REPELLENTS FOR INSECT ECTOPARASITES OF SHEEP

by

Peter J. James

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NAME: Peter J. James

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EXAMINING COMMITTEE:

Chairman: Professor T. Finlayson

Dr. P. Belton, Senior Supervisor

Dr. M. Mackauer

Mr. J.A. Shemanchuk, Research Scientist, Agriculture Canada

Dr. R.A. Costello, Entomologist, B.C. Ministry of Agriculture and Food, Cloverdale

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Repellents for Insect Ectoparasites of Sheep

Author: ______________
(signature)

Peter J. James
(name)

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ABSTRACT

Protecting animals against ectoparasites with repellents is less hazardous to the environment than using insecticides. The chance of tissue residues or subclinical toxicity and the likelihood of cross resistance are reduced. In addition, insecticides often kill ectoparasites only after they have bitten or oviposited whereas repellents can prevent these events from occurring.

Repellents have been used in smears to protect sheep against wound myiasis flies, in dressings to protect lambs against blow fly infestation of tail docking and castration wounds, and in applications to the noses of sheep to prevent oviposition by the sheep bot fly, _Oestrus ovis_ Linnaeus (Diptera: Oestridae). Dipping sheep in D.D.T. solution prevented oviposition by the wool myiasis flies, _Lucilia cuprina_ (Wiedemann) and _Lucilia sericata_ (Meigen) (Diptera:Calliphoridae) primarily through the action of D.D.T. as a locomotor stimulant.

Repellents are presently little used against sheep ectoparasites except in dressings to control damage caused by the sheep head fly, _Hydrotaea irritans_ (Fallen) (Diptera:Muscidae). Vapour repellents are usually too short-lived to be of practical value though controlled release formulations may have potential. Contact repellents, locomotor stimulants and feeding and oviposition deterrents are more persistent. Pyrethroids have shown potential against wool myiasis flies and sheep head flies and are used to repel biting flies from cattle. GH74 (1,1,-bis(p-ethoxy phenyl)-2- nitropropane) has effectively prevented oviposition of

L. cuprina on sheep's fleece for up to six months and also protects against the sheep head fly. These compounds may find practical application in the future. However, repellents appear to have little potential for control of resident ectoparasites, though some pyrethroids exert toxic effects against them.

Polyvinyl-chloride ear-tag formulations of cypermethrin and permethrin can provide season-long protection against head-flies. Studies of the effect of ear-tag formulations against other sheep ectoparasites are required. Adaptation of controlled release formulations and delivery devices for the application of repellents and insecticides to sheep should be investigated.

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TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

1.0 Introduction

The usefulness of repellents for protecting sheep against ectoparasites has been recognized for many years (Parman et al. 1927, Hearle 1938). In the early 1900's many experiments were carried out to identify suitable repellent compounds. The development of effective and long-lasting chemical insecticides in the 1940's removed the impetus for this research.

Emergence of resistance to insecticides in a number of ectoparasite species, together with increased concern about environmental contamination and insecticide residues in animal products, has lead to renewed interest in alternative control strategies.

1.1 Advantages of repellents

Presently the control of animal ectoparasites is achieved mainly by the application of insecticides directly to animals or by the large-scale treatment of insect breeding sites (Steelman 1976). The application of repellents has significant advantages over the use of insecticides. Repellents are generally of lower toxicity than insecticides and are applied only to those animals needing protection. The risk of environmental contamination is consequently much lower. It is cheaper to treat individual animals than to apply insecticides to extensive biting-fly breeding areas and less hazardous to the operator.

Some insecticides decrease the production of animals they are intended to protect (Haufe 1973). The relatively low toxicity of repellents, and the fact that many, for example, diethyl toluamide (DEET) and pyrethroids, are rapidly detoxified when absorbed (Feldman and Maibach 1970, Elliott and Janes 1980) suggests that subclinical damage to the host is less likely to occur.

To date, no effective systemic repellents have been developed. Though absorption can cause a significant loss of repellents from the skin surface of humans (Kasman _et_ _al_. 1953), in sheep where repellents will most often be applied to the overlying fleece, the amount absorbed through the skin is likely to be small. As the skin is removed from the carcase before sale, the chance of residues occurring in the meat seems low.

Insecticides often kill insects only after they have already bitten or oviposited. Where disease transmission by biting insects is important, for example blue tongue transmission by _Culicoides_ _variipennis_ (Coquillet), slow acting insecticides will be of little use in preventing disease spread. Biting by insects can induce behavioural responses in sheep which cause significant losses in themselves. Sheep under severe attack from black flies or mosquitoes cease grazing, the ewes may leave their lambs and damage may be caused to pastures by sheep bunching together in an attempt to evade the insects' attacks (Hearle 1938, Jessen 1977). Repellents which prevent insects from biting will reduce these responses. In addition, it seems that the chance of resistance developing is lower with repellents than insecticides.

2.0 The designation of repellents

Many general definitions of repellents have been used in the literature. Pfadt (1962) defines repellents as chemicals which prevent insect damage to animals or plants by rendering them unattractive, unpalatable or offensive, whereas Hocking (1963) uses the term repellent for compounds which inhibit or neutralize attraction or which in some other way bar its expression. Metcalf et al. (1962) state that substances which are only mildly poisonous, or which may not be active poisons, but which prevent damage to animals or plants by making the food or living conditions of the insect unattractive or offensive to them are called repellents.

Most often insect repellents are defined either in terms of the distribution of insects which they bring about or the behaviour which they elicit.

2.1 Definitions involving the distribution of insects

Rogoff (1952) defines a repellent as any compound which reduces the number of insects present on a surface. Kennedy (1947) says that, for practical purposes, most workers agree that a surface is repellent if insects are found to spend less time on it and so occur in smaller numbers than on other available and comparable surfaces. He demonstrates that locomotor stimulation can result in apparent attraction to a surface. In one experiment excitation of Aedes aegypti (Linnaeus) lead to increased activity and to increased numbers alighting on a D.D.T.-

treated surface. Though the period for which the mosquitoes stayed on the treated surface was reduced, this reduction was outweighed by the increased numbers alighting.

2.2 Definitions involving behaviour

Dethier et al. (1960) argue that the behaviour induced by chemicals is a better means by which to classify them than the effects they have on distribution. Dethier (1956) points out that the absence of insects on a given surface could equally well be due to attraction of some other surface as to repellency of the first. Dethier (1947) defines repellency as any stimulus which elicits an avoiding reaction. Avoidance may be brought about by a directional avoiding reaction or negative taxis (Fraenkel and Gunn 1961) such as with some mosquito repellents (Daykin et al. 1965) or by locomotor stimulation or positive kinesis, which is the mechanism normally attributed to D.D.T. and pyrethrum. (See section 5.0) In addition, an insect may be prevented from feeding or ovipositing without being repelled.

Dethier et al. (1960) divide compounds which are often combined under the term repellent into three categories on the basis of the behaviour they elicit. They define a repellent as a compound which causes insects to make oriented movements away from its source. Such compounds are distinguished from locomotor stimulants which cause, by a kinetic mechanism, insects to disperse from a region more rapidly than if the area did not contain the chemical.

A deterrent is defined as a chemical which inhibits feeding or oviposition when present in a place where insects would, in its absence, feed or oviposit. Barton Browne (1977), from a consideration of the responses of insects in host plumes in the presence of repellents (see section 5.1), suggests that Dethier et al.'s (1960) definition of a chemical repellent be changed to "a chemical, that acting in the vapour phase prevents an insect from reaching a target to which it would otherwise be attracted."

Knock-down action or rapid kill may also bring about a reduction in the number of insects observed on a surface, or in the amount of feeding or oviposition. Shemanchuk (1981) attributed the repulsion of black flies from cattle treated with pyrethroids to very rapid intoxication of the flies on contact with treated hair.

2.3 Anti-attractants

Wright et al. (1971) defined an anti-attractant as a substance with no intrinsic repellency, but with the property of diminishing the attractiveness of a lure. Many repellents under Dethier et al.'s (1960) terminology would fit this definition, which does not distinguish between the attractive stimulus as emitted by the target and as perceived by the insect. For this paper, anti-attractants will be defined as compounds which prevent production or emission of an attractive stimulus from a target and so reduce the number of insects moving toward it. Antiseptic compounds which prevent bacterial growth and putrefaction in a sheep's fleece and thus prevent emission of odours which are attractive to blow flies are anti-attractants.

2.4 The designation of repellents for this paper

Though the desirability of precise classification is obvious, in past work the way in which repellency was attained is often not clear. For the purpose of this paper the term repellent will be used in its broadest sense. That is, a compound which causes a reduction in the observed number of insects present on a surface, or in the amount of feeding or oviposition, relative to that on a control. If the behaviour of the pest by which repellency is achieved is clear, the terminology of Dethier *et al*. (1960) will be utilized with the exceptions that the term "vapour repellent" will be substituted for their term repellent, and the amended definition suggested by Barton Browne (1977) will be used.

2.5 Other classifications of repellents

Repellency may be physical or chemical (Dethier 1956, Painter 1967). Some examples of physical repellency are tail switching to keep flies away, amplified sound to repel pyralid moths (Belton 1962), and dusts which can be repellent to a number of insects (Dethier 1947). Canvas head caps fitted to sheep physically deter feeding by the sheep head fly, *Hydrotoea irritans* (Fallen) (French *et al*. 1977).

Chemical repellents have been further divided into olfactory or vapour repellents, which are sufficiently volatile to repel an insect at a distance, and gustatory or contact repellents, which the insect must touch to be repelled (Sarkaria and Brown 1951). As indicated by Dethier _et al_. (1960) this is a somewhat arbitrary distinction as the insect actually contacts molecules of repellent in both cases.

Garson and Winnike (1968) distinguish intrinsic repellency and effective repellency. A material is said to exhibit intrinsic repellency if a known amount or concentration of the material demonstrates repellency independent of time. Such repellency is measured with an olfactometer, or by testing the repellency of surfaces to which the candidate agents have been applied immediately after application. This aims to minimize the effects of characteristics of the surface and other external factors on the repellency observed. Effective repellency is measured as a function of time.

3.0 Ectoparasites of sheep

Insects which attack sheep may be placed in the following categories:

3.1 Resident ectoparasites

The important members of this group are obligate parasites which seldom live on hosts other than sheep. Included in this group are the sheep ked, *Melophagus ovinus* (Linnaeus), the sheep biting louse, *Bovicola ovis* (Schrank), the sheep sucking louse, *Linognathus ovillus* (Neumann), the sheep foot louse, *Linognathus pedalis* (Osborne), and the African sheep louse, *Linognathus africanus* (Kellogg and Paine). It is estimated that in 1965 the annual costs to the U.S. sheep industry from louse and ked infestation were $47 million and $9.4 million, respectively (Anonymous 1965). The sheep biting louse, which is the most common species infesting sheep (Marsh 1965), causes severe irritation with consequent loss of weight and reduced fleece quality. Sucking lice of the genus *Linognathus* are generally of little economic significance (Marshall 1981).

The sheep ked, if abundant, can cause losses by lowering wool production, reducing weight gains in lambs and by reducing the value of sheep skins by producing a condition known as "cockle" (Everett et al. 1969, Nelson and Slen 1968). Steelman (1976) feels that treatment for ked control alone would seldom be justified.

Transmission of both the biting louse and ked is mainly by contact between sheep (Metcalf *et al*. 1962, Murray 1968).

Keds are often transmitted from the ewe to the newly born suckling lamb. They do not normally survive as adults in the absence of a host for more than three to four days (Metcalf *et al*. 1962), although Bayvel *et al*. (1981) stated that it is possible for unhatched pupae to survive off of the sheep for as long as five weeks. Murray (1963) found that at 12°C, in the absence of a host, most *L. ovillus* were dead in four days whereas *L. pedalis* could survive for seven to ten days. Thus, clean sheep can become infested with either lice or keds by placing them in paddocks or yards recently occupied by infested sheep.

