irritant when solid, but not when vaporized. The problem of the application of residual insecticides to absorbent surfaces, such as mud, is considered; the wettable powders are generally accepted as the most efficient formulation for such surfaces, but even with these a marked loss in toxicity may occur, requiring higher initial doses and more frequent application than on non-absorbent surfaces. With volatile insecticides, such as BHC, some degree of absorption slows down the loss by volatilization, but at the usual field dosages of 0.1 g and 0.2 g of gamma-BHC per m² the decline in toxicity is still rapid. Experiments have also shown that mixtures of DDT and BHC may, in some circumstances, combine the initial high kill of the latter with the persistent moderate kill of the former.

Considering the insecticidal efficiency needed for the control of malaria, the authors find that most natural circumstances would be met by attaining a mortality-rate of about 65% of mosquitos entering treated shelters; 85% mortality would be suitable for the most severe conditions and 65% mortality for controlling moderate transmission by endophilic mosquitos.

Present practice in the dosage and cycle of application of insecticides used for the control of malaria, and particularly of DDT, is largely empirical, commonly on a basis of rough prescription without exact scientific foundation. Early workers experimented with different doses and commonly selected a dose of about 2 g per m^2 as suitable, though their selection was necessarily almost blind. It was known that total extinction of mosquitos was not necessary for control, but no body of knowledge on the degree of reduction needed to secure control had been built up. Such knowledge as there was referred largely to larvicidal techniques and was inappropriate when applied to imagocidal techniques, in which the main effect is produced by a reduction of the expectation of life of the mosquito.

Efficacy was at first judged by the reduction in adult anopheline density achieved. The demonstration that repulsion as well as destruction occurred invalidated much of this work, and its replacement by studies of the actual anopheline mortality secured is still very incomplete. Most evaluation is now based on preliminary anopheline observations followed by observation of reduction of malaria ensuing on the application of empirical, and usually large, doses. To secure precise results indicating minimal doses by such techniques would require multiplication of very large experimental schemes, which is not practicable.

The statement which follows presents information on the doses and cycles usually recommended in different parts of the world and against different mosquitos; on the available experimental evidence concerning the actual efficacy of DDT, BHC, and dieldrin; and on the degree of efficacy thought to be needed for the control of malaria under different conditions. Tentative conclusions are presented, but the one most clearly brought to light is that a considerable expansion of our knowledge is urgently needed—an expansion in the fields of basic theory, anopheline habits, the physical chemistry of insecticides, and their mode of action.

Doses and Cycles Normally Recommended

The data set out here are not given in an attempt to present the full literature, but rather constitute a detailed illustration of normal practice. Unless stated otherwise, the regimes quoted appear to be securing complete or near-complete control of malaria, though a number which have not done so are noted in connexion with the successful ones.

DDT

North and Central America. Application is usually in the form of 5% emulsion, the dose used being in the neighbourhood of 2.2 g per m^2. In the USA, where the season is short, it is usual to make only one application each year. Complete control of malaria transmission by *Anopheles quadrimaculatus* has been secured.[3] In Mexico, it is usual to apply two such doses in the year,[59] either as emulsion or in suspension, for the control of

A. albimanus and *A. pseudopunctipennis*; but Downs & Bordas [18] have noted that in the highlands, at an altitude of 7,000 feet (approximately 2,000 m) or more, one such dose in suspension may be adequate against *A. aztecus* for a period of 2 years.

South America. In British Guiana, a dose of 1.6 g per m^2 in solution or suspension was first applied at intervals of 8 months, which were then prolonged to 12 and then 18 months, and found fully effective. Typical houses are of sawn wood. The principal vector, *A. darlingi*, is highly endophilic, and its breeding has been brought to an end.[29] *A. aquasalis*, largely exophilic and zoophilic, no longer carries malaria but is not extinguished. In Venezuela, a dose of 1 g per m^2 at intervals of 3-4 months was replaced by one of 2 g per m^2 at intervals of 6 months,[23] but there is reason to believe that the 6-monthly interval may be excessive, as cases occur towards its end. The vectors are *A. darlingi*, the breeding of which has ended in some areas, and *A. albimanus*, *A. albitarsis*, and *A. pseudopunctipennis*, which continue to breed as before though they no longer carry malaria.[24] A dose of 2 g per m^2 is applied twice a year at intervals of 3 months in Argentina, at intervals of 6 months in Bolivia, and at intervals of 4 months in Brazil [59] for the control of malaria carried by *A. darlingi*, *A. aquasalis*, *A. albitarsis*, *A. pseudopunctipennis*, and *A. tarsimaculatus*. Full malaria control has been obtained, but the successful local eradication of *A. darlingi* does not seem to be happening or to be feasible in parts of Brazil,[60] where it is more exophilic. A similar dose, 2.3 g to 2.4 g per m^2, is applied once yearly for the control of *A. pseudopunctipennis*, *A. albimanus*, and *A. punctimacula* in Ecuador.[59] It is generally acknowledged that the totally exophilic *Kertezia* group is not susceptible to control by normal insecticide regimes, and methods for the prevention of breeding are still employed as a routine.

Europe and Mediterranean lands. Solutions and emulsions have been used more commonly in this area than have suspensions. In Greece, a dose of 1.8 g per m^2 was used against *A. sacharovi* and *A. superpictus*, applied once at the beginning of the 5-6-month transmission season. It is thought that the former mosquito may have become resistant,[46] but malaria is virtually eliminated and has recurred only in limited foci since treatment was discontinued.[45] In Italy, an average dose of 1.5 g per m^2 twice yearly in houses and once yearly in stables brought transmission, by the above two vectors and by *A. labranchiae*, to an end. In Yugoslavia, a dose of 1 g per m^2 once annually in emulsion is used against the same species, while in Portugal, 2 g per m^2 as a suspension are used once yearly to control carriage by *A. atroparvus*.[59] In Italy, chlordane is now commonly added to DDT preparations to kill resistant flies. In the Jordan Valley, it has been reported by Farid [20] that the exophilic habits of *A. sergenti* and the fact that the people tend to live out of doors have made control by DDT spraying (2 g per m^2) ineffective.

Africa. The Malaria Conference in Equatorial Africa [92] recommended the use of 2.2 g of the para-para′ isomer of DDT per m^2 every 6 months. All campaigns in Africa south of the Sahara have as their first objective the control of malaria carried by either *A. gambiae* or *A. funestus*, or by both, though other vectors are concerned in some places. The recommended dose has been successfully used in the Congo (Jadin [41]). In Madagascar, 1.2 g per m^2 as a suspension and 2.0 g per m^2 as an emulsion have been applied every 6 months with success (Mercier [54]); and in Mauritius, the dose has been 1.1 g to 1.65 g per m^2 every 6 months (Dowling [16]). Results have on the whole been good, and both Dowling and Jadin report cessation of breeding of *A. funestus*, which seems to be highly endophilic. In some cases results have been disappointing : the Colonial Insecticides, Fungicides and Herbicides Committee [31] reported failure in Uganda following application of 2.2 g per m^2 every 6 months, and Mastbaum [53] achieved only partial success in hyperendemic areas. His data do not permit statement of the dose in terms of weight of DDT to area of wall surface.

