INSECT REPELLENTS AND MITICIDES

BY
Major M. A. C. DOWLING, M.R.C.S., D.P.H. (Lond.), D.T.M. & H.
Royal Army Medical Corps

EARLY USE OF REPELLENTS

Before the 1939-45 war, naturally occurring essential oils such as citronella, eucalyptus, cassia and many others were in general use as insect repellents. Citronella formed the basis of the majority of proprietary repellents prepared in the form of creams and lotions. Non-toxic and pleasant to use, this substance was effective against many species of mosquitoes for fifteen to twenty minutes, but the necessity for frequent re-application and its pungent odour made it unsatisfactory for continued field use.

Pyrethrum was reported to possess good repellent power and was also in widespread use before the war. The joss sticks or cones which were burnt after dusk in many households in the East to drive away the mosquitoes contained, in many cases, pyrethrum and arsenic (31, 24, 57).

Until 1939, however, there was little stimulus to research into repellents, and no definite results were obtained from work carried out. This was due to the absence of a standard method of testing and the failure to use test insects of a comparable stage of development. The substances tested, principally the essential oils, were not chemically pure, so that conflicting results were reported (8).

The aim of this article is to provide a short account of the work carried out on repellents and miticides since 1939. The importance of both these sub-
stances as a factor in the comfort and efficiency of troops in the tropics and sub-arctic cannot be emphasized too strongly.

**Factors involved in the attracting and repelling of insects**

In spite of a considerable amount of work carried out in recent years, no conclusive evidence has been obtained about the way in which mosquito repellents act. In the early days when the essential oils like citronella were in widespread use, it was believed that the strong-smelling repellent acted by disguising the smell of the human body: a negative rather than a positive effect. The more recent compounds, however, have little or no odour detectable by man.

The work of Brown and his colleagues (2, 3, 4, 38, 47), using dummy men which could be made to reproduce a variety of natural conditions, has done much to explain the mechanism of attraction of insects to the human body. Working with different *Aedes* species, he was able to show that a moist surface attracted strongly when the atmospheric temperature was above 60° F. Below this temperature, however, warmth by convection was the important factor, and the presence of moisture did not significantly increase the attraction of a warm object. A sweat-soaked jerkin was considerably more attractive than a water-soaked one in a hot atmosphere, but continual sweating reversed the action. Similarly, a warm object attracted most strongly in the temperature range 90-110° F., but over 120° F. it was a repellent. The production of 10 per cent. carbon dioxide from the dummy head in warmed air at a rate of about 2 litres per minute doubled the attractiveness of the dummy for mosquitoes.

The most effective repellents possess the highest vapour repellency power. Maximum activity is displayed by compounds with a high atmospheric boiling-point, chiefly in the range 230-260° C. (42). They presumably act by maintaining an effective vapour concentration over a period of time, without volatilizing rapidly on the warm skin. According to Christophers (8), a repellent should have a boiling-point of at least 250° C. to give an effective protection for two hours, and a boiling-point of 280° C. to protect for six hours.

In field tests, mosquitoes are observed to approach and even to settle for short periods on treated limbs, but blood meals are not as a rule taken until the repellent begins to deteriorate. The wearer usually expects something more dramatic from a repellent, and the fact that insects may settle on the exposed, treated area will upset his confidence in the repellent used (28).

Different people vary enormously in their attractiveness to insects, some individuals receiving far more bites than others in similar conditions. In the same way, different species of insects exhibit different responses to the various repellents. This aspect of the subject is still largely unexplored, but it emphasizes the need for identical conditions in the comparison of effect of the various repellent compounds.

From Brown's work on attractants, it can be seen that a man doing active work, with the requisite production of body heat, carbon dioxide and sweating, is more attractive to mosquitoes than a resting man. But this active man will tend to lose his repellent more rapidly by absorption into skin (21), excessive
sweating (17) and the action of direct sunlight (15). Much work has therefore been carried out in an attempt to find a repellent which would resist these factors and give lasting protection to a man doing heavy work in a tropical climate.