Marshall (1981) notes that in the highland regions of central Asia, alakurt fleas, *Dorcadia ioffi* (Smit) and *Vermipsylla alakurt* (Schimkewitsch) may be abundant on sheep and may cause exhaustion, loss of hair, retarded growth, anaemia and even death of lambs.

3.2 Myiasis flies

Zumpt (1965) defined myiasis as infestation of live humans and vertebrate animals with dipterous larvae which, at least for a certain period, feed on the hosts' dead or living tissue, liquid body-substances or ingested food. A number of different forms of myiasis occur in sheep.

3.2.1 Wound

The three most important species are the new world screwworm, *Cochliomyia hominivorax* (Coquerel), which is found in North, Central and tropical South America, the old world screwworm, *Chrysomyia bezziana* (Villeneuve), which causes problems in India, South East Asia, and New Guinea, and Wohlfartia magnifica (Schiner), which has been described as the scourge of the Russian steppes and is also important in parts of North Africa (Zumpt 1965). All of these species are obligate parasites which can attack other animals as well as sheep.

Egg masses or larvae are laid in or near wounds. Very small wounds such as scratches, tick bites (Ahrens et al. 1977) or fly bites (Pfadt 1962) are susceptible to attack. The larvae feed on the cutaneous and subcutaneous tissues and severe infestations may penetrate the abdominal cavity. These pests cause enormous expense to sheep growers, not only because of the damage they do directly, but also because of the need to check sheep daily to ensure that wounds have not become infested. Bruce and Sheely (1944) stated that screwworm infestation, if uncontrolled, could wipe out entire flocks of sheep in Florida. Since then control of screwworm in the U.S.A. has been achieved by use of the sterile male technique (Novy, 1978) although there was re-emergence of screwworms as a pest in some parts during the 1970's (Cueller and Brinklow 1973).

There are more than 50 species of flies throughout the world which normally breed in carrion or refuse, but which can also occasionally cause problems to sheep husbandry when they become established in wounds (Zumpt 1965).

3.2.2 Wool

These flies oviposit in moist fleece which is often rich in putrefying material. Attractive situations include urine- and faeces-stained wool and areas made attractive by the growth of microorganisms such as *Pseudomonas aeruginosa* (Merritt and Watts 1978) and *Dermatophilus congolensis* (Gherardi *et al*. 1981). The larvae burrow into and feed on the skin and subcutaneous tissues causing great stress and often resulting in death of the sheep.

The main species of this group are *Lucilia cuprina* (Wiedemann), which is the most important wool fly in Australia and South Africa, *Lucilia sericata* (Meigen), which is the main species in New Zealand and the British Isles and also causes minor damage in North America, western Europe and southern Russia, and the black blowfly, *Phormia regina* (Meigen) and secondary screwworm fly, *Cochliomyia macellaria* (Fabricius), which attack sheep in North America. Some carcase breeding species, for example *Calliphora* spp. in Australia can also be important wool myiasis agents at times (Monzu 1979).

The cost of control of wool myiasis in Australia in the 1977/78 year was estimated at $55 million (Brideoake 1979).

3.2.3 Nasopharyngeal

The sheep bot fly, *Oestrus ovis* Linnaeus, is thought to be of Palearctic origin (Zumpt 1965) but now infests sheep in many countries of the world (Du Toit and Fiedler 1956). It is not known precisely how the adult female bot manages to place her young in the nostrils of sheep, but it is assumed that she makes quick darting attacks and deposits a few larvae on each successful run (Kettle 1973). The fly does not alight to oviposit (Metcalf et al. 1962).

The very active larvae crawl into the nasal passages, moult and eventually move into the frontal sinuses (Cobbett and Mitchell 1941). The presence of the larvae irritates the sheep and may cause nasal discharge, sneezing and difficulty in breathing. Bacterial infection sometimes follows invasion by larvae, and abscesses may form when mature larvae become trapped and die in deeper head cavities (Kettle 1973).

The economic importance of O. ovis is the subject of some debate. Buchanan et al. (1969) found no difference in growth rate and carcass evaluation between infested sheep and those maintained free of bots with crufomate, whereas Horak and Snijders (1974) found that treatment with rafoxamide resulted in a reduction of nasal discharge and an increased gain in weight. In these experiments any growth depression induced by the insecticides was confounded with the reduction in sheep bot infestation.

Cobbett (1956) feels that the greatest production loss results from the response of sheep to the presence of adult bot flies. When flies are active, sheep mob together and endeavour to avoid the flies by shaking their heads and hiding their noses in the wool of other sheep or in the dust. This behaviour stresses the sheep and interferes with grazing (Smith and Young 1959).

3.2.4 Oculovascular

In Africa, Gedoelstia cristata (Rodhain and Bequaert) and G. hassleri (Gedoelst) cause bulging eye disease or "uitpeuloog" in sheep (Basson 1962). These species normally deposit live larvae in the orbits of various species of antelope, hartebeest and wildebeest in which they evidently do not cause severe pathological changes (Basson 1966). When deposited in the eyes of sheep the larvae never develop beyond the first stage and can cause severe effects. Three forms of the disease can be distinguished; an opthalmic, an encephalic and a cardiac form.

Karakul, Merino, Persian and Afrikaner breeds of sheep are particularly susceptible. The disease usually occurs in epidemics, often associated with the migration of natural hosts into sheep raising areas. During bad outbreaks mortality may be as high as 75 per cent (Basson 1962).

3.2.5 Subdermal

Soulsby (1968) noted a number of species which cause subdermal myiasis in sheep including the torsalo, Dermatobia hominis (Linnaeus Jr.), which has a distribution in the Americas from Mexico to Argentina, Hypoderma aeratum (Austen) found in Cyprus, Crete and Turkey and Hypoderma crosii (Patton), which is found infesting sheep in India. The female torsalo does not oviposit on the host directly but attaches her eggs to another species of blood sucking fly or tick. As 48 species of flies and ticks have been recorded as carriers (Papavero 1966 quoted by Harwood and James 1979) it is unlikely that repellents would provide efficient control unless very broad spectrum compounds are found and total coverage can be achieved at application. Species causing subdermal myiasis will not be considered further in this paper.

3.3 Non-resident blood feeders

Many species of biting flies and mosquitoes feed on sheep, but few cause problems directly. Black flies are significant pests of sheep in southern Idaho (Jessen 1977), the main species being Simulium vittatum Zetterstedt which commonly attacks the ears of livestock (Shemanchuk and Taylor 1984, Townsend and Turner 1976). Sheep under attack by black flies are difficult to herd, often bunching into tight groups and refusing to move to food or water. Grazing lands are damaged by sheep bunched together in such a way (Jessen 1977). Hearle (1938) stated that mosquito attacks on sheep can be of sufficient severity to cause ewes to leave their lambs and Muller and Murray (1977) noted that severe attacks by Austrosimulium pestilens MacKerras and MacKerras have resulted in lamb deaths. Sanders et al. (1968) noted that 5 per cent of the grazing land in Texas is adjacent to salt marshes and cannot be used during the summer because of the large numbers of mosquitoes developing there. Cattle deaths have been caused in this area by the concentrated attack of mosquitoes and by suffocation from inhaling large numbers of these insects.

A more important consequence of blood feeding insects is the transmission of disease. The most important of these is blue tongue which causes extensive financial losses in sheep flocks (Jensen and Swift 1982). The blue tongue virus is transmitted by Culicoides spp., the most important of these being C. variipennis in the U.S.A. and C. pallidipennis (Carter) in Africa and Asia Minor (Harwood and James 1979).

Other important diseases of sheep which are transmitted by biting flies are trypanosomiasis, rift valley fever and Wesselsbron disease in Africa and tularaemia in North America (Jensen and Swift 1982).

In the United Kingdom the sheep head fly, Hydrotaea irritans, has re-emerged as a significant pest of sheep since the withdrawal of dieldrin from use in dip formulations (French et al. 1977). The egg, larval and pupal stages occur in thickets and woodland. The female fly, in search of a protein meal before egg laying, is attracted to serous exudates from the sheeps' eyes and nose or to blood or exudates from cuts and abrasions (Robinson and Luff 1979).

Irritation from the flies' rasping labellae causes sheep to injure their heads by knocking them against objects such as trees or fences in an effort to get rid of the fly (Hunter 1975). Feeding by head flies extends the lesions.

Appleyard et al. (1984a) reported that weight gains of lambs with head fly lesions were significantly lower than unaffected lambs, and Hunter (1975) reported reductions in weight gain of up to 9 kg. in lambs with severe head fly lesions.

4.0 History of repellents in sheep husbandry

4.1 Wound protectants

For many years repellents have been used in wound treatments and protectant formulations against screwworms and blow flies. Before 1920, materials such as pine tar, turpentine, kerosene, gasoline, axle grease, tannic acid, lampblack and calomel were used with varying degrees of success (Parman et al. 1927). Insecticides used for screw-worm treatment in these times were very toxic and many animals died following their use (Parman et al. 1927). In addition, it is often difficult to maintain lethal concentrations of insecticides on wound surfaces as they tend to be removed by bleeding or suppuration from the wound. Repellents which act in the vapour phase could, however, be applied to the surrounding skin or wool to provide protection against gravid adult flies ovipositing on the wound.

From 1920 to 1930 large numbers of compounds were tested for repellency against attractive baits (Bishop et al. 1923, Bishop et al. 1925, Parman et al. 1927, Parman et al. 1928). As recognized by Parman et al. (1927) it is not possible to extrapolate these results directly to live animals, but the method does provide a cheap and convenient method of preliminary screening. These authors examined the repellent action of 353 compounds and mixtures against Cochliomyia hominivorax.

Products obtained from pine trees including pine oil, crude turpentine, pine tar and pine tar oil were amongst the most effective. Pine tar oil was recommended for field use because of its cheapness, availability, non-toxicity and adhesiveness and because it was less irritating to animal tissues than the other materials.

Compounds found by Parman et al. (1928) to have the best repellency against flies including C. hominivorax, Musca domestica Linnaeus, Lucilia sp., Piophila casei (Linnaeus), Sarcophaga sp., Phormia regina, Ophyra sp. and Muscina stabulans (Fallen) fell into three main groups.

i) Products from the destructive distillation of the long-leaf pine (Pinus palustris) including pine tar, pine tar oil, pine oil and wood naptha.

ii) Pyrethrum powder

iii) Strong inorganic antiseptics (mercuric chloride and copper compounds).

Parman et al. (1928) stated that by 1928 pine tar oil was being used by ranchers for protection of wounds against screwworm and blowfly maggot infestation. Pine tar oil has also been shown to be repellent to the sheep maggot fly, L. sericata in Britain (Hobson 1936) and is used in formulations to protect against the sheep head fly, Hydrotaea irritans (French et al. 1977). Hearle (1938) stated that pine tar can be used to protect against the sheep bot fly and as a repellent against ticks. In addition, pine products have been shown to be repellent to a number of forest insects (Nijholt 1980, Nijholt et al. 1981, Alfaro et al. 1984).

Pyrethrum compounds did not prevent infestation by blow flies although no screwworm infestations were recorded over a five day observation period. However, Parman _et al_. (1928) concluded from preliminary tests that pyrethrum would not be of practical value as a wound protectant against screwworms.

The effect of copper compounds was attributed to their action in checking or changing the normal decomposition processes of meat thus reducing its attractiveness to blow flies. Mote (1922) recommended treatment of the early stages of blow fly strike by rubbing the infested area with copper sulphate. This he says dries the wound and stops decomposition which gives rise to the putrid smell responsible for attracting blow flies. In these experiments, copper salts were acting as anti-attractants. Johnstone (1951) found that if copper sulphate was used in strong concentrations it could delay healing and cause necrosis. This predisposed sheep to severe flystrike.