South and South-East Asia. It has been usual in India to apply smaller doses than elsewhere, at shorter intervals, and to select the dose according to the nature of the vector with much greater discrimination. There are many records of careful field estimation of efficacy, largely in terms of reduction of anopheline density, from which a variety of combinations of dose and cycle have been selected. Jaswant Singh [42] mentions the following as effective :

Place	*Vector*	*Dose (g per m^2)*	*Period of efficacy*
Delhi	*A. culicifacies*	0.55	6-8 weeks
South India	*A. fluviatilis*	0.55	3 months
Bombay	*A. fluviatilis*	0.55	2 months
Bombay	*A. culicifacies*	0.55	6 weeks
North Bengal	*A. minimus*	0.66	8 weeks

Such doses are in wide use. The ones quoted for Bombay refer to a very extensive scheme reported by Viswanathan & Rao,[84-86] in which the selection extended to varying the maximum height of application and to discriminating between human and cattle shelters according to the vector. Similar small doses, 0.5 g per m^2 once every 6 weeks, were recommended for use in Assam against *A. minimus* by Gilroy.[30]

Similar small doses at short intervals are now used in the highly successful campaign against transmission by *A. culicifacies* in Ceylon; originally 1.3 g per m^2 were applied at intervals of 6 weeks, but this was later reduced to 1.1 g per m^2 and then to 0.55 g per m^2, repeated at intervals of 6-8 weeks and found fully effective by Rajendram & Jayewickreme.[61] In a part of Ceylon that was previously subject to epidemic recurrences, the breeding of *A. culicifacies* has been reduced by this process, although it has not affected exophilic species.

WHO demonstration teams in South-East Asia have tended to follow the more usual practice, and as the result of a major trial in East Pakistan, a dose of 1.7 g per m^2 in suspension was recommended for the control of transmission by *A. minimus*, and of 1.2 g per m^2 when *A. philippinensis* was the vector; in both cases a single annual application was recommended to cover a transmission season extending in all from May to October.[58]

In Malaya, the Malaria Advisory Board,[52] after reviewing local evidence, recommended the application of 1.1 g per m^2 every 3 months, or 2.2 g per m^2 every 6 months, for the control of transmission, which is mainly by *A. maculatus*, *A. sundaicus*, and *A. umbrosus*. There has been a recent natural recession of malaria in this country which complicates analysis of the needs. There have been a number of trials in Indonesia by WHO workers and others which have been summarized by Soeparmo & Stoker,[74] and which have led to the general adoption of a dose of 2.0 g per m^2 in suspension, applied once a year only, for the control of transmission by *A. sundaicus*, *A. maculatus*, *A. aconitus*, and *A. minimus*.

In territories further east, and possibly throughout the whole mountain mass of Indo-China in the broad sense, highly but not completely exophilic species are largely responsible for transmission. It is known that a WHO team is carrying out trials against *A. balabacensis* in Borneo, but the dosage and results have not yet been reported. Another team is carrying out trials in the Philippine Islands against *A. minimus flavirostris*, and doubt was expressed about the outcome before the project was undertaken.[73] The writers believe that success has since been obtained.

Australasia. The writers are not aware of the regimes used in large-scale work in this area, where members of the *A. punctulatus* group are the vectors.

The impression gained from our survey of practice is that workers have been actuated by two different motives, dependent on economic conditions: one group has searched for a maximum period between sprayings and has not been greatly concerned about dosage, while the other has searched for a minimum effective dose with less regard for the expense of frequent repetition of application. The majority of workers in both groups have arrived at materially the same conclusions on the practical application, and most of the regimes represent about 0.33 g per m^2 for every month of effective action demanded. There are a number of divergences from this general rule and differences in result. Undoubtedly some of them are due to the varying qualities of wettable powders in use. Success above the average appears to depend very much on the endophilic habits of the vector; and reduction or ending of breeding of some endophilic species has been secured, as in the case of *A. darlingi*, *A. funestus*, and *A. culicifacies*. The utility of lesser doses seems to depend partly on endophilism and partly on the nature of the typical wall surfaces, though the literature on normal practice contains so few references to this feature that assessment is very difficult.

The difficulties and demands for higher efficiency are probably more related to exophilism than to any other feature, though anopheline density and feeding-habits must clearly play a part in producing them.

BHC

There is no accumulation of experience leading up to the formulation of accepted practice in the use of BHC comparable to that in the case of DDT. Original work by Davidson [11] against *A. gambiae* was inconclusive but led to trials of a dose of 0.11 g per m^2 of the gamma-isomer against *A. moucheti*, with apparently successful results for 3 months.[12] The Colonial Insecticides, Fungicides and Herbicides Committee [31] recommended the use of the same dose against *A. gambiae* and *A. funestus* every 3 months, though the published results of their experiments suggested that full success had barely been achieved with this dosage. The Malaria Conference in Equatorial Africa [92] recommended the use of the same dose and interval in campaigns against these species. Doubts which arose about the utility of DDT in Africa led to the wider use of BHC on that continent than elsewhere, but very varying doses were adopted. In Southern Rhodesia, 0.5 g per m^2 was recommended and used, to be reapplied every 3 months; [2, 8] in Mauritius, 0.13 g to 0.21 g per m^2 every 3 months [16] was found effective, though BHC was abandoned in favour of DDT in order to minimize the annual number of spraying rounds; in Madagascar, 0.1 g per m^2 was used, apparently every 6 months,[54] though it was more commonly used mixed with DDT and chlordane.[6] Prolonged and careful trial in Nigeria has shown that a dose of 0.16 g per m^2 every 3 months is fully adequate to control *A. funestus*, even to the point of possible local elimination, but it is barely adequate for the full prevention of transmission by *A. gambiae*.[9] This difference in the susceptibility of species is similar to that found in Mauritius by Dowling [16] and in the Belgian Congo by Jadin [41] and is probably related to the degree of exophilism rather than to susceptibility to the direct effects of the insecticide.

It has been usual in India and Ceylon to restrict dosage to a minimum, and, where considered necessary, to limit the interval between applications rather than to increase dosage; but again no firm practice has been established. There have been several trials, among which those of Jaswant Singh et al.[44] led to the approval of 0.11 g per m^2 as effective for 7-8 weeks against *A. culicifacies*, and that by Viswanathan et al.[87] to the recommendation of 0.12 g per m^2 every 3 or 4 months against this mosquito and *A. fluviatilis*. However, Subramanian & Vaid,[75] in attempting to control transmission by the same two species, found 0.12 g per m^2, applied at intervals of 2 months, ineffective in some parts of the area concerned. Gilroy [30] recommended a dose of 0.11 g per m^2 as effective for 6 weeks against *A. minimus* and one of 0.22 g per m^2 as effective for 3 months or more.

In the programme of control of *A. culicifacies* in Ceylon, a dose of 0.11 g to 0.12 g of gamma-BHC per m^2 was substituted for 0.55 g of DDT per m^2, applied every 6 to 10 weeks, and found to maintain the good results previously obtained.[61]

In Malaya, the Malaria Advisory Board,[52] reviewing experiment and practice against *A. maculatus*, *A. sundaicus*, and *A. letifer*, advised the use of 0.22 g per m^2 every 3 months as effective.

Elsewhere the normal practice seems to be to use larger doses than in the East. In Spain, 0.5 g per m^2 has been widely used against *A. atroparvus* and possibly other members of the *A. maculipennis* complex, and has been renewed every 6-8 weeks during the transmission season.[47, 48, 63, 71] In Mexico, Downs & Bordas,[18] working at an altitude of over 7,000 feet (approximately 2,000 m), found 0.22 g per m^2 effective against *A. aztecus* for periods exceeding 12 months, under circumstances where 2.2 g of DDT per m^2 were effective for 2 years.

Dieldrin

There is no accepted body of current practice with this insecticide as an agent for the control of malaria. Experimental and pilot trials appear to have been carried out with doses of 0.4 g per m^2 and 0.25 g per m^2, but they have not yet been adequately reported on.

Experimental Evidence of Killing-Power in the Field

Experimental methods used

In most, if not all, of the major control schemes involving the application of residual insecticides to shelters harbouring adult mosquitos, entomological assessment of the efficiency of the insecticides has been based on records of the reductions in numbers of the daytime-resting population of treated shelters. No account has been taken of mosquitos entering and leaving the shelters during the night, and the possibility of some of the mosquitos escaping the action of the insecticides has been ignored.