**LABORATORY AND FIELD METHODS USED FOR TESTING REPELLENTS AND MITICIDES**

(a) **Repellents**

Granett of Rutgers University was the first to introduce systematic and controlled research in this field. He formulated the properties of the ideal repellent in order to provide a clear aim for investigation. These properties are enumerated below:

1. It should have a lasting effect against a variety of insects, preferably for at least twelve hours (overnight).
2. It should be odourless or have a pleasing odour.
3. It should cause no irritation to the skin even after repeated applications, and should be harmless if accidentally inhaled or swallowed.
4. It should have no adverse effect on clothing (staining, bleaching, fibre-weakening, etc.).
5. It should not have an objectionable oily appearance or feel on the skin, and should be easily washed off with soap and water, but resistant to sweat and rain (45).
6. It should be cheap and easy to prepare commercially from readily available materials.
7. It should be stable for prolonged periods in all conditions and climates (24).

Granett also introduced a method for testing repellents using as standard insects *Aedes aegypti* and *Anopheles quadrimaculatus* adult females at identical stages of development. This method was adopted by the Orlando Experimental Station, Florida, where a major part of the basic work on repellents has been carried out (14). The principal criterion in the test was the time taken to the first bite when the forearm, treated with repellent, was exposed to the unfed mosquitoes. Observations were later prolonged beyond this point in order to demonstrate the efficiency and duration of protection.

No substance was accepted for further trial unless the average time to first bite with the different species was more than:

- *A. aegypti* ... ... ... 180 minutes
- *A. quadrimaculatus* ... ... ... 120 "

It was emphasized that tests must be carried out under constant environmental conditions, and that test individuals must remain in the environment throughout the period of test. This was due to the observed fact that the intensity of repellent effect and its duration varied greatly with these factors.

After laboratory testing at Orlando, the most effective materials were first
examinined by the Food and Drug Administration for chronic toxicity and liability to skin irritation in humans. They were then tested in the field on a large scale, and the impressions of the wearer, together with observations on biting rates, were taken in conditions which included heavy sweating.

In the report of the Mosquito Repellent Enquiry at Cambridge (31) it was considered that the "time to first bite" method did not give enough data about the degree of repellency and its effective duration. A different method was described, based on careful recording of the behaviour of *A. aegypti* during exposure to a treated arm.

(b) Miticides

With the extension into the far-eastern theatre of the 1939-45 war, the protection of troops against trombiculid mites, vectors of scrub typhus, formed a new and urgent problem. Much of the initial work on this subject was carried out by McCullough, for Australian forces were operating in endemic typhus areas. He demonstrated (28) that effective compounds did not act as repellents but as miticides, immobilizing the mites and killing them before they could attach and transmit the disease.

The Orlando Experimental Station confirmed this finding and evolved a standard method of investigation (33) which depended on the time taken for immobilization of mites introduced on to a square of cloth impregnated with test substance at a dose of .4 ml. (or 4 gms.) per square foot. This "stopping time" provided a good comparison between the efficacy of different miticides, and allowed the rapid screening of a large number of compounds.

It was demonstrated that protection of the wearer could be best assured by the impregnation of the entire clothing rather than by barriers applied at the points of entry for mites (54). This was due to the absence of repellent effect. After preliminary screening by the Food and Drug Administration, the most effective materials were subjected to the following tests with impregnated clothing in field trials:

1. The effect of prolonged impregnation with miticides on clothing materials in common use was carefully studied.
2. The effect of different clothing materials on the intensity and duration of miticidal effect.
3. The effect of heavy sweating, rain soaking, water rinsing and laundering with soap and water on the intensity and duration of miticidal effect.
4. The total duration of effect in different clothing materials during continuous wear, with normal laundering every five or six days.
5. The personal observations of the wearer, and the effect, if any, of the miticide on his skin, were carefully recorded throughout the period of trial (33).