Over the years many essential oils have been suggested as repellents. Bishop _et al_. (1923) found that oils of cloves, cassia, citronella, fennel, sassafras and anise showed promise as blow fly repellents. Parman _et al_. (1927) noted that many essential oils showed repellent action against blow flies and screwworms but that none was effective in preventing infestation of baits. Oil of citronella from Ceylon and American pennyroyal oil, both commonly used as mosquito repellents at that time, also showed good repellent action against screwworm flies and blow flies. Since then many other studies have demonstrated repellent effects of essential oils against house flies and blow flies (Hobson 1937, Lennox and Hall 1940, MacKerras and MacKerras 1944, Waterhouse 1947, Osmani 1971, Subramanian and Monahan 1980) but none has found widespread application as a wound protectant. The use of oil of citronella in lamb marking dressings is discussed in section 4.3.

Bishop et al. (1925) found that irritant gases developed for use in the war showed repellent action against screwworms and a number of species of blow flies. The most effective was chloropicrin which, when sprayed on live cattle, was also repellent to horn flies, stable flies and house flies. Testing of these compounds was not pursued because of inability to find suitable diluents. Other compounds found to have repellent action and which have received limited use include furfural (Bishop et al. 1923) and napthalene derivatives (Parman et al. 1927).

4.2 Wound and wool myiasis treatments

Lennox (1941) listed 10 criteria of a good myiasis dressing. Of paramount importance is that it should kill the infesting larvae and protect the wound from re-infestation. The latter can be achieved by preventing oviposition by adult flies or by persistent ovicidal or larvicidal action.

Bruce and Sheely (1944) recommended a mixture of benzol and pine tar oil for the treatment of screwworm infestations. The benzene kills the larvae while the pine oil repels adult flies and prevents further oviposition. Loeffler and Hoskins (1946) pointed out that a rapid larval kill, as given by benzol, is undesirable because it necessitates the manual removal of dead larvae from the wound in order to avoid septic effects from the putrefaction products. They suggested that an ideal myotic wound treatment should repel maggots from the wound before killing them. Of the compounds they evaluated, diphenylamine, butyl carbitol chloroacetate and epichlorohydrin were the ones which best fulfilled these criteria. No determination was made of the repellency of these compounds to ovipositing *L. sericata* females.

Parish and Knipling (1942) found that diphenylamine was more than twice as effective as pine tar oil in preventing screwworm re-infestations. It also provided more long lasting protection. They did not investigate whether protection was due to repulsion of ovipositing flies or to insecticidal action against eggs or larvae.

Diphenylamine is combined with benzol, turkey red oil (sulphonated castor oil) and lamp black in a formulation known as Smear 62, which was developed by the U.S.D.A. Bureau of Entomology and Plant Quarantine for protection against blowfly and screwworm infestation and sold commercially under various trade names (Bruce and Sheely 1944).

With the development of lindane, another smear, EQ-335, was developed and received wide usage in the United States until the control of screwworm by the sterile male technique (Novy, 1978). Smear EQ-335 consists of Lindane, pine oil, mineral oil, emulsifier and silicon aerogel. Brundett and Graham (1958) stated that it was common for protection from EQ-335 to fail within two to four days. In order to provide good protection the smear had to be re-applied every second day until the wounds healed. Brundett and Graham tested a contact insecticide, Bayer 21/199, which was systemic and gave protection for at least 10 days.

4.3 Lamb marking dressings

At marking, lambs have their tails docked and the males are usually castrated. This may leave wounds which can become flystruck. Johnstone (1951) pointed out that lamb marking dressings, which are applied to docking and castration wounds to prevent flystrike, have different functions to perform than dressings for the treatment of flystruck sheep. He stated their principal requirements are that they should prevent oviposition in or around wounds and exert the least possible hindrance to healing.

As wounds are usually still bleeding at the time of application, any compound applied will be carried away from the wound surface. Protection will be dependent on the vapour action of materials persisting on the surrounding skin and fleece. At times in Australia, feeding by bush flies (Musca vetustissima Walker) can irritate newly marked sheep and cause a significant delay in healing. This makes them more prone to infection and strike by blow flies (Baillie 1979). Repellent action against these flies would also be an advantage in some areas.

Lennox and Hall (1940) found oil of citronella amongst the most repellent of 38 oils tested against liquid carrion baits by the method of Freney (1937). In tests of compounds effective in repelling L. cuprina from artificially attractive plugs implanted in the fleece of sheep, Ceylon oil of citronella has consistently been amongst the most effective (Lennox and Hall 1940, MacKerras and MacKerras 1944, Waterhouse 1947). Oil of citronella from Java is a poor repellent, however (MacKerras and MacKerras 1944, Waterhouse 1947).

Swabbing 5 per cent and 10 per cent oil of citronella solutions onto wounds and the surrounding fleece immediately following marking significantly reduced the incidence of strike (Lennox and Hall 1940). This reduction was noted at all stages of healing of the wound. Johnstone (1951) found that adding oil of citronella to insecticidal blow fly dressings containing boric acid increased protection against infestation of marking wounds. The repellency of oil of citronella decreased rapidly from the fifth day after application (Johnstone and Southcott 1954). As at least seven days are required for complete healing of wounds, a means of prolonging the period of repellency of lamb-marking dressings is needed. Huon pine oil, dimethyl phthalate, D.D.T. and B.H.C. all gave inferior protection compared to oil of citronella when added to blow fly dressings.

Johnstone (1951) and Johnstone and Southcott (1954) also tested the effectiveness of dibutyl phthalate and dimethyl phthalate in blowfly dressings. Dimethyl phthalate gave very variable results and was not considered for further testing (Johnstone 1951). Khan (1965) found that dimethyl phthalate had greater effect in preventing blood feeding by mosquitoes when painted on their tarsal receptors than when painted on their antennae. He pointed out that dimethyl phthalate has a relatively low vapour pressure and that contact repellency may be important to its efficiency. This could explain the variable results obtained when it was incorporated in lamb-marking dressings. Dibutyl phthalate was found by Johnstone and Southcott (1954) to enhance the effect of lamb-marking dressings, but protection was not as long lived as with oil of citronella.

Johnstone (1951) pointed out that when no dressings were applied and flies were not active, healing is very rapid. Except in areas with a high fly risk at lamb-marking time, it is probably preferable not to use any dressings. Perhaps for this reason the study of repellents for use in lamb-marking dressings has not been pursued.

4.4 Repellents against wool myiasis flies

4.4.1 Vapour repellents

Cragg and Cole (1956) produced evidence which suggests that the efficiency of a fly species as a wool myiasis agent is closely correlated with the strength of attraction of the females to wool. When the female oviposits on the fleece her behaviour follows a predictable sequence of events defined for <u>L. sericata</u> by Cragg (1956). These steps are:

i) Approach to the attractant - The fly arrives in the vicinity of the attractive material.

ii) Searching and settling - The surface of the fleece is explored by a series of short flights or by walking. During this period the proboscis is used to test the fleece surface.

iii) Preparation for egg laying - The ovipositor is extended and used to test the surface of the fleece.

iv) Oviposition - During this phase the insect is unresponsive to external stimuli.

v) Post oviposition - The ovipositor is withdrawn and after a short pause, the fly leaves.

Barton Browne (1979) stated that L. cuprina followed a similar sequence.

Hobson (1936) and MacKerras and MacKerras (1944) developed testing methods to evaluate repellents for use against wool myiasis flies. Plugs of cotton wool were soaked in attractive material and then implanted in the fleece of live sheep. Hobson applied the repellents to the cotton wool plugs together with the attractant. Pine tar oil, pennyroyal, clove and wintergreen oils and chloronapthalene were the most effective (Hobson 1936, 1937).

MacKerras and MacKerras (1944) mixed the test substances in paraffin oil which was applied to the fleece surface in a circle about 1 cm. from the attractive plug. The oily ring itself, whether paraffin or olive oil, seemed to provide a physical barrier to flies which attempted to reach the plug by walking on the surface of the fleece. Waterhouse and Scott (1950) noted that kerosene had a similar effect, but that addition of paraffin, which increased its oiliness, did not increase its repellency. Kerosene is more volatile than paraffin and is known to reduce oviposition in the vapour phase (Barton Browne and Norris 1961). Vapour repellency could mask the effect of increased oiliness.

Flies were able to reach the plug or the fleece between the plug and the paraffin ring by flying. Ceylon oil of citronella incorporated in the paraffin ring significantly reduced the number of ovipositions in comparison to controls (Lennox and Hall 1940, MacKerras and MacKerras 1944, Waterhouse 1947). With 10 per cent oil of citronella the repellent effect was strong on the day of application, weak at the end of seven days, and negligible at the end of two weeks (MacKerras and MacKerras 1944). Other compounds found to be repellent were a proprietary dressing containing sandalwood oil, the oil of Zieria smithii, an Australian rutaceous shrub, Huon pine oil, oleic acid, Indalone, dimethyl phthalate and ethyl hexanediol (Waterhouse 1947).

Dimethyl phthalate and Rutgers 612 retained effectiveness for at least a week, which is much longer than the protection observed against biting flies when these compounds are applied to human skin. This is presumably because they were held in the wool or wool yolk (see section 6.1.2) and thus less subject to losses by evaporation, abrasion and percutaneous absorption which are significant causes of loss from human skin (Khan 1977).

The method of MacKerras and MacKerras (1944) tests mainly for vapour repellency. As flies are able to stand on the untreated fleece between the paraffin ring and the attractive plug to oviposit, they are able to avoid any contact repellency. Hobson (1940) concluded that vapour repellents were unsuitable for sheep blow fly control as they will not persist in the fleece. Waterhouse and Scott (1950) stated that none of the repellents tested until that time was sufficiently cheap or persistent to be of practical use as a preventative of body strike.

4.4.2 Organochlorine insecticides

As wool myiasis flies are in close contact with the fleece for at least 5 minutes before oviposition begins (Cragg 1956) contact repellents or toxicants can be effective in preventing oviposition.

Cragg (1945) noted that L. sericata alighting on D.D.T.-dipped sheep became so excited that they could not oviposit. On no occasion was a complete and compact batch of eggs deposited. This effect lasted up to 43 days. Waterhouse and Scott (1950) found that D.D.T., B.H.C. and chlordane all reduced the amount of oviposition by L. cuprina. D.D.T. was the most effective of these and when applied as a 2 per cent solution, gave excellent protection for six to eight weeks. In one experiment, in which D.D.T. was applied with a knapsack sprayer protection lasted for over four months. The authors attributed this period of protection to the greater volume of spray applied.

4.4.3 Organophosphate formulations

Snelson (1959) noted the ability of L. cuprina females to oviposit selectively on areas of the sheeps' fleece which accidentally remained untreated with an insecticide formulation, "Diazinon 20E" (Geigy (Australia) Ply Ltd.). Repellency or deterrency may severely impair the effectiveness of insecticides applied to sheep to control wool myiasis by directing flies to oviposit in untreated areas. Barton Browne and Norris (1961) found that "Diazinon 20E" formulation deterred oviposition by L. cuprina for at least seven weeks after treatment. When individual components of the formulation were tested, it was found that repellency was not due to the diazinon, but to a solvent "Stanvac PY" used in the formulation. Flies were seen on the treated areas in quite large numbers and appeared to exhibit normal behaviour. It seems that the treated areas were not strongly repellent and did not affect distribution of the flies by locomotor stimulation. When kerosene was substituted for "Stanvac PY" in the formulation, oviposition was still reduced, but the effect was much less marked than with the original solvent.

Experiments in oviposition containers, in which flies were prevented from contacting the solvents, demonstrated that the odour of these solvents was an oviposition deterrent. It is difficult to test for contact repellency in the presence of a vapour effect, but the authors presented circumstantial evidence which suggested that gustatory action may also have been important. Deterrency was not due simply to sublethal toxicity.