That the insecticides DDT, BHC, and dieldrin all have some irritant effect on mosquitos, causing them to leave treated surfaces before succumbing to their effect, has been shown conclusively by the experiments of Davidson [13] and Hadaway & Barlow; [38] Baranyovits [4] also confirmed these findings on flies. In these experiments, mosquitos were allowed to rest on and escape freely from surfaces treated with the insecticides. The resting time was recorded and, on leaving the surface, the mosquitos were caught and the mortality determined 24 hours later. Table I summarizes Davidson's results two weeks after the application of various doses, the test insects being wild-caught blood-fed *A. gambiae* and *A. funestus*.

DDT was the most irritant of the three insecticides, and a very large proportion of the mosquitos escaped its action. The longest contact times and highest mortality-rates were recorded with dieldrin. BHC also showed

TABLE I. MOSQUITO MORTALITY AFTER CONTACT WITH DDT, BHC, AND DIELDRIN

Insecticide	*Anopheles gambiae*		*Anopheles funestus*	
	contact time (minutes)	corrected mortality-rate after 24 hours (%)	contact time (minutes)	corrected mortality-rate after 24 hours (%)
DDT	8	16	10	39
BHC	22	58	57	68
Dieldrin	28	96	36	92

a long contact time and moderately high mortality-rate, but was not as efficient as dieldrin.

Hadaway & Barlow,[38] using *A. stephensi* as the test insect, also showed rapid activation by DDT, but showed higher kills when the deposit consisted of small, readily available particles. On a surface freshly treated with BHC, activation was just as rapid as with DDT, but the former is so much more toxic that even very short contact usually proved fatal. A few days after treatment, when the surface BHC had been absorbed, *A. stephensi* rested much longer and invariably remained until a toxic dose was taken. These authors thus conclude that, although BHC in its solid state is highly irritant, it is not so when vaporized.

It will be seen in the accounts given later of field experiments on the efficiency of residual insecticides that the results in general conform to the findings of these simple laboratory experiments.

In the light of this "contact-repellent" property, accurate knowledge of the mortality among mosquitos entering treated shelters depends on a knowledge of the number dying inside the shelters, and of the number dying among those activated and leaving the shelters; the latter can be caught with the aid of window traps and any delayed mortality among them determined.

The percentage mortality produced by the insecticide is then

$$100 \times \frac{\text{(number dead in sideshelter)} + \text{(number dying later in window trap)}}{\text{(number dead in shelter)} + \text{(total in window trap)}}$$

Allowance has then to be made for any mortality occurring among mosquitos caught from untreated shelters, using the formula given by Abbott :[1]

$$\frac{x - y}{x} \times 100$$

where x = percentage survival in the untreated shelter, and
y = percentage survival in the treated shelter.

The following data summarize most of the field experiments made in various parts of the world, in which attempts have been made to assess this real mortality occurring among mosquitos entering shelters treated with DDT, BHC, and dieldrin, and which refer to many anopheline species. Tables II and III show the results in those cases where detailed observations in experimental huts fitted with window traps are available, including records of the numbers of dead mosquitos inside the huts and the numbers dying later in the window traps. The total mortality-rates have for the most part been corrected by Abbott's formula.

Most of the huts used in these experiments provided other means of egress for mosquitos besides the window trap—as, for instance, through gaps in the eaves—and it is possible therefore that many of the activated mosquitos were not caught. If this did happen to any great extent, then the mortality-rates recorded would differ materially from those actually occurring. If a large proportion of the mosquito population was activated to leave, and there was only a small delayed-mortality rate among them—as may occur with DDT—the effect of missing some of these escaping mosquitos would be that the total mortality-rate recorded would be higher than the actual. If only a small proportion was activated to leave and a high delayed-mortality rate occurred among them—as may be the case with BHC—a lower mortality-rate than the actual would be recorded. Finally, if a high proportion left and a high delayed-mortality rate occurred—as may happen with dieldrin—there would be little difference between recorded and actual mortality-rates.

The continued capture of large numbers of mosquitos in treated huts, and the absence of any appreciable mortality in the nearby control hut in Davidson's experiments,[13] led to the opinion, however, that few mosquitos escape undetected from these trap huts.

DDT

A. gambiae, A. melas, and A. funestus in Africa. Hocking[40] was the first worker to attempt assessment of the total mortality occurring in dwellings treated with DDT and harbouring *A. gambiae* and *A. funestus* in Africa. Using tents, huts lined with different materials, and wooden trap huts sprayed with DDT in kerosene at dosages of 0.55 g, 1.1 g, and 2.2 g of DDT per m^2, this author recorded :

(*a*) The morning percentage-mortality expressed as

$$\frac{\text{number dead on floor}}{\text{(number dead on floor)}+\text{(number remaining alive inside hut)}} \times 100;$$

(*b*) The delayed-mortality rate among those caught alive by hand in the morning.

TABLE II. MOSQUITO MORTALITY-RATES PRODUCED BY DDT IN FIELD EXPERIMENTS

Author	Type of hut	Formulation	Dosage of DDT (g per m²)	Corrected mortality-rate (%) months after spraying 1	2	3	4	5	6	7	8	9
		***A. gambiae*, *A. melas*, and *A. funestus* in Africa**										
I Muirhead-Thomson [56]	mud and thatch	kerosene solution	1.1	practically nil for 6 weeks								
Muirhead-Thomson [56]	mud and thatch	kerosene solution	2.8	practically nil for 4 weeks								
II Muirhead-Thomson [57]	mud and thatch	wettable powder	4.4	2								
III Wilkinson [90]	wood and fibre-board (Magoon type)	wettable powder	3.7	100	97	100	100					
Wilkinson [90]	mud and thatch	wettable powder	1.6	90	70	57						
Van Tiel [81]	fibre-board (Magoon type)	oil-bound suspension	1.9	100	100	100	100	100	92			
Van Tiel [81]	fibre-board (Magoon type)	wettable powder	1.9	100	100	100	100	100	100			
Van Tiel [81]	mud and thatch	oil-bound suspension	roof 1.1 walls 0.6	100	100	100	100	100	100			
Van Tiel [81]	mud and thatch	wettable powder	roof 1.1 walls 0.6	100	100	100		71	100			
IV Davidson [13]	mud and thatch	wettable powder	1.1	35	14	13	0	10	13	9	8	15
Davidson [13]	mud and thatch	oil-bound suspension	3.4	61	53	31	2	11	35	48	18	12
Davidson [13]	gravel and dung ; thatch	paste	0.8	57	20	23						
Davidson [13]	gravel and mud ; thatch	suspension of crystals (30 μ)	1.4	77	62	68	55	60	60	43	56	49
Davidson [13]	gravel and mud ; thatch	suspension of crystals (30 μ-70 μ)	0.6	41	38	63	53	64	52	33	51	51
Davidson [13]	gravel and mud ; thatch	paste	2.6	62	60	68	47	59	65	42	39	38
Davidson [13]	gravel and mud ; thatch	wettable powder	2.5	54	65	60	58	64	47	50	61	56
		***A. minimus* and others in Assam**										
V Bertram [7]	mud and thatch	wettable powder	0.5	13								
Bertram [7]	mud and thatch	wettable powder	2.4	75								
VI Gilroy [30]	mud and dung ; thatch	wettable powder	0.5	80								
Gilroy [30]	mud and dung ; thatch	wettable powder	1.0	83								
Gilroy [30]	mud and dung ; thatch	wettable powder	1.5	79								
Gilroy [30]	mud and dung ; thatch	wettable powder	2.0	51								
Gilroy [30]	mud and dung ; thatch	wettable powder	2.5	47								
		***A. maculatus* in Malaya**										
VII Wharton [88]	wood and thatch lined with sisalkraft	wettable powder	2.2	83	81	83	87					
VIII Wharton [89]	wood and thatch lined with sisalkraft	wettable powder	2.2			65	70	69	43	36		
		***A. pseudopunctipennis* in Mexico**										
IX Downs & Bordas [17, 18]	mud and thatch	wettable powder	2.2									77

I. Mosquito population : 95% *A. melas*, 5% *A. gambiae* ; delayed-mortality rates after 48 hours ; dosages not chemically estimated.
II *A. gambiae* only ; delayed-mortality rates after 48 hours ; dosage not chemically estimated.