As with the tests for repellency, great attention was paid to constant environmental conditions, as the stopping times and attachment rates of mites were
shown to vary markedly with humidity, temperature, the time of day, the wearer, and the length of wear and pre-wear of impregnated cloth (20).

The Results of Research in Repellents

After extensive screening of products in laboratory and field trials at the Orlando Experimental Station, four compounds were shown to possess outstanding properties as repellents when applied to the skin, and they were in no way toxic to humans (24, 45). The four repellents are described briefly below:

1. *D.M.P.* (dimethyl phthalate) possessed a high degree of repellency to *Anopheles*, *Culicoides* and *Simulium* species, giving an average protection in the field of three hours (1, 9, 48).

2. *Rutgers 612* (2-ethyl-1, 3-hexanediol): Colourless and almost odourless like *D.M.P.* and with comparable effect. This compound was strongly active against *Aedes* and *Culex* species as well as *Anopheles*. Its repellent action against *A. aegypti* could be prolonged by the addition of an alcohol (24).

3. *Indalone* (n-butyl mesityl oxide oxalate): This material proved to be an excellent repellent against biting flies, especially *Stomoxys* species, an advantage not possessed by the others. Field tests with *Glossina palpalis* showed that indalone was an effective repellent against this tsetse species (15). This repellent undergoes dimerization when exposed to sunlight, and the dimer is inactive, but the repellent effect lasts several hours (18).

4. *Dimethyl carbate* (cis-bicyclo, 2, 2, 1-5 heptane-2, 3-dicarboxylic acid dimethyl ester) was not used so frequently as the others, although it replaced Rutgers 612 when the latter was in short supply. It was shown to be the most effective of the repellents against Alaskan mosquitoes (average time to first bite one hour twenty-five minutes against nineteen minutes for *D.M.P.* (1)).

These four were all non-toxic, but were all plastic solvents. They should therefore be kept away from fountain pens, spectacle frames, watch-glasses, nylon and artificial silk stockings, etc. Contact with mucosae or conjunctivae may give rise to intense local irritation, and Rutgers 612 often may produce a burning sensation when applied to sore or sunburnt skin (24, 45, 53).

Further investigation showed that mixtures of three (ternary) of these repellents gave better results than the individual repellencies would lead one to expect, indicative of synergistic action. The most effective mixture in laboratory and field tests was 6-2-2, consisting of:

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>D.M.P.</td>
<td>...</td>
<td>...</td>
<td>6 parts by weight</td>
</tr>
<tr>
<td>Rutgers 612</td>
<td>...</td>
<td>...</td>
<td>2</td>
</tr>
<tr>
<td>Indalone</td>
<td>...</td>
<td>...</td>
<td>2</td>
</tr>
</tbody>
</table>

This repellent mixture, which became the standard U.S. Army issue during the war, gave full protection for at least four hours against a wide range of
Insect Repellents and Miticides

This included most species of mosquitoes, midges, biting flies, simulids and the larval and nymphal forms of ticks. Trombiculid mites were immobilized and killed (13, 24, 30, 34, 45, 48). The wide range of nuisance and disease-vector insects repelled by 6-2-2 made this mixture a more effective all-purpose repellent than D.M.P. alone. The latter, however, was cheap and readily available commercially and it has proved its efficiency in the field as a universal issue in the British Army.

THE RESULTS OF RESEARCH IN MITICIDES

In the early part of the war, research on miticides was retarded by the discovery that the established repellents, D.M.P. and 6-2-2, were efficient in this respect, making possible a single, all-purpose issue to troops. There was considerable variance in opinion about the duration of miticidal effect of D.M.P. in impregnated clothing, as the following reports from different sources show, but all were agreed that the repellents would not withstand laundering, which reduced their value in the field.

1. Sprinkled evenly over clothes (24 ml. average dose), the effect of D.M.P. lasted up to eight days, but washing of clothing reduced the safe period to two days (54).