4.4.4 Halocyclopropane compounds

Holan et al. (1978) indicated a structural link between pyrethroids and D.D.T., and van den Bercken et al. (1973) have indicated similarities in their action. Holan (1971) and Holan et al. (1978) synthesized a number of compounds with similarities in structure which have low mamalian toxicity and which show repellency against house flies and blow flies (Virgona et al. 1976, 1983). The one that has received the most attention is 1,1-bis (p-ethoxy phenyl)-2-nitropropane (GH74).

Virgona et al. (1976) measured the contact repellency of 27 insecticidally active compounds with low vapour pressures against L. cuprina. In some cases an "index of antifeedancy" was calculated from the amount of the blood baits that flies ingested. GH74 gave the highest index of repellency (75) which was significantly greater than that of D.D.T. (26). GH74 also gave a high "index of antifeedancy".

This experiment was carried out with female flies which had not been fed protein and thus were not gravid. Gravid females searching for an oviposition site respond differently to non-gravid females (Hobson 1937). Virgona et al. (1976) suggest from regression analysis of the amount of food ingested by the flies and the number of landings on the baits, that flies alighting on the baits did so to feed. Although feeding from the oviposition site is a normal step in the sequence of events leading to egg laying (Hobson 1940), these results are not directly applicable to protection against wool myiasis.

Barton Browne and van Gerwen (1982) found that GH74 effectively reduced oviposition on in vitro preparations for up to 40 weeks after treatment. When sheep were jetted with GH74 and their fleeces made attractive with either dilute faeces solution rubbed into the fleece, or artificially induced fleece rot, up to six months protection was provided. This is significant as currently available larvicides such as cyromazine, can only provide 12 to 14 weeks protection (Hart et al. 1982). The period of protection was reduced when lower concentrations were used and when the compound was applied by tip spraying rather than by jetting (Barton Browne and van Gerwen 1982, van Gerwen and Barton Browne 1983). Even tip spraying gave six weeks protection.

Jetting sheep with short wool does not reduce the period of protection although the amount of active ingredient applied is significantly lower (van Gerwen and Barton Browne 1983). This indicates that, as is desirable for an oviposition deterrent, GH74 has low mobility in the fleece. Thus, it remains in high concentration in those parts of the fleece that are likely to be contacted by flies.

A high incidence of oviposition was noted near the tails of GH74-treated ewes in which diarrhoea had been induced (Barton Browne and van Gerwen 1982). Eighty per cent of the egg masses were located within 1 cm. of the bare perineal region. This indicates that they had been laid by females standing on the non-wool bearing skin and inserting their ovipositors into the fleece.

Extraneous material in the fleece, such as faeces, free water or dust, may provide a platform on which the fly can stand to oviposit. The effect of this on the efficiency of GH74 needs to be assessed. Though it seems unlikely that strikes would begin from eggs deposited singly or in partial egg masses, as pointed out by Barton Browne and van Gerwen (1982), it cannot be reliably stated that strike would not occur. Further trials are needed to establish this.

4.4.5 Pyrethroids

The repellent effects of pyrethrum and artificial pyrethroids are well known (Jones and Sylvester 1966, Chadwick 1975, Blackman and Hodson 1977, Cline et al. 1984). Preliminary experiments have indicated that the synthetic pyrethroids cypermethrin, permethrin and decamethrin have similar activity to GH74 in preventing oviposition by L. cuprina (Barton Browne 1979, Orton and Shipp 1984). Cypermethrin increases the number of eggs laid in partial egg masses or as single eggs and increases the amount of off-target oviposition. At high concentration however, cypermethrin simply moves oviposition off-target whereas GH74 shuts it down completely. The former action is preferable as eggs are likely to be deposited in situations where they will not develop. Flies affected by GH74 may simply withhold their eggs and deposit them later in places where a strike may occur.

Permethrin is slightly less effective in preventing oviposition than deltamethrin and cypermethrin (Orton and Shipp 1984). These authors suggested that the relatively high mamalian toxicity of deltamethrin makes it a less desirable candidate for future use than cypermethrin. To date, no experiments testing the effectiveness of artificial pyrethroids against strike in vivo have been reported.

4.5 Repellents against sheep bot flies

For many years the recommended control measure was to smear sheeps' nostrils with pine tar in order to deter larviposition (Hearle 1938, Metcalf et al. 1962). To be effective this had to be carried out at weekly intervals (Metcalf et al. 1962). Application using "salt logs" was recommended to reduce the amount of labour needed to treat large flocks. Holes, 5 to 7.5 cm in diameter, were bored into a log, salt placed in the bottom so that sheep could just reach it, and then the margins of the holes covered with pine tar. In an endeavour to reach the salt the sheep smeared its nose with pine tar.

Smith and Young (1959) say that these methods seldom resulted in effective control. They were superseded by the use of lindane and B.H.C. which were injected into the sheep's nostrils to treat affected sheep (Du Toit and Fiedler 1956, Smith and Young 1959) and later by systemic insecticides such as rafoxamide (Horak et al. 1976).

4.6 Repellents against sheep head flies

French et al. (1977) examined the effectiveness of a number of fly repellent preparations for activity against sheep head flies. Good control was gained from creams containing 0.05 per cent crotoxyphos and pine tar oil (Young's headfly repellent). Increasing the concentration of crotoxyphos to 0.5 per cent did not improve the degree of protection provided when the cream was applied at fortnightly intervals. Spraying with 1.0 per cent crotoxyphos (Flymort 24) gave little protection. Application of bromophos or phosmet cream, diazinon gellant, Negusunt ointment (propoxur, coumaphos and sulphonilimide) and dipping with chlorfenvinphos also failed to give satisfactory protection. These compounds are all organophosphate insecticides. There appears to be no evidence that they are repellent. To reduce the severity of lesions they would need to induce toxic effects in the head fly quickly enough to prevent the flies feeding.

Crotoxyphos is a systemic insecticide with residual action (McEwen and Stephenson (1979). Berlyn (1978), in experiments in which preparations of 0.05 per cent crotoxyphos were smeared on the attractive spheres of Manitoba traps (Thorsteinsen _et al_. 1965), found that crotoxyphos significantly reduced the number of flies attracted. To become caught in Manitoba traps insects must fly vertically following attraction to the spheres. Berlyn's results could be explained by a rapid toxic action of crotoxyphos.

GH74 and a proprietary formulation, Marshall's anticap, also gave good protection against head flies (French _et al_. 1977). GH74 has contact repellent and antifeedant action on _L. cuprina_ (Virgona _et al_. 1976). A similar action seems likely against head flies. No description is given of the composition of Marshall's anticap other than that it contains animal oils. Although the above treatments reduced head fly damage none resulted in significant increase in weight gain.

In French *et al*.'s (1977) experiment, permethrin applied as a 0.1 per cent spray, as a 1.0 per cent salve or added to a dip formulation failed to reduce the incidence of head fly lesions, but the frequency of application was not stated. When permethrin was used as a 5.0 per cent salve a slight reduction in damage resulted.

Appleyard (1982) was able to significantly reduce the number of sheep showing lesions and the severity of lesions, by spraying sheep with 0.1 per cent permethrin at 14 day intervals. The problem was not completely eliminated, however. Similar treatment also controlled head fly feeding in the fighting wounds of rams. In previous years these rams were so severely affected that housing was required to protect them from the flies' attacks.

Spraying the heads of sheep with 0.1 per cent permethrin at monthly intervals achieved a slight reduction in the severity of damage but protection did not extend beyond 14 days (Appleyard *et al*. 1984a). Deltamethrin, at 0.01 per cent, was tested and found ineffective. The high cost of deltamethrin makes the application of more concentrated solutions for head fly control uneconomical (Appleyard *et al*. 1984a).

Once lesions have been made the head becomes much more attractive and more difficult to protect with repellents. Polyvinyl-chloride ear tags containing 8.5 per cent w/w cypermethrin gave good protection throughout the fly season (Appleyard et al. 1984a,b). The constant presence of ear tags does not allow a chance for head fly lesions to begin.

In Appleyard's (1982) work, most of the severe lesions were associated with the site of insertion of ear tags. These were ear tags for identification, not pyrethroid ear tags. In the experiments of Appleyard et al. 1984 a,b) ear tags were tied on with twine without making a new wound rather than inserted through the ear. As abrasions resulting from the twine were protected by the cypermethrin tags (Appleyard et al. 1984a), it seems likely that the protective effect would be strong enough to protect wounds caused by the insertion of ear tags. Experiments are needed to test this. If protection persists through the fly season, the tags could be applied in time to allow wounds to heal before the flies become active.

Permethrin tags (10 per cent w/w) gave good protection throughout the season, though not quite as good as the cypermethrin tags. However, sheep fitted with fenvalerate tags (8.5 per cent w/w) suffered a slightly higher incidence of head fly damage during most of the summer than did controls with blank ear tags (Appleyard et al. 1984b).

Both cypermethrin and permethrin tags conferred substantial protection to lambs when applied to their mothers (Appleyard et al. 1984 b). The means by which this was achieved are unknown. The authors suggested that it could be due to a reduction in the fly population because of toxicity of the tags or to transfer of pyrethroids to the lambs. The first of these explanations seems unlikely because of the ability of Hydrotaea irritans to recolonise treated areas rapidly from several kilometres away (Robinson and Luff 1979). However, the number of flies in the immediate vicinity of the lambs' head may be reduced. As pyrethroids do not have systemic action (Elliott 1977) it is unlikely that protection is conferred through the ewes' milk. Most pyrethroids are lipophilic (Ruscoe 1977) and presumably can dissolve in wool wax. It seems most likely that pyrethroids from the ear tags were rubbed onto the lambs' fleece during various maternal activities.

4.7 Repellents against biting flies

No reports were found of the use of repellents to protect sheep from attack by biting flies. This may be because problems that are serious are usually local in occurrence. However, the effectiveness of repellents for protecting cattle and horses against species which also attack sheep has been examined.

For example, Bruce and Decker (1951) obtained significant increases in the butterfat production of dairy cattle by protecting them against tabanids with sprays of not less than 0.1 per cent pyrethrins and 1.0 per cent piperonyl butoxide. Blume et al. (1971) concluded that three to six applications of 50 per cent DEET would be required to completely protect livestock from the probing and feeding activities of tabanids and stable flies. When higher concentrations were used some cattle salivated excessively and had a nasal discharge and some horses exhibited exfoliation. Shemanchuck (1981) found that spraying cattle with pyrethroids gave up to 10 days protection against blackflies, and Blackman and Hodson (1977) found that permethrin sprays could protect cattle against _Stomoxys calcitrans_ (Linnaeus) for up to 4 days and against _Culicoides_ sp. for 10 days.

Most of the body of Merino sheep is protected against the attack of biting flies by dense fleece (Muller and Murray 1977), although Schmidtmann _et al_. (1980) found that _Culicoides_ spp. attacked Suffolk-cross ewes on the body irrespective of the presence of thick wool. Most attacks are likely to be concentrated on the face and ears and, to a lesser extent, on the legs and perineal region.

The main species attacking sheep in southern Idaho, _S. vittatum_, bites mainly in the ears, around the eyes and on the side of the head (Jessen 1977). This is also true of biting midges in Australia (Muller and Murray 1977). Beadles _et al_. (1977) showed that in cattle these are the areas contacted by ear tags. Knapp and Herald (1981) showed that fenvalerate ear tags repelled face flies from these parts of the faces of cattle, although flies were still seen lighting around the nose. Investigation of the effectiveness of pyrethroid ear tags in protecting against biting flies in areas where they cause problems to sheep raising would be worthwhile.

4.8 Tick repellents

Tick repellents are beyond the scope of this review. However, Ahrens et al. (1977) pointed out that tick infested ears are highly susceptible to oviposition by the screwworm fly. In areas heavily infested with Gulf Coast ticks, (*Amblyomma maculatum* Koch) up to 90 per cent of screwworm cases occur in the ears of cattle. Thus, control of ticks with repellents and slow release devices such as examined by Ahrens et al. (1977) and Ahrens and Cocke (1978) can significantly reduce the problem of screwworm myiasis. Insecticides which kill ticks only after they begin feeding will not be effective as the feeding sites will remain as foci for screwworm infestation.