III. *A. gambiae* and *A. funestus* ; only immediate-mortality rates recorded ; control mortality : nil ; periods do not correspond exactly to months.
IV. *A. gambiae* and *A. funestus* delayed-mortality rates after 12 hours.
V. Delayed-mortality rates after 24 hours ; uncorrected mortality-rates for first 6 weeks for all mosquitos (57% anophelines) recorded as first month ; dosages not chemically estimated.
VI. Delayed-mortality rates after 24 hours ; results for first 5 weeks for all anophelines (about 50% *A. minimus*) recorded as first month ; control mortality estimated by us at 24% ; dosages not chemically estimated.
VII. Delayed-mortality rates after 24 hours ; figures taken from graph ; dosage not chemically estimated.
VIII. Delayed-mortality rates after 48 hours ; figures taken from graph ; dosage not chemically estimated.
IX. Delayed-mortality rates after 48 hours ; average corrected mortality-rates for period 7-10 months after spraying ; dosage not chemically estimated.

TABLE III. MOSQUITO MORTALITY-RATES PRODUCED BY BHC IN FIELD EXPERIMENTS

Author	Type of hut	Formulation	Dosage of gamma-BHC (g per m²)	Corrected mortality-rate (%) months after spraying 1	2	3	4	5	6	7	8	9
		A. gambiae and *A. funestus* in Africa										
I Muirhead-Thomson [57]	mud and thatch	wettable powder	0.26	100	100	100						
II Wilkinson [90]	wood and fibre-board (Magoon type)	wettable powder	0.39	100	100	92	100					
Wilkinson [90]	mud and thatch	wettable powder	0.30	100	97	97	85					
III Davidson [13]	mud and thatch	wettable powder	0.22	99	95	56	51	35	21	6	0	4
Davidson [13]	gravel and dung ; thatch	oil-bound suspension	0.08	57	26	9						
Davidson [13]	gravel and dung ; thatch	wettable powder	0.05	80	18	12						
Davidson [13]	gravel and mud ; thatch	wettable powder	0.23	100	92	70	35	26	26			
Davidson [13]	gravel and mud ; thatch	oil-bound suspension	0.20	100	88	59	43	41	38			
		A. minimus and others in Assam										
IV Bertram [7]	mud and thatch	wettable powder	0.12	96								
V Gilroy [30]	mud and thatch	wettable powder	0.12	79								
Gilroy [30]	mud and thatch	wettable powder	0.22	100	100	nearly 100						
		A. maculatus in Malaya										
VI Wharton [88]	wood and thatch lined with sisalkraft	wettable powder	0.44	100	99	88	88					
VII Wharton [89]	wood and thatch lined with sisalkraft	wettable powder	0.44			85	88	72	51	3		
		A. pseudopunctipennis in Mexico										
VIII Downs & Bordas [17, 18]	mud and thatch	wettable powder	0.22									96

I. *A. gambiae* only ; delayed-mortality rates after 48 hours ; dosage not chemically estimated.
II. *A. gambiae* and *A. funestus* ; only immediate-mortality rates recorded ; control mortality : nil ; periods do not correspond exactly to months.
III. *A. gambiae* and *A. funestus* ; delayed-mortality rates after 12 hours.
IV. Delayed-mortality rates after 24 hours ; uncorrected mortality-rates for first 6 weeks for all mosquitos (57% anophelines) recorded as first month ; dosage not chemically estimated.
V. Delayed-mortality rates after 24 hours ; results for first 5 weeks for all anophelines (about 50% *A. minimus*) recorded as first month ; control mortality estimated by us at 24% ; dosages not chemically estimated.
VI. Delayed-mortality rates after 24 hours ; figures taken from graph ; dosage not chemically estimated.
VII. Delayed-mortality rates after 48 hours ; figures taken from graph ; dosage not chemically estimated.
VIII. Delayed-mortality rates after 48 hours ; average corrected mortality-rate for period 7-10 months after spraying ; dosage not chemically estimated.

These mortality-rates shortly after spraying may be summarized as follows :

Dosage of DDT (g per m²)	*Morning mortality (%)*	*Delayed mortality after 12 hours (%)* treated shelters	untreated annexes
2.2	72-93	54	44
1.1	50-82	16-39	36
0.55	43-57	28	25

Although Hocking did not use window traps to observe the mortality among escaping mosquitos, he did attach untreated annexes to treated tents and found delayed-mortality rates among mosquitos caught in these annexes, as shown in the above tabulation.

The persistence of the lethal effect in these experiments varied according to the nature of the treated surface. It was longest in tents, little drop in effectiveness being apparent after 6 months with dosages of 2.2 g per m² and 1.1 g per m². The first of these dosages remained effective (morning mortality still 65%) for 12 months and even the dosage of 0.55 g per m² showed some effect after one year. These long durations of persistence and apparently high mortality-rates may support the laboratory findings of Barlow & Hadaway,[5] who used absorbent fibrous surfaces such as wall-board and filter-paper and found that a solution of DDT in oil remained in a supersaturated state in and around the fibres. The movement of insects on such surfaces caused crystallization; the crystals protruded from the surface and were more readily available to the insects than the oil solution from which they were derived.

As would be expected, Hocking found less persistence on mud plaster; after 4 months there was a considerable fall in the morning mortality-rate given by a dosage of 1.1 g per m², and Hadaway & Barlow [34] showed losses of 81%-92% of DDT from mud surfaces when the insecticide was applied in oil solution.

On compressed fibre-board, which Hocking considered very absorbent, the persistence was still shorter. A dosage of 2.2 g per m² lost much of its effect after 3 months, and 1.1 g per m² after 2 months; 0.55 g per m² had a moderate effect lasting 2½ months. This would not appear to support the findings of Barlow & Hadaway mentioned above,[5] unless absorption was so rapid that none of the solution remained on or near the surface.

On wood, the morning mortality-rate dropped considerably after 4 months with a dosage of 2.2 g per m², and after 3 months with 1.1 g per m². Hocking attributed this to absorption.

Hocking also studied the effect of limewashing hessian walls 3 months and 1 month before DDT impregnation. It almost completely destroyed the value of treatment. The effect of 1.1 g per m², applied even 3 months after limewashing, lasted only 1 month, and when applied 1 month after the persistence was negligible.

Hadaway & Barlow [33] found a similar marked loss in toxicity when DDT as a solution in kerosene was applied to limewash. They were of the opinion, however, that this loss was due entirely to absorption and not to decomposition or adsorption, as most of the insecticide could be recovered analytically. Hadjinikolau & Busvine,[39] on the other hand, found DDT in limewash effective against *Aëdes aegypti* in the laboratory for relatively long periods (6-8 weeks at 1.8 g of DDT per m^2), and this has been confirmed by Maier et al.[51] and Downs et al.[19] The latter authors, while admitting that absorption may be the first stage in loss of toxicity, explain Hadaway & Barlow's findings by the fact that the whitewash used by the latter contained 2.6% Fe_2O_3, which caused the decomposition of the DDT (see page 802). They themselves even go so far as to recommend whitewashing before spraying, provided that the whitewash has a low iron content. This may prevent decomposition of the DDT by the iron in the mud below. Hadaway & Barlow [37] were later able to show that the rate of loss by absorption on mud of DDT was slowed down by limewashing.

In studying the effect of his various treatments, Hocking came to the conclusion that there was no actual repellent action which limited entry, but that there was a tendency for the mosquitos to escape after contact with the insecticide, and that this was more marked in lightly treated shelters than in more heavily treated ones. In conclusion, this author arrived at the opinion that an impregnation of about 2.2 g of DDT per m^2 produced a mosquito mortality-rate approaching 100% on most surfaces, and that the effect lasted for at least 4-6 months unless lime was present.