2. Impregnation with a 5 per cent. emulsion (soap) of D.M.P. lasted five weeks against sun, rain, walking in wet grass, excessive sweating, but would not withstand laundering with soap (62).

3. Applied as an emulsion to outer garments, D.M.P. was effective up to four weeks in unwashed clothing. It lost its efficacy rapidly after wading in water, drenching with tropical rain or sweat, and laundering with soap and water. Rutgers 612 was shown to be as effective as D.M.P. (26).

In Australia, work was carried out to find a substance which would resist laundering and drenching. Dibutylphthalate (D.B.P.) was found to be as effective a miticide as the related compound D.M.P. with much better lasting properties. It was shown that D.B.P.-impregnated clothing retained its miticidal effect through eight washes and was unaffected by heavy rainfall and sweating. In 1943 D.B.P. was manufactured on a large scale in Australia and issued to troops with simple instructions for fortnightly impregnation of clothing in the field (see "Application of Miticides" later) (8, 25, 54).

Meanwhile, at the Orlando Experimental Station extensive screening of compounds began in the hope of discovering an efficient miticide which would withstand repeated heavy laundering. Four substances were finally selected for further testing, and these are listed below:

(a) D.M.P.—A very efficient miticide before laundering. In view of its excellent mosquito repellency, tests were initiated to try and prolong its persistence in cloth so as to give a double effect.
(b) D.B.P.—This substance was included because it was used extensively by the Australian forces, with reported good resistance to washing. It was of no value as a mosquito repellent.

(c) Phenyl cyclohexanol.—This was found to be a good miticide with lasting properties and also a mosquito repellent similar in efficacy to Rutgers 612. It possessed the disadvantage that it occasionally gave rise to irritation of hands and face.

(d) Benzyl benzoate.—This was the most effective miticide of all with the best resistance to laundering. It was, however, of no value as a mosquito repellent (33).

Crude benzene hexachloride (B.H.C.) containing 12 per cent. of the gamma isomer was also found to be a very efficient miticide. It worked both by contact and fumigant action with good residual effect through several launderings. It was abandoned as a clothes impregnant because of its toxicity and the intense irritation caused to skin and eyes. Its use, however, when applied as a dust (10 lbs. per acre) to mite-infested areas produced effective control of mites in the field.

Further testing of the four selected miticides gave the following results:

(a) D.M.P.—The efficacy was lost after a single laundering of impregnated clothing in warm soapy water. Further work to find a method of prolonging its persistence in cloth failed, so D.M.P. was considered unsuitable for use (55).

(b) D.B.P.—Results obtained were variable and disappointing. It was less effective initially as a miticide than D.M.P. (stopping time six minutes against less than two for D.M.P.).

(c) Phenyl cyclohexanol.—Similar to D.B.P.

(d) Benzyl benzoate.—This was by far the most effective, and clothes treated with 5 per cent. emulsion were still highly miticidal after three heavy launderings with warm soapy water (33).

Benzyl benzoate was then tried out exhaustively under field conditions to determine the effect on the clothing and on the wearer, and also the duration of miticidal effect of impregnated clothes during long periods of wear and repeated heavy launderings. The results of this investigation are tabulated below:

1. No skin lesions of any sort or skin irritation could be attributed to benzyl benzoate after sixteen weeks of trial.
2. The clothing was laundered thoroughly every five to six days, and benzyl benzoate alone lasted through three to four washes. An emulsion containing 5 per cent. benzyl benzoate with 5 per cent. vinylite resin as a binder lasted through five washes.
3. Impregnated clothing was slightly warmer than the untreated, but no characteristic of the benzyl benzoate impregnated clothes rendered them any more unsuitable for tropical wear than untreated clothes.
(4) The lower limit of miticidal activity was a concentration of 0.1 per cent in the clothing. Below this figure protection could not be guaranteed.

(5) Even wool garments impregnated with benzyl benzoate showed satisfactory in miticidal properties, but were slightly less resistant to laundering than cotton garments (7).