5.0 Mode of action

Insects normally follow a predictable behavioural sequence before feeding (Hocking 1963) or ovipositing (Dethier 1947, Cragg 1956, Barton Browne 1979). A chemical that interferes with the successful completion of any step in the sequence may act as a repellent. The degree of repellency observed can be affected by many factors including the physiological state of the insect, the environmental conditions, the presence and density of other insects, differences between samples and broods, the method of application and a whole group of variables associated with differences in host attraction. Some of these factors were reviewed by Dethier (1956).

5.1 Vapour repellents

Despite extensive studies, particularly with mosquitoes, the mode of action of vapour repellents is still incompletely understood. Early repellents were mainly volatile and odorous materials such as oils of citronella, pennyroyal, lavender and camphor which were presumed to act via the olfactory sense. However, Khan (1965) showed that dimethyl phthalate, ethyl hexanediol (Rutgers 612), diethyl toluamide (DEET) and indalone, acting in the vapour phase, can also interfere with many other behavioural responses. He postulated that these repellents also blocked contact receptors important in stimulating feeding and oviposition and may have interfered with the functioning of thermoreceptors which induce probing, mechanoreceptors important for orientation to gravity and airflow, visual receptors and auditory organs used in locating mates. He noted that the only receptors that did not appear to be affected were those of the common chemical sense.

Wright *et al*. (1971) suggested that repellents interfered with host finding because they had similar infra-red absorption spectra as that of water. Though mosquitoes were attracted to warm, moist air streams, very high humidities repelled them. Wright suggested that mosquitoes sense the infra-red spectra of repellents and act as though they are entering a zone of high humidity. If this is so, repellents should loose their effect or even become attractive at low humidities. Hocking and Khan (1966) found no evidence that repellents acted by mimicking the infra-red spectrum of water. Indalone became more repellent as the humidity decreased. Rayner and Wright (1966) concluded from a study of 62 repellents that the correlation between infra-red absorption and repellency was probably less direct than earlier suspected and did not differentiate compounds well enough to be used as a preliminary screening technique.

Aedes aegypti females did not exhibit negative anemotaxis when placed in an air stream permeated with dimethyl phthalate (Wright & Rayner 1960). Wright (1975) stated that no known compounds repel mosquitoes very far down wind.

Daykin *et al*. (1965) found that the number of random flights undertaken by mosquitoes increased with an increase in the concentration of carbon dioxide associated with the approach of a host. This increased the chance of mosquitoes encountering an air stream emanating from a host. If the concentration of carbon dioxide was maintained at an elevated level, the mosquitoes gradually adapted to it, and the frequency of random flights returned to its normal level.

Kellogg (1970), from electrophysical studies, identified sensory hairs on the antennae of *A. aegypti*, which increased their rate of discharge when the air passing over them increased in humidity. Once a mosquito encountered a host stream which had elevated humidity, the rate of discharge of neurons in the sensory hairs increased. The mosquito moved into the host stream without turning. If the mosquito passed out of the stream of humid air, the rate of discharge decreased and the mosquito turned. This usually kept it within the host plume. In fact, host plumes are complex stimuli which differ in the presence or absence and concentration of a large number of chemical components. Many more receptors are involved in host finding than simply temperature and humidity sensors (McIver 1981).

Exposure to repellents had a similiar effect to exposure to carbon dioxide (Wright 1975). Initially mosquitoes became more excited and this excitation was followed by adaptation to the repellent. Exposure to repellents also induced adaptation to elevated levels of carbon dioxide. Wright (1975) suggested that when repellents were infused into an area, they reduced or removed the normal response of mosquitoes to host-evolved carbon dioxide.

Kellogg (1970) found that repellents also prevented moisture sensors responding to increased humidity and sometimes even reduced their rate of firing. Daykin et al. (1965) found that when mosquitoes encountered a host-generated plume which contained a repellent, they usually failed to enter it. When they did enter it, they emerged from the other side without turning. The decrease in firing rate of the sensory neurons caused by encountering a host plume containing repellents would, according to this hypothesis, cause the insects to turn and thus send them away from their target. If mosquitoes did enter the host plume, on leaving there would be no further reduction in the firing rate of neurons and the mosquito would continue out of the plume without deviating.

Wright (1975) suggested that repellents may act by blocking the pores in the cuticle of sensory hairs. The shape of repellent molecules and the strength of adsorption to the cuticle on the pore, would be key factors affecting the efficiency of the repellent. Variation between mosquito species in their response to repellents was explained by differences in cuticular structure and the consequent strength with which repellent molecules were adsorbed. This hypothesis fails to explain the effects on senses other than the olfactory sense noted by Khan (1965).

McIver (1981) presented a slightly more sophisticated model of the action of DEET against A. aegypti. She listed four steps that must occur before a behavioural pattern is elicited by an external stimulus. They are: a) reception of the stimulus by the appropriate sensory system; b) decoding and integration of the information in the responses of the sensory system by the central nervous system; c) activation of the appropriate efferent system; and d) response.

She pointed out that there are a number of different morphological and physiological forms of neurons each of which can respond to different stimuli and which could theoretically give rise to an enormous number of different responses. The mosquito's response to a host plume is a result of the sensory pattern sent to the central nervous system by the firing of these neurons and the efferent behaviour it brings about. Davis and Sokolove (1976) have demonstrated that repellents can stimulate olfactory chemosensilla in A. aegypti. This also seems to be the case with P. regina, S. calcitrans and M. domestica (Dethier 1956). McIver (1981) quoted the work of a number of authors who demonstrated that neurons associated with the various olfactory chemosensilla reacted to the presence of repellents in different ways. For example, DEET presented in a plume with lactic acid, which is a known attractant, weakened the response of nerve cells normally excited by lactic acid and increased inhibition of those normally inhibited (Davis and Soklove 1976).

According to the model proposed by McIver (1981), DEET interacts with lipid molecules in the dendritic membranes, thus, changing the sensory pattern presented to the central nervous system. This alters the mosquito's response to the presence of attractants. Different species of insects have different responses to repellents because they detect different sensory cues and thus have their sensory patterns altered in different ways.

McIver (1981) indicated that the reaction of mosquitoes to repellents occurs so rapidly that vapours must be detected by chemosensilla. However, they may also enter the body through the spiracles. She quoted research which indicated that in the cockroach Periplanata americana, (Linnaeus) sensilla other than chemically sensitive ones do not respond directly to vapour repellents. She suggested that the interaction of repellent molecules with body cell membranes, following entrance through the spiracles, could adversely affect a number of physiological processes. This may indirectly bring about the effects observed on behaviour mediated by non-olfactory stimuli. The degree to which this mode of action can be extrapolated to other vapour repellents is questionable.

It should also be noted that vapour deterrency need not act only by preventing the insect from landing and remaining on the host. Barton Browne (1960) provided evidence for the existence of olfactory receptors on the ovipositor of *P. regina* and suggested that they enable the fly to place its eggs in positions with optimal concentrations of oviposition stimulants. Rice (1976) identified two olfactory pegs and five gustatory setae on the ovipositor of *L. cuprina* which presumably serve the same purpose. Chemicals acting in the vapour phase could deter oviposition without repelling flies from the surface of the fleece by acting on these receptors.

5.2 Contact repellents

5.2.1 D.D.T.

D.D.T. is best known as an insecticide but it is also effective as a repellent. From tests with olfactometers Hocking and Lindsay (1958) concluded that technical grade D.D.T. exerted vapour repellency to *Culex tarsalis*, Coquillett *Drosophila melanogaster* Meigen and *M. domestica*. However, Dicke *et al*. (1952) in similar experiments with house flies found D.D.T. to be attractive. D.D.T. has low vapour pressure and its contact repellency is more widely reported than its vapour action.

Kennedy (1947) found that D.D.T. on a surface reduced the duration of resting periods, increased the number of insects alighting and reduced the number of mosquitoes present on the surface at any one time. This was due to excitation by D.D.T. Excitation persisted for some time after mosquitoes left the treated surface. Thus, when treated and untreated surfaces were exposed in the same cage, little difference was observed in the number of insects found resting on them.

Cragg (1945) noted that oviposition by L. sericata was markedly reduced on D.D.T.-treated fleece. Where eggs were laid they were scattered and on no occasion was a complete and compact batch of eggs seen. This is the pattern of egg deposition observed when flies oviposit while affected by a locomotor stimulant (Barton Browne and van Gerwen 1982).

Waterhouse and Scott (1950) found that D.D.T. also reduced oviposition on sheep by L. cuprina. Female L. cuprina appeared to occur in equal numbers on treated and untreated fleece, but less searching for suitable oviposition sites with the ovipositor partially extended was noted when D.D.T. was present. This indicates oviposition deterrency per se. In this experiment flies were exposed simultaneously to both treated and control areas on each sheep. Thus, persistent excitation in flies which visited D.D.T. treated fleece first and then the untreated section of the fleece could explain the apparent absence of repellent activity found by Waterhouse and Scott (1950).

Gahan et al. (1945) found that D.D.T. excitation was not sufficient to prevent biting by Anopheles quadrimaculatus

Say. Excited mosquitoes continued to bite until actually knocked down.

The toxic action of D.D.T. may also be important in producing deterrent effects. Cragg (1945) found that five weeks after dipping in D.D.T., 30 to 60 seconds contact with the treated fleece was sufficient to cause toxic effects in adult L. sericata. As this species usually spends considerably longer than this on the fleece surface before ovipositing (Cragg 1956), toxic action could prevent egg laying. Du Toit and Feidler (1951) found that though D.D.T. killed blow fly larvae, it was not as efficient on live sheep as other organochlorine insecticides. They concluded that this was because of its poor ability to diffuse into the yolk covering of new wool growth (see section 6.3). Poor mobility in the fleece probably helps prolong the oviposition deterrent effect of D.D.T.

Resistant house flies have been reported to be less sensitive to vapour repellency of D.D.T. than normal house flies (Hocking and Lindsay 1958). Virgona et al. (1983) examined the effect of a number of different insecticide resistance factors on repellency and concluded that the degree of repulsion displayed by each strain corresponded broadly with the type and number of resistance factors present. The factors which produced most resistance to repulsion by D.D.T. were "Kdr" or knockdown resistance, which is related to an alteration in the structure of the neurons, and "Pen" which gives a reduced rate of penetration. Not all toxicity resistance mechanisms conferred resistance to repellency. The factors "Ses" and "Deh", which code for enzymic detoxification of D.D.T., by themselves, had no effect on repellency. However, they may have been significant when interacting with other resistance factors (Virgona et al. 1983).

Application of synergists increased the toxicity of D.D.T. but had no effect on its repellency. Though D.D.T. had a negative temperature coefficient for toxicity, this was not the case for its index of repellency. From these observations Virgona et al. (1983) concluded that the physiological response which resulted in repellency proceeded by a different mechanism from the changes which killed the insect.

5.2.2 GH74

Of the halocyclopropane insecticides synthesized by Holan (1971), GH74 had the highest index of repellency against L. cuprina (Virgona et al. 1976). It suppressed oviposition by L. cuprina (Barton Browne and van Gerwen 1982, Orton and Shipp 1984) and has been shown to repel house flies (Virgona et al. 1983) and sheep head flies (French et al. 1977). Virgona et al. (1976) showed that repellency resulted in an antifeedant effect. It is likely that it is by this means that the damage caused by sheep head flies is reduced.

Barton Browne and van Gerwen (1982) found that the number of flies on the surface of GH74-treated fleece did not differ from controls when they were examined two minutes after exposure. At all times after this a clear repellent effect was noted. This indicated that it was unlikely that GH74 acted as a vapour repellent reducing the rate at which flies arrived at, and alighted on, the fleece.