Hadaway [32] was among the first to use mud and thatch huts fitted with window traps in Africa, but was unfortunate in his choice of site, *A. gambiae* almost disappearing from the area at the time of his experiments. He therefore resorted to the release of blood-fed *A. gambiae* into two huts treated with DDT, in a kerosene-solution and in suspension, at a dosage of 1.0 g of DDT per m^2, and recorded the mortality-rates 18 hours later among those escaping into the window traps. There was no means of egress from these huts other than into the window traps, and so it was concluded that mosquitos not caught in them had been killed by the insecticide, as 12 hours after their release no live mosquitos were recovered by "Flitting". In a control hut, 78% of released mosquitos were recovered by "Flitting" and in the window traps. The following tabulation summarizes Hadaway's findings more than 4 months after spraying :

Treatment	*Number of* A. gambiae *released*	*Number in traps*	*Number presumed dead*	*Corrected delayed-mortality rate in window traps (%)*	*Total mortality (%)*
DDT in kerosene	338	61	279	16	86
DDT wettable powder	316	46	270	11	87

Table II records results obtained by several other workers in Africa using almost identical methods and producing more accurate estimates of total mortality-rates than those already given. Most of the results from mud-walled and thatch-roofed huts show a moderately high but never complete mortality-rate, with the exception of those of Muirhead-Thomson [56, 57] and Van Tiel.[81] The almost complete absence of kill recorded by Muirhead-Thomson [56] in West Africa, where *A. melas* was the predominant vector, can be attributed to his use of DDT in solution in kerosene on an absorbent surface. A similar lack of kill recorded in East Africa [57] against *A. gambiae*, using a DDT wettable powder, has been attributed by Hocking, in an appendix to Wilkinson,[90] to the poor qualities of dispersion and the large particle-size of the formulation used. Hadaway & Barlow,[35] in their laboratory studies of aqueous suspensions of insecticides, showed an inverse relationship between particle size and toxicity, smaller particles being more readily picked up and retained on the tarsi of mosquitos than larger particles. Particles 20 μ and less in diameter gave the highest kills. The particle size in the formulation used by Muirhead-Thomson [57] is thought to have been in the region of 60 μ.[13]

Van Tiel [81] produced almost complete kills among *A. gambiae* and *A. funestus* for a period of 6 months using an oil-bound suspension and a wettable powder, but the number of mosquitos from which these results were calculated is small.

Both Van Tiel [81] and Wilkinson [90] produced higher mortality-rates in wooden experimental huts lined internally with fibre-board, presumably a less absorbent surface than mud.

Davidson's results are based for the most part on very large numbers of *A. gambiae* and *A. funestus*, and record observations using six different formulations of DDT.[13] The lowest kill was given with the formulation used by Muirhead-Thomson.[57] Using the oil-bound suspension of Van Tiel [81] at a much higher dosage, a kill of only 50%-60% was produced in the first 2 months after treatment. A dosage of 0.8 g per m^2 on a very absorbent surface (gravel and dung) was only moderately efficient for 1 month. The highest monthly mortality-rate produced by the other treatments was only 77%, and for the most part mortality-rates varied between 50% and 60% for 6 months, after which time there were signs of decrease in efficiency. Four formulations were used in huts with walls made of a mixture of gravel and mud, but only minor differences in mortality and persistence were manifest at such differing dosages as 0.6 g per m^2 and 2.6 g per m^2. Initial mortality-rates up to 2 months after spraying in two huts treated with specially prepared suspensions of DDT crystals in two size-ranges —less than 30 μ and 30 μ-70 μ—confirmed Hadaway & Barlow's laboratory findings.[35]

The marked irritant properties of DDT were evident in all these treatments, the greater proportion, and sometimes as much as 90%, of the mosquitos being caught in the window traps. Only slight differences in the mortality-rates of *A. gambiae* and *A. funestus* were noted, though the latter was possibly slightly more susceptible.

Davidson was unable to confirm the laboratory work of Hadaway & Barlow [36, 37] on the absorption of solid insecticides by mud. These workers had shown a very rapid disappearance of DDT crystals from mud surfaces with a rapid accompanying loss in toxicity, kills of *Aëdes aegypti* being negligible within a few days of spraying. They were driven to the conclusion that kills in mud-and-thatch huts were almost entirely due to deposits of the insecticide persisting on the relatively non-absorbent thatch surface of the roof. Davidson,[13] however, sprayed the roof only in one of his huts, using an oil-bound suspension of DDT at a dose of 2.0 g per m^2, and recorded mortality-rates of only 30%-40% in the first 3 months after spraying, declining to just over 10% in the fifth and sixth months. Hadaway & Barlow [38] later attributed the significant kills with DDT recorded by Davidson to the fact that the walls of most of his huts contained 50% gravel and were therefore not so absorbent as the pure mud which they used in their laboratory experiments.

A. minimus and others in Assam. Bertram [7] recorded a mortality-rate of only 13% for 6 weeks among all the mosquitos entering a hut treated with a DDT wettable powder at 0.5 g per m^2. With 2.2 g per m^2, however, the rate was 75% over the same period. Gilroy [29] produced much higher mortality-rates with 0.5 g per m^2 for 5 weeks after spraying, but in the sixth week his rates were very low. He also showed an inexplicable decrease in the mortality-rate at dosages above 1.5 g per m^2.

A. maculatus and others in Malaya. In huts lined with the paper-like sisalkraft, Wharton [88] recorded mortality-rates of over 80% among *A. maculatus* for 4 months after spraying with a DDT wettable powder at 2.2 g per m^2; this species does not normally rest in houses after feeding. In a repetition of the trial, using the same hut and dosage, Wharton was able to show a marked decrease in efficiency from the sixth month onwards after treatment.[89]

Reid [62] noted the mortality-rates among different species of anophelines entering huts of the type used by Wharton and treated with a DDT suspension at 2.2 g per m^2. Over the period 6-9 weeks after spraying, the mortality-rate among *A. maculatus* was over 80%, and that among other species was :

A. umbrosus	84%
A. barbirostris ...	61%
A. sundaicus	60%
A. letifer	31%

On this basis he postulated considerable differences in the susceptibility of species to DDT.

A. culicifacies in India. Most assessments of efficiency of insecticides recorded from India are based on reductions in daytime-resting mosquito populations in treated huts. Jaswant Singh et al.,[44] however, do record mortality-rates among *A. culicifacies* caught in window traps and escaping from mud-and-thatch huts treated with emulsions and suspensions of DDT at 0.6 g per m^2 and 2.2 g per m^2, though the numbers dead inside the huts are not recorded. Very high mortality-rates, approaching 100% in most cases, were shown for these escaping mosquitos in the first month after spraying with both dosages, and they were maintained for at least 2½ months with the higher dosage; where 0.6 g per m^2 was used, the mortality-rate dropped to 75% 6 weeks after treatment. Chemical analyses of scrapings from wall surfaces at varying intervals after treatment showed a more rapid loss from the mud surface when DDT had been applied in emulsion than when applied in suspension, thus confirming Hadaway & Barlow's findings.[34] Jaswant Singh et al. concluded that the larger dosage did not show a proportionate increase in duration over the smaller one. A low dosage and frequent application is very much favoured in India on the grounds that frequent replastering of houses is a common custom in the country, and that a lower percentage of houses will be missed if frequent applications are made.[43]

A. maculipennis in Iran. Garrett-Jones,[27] working in an area where the only variety was the type-form *A. maculipennis maculipennis*, sprayed the houses of several villages with DDT, in solution, in paste form, and as a wettable powder, at dosages of 1.0 g per m^2 and 2.0 g per m^2 Collections made from treated houses fitted with window traps showed a marked reduction in the total mosquitos when compared with those from untreated houses. The most marked reduction was in the number of mosquitos leaving the treated houses at dusk, precisely the same effect as was repeatedly observed by Davidson [13] in the case of *A. gambiae* and *A. funestus*. After an observation period of 12 hours, Garrett-Jones recorded only a 20% delayed-mortality rate in mosquitos from treated huts. No record of the number of dead mosquitos in treated houses was made, however, and no attempt was made to assess the duration of the effect of the insecticide.