In subsidiary tests against ticks, benzyl benzoate was the best of all materials tried, and impregnated clothing gave protection for at least eight days (more effective and for longer duration against larval and nymphal forms than against the adult ticks) (36).

Benzyl benzoate was therefore adopted for use as a miticide by the U.S. Army. When in scarce supply, it was mixed in equal parts with D.B.P., as it was shown that the miticidal activity and duration of benzyl benzoate was unaffected in this combination (52).

Methods for the Application of Skin Repellents and Clothing Impregnants

Before the problem of mite-borne typhus arose in the early part of the 1939-45 war, repellents applied to the skin at regular intervals were considered to give adequate protection. The successful impregnation of clothing with D.B.P. by the Australian forces led to a search for some compound as clothing impregnant which, combined with an effective skin repellent, would give complete protection to the wearer from assault by any of the variety of disease-carrying and nuisance insects. It was soon observed that the vehicle in which a repellent was made up was an important factor in its efficiency and persistence, as also was the method of impregnating clothing and applying the repellent to the skin. These factors are considered briefly in the ensuing paragraphs.

(a) The Application of Repellents

D.M.P. and 6-2-2 in pure, liquid form were found to be satisfactory for field use and were extensively employed during the war. Observations in the field, however, showed that, on the sweating skin, the repellents tended to drain or "creep" (31) to the dependent parts of areas treated, and were removed by friction against the clothing or the action of wiping away excess sweat. At the same time, even the most efficient repellent was eventually washed away by heavy sweating during exertion, or underwent deterioration in the direct sunlight. Re-application was therefore necessary every one to one and a half hours instead of the three hours which was the safe limit in the laboratory experiments (15, 17).

Research was therefore instituted in an attempt to find a suitable vehicle which, in individual containers, would be stable in all climates, which would maintain or even potentiate the effect of the incorporated repellent, and which would be resistant to washing off by heavy sweat and, if possible, to rubbing off by the friction of the clothing.

The preparation of repellents in cream form not only improves the cosmetic appearance but also often enhances the efficiency of the repellent by extending...
the duration of its effect (24). The Mosquito Repellent Enquiry at Cambridge (1943-45) revealed that lotions, ointments with petroleum jelly base and vanishing creams were on the whole unsatisfactory as vehicles for D.M.P. Clay pastes, with the addition of shellac to form a rub-proof skin, tended to reduce the repellent effect. A cream with a waxy consistency (see No. 2 below) appeared to give the best results (31). It has also been observed that, to be effective against midges, the proportion of active ingredient should not fall below 40 per cent. v/v (48), but this does not seem to be universally applicable.

Four different specifications for creams which remain stable and have stood up to exhaustive tests are listed below:

1. D.M.P. 70
   Mag. stearate 30
   Arachis oil 27.5
2. D.M.P. 12.5
   White wax 9
   Unemul 40
   Protein 10
3. D.M.P. 50
   Bentonite 65
4. D.M.P. 33
   Cal. stearate 2

The first three creams (31) were shown to undergo no deterioration over a two-year test period; they were easy to apply and were as effective as pure D.M.P. throughout the test. The fourth cream was put out by Orlando and was claimed to prolong the repellent action of D.M.P. up to six hours in the field (44).

Certain practical points were raised with reference to the application of repellents to the skin. First, to obtain good effect the repellent should not be dabbed on here and there, but should be applied evenly over all exposed surfaces. Second, when the skin is hot and moist with sweat, a feeling of complete cover is given by application of too small a dose of repellent to be effective. These points, combined with the fact that there is frequently no apparent mosquito nuisance in highly malarious areas, led to irregular and inefficient application of repellent, which could only be remedied by good discipline (28).