L. cuprina, when on GH74-treated fleece, walked rapidly and often remained there for only short periods of time. Flies which entered cavities in the fleece often emerged quickly and took flight soon after (Barton Browne and van Gerwen 1982). Where eggs were deposited they were in partial egg masses or as scattered eggs. Oviposition was often off target and conducted while the fly was moving (Orton and Shipp 1984). These behaviours are atypical (Barton Browne 1979).

In Barton Browne and van Gerwen's (1982) experiment the major reduction in the number of flies occurred before significant numbers of ataxic flies were seen. Orton and Shipp (1984) found no significant mortality at OSC^{50} (the concentration which caused 50 per cent suppression of oviposition). They concluded from a comparison of relative toxicological and suppressive activities that supression was not simply sublethal toxicity. This is in accord with Virgona *et al*. (1983) who concluded that repellency and toxicity were brought about by different mechanisms.

Both D.D.T.-resistance factors "Kdr" and "Pen", reduced the repellent effect of GH74 in house flies (Virgona *et al*. 1983). However, factors which confer resistance to D.D.T. by enzymic detoxification ("Ses" and "Deh") did not, by themselves reduce the repellency of GH74 although they may have had an effect when interacting with other resistance factors.

5.2.3 Pyrethroids

Pyrethroids can induce repellent effects in a number of ways. The predominant action may be different at different concentrations and at different times after application. When permethrin was applied to cabbage leaves to control larvae of the diamond back moth (*Plutella xylostella* (Linnaeus)) it exerted an ovicidal effect for approximately 3 days, a larvicidal effect for about 12 days and acted as an antifeedant for approximately 19 days (Ruscoe 1977). Chadwick (1975) suggested that increasing the doses of pyrethroids in smoke from mosquito coils produces the following sequence of effects:

i) deters mosquitoes from entering huts filled with pyrethroid smoke

ii) increases activity and egress from huts

iii) inhibits biting

iv) knocks down

v) kills

Blackman and Hodson (1977) found that immediately after spraying cattle with permethrin the duration of visit of S. calcitrans was brief. Thereafter, the degree of repellency decreased until flies were able to engorge. However, a high kill of flies was still achieved.

Pyrethroids generally have low vapour pressures (Nishizawa 1971) and although this does not preclude vapour repellency, it reduces its likelihood.

Schreck et al. (1978) suggested that resmethrin-impregnated cloth may induce some degree of vapour repellency in reducing the number of mosquitoes landing on uncovered skin. They point out however, that the action of resmethrin is not clear and that protection may equally well be brought about in other ways. Repellency exerted by pyrethroids in mosquito coils (Chadwick 1975) could also be considered vapour repellency.

The attributes of pyrethroids as contact repellents have been demonstrated for a range of insect species (Ruscoe 1977, Virgona et al. 1976, Cline et al. 1984, Schreck et al. 1978). Contact repellency may be induced by locomotor stimulation, knockdown, toxicity or by deterring feeding or oviposition. Different actions may be related. For example, Chadwick (1975) suggested that the bite inhibiting and knockdown actions of pyrethroids in mosquito coils were closely associated. Barton Browne (1977) discussed the apparent antagonism between locomotor stimulation and both feeding and oviposition. Orton and Shipp (1984) suggested that pyrethroids activated L. cuprina to such a degree that normal oviposition could not take place.

Pyrethroids have similar action to GH74 at low concentrations but their actions differ when concentrations are higher. At high concentrations, pyrethroids allow oviposition to continue but only as single eggs and only off target, whereas GH74 shuts down oviposition altogether. Orton and Shipp (1984) suggested that this was evidence of sensory disruption. Neurophysical evidence of Virgona et al. (1982) supports this explanation.

GH74, cypermethrin and deltamethrin all suppressed oviposition by L. cuprina for some time after flies had been removed from treated surfaces. Orton and Shipp (1984) found that three hours after exposure, oviposition was still below 20 per cent of that of controls. It had returned to normal after 24 hours.

Often locomotor stimulants take some time to act (Barton Browne and van Gerwen 1982). Repellent creams containing permethrin were found to be ineffective for controlling malaria transmission by mosquitoes (Hocking 1963). Although the cream did repel mosquitoes it did so only after the mosquitoes had already bitten and thus, had the opportunity to transmit the malaria plasmodium.

Knockdown and fast acting toxicity can also produce repellent effects. Shemanchuk (1981) noted that the repellency achieved against black flies by spraying cattle with pyrethroids was due to rapid intoxication of the black flies on contact with treated hair. He noted that permethrin appeared to act more quickly than cypermethrin. When cypermethrin was applied in ethanolic solution, partially engorged females were found, indicating that the formulation did not act quickly enough to repel or knock down flies before they could take a partial blood meal. No tests were conducted to determine whether affected black flies eventually died or recovered, or whether vapour repellency or locomotor stimulation was also involved.

Pyrethroids with rapid knockdown action tend to be more polar. This presumably results in quicker penetration of the insect's cuticle. Pyrethroids with higher toxicity tend to be more lipophilic, and most do not have rapid knockdown action (Briggs et al. 1974).

Cline et al. (1984) reared *Tribolium confusum* du Val on media treated with sublethal doses of synergised pyrethrins. They found that though resistance developed to the toxic effects of these compounds, the insects remained significantly responsive to their repellent action. Orton and Shipp (1984) noted dissimilarities between the profiles for oviposition suppression and toxic effects for both cypermethrin and permethrin in *L. cuprina*. These experiments indicated that the repellency of pyrethroids was brought about by a different mechanism than lethal action. However, Virgona *et al*. (1983) showed that house flies selected for pyrethroid resistance had a lower index of repellency to pyrethrum, bioresmethrin and permethrin than unselected flies. As with D.D.T. and GH74, it is likely that the mechanism by which insecticide resistance is mediated will determine the effect of resistance on repellency.

Lethal action of pyrethroids can also produce effects that may be interpreted as repellency. When testing repellents it is often desirable to run treated and untreated animals separately (Barton Browne and van Gerwen 1982). Insecticides can reduce the number of insects on treated surfaces in such experiments by reducing the local population of insects. This is especially so for ectoparasites with low dispersal capabilities such as ticks (Schreck *et al*. 1982). Appleyard (1982) suggested that reduction in head fly damage brought about by the application of permethrin to sheep was due in the short term to the repellent effect of permethrin, and in the long term, to reduction in the head fly population through its toxic action. In addition, quick acting toxicants may rapidly remove ectoparasites from the surface of an animal to produce an apparent repellency.

Results with fenvalerate have been less consistent than with other pyrethroids. Appleyard *et al*. (1984) found that fenvalerate ear tags had no effect on the number or severity of head fly lesions. However, fenvalerate tags have given good control of horn flies (Ahrens and Cocke 1978) and face flies (Knapp and Herald 1981). In the experiment of Knapp and Herald (1981) face flies were repelled from around the eyes and the sides of the face but not from the muzzle. The skin on the sides of the face and around the eyes is frequently contacted by ear tags (Beadles _et al_. 1977). Shemanchuk and Taylor (1984) found that when cattle were sprayed with fenvalerate good protection was provided against black flies. Polyvinyl-chloride ear tags containing 8 per cent w/w fenvalerate applied to the ears of steers failed to provide satisfactory protection, however. Many parts of cattle that are attacked by black flies (Shemanchuk and Taylor 1984) do not often come into contact with ear tags (Beadles _et al_. 1977), so the concentration of fenvalerate on the skin and hair would be low.

Rani and Osmani (1984) found that fenvalerate had poor repellency against house flies. At concentrations of 0.01 per cent, knockdown of male and female house flies took 15 and 20 minutes respectively. Knockdown or toxic effects could account for the repellency observed against horn flies or face flies. At lower concentrations fenvalerate may not be repellent to head flies or black flies and may not knock them down or induce toxic effects until after they have completed feeding.

Ruscoe (1977) stated that permethrin is active against the eggs and larvae of most insect species although there are exceptions. Nicholson et al. (1983) found that the larvae of L. sericata were able to tolerate much higher doses of permethrin than the adult stage. Forsythe and Lehman (1979) stated that pyrethroids do not show promise for the control of blow fly strike caused by L. cuprina because of poor larvicidal activity and limited persistence. It seems unlikely that presently available pyrethroids applied to deter oviposition would have significant larvicidal effects.

Biting lice have been eradicated by applications of cypermethrin (Hall 1978, Henderson and McPhee 1983), deltamethrin (Kettle et al. 1983) and cylohalothrin (Rundle and Forsythe 1984). Control of L. ovillus, L. pedalis and M. ovinus was achieved by dipping in cylohalothrin (Rundle and Forsythe 1984). Thus, application of pyrethroids to deter oviposition by wool myiasis flies or to repel biting flies may also give some protection against resident ectoparasites.

5.2.4 Physical repellents

The physical repellency of oily substances has been demonstrated for a number of flies which attack sheep. MacKerras and MacKerras (1944) showed that paraffin or olive oil on the surface of the sheep's fleece provided a mechanical obstruction which walking L. cuprina tended to avoid. Hobson (1940) found that a range of different oils, when applied to sheep by spraying or dipping, provided protection against oviposition by L. sericata.

Oily and greasy substances have also been used to protect against biting flies. Hearle (1938) noted that oily dressings incorporating compounds such as raw linseed oil, fish oil and oil of tar were applied to work horses in order to protect them against black flies. Townsend and Turner (1976) found that petroleum jelly smeared on the inside of horses' ears protected against the attacks of S. vittatum. This treatment caused flies to drop off of the ear after landing. Formulations with higher viscosity seemed to deter black fly feeding for longer but addition of insecticides did not prolong the period of protection. Black flies resumed feeding in the first spots to become free of the treatment.

It seems likely that part of the protection provided against screwworm flies and blow flies by the application of tarry dressings to wounds is due to physical protection of the wound surfaces.

5.3 Other modes of action

Parman et al. (1928) suggested that repellents of blow flies may act by deodorizing sources of attraction. They noted the following ways in which deodorization could occur:

i) Absorption of attractive odours - The ready solubility of many odorous substances in oils and fats is well known. When oily liquids are smeared over attractive targets it is likely that part of their action in reducing the number of flies attracted is by absorbing attractive vapours.

ii) Adsorption of attractive odours - Applying animal charcoal to the surface of attractive baits reduces the number of flies visiting them. This may be due to adsorption of the attractive odours.

iii) Chemical neutralization, oxidation or reduction of odorous compounds.

iv) Inhibition of the formation of odours. The apparent repellent effect of copper compounds may be due to their ability to inhibit bacterial growth and thus, production of the attractive odours of decomposition. The phenols in pine tar oil may contribute to its effectiveness as a repellent in this way.

v) Masking of odours - The authors suggest that essential oils repel by this means.

Compounds which act in ways described in points (i) to (iv) are anti-attractants.

Lennox and Hall (1940) stated that part of the reason for the effectiveness of oil of citronella as a wound protectant was that it promoted healing of wounds and thus reduced the period of time for which they were attractive to flies. Barton Browne (1962) noted that female _L. cuprina_ would not oviposit unless tarsal contact had recently been made with water. Fleece rot, which is a major factor predisposing sheep to body strike in Australia (Watts et al. 1979), does not occur when the fleece is dry. Compounds which dry the fleece such as that developed by Hall et al. (1980), and compounds which promote healing could also be considered anti-attractants.

6.0 Application of repellent

6.1 Factors affecting choice of application method

6.1.1 Biology of the ectoparasite

The aim of application is to place the repellent where the pest will encounter it and be repelled before it causes any damage. For rational design of application methods, a detailed knowledge of the parasite's life history is necessary. In particular, the means by which it initially contacts the sheep and its habits and distribution while present on the sheep, need to be known.

The parts of the sheep which require treatment in order to obtain most efficient control differ for different ectoparasite species. For example, to prevent larviposition by the sheep bot fly, repellents need to repel the flies from the sheep's nostrils. To control blow fly strike by _L. cuprina_, protection needs to be provided near the breech and along the sheep's backline (Watts _et al_. 1979).