A. quadrimaculatus in the USA. Gahan & Lindquist[25] and Gahan et al.[26] noted marked reductions in the number of daytime-resting *A. quadrimaculatus* in buildings treated with DDT, and observed irritated mosquitos leaving them. Releasing *A. quadrimaculatus* into treated rooms, catching them as they tried to escape, and keeping them for 24 hours afterwards, these workers record mortality-rates in the region of 90% 40 days and 70 days after spraying with doses of 0.62 g and 0.75 g of DDT per m^2 respectively. The control mortality-rate was, however, in one case as high as 53%.[25] No records of total mortality-rates were made.

The use of window traps to catch mosquitos escaping from DDT-treated buildings originated in the USA. Metcalf et al.[55] released *A. quadri-*

maculatus into rooms sprayed with DDT emulsion at 2.8 g per m^2 and fitted with such traps, and showed nearly 100% mortality among escaping mosquitos for at least 15 weeks afterwards. The highest mortality-rates were recorded in unoccupied rooms, and occupied ones lost their toxicity more rapidly. These authors concluded that in occupied houses DDT at this dosage is fairly effective for 1 month and has some effect up to 2 months.

Tarzwell & Stierli [77] similarly record window-trap mortality-rates in occupied and unoccupied rooms treated with DDT in solution in kerosene and in emulsion at 1.7 g per m^2 and 2.2 g per m^2. In two houses, for example, the corrected 24-hour mortality-rates among these escaping mosquitos were estimated from a graph to be between 70% and 76% in one, and between 40% and 59% in the other, in the third and fourth months after spraying. For over 5 months, 90% of the mosquitos were found dead on the floor of the houses. These authors observed little difference between the efficiency of 1.7 g per m^2 and 2.2 g per m^2 but considered that 1.1 g per m^2 was too low a dosage. In occupied houses, mortality was less than in unoccupied ones, and 2-6 weeks after spraying the corrected 24-hour mortality-rate among escaping mosquitos was only 39% in an occupied house. Release experiments were also carried out in vacant rooms, in which the wall surface was for the most part of wall-board, treated with DDT in solution in kerosene at 8.8 g per m^2 and in emulsion at 1.1 g, 2.2 g, and 4.4 g per m^2. The effective mortality-rate 24 hours after release was in all cases between 94% and 100% up to 10 weeks after spraying, while 2.2 g per m^2 gave good kills for more than 11 months.

A. albimanus in Panama. Dealing with a vector species which does not normally rest in houses during the daytime, Trapido [78] caught mosquitos entering DDT-treated houses during the evening and early morning and kept them for 24 hours afterwards. The houses were cane-walled and thatch-roofed and were sprayed, both inside and out, with a solution of DDT in kerosene at an unspecified dosage. A very marked reduction in the numbers caught and in the percentage feeding was observed in treated houses. Mortality was higher among gorged than among ungorged females, though significant survival occurred after 4 months; the urge to rest after feeding accounted for the higher mortality among them. The author concluded, however, that, even when gorged females began to escape, a considerable measure of protection was still being afforded by a continued reduction in biting frequency. It should be pointed out, however, that unless collections of dead mosquitos inside treated houses are made it is impossible to say whether insecticides act by reducing entry and preventing feeding.

After spraying two villages with DDT for 8 years and 5 years respectively (20 and 13 sprayings respectively), Trapido [79] no longer observed the drastic reduction of *A. albimanus* nor the selective mortality of gorged females, though a reduction in feeding persisted. Tests for the possible appearance of resistance to DDT in this species were negative.[80]

A. pseudopunctipennis in Mexico. Downs & Bordas [17] recorded experiments strictly comparable with those of Muirhead-Thomson,[56,57] using mud-and-thatch huts fitted with window traps. In a hut treated with a DDT wettable powder at an estimated dosage of 2.2 g per m^2 the total mortality-rate between the seventh and tenth months after spraying has been calculated as 77% from figures given by these authors; the delayed-mortality rates were recorded in this case 48 hours after capture; 65% of the mosquitos entering the hut were found dead on the floor; the remainder were found in the window trap.

Downs et al.[19] have also shown variations in the persistence of DDT on different mud surfaces in Mexico and have been able to show a definite relationship between the iron content of the mud and the persistence of DDT. Iron was found to have a catalytic effect on the decomposition of DDT by Fleck & Haller.[21] Hadaway & Barlow [37] are, however, of the opinion that the loss in toxicity is in the first place due to absorption, implying different rates of absorption on different muds, and that the catalytic decomposition of absorbed DDT is of secondary importance.

A. darlingi in South America. The rapid disappearance of *A. darlingi* from areas where house-spraying with DDT was the only method of malaria control used, as in British Guiana [28] and in Venezuela,[22] leaves no doubt as to the efficacy of DDT against this species. In British Guiana, where most of the coastal houses are made of non-absorbent materials, such as wood and metal, this success was achieved with DDT in solution in kerosene. Before the large-scale malaria-control programme was put into practice in that country by Giglioli, Symes & Hadaway [76] had made all-night observations on *A. darlingi* entering specially constructed wooden huts which had been treated with DDT in kerosene at an estimated dosage of 1.1 g per m^2. Irritation and escape were observed, and only a small proportion of the total entry was recovered dead on the floor. However, specimens taken alive from treated walls and kept in cages all died within 12 hours.

BHC

A. gambiae, A. funestus, and A. moucheti in Africa (see table III). In release experiments similar to those already described for DDT, Hadaway,[32] using a BHC wettable powder at 0.12 g of the gamma-isomer per m^2, showed no survival of *A. gambiae* for the first 6 weeks after spraying, and only 14% survival 3 months after spraying.

The results of Muirhead-Thomson,[57] Wilkinson,[90] and Davidson [13] all show a high efficiency for at least 3 months, and in some cases 4 months, when BHC is used at a dosage of over 0.2 g of the gamma-isomer per m^2, either as a wettable powder or in oil-bound suspension. Lower dosages of 0.05 g and 0.08 g of gamma-BHC per m^2 produced high kills for only 1 month.[13] In contrast to the marked escape from DDT-treated huts, most of the mosquitos entering BHC-treated huts were found dead inside the huts, and only small proportions reached the window traps. Three months after spraying, significant kills of *A. gambiae* and *A. funestus* suspended in cages in BHC-treated huts without actual contact with treated surfaces were clearly demonstrated by Davidson.[13] The fumigant action of this insecticide even after its disappearance by absorption from mud surfaces had already been proven in the laboratory by Hadaway & Barlow.[37]

Davidson,[12] in carrying out a malaria-control programme on a plantation in the Belgian Congo, assessed the efficiency of BHC (in 3 different wettable powders) against adult *A. moucheti* by fitting existing houses with window traps and also using human-bait traps inside the houses. Mosquitos caught by these two methods were kept for about 6 hours, and the delayed-mortality rate was recorded. Both window-trap and human-bait-trap catches were markedly reduced in numbers for long periods after treatment (more than 4 months), and the indications were that this reduction was due to the mosquitos' dying inside the houses; using existing occupied houses it was impossible to collect all the dead mosquitos, and so no attempt could be made to calculate the total mortality occurring. High mortality-rates were recorded among *A. moucheti* caught alive for at least 2 months, and in some cases up to 3 months, after treatment with about 0.11 g of gamma-BHC per m². As an example, in one village the corrected delayed-mortality rates were :

	Months after treatment			
	1	2	3	4
Window-trap catches	86%	69%	78%	5%
Human-bait-trap catches	57%	64%	91%	36%

From the continuing reduction in numbers trapped over these periods it would appear that efficient control was being maintained for at least 3 and possibly 4 months.

A. minimus and others in Assam (see table III). The initial superiority of BHC over DDT has been clearly demonstrated in Assam by both Bertram [7] and Gilroy.[30] Complete kills were obtained by the latter for 3 months at an estimated dosage of 0.22 g of the gamma-isomer per m².