It was observed that direct application of 20 ml. D.M.P. to shirt and trousers by shaker bottle protected the wearer against *Aedes* bites for two to three days (28). It should be remembered, however, that D.M.P. is a plastic solvent, and any nylon or other synthetic fibres in the cloth may be damaged by impregnation (27). The brief endurance, moreover, of D.M.P.-impregnated clothing in strenuous circumstances of wear in the field limits its value in this respect.

Spraying with D.M.P. of anti-mosquito sleeping nets with a wide mesh of ½ inch has been reported to repel mosquitoes for several days, allowing for cooler sleeping than under the standard net (45). Based on the results of work carried out by the Medical Research Institute of India, veils, gauntlets and overboots consisting of ½-inch mesh netting impregnated with D.M.P. were introduced. These items, packed in small wallets, were issued to British troops operating in malarious areas as "individual anti-mosquito outfits," and proved invaluable in forward areas where other means of protection were impracticable. The outfit was re-impregnated weekly with D.M.P. (or more frequently if in constant use) (8). More recently it has been shown that protective netting, impregnated and kept in small, air-tight tins (e.g., flat 2-ounce tobacco tins), will retain its
Insect Repellents and Miticides

repellent power for ten to twenty days (48). There are certain disadvantages to this form of protective clothing. The veils may give rise to headache, but if worn well away from the face should be imperceptible. Gloves and veils may catch in undergrowth during active duty in jungle warfare but when used with discretion for sleeping in forward areas and for protection of wounded, the outfits can be of greatest service to the soldier. They should, of course, be used in conjunction with an effective skin repellent.

It was later demonstrated that D.M.P., when applied to clothing at a dosage of 4 c.c. per square foot, was completely repellent to land leeches for as long as six days. Special attention should be paid to treatment of the tongue, face-holes and neck of shoes or boots; to the socks and the lower part of the trouser legs (41). This was a valuable protective as terrestrial leeches can be the source of considerable trouble to travellers or troops in jungle conditions.

(b) The Application of Miticides

It has already been observed that the repellents in general use in the war, D.M.P. and 6-2-2, were effective as clothes impregnants against mites. The repellents were applied by drawing the mouth of the issue bottles over clothing, especially at the probable points of mite entry. This was a simple method, requiring no special equipment and no fresh issue of a specific miticide (33).

Following McCullough’s work, however, in which it was shown that D.M.P.-impregnated clothing would not withstand tropical conditions and laundering, D.B.P. was issued to troops at a scale of 2 ounces per man per fortnight. The liquid was poured into a tin lid, the fingers dipped into it and the miticide applied in smears with a stroking motion over the cloth. On the average, 1 ounce was equivalent to 75 smears, and direct application was made to the clothing in the following routine manner:

- 6 smears each sock (or boots, if socks not worn);
- 10 smears each trouser leg;
- 10 smears on trouser waist and fly;
- 6 smears each shirt sleeve;
- 20 smears on body of shirt;
- 10 smears on underpants (An extra ½ ounce per man per fortnight required if these to be treated in addition).
- 10 smears on singlet

Two sets of clothing were impregnated at the same time and worn alternately. Thus, when the clothing was washed daily after wear, the fortnightly re-application followed seven washes and seven days of wear of each suit of clothes (54).

The researches at Orlando led to the adoption by the U.S. Army of benzyl benzoate, already in extensive use as an acaricide, as a clothing impregnant. It was shown to give consistently good results even after heavy laundering and the most strenuous of field conditions. It was supplied as an emulsion concentrate:

<table>
<thead>
<tr>
<th>Benzyl benzoate</th>
<th>...</th>
<th>...</th>
<th>90</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emulsifier</td>
<td>...</td>
<td>...</td>
<td>10</td>
</tr>
</tbody>
</table>
(Tween 80 or Tween 60 were used, or equal parts of each if sea water to be used in dilution.)

The concentrate was diluted with water to 5 per cent. (about \( \frac{1}{2} \) pint to 1 gallon of water), and the clothing impregnated by dipping and allowing to dry (10). In the preparation of emulsion from the concentrate, it was recommended that equal quantities of concentrate and water should first be shaken together to produce a creamy emulsion before final dilution to the required proportions.