The vertical distribution of ectoparasites within the fleece and skin also needs to be considered. If a contact repellent applied to prevent wool myiasis is aimed against ovipositing adults, the compound will need to be present in the top few centimetres of the fleece. If it is intended to prevent larval feeding, it will need to be present at the base of the fleece and on the skin surface.

The importance of a detailed knowledge of the life history of ectoparasites is demonstrated by the results of Raun (1955) with cattle. Pyrethrins applied to the legs and lower body effectively controlled warble infestation by *Hypoderma lineatum* (Villers) but not by *Hypoderma bovis* (Linnaeus). *H. lineatum* spends a period of time standing on the skin of cattle attaching a number of eggs to a single hair. Pyrethrins repelled H. lineatum and thus, prevented warble infestation by this species. *H. bovis*, on the other hand, makes quick darting attacks and deposits one egg at each attack. The contact repellency of the pyrethrins had no effect on this mode of egg laying.

6.1.2 Characteristics of the repellent and its interaction with fleece and skin components

Knowledge of the characteristics of the repellent and its behaviour once it has been applied to the sheep, is also necessary. Persistence of the compound will be important in determining the formulation to be used and the method of application. Most vapour repellents are short lived in the fleece, and pyrethrum degrades quickly. Such chemicals require constant replenishing. With systemic compounds application methods must be chosen which efficiently introduce the chemical into the systemic circulation. To date, no systemic repellents have been developed.

The choice of application technique for most repellents will depend heavily on their mobility in the fleece and on the skin surface. Pitman and Rostas (1981) pointed out that wool fibres possess chemically reactive groups, such as thiol, amino and carboxyl groups and have hydrophobic sites which can react with, and affect the efficiency of, chemicals applied to the fleece. Hoffman et al. (1963) found that though scouring of wool removed much of the arsenic applied by dipping, some remained tightly bound to the wool fibres after repeated scourings. Schreck et al. (1980) suggested that the poor correspondence they found between biological effect and permethrin content in treated cloth was due to poor availability of the chemical at the surface of the fibres. Chemical which becomes too tightly bound to the wool fibre will not be available to repel.

Sheep excrete an emulsion, normally referred to as wool yolk. There is an intact layer of yolk on the skin surface and an almost continuous layer on the wool fibres (Jenkinson and Lloyd 1979). Wool yolk is a complex substance which has been analyzed in detail by Freney (1940). It is composed predominantly of ether soluble components known as wool wax, most of which are secreted by the sebaceous glands, and water soluble compounds known as suint, most of which are secreted by the sudoriforous glands. There are also small quantities of other compounds presumably derived directly from the epithelial cells and blood. Sinclair (1979) stated that it is reasonably believed that it is the wax component which influences insecticide mobility but that there is insufficient information to justify this conclusion. The composition of wool yolk is not constant and is influenced by such factors as season, hormonal cycles and diet (Smith and Jenkinson 1976, Christensen and Dobson 1979). Solubility of chemicals in the wool wax is likely to be affected by changes in composition. Pitman and Rostas (1981) indicated the need to elucidate solubility characteristics of skin emulsions under conditions likely to be encountered by sheep and cattle if good topical delivery systems are to be developed.

The effectiveness of repellents may be determined, to a large degree, by their solubility and mobility within the wool yolk. If a chemical with high solubility is applied to the tip of the fleece it will diffuse down through the layer of emulsion covering the wool fibre and into the sebum contained in the sebaceous gland (Du Toit and Fiedler (1951). It may also move laterally through the layer of sebum on the skin surface. This may be advantageous in that it spreads the chemical through the fleece and allows it to diffuse into the wool yolk on the new wool growth. The efficiency of larval repellents and antifeedants would be increased by such an action.

However, diffusion through the wool yolk and into newly secreted sebum constantly dilutes the concentration of active ingredient. With an oviposition deterrent which acts against the fly at the fleece surface, mobility could be a disadvantage. A compound which is held at the surface of the fleece and does not diffuse would be preferable so that a high concentration is maintained in the portion of the fleece contacted by the fly. Van Gerwen and Barton Browne (1983) found that the period of protection provided by GH74 against oviposition by L. cuprina was not affected by the length of fleece present at application. This suggests that GH74 does not translocate very far in the fleece.

Non-wool bearing areas generally have a poor yolk covering (Roberts 1966). Chemicals which dissolve in wool yolk can only be expected to persist for a day or two in these regions (Sinclair 1979).

6.1.3 Characteristics of the fleece

The length of fleece affects the barrier that has to be penetrated to reach the skin surface. It can also influence the amount of chemical needed and the degree of dilution of the chemical in the fleece. When a substantial fleece is present, care will be needed to ensure that application of chemical does not reduce its quality (Sinclair 1965). Different breeds vary widely in fleece conformation, wool density and proportion of non-wool components in the fleece (Carter and Clarke 1957). This will also affect the efficiency of different application techniques.

6.1.4 Economic considerations

The ease of mustering, cost and amount of labour involved, the availability of application equipment and the amount of chemical used, will all affect choice of method.

6.2 Methods of application

6.2.1 Dipping

This is the traditional method of application of chemicals to the fleece. The sheep is completely immersed in a chemical bath for a period of time sufficient to allow penetration of solution to the skin surface. This allows maximum opportunity for chemicals to become bound to the wool fibre or dissolved in the wool yolk. Dipping also penetrates crevices, such as those formed by inguinal folds, which are difficult to treat by other methods (Kirkwood et al. 1978).

Dipping deposits a high concentration of chemical in the fleece and gives more complete coverage than other techniques (Kirkwood et al. 1978, Kettle et al. 1983) but is slow and labour intensive. It is also inefficient in that chemical is often applied to regions on the sheep which are not contacted by ectoparasites. Wool values can be reduced by discolouration of the fleece caused when large numbers of sheep, or dirty sheep, are treated with the same dipping fluid (Sinclair 1965). Bacterial infections can spread in dips, and dipping sheep with more than one month's wool growth can increase the incidence of infection with Dermatophilis congolensis (Roberts and Graham 1966).

6.2.2 Jetting

The technique for efficient hand-jetting is decribed by Brown (1966). Insecticide is forced into the fleece at high pressure from a hand held jetting wand. Jetting wands are "T" shaped or shaped like a question mark with protruding nozzles which are combed through the fleece. When sheep are properly jetted the fleece is wet down to the skin.

With hand jetting, high concentrations of chemical can be placed at sites in the fleece that have a high risk of infestation (James and Russell 1980). However, hand jetting is tedious, labour intensive, time consuming and, hence, expensive.

6.2.3 Showering

Sheep are held in a circular or rectangular steel pen and showered with a large volume of chemical solution which is applied from nozzles mounted on a stationary or rotating, overhead boom. Stationary nozzles mounted in the shower floor spray the underside of the sheep (Kirkwood et al. 1978). This method relies on a large volume of solution and gravitational penetration rather than high pressure to introduce chemical into the fleece.

Showers are effective in controlling ectoparasites on newly shorn sheep but are not so effective when sheep are carrying a fleece (Kirkwood et al. 1978, James and Russell 1980). Good penetration into the fleece can be achieved along the sheeps' backline if sheep are left in the shower long enough (James and Russell 1982) but poor penetration is achieved on the breech and on the abdomen (Kirkwood et al. 1978, James and Russell 1980, 1982).

Showers are usually quicker and require less labour than dipping or hand jetting, but wool staining can occur if the dipping fluid becomes dirty (Sinclair et al. 1964).

6.2.4 Spraying

Spraying may be defined as the application of chemicals, under pressure, from above the surface of the fleece, whether from hand-held devices or from spray races.

As shown by James and Russell (1980), the fleece surface is a very effective barrier to the penetration of insecticide. They found that a commercially available spray race, operated at a pressure of 758 Kpa, seldom penetrated more than 2 cm into the fleece. With chemicals that are highly soluble in wool yolk it may be possible to apply a concentrated solution to the fleece tip and rely on diffusion to achieve penetration. Chemicals placed on the surface are more prone to loss by volatalization and abrasion. Sinclair (1979) stated that the main disadvantage of spraying is the need for uneconomically large deposits to achieve effective concentrations of chemicals in the fleece.

Spraying is an attractive method of application as it is easily automated, entails much less labour than the aforementioned methods, and large numbers of sheep can be treated in a short period of time. It may be a useful method for applying oviposition deterrents or contact repellents that exert their effect at the fleece surface, and which are relatively immobile in the fleece. Automatic spray arches, or treadle-activated sprayers, such as described for cattle by Raun (1955) and Granett et al. (1965) could be installed in entrances to water or salt blocks to renew repellent deposits periodically.

6.2.5 Air misting

Preliminary experiments suggest that blowing insecticide into the fleece of sheep may be an efficient way of applying chemical to the fleece in automated systems (Connell et al. 1984). Jets of air blow open the fleece and carry insecticide into the fleece and down to the skin.

6.2.6 Backline treatments

These are treatments which are applied in a strip along the backline. They differ from "spot on" or "pour on" formulations in that they rely on peripheral spread of active ingredient rather than systemic action to bring them into contact with target insects (Kettle 1983). Bayvel et al. (1981) suggested the following advantages of backline tretments over dipping and showering: they are easier to apply; less labour is required; no mixing is necessary; the dose is readily measured; a low volume is applied, hence there is little wetting of the fleece; there are no problems of bacterial infection due to recycled dip solution; there is no excess solution to dispose of; backline treatments are used immediately after shearing so no re-mustering of sheep is necessary; there is no environmental contamination; and it is easier to treat small groups of sheep.

The degree of coverage that can be expected from backline treatments will depend on many factors. The formulation applied, the amount of wool and wool yolk present, skin temperature, amount of suint, follicle density, body conformation, weather, site of application and stock handling immediately after treatment may all be important (Pitman and Rostas 1981, Kettle et al. 1983). Measurement of residues in the fleece indicated that the coverage with deltamethrin when applied as a backline treatment of Decacide® was very uneven in comparison to dipping (Kettle *et al*. 1983). Nevertheless, backline treatment with Decacide® killed all lice within 24 hours and within two to seven days when applied to sheep newly shorn and with three weeks wool growth respectively. The above experiment was conducted with Perendale ewes. With Merino sheep four to six weeks were needed to give a complete kill (Bayvel *et al*. 1981).

6.2.7 Controlled release systems

Application of insecticides in controlled release systems has a number of advantages over conventional techniques.

Doses need not be as large so there is less chance of tissue residues. Insecticides which have poor persistence do not require continual reapplication and there is a lower risk to the operator and of environmental contamination.

Beadles et al. (1977) believe that the majority of livestock ectoparasites could probably be controlled with well designed, slow release devices. It seems that utilization of a number of the systems described in the following sections could improve the degree of control obtained with insecticides or repellents. However, with the exception of polyvinyl-chloride ear tags, they have received little use for ectoparasite control. In particular, they present new possibilities for the use of vapour repellents which in the past have been too short-lived to be of much practical use.

The following controlled release systems described by Cardarelli (1975) may have application to the release of repellents and insecticides on sheep.

i) Diffusion - dissolution matrices

The active ingredient is dissolved in compounds such as natural rubber or other polymers which have the physical characteristics of elastomers. Molecules at the surface desorb into the atmosphere or contacting medium. Active ingredient from the interior of the matrix moves to take the place of the desorbed molecules and a continual loss of active ingredient occurs from the surface.

ii) Three-phase carrier systems

Where the active ingredient is not soluble in the elastomeric or plastic matrix, a carrier which is soluble, is used. The carrier migrates to the surface of the matrix and releases the active ingredient.

a) Ear tags

Polymer matrix ear tags, most commonly polyvinyl chloride, are the only controlled release systems that have received any widespread use for ectoparasite control. Active ingredients which have been tested in ear tags include dichlorvos (Harvey et al. 1984), chlorpyriphos (Ahrens et al. 1977), tetrachlorvinphos (Ahrens et al. 1977, Harvey et al. 1984, Shepherd 1980), and the pyrethroids permethrin, cypermethrin, deltamethrin and fenvalerate (Appleyard et al. 1984a,b, Ahrens et al. 1977, 1978, Ahrens and Cocke 1979, Harvey and Brethour 1979, Knapp and Herald 1981, 1984, Miller et al. 1983, 1984, Shemanchuk and Taylor 1984, Williams and Westby 1980, Wright et al. 1984).