A. maculatus in Malaya (see table III). Using the comparatively high dosage of 0.44 g of gamma-BHC per m² (applied with a brush) on a relatively non-absorbent surface, Wharton [88, 89] also showed the superior efficiency of BHC over DDT and produced high kills for 6 months.

Reid [62] found BHC more effective than DDT against all the anopheline species entering huts similar to those used by Wharton.

A. culicifacies in India. Jaswant Singh et al.[44] state that they found little difference between the efficiency of BHC at 0.11 g of the gamma-isomer per m² and DDT at 0.55 g per m², as determined by reductions in daytime house-catches and survivals in window-trap catches. In the BHC-treated village no survivals were recorded in the first 6 weeks after spraying, but in the ninth week 12% of the escaping mosquitos survived. This is actually considerably less than the percentage survivals these authors recorded for DDT at 0.55 g per m^2 in the second month after spraying, and it would appear that BHC was more efficient than DDT at these dosages.

A. pseudopunctipennis in Mexico (see table III). Downs & Bordas [17] also found BHC more efficient than DDT and record the remarkable kill of 96% (as compared with 77% for DDT) 7-10 months after spraying at a dosage of 0.22 of the gamma-isomer per m^2. During this period a higher proportion of the total mosquitos was found dead inside the hut (80%) than occurred in a similar hut treated with DDT (65%).

Mixtures of DDT and BHC

Davidson [13] showed that a mixture of BHC and DDT gave the initial high kill (lasting about 3 months) of BHC and the persistent moderate kill of DDT. Using a mixture containing 13% BHC and 40% DDT in oil-bound suspension at calculated dosages of 0.08 g of gamma-BHC per m^2 and 2.5 g of DDT per m^2 in a hut with walls of mud and gravel and a roof of palm thatch, he recorded the following monthly corrected mortality-rates among *A. gambiae* and *A. funestus* :

Month	1	2	3	4	5	6	7	8	9	10	11	12
Mortality * (%) . .	94	86	70	58	80	55	41	58	55	49	42	34

* For mortality-rates after 6 months we are indebted to Mr. G. F. Burnett of the Colonial Insecticides Committee, Research Unit (Great Britain), and we are grateful to Mr. C. B. Symes of the Colonial Office for permission to publish them.

Jaswant Singh et al.[44] also used a mixture of BHC and DDT, but in this case a mixture of wettable powders at much lower estimated dosages (0.06 g of gamma-BHC per m^2 and 0.28 g of DDT per m^2). In their estimation, this mixture was effective for at least 9 weeks against *A. culicifacies* and was more efficient than BHC by itself at 0.11 g of the gamma-isomer per m^2 or DDT by itself at 0.55 g per m^2.

Dieldrin

Davidson,[13] in his work in Kenya on the efficiency of various insecticides in experimental huts against *A. gambiae* and *A. funestus*, found the most efficient of all to be dieldrin. The hut used had walls of mud and gravel and a roof of palm thatch. A wettable powder containing 25% dieldrin was applied at an estimated dosage of 0.6 g of dieldrin per m^2; although analyses of sample papers put up at the time of spraying yielded the very low average figure of 0.08 g of dieldrin per m^2, this was considered to be much lower than the actual dosage applied. The following monthly corrected mortality-rates were recorded :

Month	*Mortality* * (%)	*Month*	*Mortality* * (%)
1	100	13	84
2	100	14	74
3	100	15	82
4	90	16	73
5	91	17	62
6	87	18	65
7	81	19	54
8	88	20	68
9	95	21	67
10	91	22	51
11	94	23	49
12	91		

* For mortality-rates after 6 months we are indebted to Mr. G. F. Burnett of the Colonial Insecticides Committee, Research Unit (Great Britain), and we are grateful to Mr. C. B. Symes of the Colonial Office for permission to publish them.

Thus a total mortality-rate of over 60% persisted for the remarkable time of 18 months, and had barely fallen below 50% after 23 months.

Dieldrin was also shown to have a remarkable particulate effect,[14] continuing to kill a high proportion of *A. gambiae* and *A. funestus* suspended overnight in cages inside the treated huts without actual contact with treated surfaces for at least 9 months after spraying.[13]

This remarkable, high, long-lasting kill has again been attributed by Hadaway & Barlow [38] to the relatively non-absorbent mud-and-gravel wall surface and non-absorbent thatch-roof surface, and its uniform production cannot be assured in the absence of experiments on fully absorbent materials.

Insecticidal Efficiency Required for Controlling Malaria

The concept that it is not necessary to secure the complete absence of vectors to eliminate transmission is old, and due to Ross; [65] it is supported by field measurement of critical densities such as that of Russell & Rao.[70] The original concept and its exploration were based on the idea that mosquito density was the sole variable factor, and paid no attention to the effect of variations in the expectation of life, though their importance has always been implicitly accepted. The first use of pyrethrum insecticides quickly demonstrated that concepts based on this latter factor were applicable, and must differ from those based on density. Experiments by Park Ross,[64] de Meillon,[15] Russell & Knipe,[66-68] Russell, Knipe & Sitapathy,[69] and Viswanathan [82, 83] rapidly showed that anopheline destruction which fell far short of local elimination resulted in great reduction of malaria, the actual reduction in density of mosquitos being relatively slight. It is notable that some of these workers achieved control of *A. gambiae*, which is one of the most difficult to control and is now known to be partly exophilic and highly anthropophilic, and is commonly very numerous, as well as of *A. minimus* and *A. fluviatilis*, two very dangerous anthropophilic vectors, and of *A. culicifacies*, which is endophilic but often a relatively weak carrier, being often zoophilic and short-lived. During these studies, Viswanathan [83] made a preliminary documentation of the reduced expectation of life of *A. minimus* resulting in elimination of transmission.

The advent of residual insecticides, more potent than pyrethrum, diverted attention from this body of evidence and resulted in the general adoption of a criterion of virtual local elimination of adult mosquitos as necessary for control.

An exploration of the actual mortality-rates needed for this purpose has recently been summarized by Macdonald.[50] The exact numerical conclusions are necessarily tentative and subject to confirmation, and the simpler restatement of them in table IV is subject to the same qualification; the authors have, however, little doubt that the method of approach is correct and that the figures given represent the approximate order of truth. This work indicates strongly the existence of critical values which may be expressed in terms of mosquito mortality or expectation of life. The attainment of particular mortality-rates depends on the efficacy of the insecticides and on the proportion of mosquitos coming into contact with them, and for this reason required mortality-rates in the treated shelter are given for species which enter them every day, three days out of four, and one day out of two, these last two being called moderate and medium endophilic types respectively. The figures are calculated on the assumption that temperatures are high enough for rapid completion of the extrinsic cycle, and much lower mortality-rates would be needed at low temperatures.

TABLE IV. PROBABLE INSECTICIDAL EFFICIENCY WITHIN TREATED SHELTERS NECESSARY FOR CONTROL OF MALARIA

Original mosquito-density	Degree of endophilism of vector *		
	complete **	moderate†	medium ††
	mortality-rate (%)		
Very dense (250 bites per night)	40-50	50-63	75-88
Dense (100 bites per night)	35-45	43-57	60-80
Moderate (10 bites per night)	25-35	30-45	40-62
Mild (1 bite per night)	18-27	21-33	26-44

* The first figure refers to a species with an anthropophilic index of about 10%, and the second to one with an index of 100%.
** Species entering treated shelter every day
† Species entering treated shelter three days out of four
†† Species entering treated shelter one day out of two

Within the ranges of variation observed in nature, endophilism is clearly the most important factor operating; original density, which indicates the amount of breeding in the locality, is next in importance; anthropophilism, though it plays a part, is the least important.

A tentative and purely preliminary exploration of the theoretical background of mosquito eradication by imagocidal work has been made by Macdonald.[49] Knowledge on which to base numerical conclusions is inadequate, but it may be suggested that a minimum maintained-mortality rate of between 60% and 70% per day is needed. Such mortality is attainable within treated shelters, but the effect of even moderate exophilism would be to make it well-nigh unattainable except with extremely potent insecticides.