It was also recommended that, as an added protection, the clothing treatment should be combined with the dusting of D.D.T. powder (10 per cent. in talcum) in the socks and shoes. This retained its miticidal effect through at least two launderings (40).

It was observed that a mixture of D.B.P., benzyl benzoate and an emulsifying agent (45 : 45 : 10) gave equally good results as an emulsion, withstanding sun, rain and several weekly launderings. This concentrate was also on issue by the U.S. Army Quartermaster when benzyl benzoate was in short supply.

**RECENT DEVELOPMENTS**

In recent years much attention has been given to the development of an all-purpose impregnant for clothing which will be effective as a repellent against mosquitoes (including the sub-arctic species), biting flies, ticks, fleas and mites. This, combined with a good skin repellent for the exposed parts, should give complete protection for the wearer in all circumstances against the bites of nuisance and disease-carrying insects.

Smith and Cole (50) screened a number of known repellents in both laboratory and field tests. Stockings were impregnated with the repellents at a dosage of 2 and 3 gms. per square foot, worn for successive eight-hour "wear periods," and then tested in the field against salt-marsh mosquitoes for five minutes each on three different persons. Compounds were excluded which did not maintain a high repellency after three successive periods of eight hours' wear, which caused irritation or were toxic to the wearer, which stained fabrics or had a strong odour. 2-butyl-2 ethyl-1, 3-propanediol gave excellent protection after fifty-six hours' wear (3 gms. per square foot) and thirty-two hours' wear (2 g., per sq. ft.), and indalone after forty-eight and sixteen hours' wear respectively. D.M.P. and repellent 6-2-2 gave only short protection at the higher and none at the lower dosage.

Indalone and 2-butyl-2 ethyl-1, 3-propanediol were then combined with the best tick and flea repellents and miticides in different proportions in the search for a good all-purpose clothing treatment. The most successful mixture was 

\[ M.1960, \text{ consisting of:} \]

\[
\begin{align*}
2\text{-butyl-2 ethyl-1, 3-propanediol} & \quad \ldots \quad \ldots \quad 30 \\
N\text{-butylacetanilide (ticks and fleas)} & \quad \ldots \quad \ldots \quad 30 \\
\text{Benzyl benzoate (miticide)} & \quad \ldots \quad \ldots \quad 30 \\
\text{Tween 80 (emulsifier)} & \quad \ldots \quad \ldots \quad 10
\end{align*}
\]
This mixture, tested against *A. quadrimaculatus*, *A. aegypti* and salt-marsh mosquitoes, proved to be a more efficient and longer-lasting repellent against each of the three species than any individual repellent, including D.M.P., Rutgers 612, indalone and the mixture 6-2-2. Its effect against ticks, fleas and mites was assured by the inclusion of N-butylacetanilide and benzyl benzoate (50). These results were later confirmed by Smith and Gilbert (51).

The standard dosage of M.1960 as a clothing impregnant varies with the type and weight of cloth to be treated, as shown in the following table:

<table>
<thead>
<tr>
<th>Type of cloth</th>
<th>Weight of cloth (lbs.)</th>
<th>M.1960 Concentrate (gallons)</th>
<th>Water (gallons)</th>
<th>Proportion of M.1960 in emulsion per cent.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton</td>
<td>60</td>
<td>1.5</td>
<td>4.0</td>
<td>27.3</td>
</tr>
<tr>
<td>Woollen</td>
<td>60</td>
<td>0.75</td>
<td>6.75</td>
<td>10.0</td>
</tr>
</tbody>
</table>

To prevent wastage of M.1960, simple instructions have been issued by the Bureau of Entomology and Plant Quarantine for re-use of emulsion residue after one clothing treatment (62).

A recent study in North Borneo has demonstrated that M.1960-impregnated clothing is completely effective against terrestrial leeches even after five washes and exposure during heavy rains. One gallon of the emulsion concentrate was sufficient when diluted with water for the treatment of twenty-eight uniforms (56).

Further screening of compounds at Orlando revealed that benzyl p-chlorobenzoate was as effective a stopping agent to mites as benzyl benzoate. Mixed in equal parts with benzyl benzoate, the miticidal effect of impregnated clothing lasted through at least three more launderings than the benzyl benzoate by itself (35). Another compound, benzil, was even more efficient, still retaining 97 per cent. of its miticidal activity after ten launderings (11).

As a help to future laboratory procedures, it has been demonstrated (21) that tests for the screening of repellents and observing their mode of action can be carried out with guinea-pigs, which reproduce approximately the same results as in man. This method has the advantage that smaller amounts of the test compound are necessary and toxicity to the host is not such a major consideration.

**CONCLUSION**

There is no doubt that the protection of troops from disease-carrying and nuisance insects is a vital factor in promoting their efficiency in both tropical and sub-arctic conditions. In the light of laboratory research and field experience, such protection can be assured by the combination of an effective skin repellent with a clothing impregnant.

No skin repellent has yet been described which can guarantee its wearer full protection through the hours of sleeping, so that reliance must be placed for this purpose on mosquito nets and individual anti-mosquito outfits which have proved their efficacy in the field. The repellent mixture 6-2-2 protects
against a wider range of biting insects than D.M.P. alone, and its effect is of longer duration. D.M.P., however, is readily available in pure form; the effect of heavy sweating and the direct rays of the sun on the repellent reduces the significance of the slightly longer action of 6-2-2.

Attempts to discover a vehicle which would prolong the action of D.M.P. by preventing loss due to sweating and direct friction have been disappointing in their results, although the wax-arachis oil base cream and the bentonite-calcium stearate paste (described above) are worthy of trial under tropical conditions. In the absence of a suitable vehicle, the skin repellent is best issued in pure liquid form as at present.

With regard to the impregnation of clothing, D.M.P. is unsuitable for general issue as it will not stand up to tropical conditions and the frequent laundering which they necessitate. Benzyl benzoate, already in general use as an acaricide against scabies, has been exhaustively tested and is a reliable miticide which will withstand long wear and many washes. The most suitable form of issue is an emulsion concentrate (Benzy1 benzoate 90, emulsifier 10) which can be diluted in the field (½ pint to 1 gallon of water) for the impregnation of clothing.

It is unfortunate that no all-purpose compound has yet been described which can be used with equal effect as skin repellent and clothing impregnant, with all the advantages of a single issue for a dual purpose. The ideal repellent has yet to be discovered, and there is still considerable scope for research in this subject.

ACKNOWLEDGMENTS

I would like to thank Major-General F. C. Hilton-Sergeant, M.B., Q.H.P., Commandant, Royal Army Medical College, for his permission to publish this article; Colonel W. H. Moursund, Jr., Assistant Army Attaché (Medical) at the American Embassy, for obtaining permission to quote from classified sources; and also the librarian at the R.A.M. College, Mr. M. Davies, who has given valuable help in the tracing of references.

REFERENCES

(6) Chemical Trades Journal (1946), 118, Jan.-June, 52.
Insect Repellents and Miticides

(20) Insect and Rodent Control (1951), U.S. Army Res. and Dev. Rept., XIII, April-June.
(33) Office of Scientific Research and Development (1944), I.C.C. Rept. No. 4.
(37) Oil, Paint and Drug Reporter (1945), 148, No. 14, 35.
(46) Schimmel Briefs (1946), 1, No. 137, August.
(48) Second Report on Control of Midges (1948), Dept. of Hlth., Scotland, H.M.S.O.
(53) **Soap, Perfumery and Cosmetics** (1946), 19, 365.
(59) **Travis, B. V., et al.** (1949), *J. Econ. Ent.*, 42; 686-694.
(60) University of Virginia (1945), *Monthly Rept.* No. 6.