An insecticide which was to meet the requirements of control under all circumstances would be very potent indeed, and more potent than any DDT preparation tested by Davidson. Fortunately, most natural circumstances would be met by attaining a mortality-rate of about 65% among mosquitos entering treated shelters, and some common ones by an insecticide producing a 45%-mortality rate. Though workers will adjust their standards to local conditions, it is suggested that the normal criterion of efficacy in an insecticide should be the attainment of a 65%-mortality rate within the day among all mosquitos entering a treated shelter. One producing an 85%-mortality rate might be rated as suitable for use under the most severe conditions, and one not exceeding 50% mortality as suitable for the control of moderate transmission by endophilic mosquitos only.

Conclusions on Dosage

Present evidence indicates that the toxicity and persistence of residual nsecticides, especially the non-volatile ones, depend not so much on dosage as on the physical form of the insecticide. The continued presence of the insecticide on treated surfaces in a form easily picked up and retained by insects settling on them is the main criterion of efficiency. Dosage is important in so far as it affects the persistence of the insecticide in this available form, and it will depend to a very large extent on the nature of the surface, especially the absorptive properties, to which the particular formulation is applied.

The physical form which the insecticide assumes after its application in solution or emulsion to non-absorbent surfaces depends very largely on the types of solvents used in these formulations, and to some extent on the nature of the treated surface. In the case of wettable powders, the form of the insecticide can be standardized and specifications have been prepared by the WHO Expert Committee on Insecticides.[91] It is very strongly recommended that only preparations complying with these specifications should be brought into routine use.

The problem of the application of residual insecticides to absorbent surfaces, such as mud, so universal in malarious countries, is far from solved. It is generally accepted that wettable powders are the most efficient formulations for such surfaces, but even with these a marked loss in toxicity may occur owing to absorption, and higher initial dosages or more frequent applications are required than on non-absorbent surfaces.

With volatile insecticides, such as BHC and aldrin, some degree of absorption seems to be advantageous in that it slows down the loss by volatilization, though kills are still maintained by their fumigant effects; but at the usual field dosages of 0.1 g and 0.2 g of gamma-BHC per m^2 the decline in toxicity is still rapid and necessitates frequentre application. The use of higher dosages of volatile insecticides on absorbent surfaces might well bring the effect of these insecticides more into line with the long-lasting high efficiency of non-volatile ones, such as dieldrin, on non-absorbent surfaces.

The fumigant effect of volatile insecticides and the particulate effect of the non-volatile dieldrin are great advantages in that they may offset deficiencies in spraying technique, especially lack of uniformity of application.

The marked irritant effect of DDT on mosquitos makes adequate dosage in readily available form imperative.

Strictly subject to these qualifications, the following tentative conclusions are put forward :

1. Field tests, experiment, and theory suggest that DDT may not be sufficiently lethal to control extreme conditions of transmission.

2. DDT can, however, control malaria under most natural conditions, and meets the normal criterion of efficacy. A dose of 2.0 g per m^2 is likely to be effective on most types of surfaces, including many mud and soft-plaster walls, for about 6 months. On hard, non-absorbent walls it may be effective for 18 months or more.

3. Smaller doses, such as 0.5 g per m^2, are effective under many circumstances, and on many mud walls, for 6-8 weeks, but the data on which to lay down a relationship between dose and period of efficacy are quite inadequate.

4. A dose of 0.2 g of the gamma-isomer of BHC per m^2 on mud or other walls may be expected to meet normal requirements for 3 months, exceptionally rigorous ones for 2 months, and mild ones for about 4 months or perhaps longer.

5. A dose of 0.1 g of the gamma-isomer of BHC per m^2 may be expected to meet normal requirements for about 6 weeks and mild ones for a longer period, perhaps 2-4 months.

6. Dieldrin applied at a dose of 0.6 g per m^2 on mud and gravel walls appears to meet exceptionally rigorous requirements for about 12 months, normal requirements for about 18 months, and mild requirements for

possibly 2 years. The possibility of mechanical removal, or obscurement by smoke deposits, during these long periods must, however, be borne in mind. The relationship between wall surfaces and dieldrin persistence is as yet inadequately studied; laboratory indications are that it may be less persistent on some types of mud wall.

7. Field data on the action of smaller doses of dieldrin are not available. Doses such as 0.25 g per m^2 might well have a valuable persistent effect, and deserve careful study.

RÉSUMÉ

Un certain empirisme préside encore au choix de la dose d'insecticide employée dans la lutte contre le paludisme. Une dose de 2 g/m^2 est généralement adoptée pour les produits du type DDT. L'efficacité a été établie jusqu'ici surtout d'après la diminution de la densité anophélienne à la suite du traitement. Le fait que la « répulsion » exercée par l'insecticide sur le moustique concourt à cette diminution rend très approximatives les estimations du pouvoir létal des insecticides. Les données sur la mortalité réelle provoquée par ces produits sont encore fragmentaires.

Cette étude contient des renseignements sur les doses de DDT, de HCH et de dieldrine en usage dans les diverses parties du monde et des indications sur les meilleurs résultats obtenus avec divers insecticides sur de nombreuses espèces de moustiques vecteurs du paludisme. Ces informations mettent en lumière la nécessité d'approfondir les recherches sur la biologie des anophèles, la physico-chimie des insecticides et leur mode d'action.

Des recherches expérimentales ont été faites par les auteurs sur le pouvoir répulsif et létal du DDT, du HCH et de la dieldrine sur plusieurs espèces de moustiques. Les résultats expérimentaux ainsi que les observations sur le terrain autorisent les conclusions suivantes :

La toxicité et la durée d'action des insecticides à effet rémanent — particulièrement les non volatils — dépendent moins de la quantité pulvérisée que des caractères physiques de la préparation utilisée. La quantité n'est importante que dans la mesure où elle affecte la persistance de l'insecticide sous une forme assimilable par l'insecte, ce qui dépend, en grande partie, du pouvoir absorbant des surfaces.

Les caractères physiques de l'insecticide, en solution ou émulsion, après application sur des surfaces non absorbantes, dépendent en grande partie des véhicules utilisés pour ces préparations. Les caractéristiques des poudres mouillables ont pu être standardisées et des normes ont été établies par le Comité d'experts des Insecticides, de l'OMS.

Le problème de l'application des insecticides à action rémanente sur des surfaces absorbantes, telles que la boue séchée, est loin d'être résolu. Il est admis que les poudres mouillables sont les préparations qui conviennent le mieux à ce genre de surfaces. Avec les insecticides volatils, tels que l'aldrine ou le HCH, une certaine absorption paraît avantageuse, parce qu'elle diminue les pertes par volatilisation.

Le DDT peut tenir le paludisme en échec dans la plupart des conditions qu'offre la nature et il satisfait aux critères d'efficacité établis. Une dose de 2 g /m^2 sera efficace durant environ 6 mois sur la plupart des surfaces — même la boue séchée ou le plâtre; l'effet peut durer jusqu'à 18 mois sur les parois non absorbantes. 0,5 g/m^2 peut suffire pour 6-8 mois. Il semble cependant, d'après l'expérience, que le pouvoir létal du DDT puisse ne pas être suffisant pour combattre le paludisme dans des conditions d'extrême infection.

Une quantité de 0,2 g d'isomère gamma du HCH peut être efficace durant 3 mois, dans des conditions normales, et 0,1 g durant 6 semaines. La dieldrine à raison de 0,6 g/m² sur les parois de boue peut suffire pendant 12 mois dans des conditions de forte infection, durant 18 mois dans des conditions moyennes et jusqu'à 2 ans en cas de faible infection. L'inactivation de la dieldrine par la fumée qui se dépose sur les parois doit être prise en considération. L'étude de l'effet de doses plus faibles encore, telles que 0,25 g/m², doit encore être vérifiée.

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