Such tags have been tested against horn flies (Ahrens and Cocke 1979, Harvey and Brethour 1979, Knapp and Herald 1984, Miller et al. 1983, 1984, Williams and Westby 1980), face flies (Knapp and Herald 1981, 1984, Miller et al. 1984, Williams and Westby 1980), black flies (Shemanchuk and Taylor 1984), head flies (Appleyard et al. 1984a,b, Wright et al. 1984), Haematobosca stimulans (Meigen) and Morellia simplex (Loew), (Wright et al. 1984), and ticks (Ahrens et al. 1977, 1978, Gladney 1976).

The degree of control achieved is related to the biology of the ectoparasites. Ear tag formulations have generally given good protection against horn flies, although it appears that resistance to fenvalerate, permethrin and tetrachlorvinphos may have recently developed (Harvey et al. 1984). Horn flies spend most of their time resting on cattle and are thus, likely to encounter surfaces rubbed by an ear tag. For this reason application of one tag per head (Harvey and Brethour 1979), tagging only one of each three cows (Shepherd 1980) and tagging only the nursing calves (Knapp and Herald 1984) has given good horn fly control.

Control is not as complete with ectoparasites that are not so closely associated with cattle. Only a small proportion of face flies are present on cattle at any one time. During this time they are usually found feeding from the mucus membranes of the nose and eyes. Williams and Westby (1980) found that tagging with fenvalerate tags gave 50 per cent control of face flies over a thirteen week period compared to 95 per cent for horn flies. Knapp and Herald (1981) showed that fenvalerate ear tags repelled face flies from around the eyes but not from the nose.

Black flies are even less closely associated with cattle. They generally require only one blood meal before returning to rivers or streams to oviposit. Cattle are bitten on the underline, legs, sides of the body, sides of the neck and face (Shemanchuk and Taylor 1984). Many of these areas are seldom, if ever, contacted by ear tags (Beadles et al. 1977). Shemanchuk and Taylor (1984) found that 10 per cent w/w permethrin ear tags provided 13 days protection while 8 per cent w/w fenvalerate ear tags at no time provided satisfactory protection.

The rate of release of active ingredient from ear tags follows a parabolic curve characteristic of the diffusion process. The highest rates are released soon after tagging. The release rates can be predicted from equations for the release of solutes from dissolved monolithic systems (Miller et al. 1983). Knapp and Herald (1984) stated that correlation of the release rates of controlled release ear tags, with the realized ectoparasite control, should allow one to time the tagging of animals. They found that 1.75 to 2.0 mg per day of fenvalerate must be released to obtain above 80 per cent reduction of face flies. To maintain horn fly burdens below five flies per cow, release rates above 1.0 mg, per day and 1.9 mg per day were required for fenvalerate and permethrin ear tags respectively (Miller et al. 1983). The release rate depends on the concentration of active ingredient present in the matrix, the surface area exposed, the rate of removal of active ingredient from the surface of the tag and the concentration of plasticizer (Miller et al. 1983, 1984). As both fenvalerate and permethrin tags lost their effect when greater than 50 per cent of active ingredient was still present, Miller et al. (1983) suggested that their efficiency can be improved.

The concentration of active ingredient at a particular point on the integument will also depend on the frequency of contact of the ear tag with that point and the amount of transfer that occurs at each contact. Though Beadles et al. (1977) have studied the areas contacted on cattle by various constant release devices, these studies are lacking in sheep. The efficiency of transfer of repellents or insecticides from controlled release matrices to the wool of sheep also does not appear to have been investigated.

The protection provided against head fly damage by permethrin and cypermethrin ear tags (Appleyard et al. 1984a,b) indicates that studies of their effect against other sheep ectoparasites would be worthwhile. Blow fly strikes in fighting wounds on rams' heads can impose significant losses by causing infertility and, in severe cases, death of rams (Watts et al. 1979). Ear tag formulations may be effective in preventing blowfly and screwworm infestations of these wounds.

The protection against head flies conferred to lambs by tagging their mothers (Appleyard 1984b) indicates that permethrin and cypermethrin may be transfered to the fleece and maintain their effect. Investigations of the effect of ear tag formulations on wool myiasis flies, biting flies and resident ectoparasites of sheep would be worthwhile.

b) Other designs

Other forms of constant-release devices investigated for use with cattle include neckstraps, halters, leg bands and tail tags (Beadles et al. 1977). Hunt et al. (1980) achieved control of H. lineatum with dichlorvos-impregnated strips attached to the legs of cattle. Resin strips impregnated with dichlorvos and fitted as neck collars controlled biting lice on Angora goats (Darrow 1973). Similar collars are used to control fleas on cats and dogs (Fox et al. 1969). Investigation of similar devices for use on sheep may be worthwhile. It is interesting to speculate that controlled release devices containing repellents or insecticide could be attached in the fleece at strategic locations. For example, such devices located at the withers and on the loins of sheep may control body strike of sheep which begins at these spots in approximately 80 per cent of cases (Watts et al. 1979).

iv) Retarding volatility

The active ingredient is applied in a film-forming polymeric solution. Following application the solvent evaporates and the active ingredient is released slowly from the film surface into the surrounding medium. Cardarelli (1975) quoted patent applications in which it was claimed that incorporating DEET in formulations with Carboset, which is a film forming gel, has prolonged mosquito repellency to 24 hours. Khan et al. (1977) found that formulating mosquito repellents with a commercially available polymer (Areoplast® dressing, Parke-Davis and Co.) increased their resistance to both water washing and abrasion, and thus prolonged their effect. Cardarelli (1975) noted that controlled release repellent or insecticidal gels and foams could be incorporated in formulations suitable for spraying on sheep.

Khan et al. (1975a) showed that fixatives, which are commonly used in perfume formulations to diminish the evaporation of the scent, increased the period of effective repellency of DEET, dimethyl phthalate, ethyl hexanediol and Indalone. Vanillin also increased the period of protection of all repellents tested. The period of repellency of DEET was increased from 5.2 hours to 14.5 hours and of triethylene glycol ethylhexyl ether from 8.3 hours to 22.0 hours (Khan et al. 1975b).

v) Microencapsulation

The insecticide or repellent is contained within a permeable or semi-permeable envelope. The active ingredient diffuses though the membrane and is gradually desorbed from its surface. Microencapsulation has been used to prolong the period of protection of pyrethroids applied to protect against household pests (Bennett et al. 1977). Microcapsules can be made opaque to ultra-violet light which causes degradation of some pyrethroids.

vi) Leaching

Active ingredients which are not soluble can be incorporated into matrices by mechanical bonding. Matrix and active ingredient molecules are released by leaching.

vii) Exfoliation

This is similar to leaching except that an elastomeric or plastic matrix which will degrade when exposed to physical, chemical or biological attack is used.

viii) Other systems

Cardarelli (1975) also describes a number of newer controlled release materials which may be of use for the application of repellents. Amongst these are:

i) Nitrile acrylic polymers and polyurethanes. Ultra-porous elastomeric foams have up to 70 per cent void which could be filled with repellents or other active ingredients. Some have been developed which can release as little as 3 per cent per year.

ii) Ultra-microporous plastics. These materials have molecular size pores of 14 to 60 Å. They have been made into micro-beads of 10 to 20 um which can carry 90 per cent of their own weight of liquid.

iii) Polymeric fibre controlled release vapour dispenser systems. These consist of parallel arrays of hollow polymeric fibres fixed to a tape backing. After filling with active ingredient the fibres are heat-sealed at regular intervals along the length of the tape. Release is activated by cutting the tape. A cross section of liquid surface equivalent to that of the fibres is exposed to the air. The reservoir, and thus the longevity of action, is determined by the length of the fibres. Multicomponent mixtures can be released in the desired ratios by filling the required proportions of the fibres with different components.

iv) Controlled pore ceramics. These are currently being used as carriers for enzymes.

7.0 Potential for the use of repellents

7.1 Resident ectoparasites

Resident ectoparasites are spread mainly by direct contact between sheep. Repellents may slow the spread of ectoparasites within a flock but have no effect on the source of the infestation. Insecticidal treatment, which if applied properly, both eliminates the source of infestation and protects clean sheep, seems a more rational approach to the control of resident ectoparasites.

Antifeedants, which starve ectoparasties to death, could be effective, although the extra time until death would increase the chance of transmission to untreated sheep. The present availability of safe and efficient insecticidal compounds, which are easy to apply and leave few tissue residues (Bayvel et al. 1981, Henderson and McPhee 1983, Kettle et al. 1983) indicates that there is little reason for the development of repellents or antifeedants.

7.2 Wound myiasis

As compounds are often removed from wound surfaces by bleeding or suppuration, vapour repellents which act at a distance have advantages over contact repellents or insecticides. In the past, vapour repellents did not persist sufficiently to provide protection until wounds had completely healed (Johnstone & Southcott 1954). Incorporation of repellents into controlled-release formulations, such as foams or gels, or microencapsulated forms, may overcome this disadvantage.

The time it takes for a wound to heal determines the time the wound is susceptible to fly attack. Protectant compounds applied to the wool and skin around the wound, rather than to the wound surface, are less likely to interfere with the healing process. A larvicide should be added to any wound protectant formulation so that if the protection provided by the repellent breaks down, there will only be limited spread of the strike. The protection provided by pyrethroid ear tags against sheep head fly (Appleyard et al. 1984a,b) implies that similar tags could be of use for protecting rams against blow fly and screwworm infestation in fighting wounds.

7.3 Wool myiasis

The experiments conducted by Barton Browne and van Gerwen (1982) and van Gerwen and Barton Browne (1983) showed that GH74 has definite potential for use against fleece myiasis flies. Barton Browne (1979) noted that the cost of the chemical may be high. As up to six months protection can be gained, compared to 14 weeks with presently available compounds (Hart et al. 1982), this will be largely offset by the reduced cost of application.

Van Gerwen and Barton Browne (1984) showed that spraying GH74 onto the fleece gave persistent protection. This is a distinct advantage as it removes the need for more labour intensive methods (see section 6.2).

Suppression of oviposition by GH74 lasted for at least three hours after exposure (Orton and Shipp 1984). As fleece myiasis flies usually spend many minutes exploring the fleece before ovipositing (Cragg 1956), it is likely that they will become affected by GH74 even if application leaves small patches untreated. The need to muster sheep for treatment may be removed altogether by applying GH74 through automatic sprayers similar to those described by Granett et al. (1955).

This type of treatment would not be favoured for the application of insecticides because of the selection pressure it imposes for the development of resistance. However the degree to which such treatment would screen for resistance to oviposition deterrents is not clear. Flies may leave treated sheep without ovipositing and deposit their eggs later on untreated sheep or in carrion. If most of the sheep in an area are treated with an oviposition deterrent the predominant selection pressure could be for more efficient carcass breeding strains. Of course many other factors will also be involved.

The reduced effectiveness of GH74, when applied around the tails of sheep with diarrhoea should not prove a serious disadvantage as breech strike can be well controlled using other techniques (Baillie 1979). Nevertheless, as indicated by Barton Browne and van Gerwen (1982), field trials are needed to ensure that significant numbers of strikes do not develop from the deposition of incomplete egg masses or from flies ovipositing while standing on foreign matter present in the fleece.

Pyrethroids have been shown, in preliminary experiments, to have similar action to GH74 in preventing oviposition by L. cuprina (Barton Browne 1979, Orton and Shipp 1984). Forsythe and Lehman (1979) indicated that access to the world sheep dip market, which is aimed mainly at the control of resident ectoparasites, is very important in determining the economic viability of developing compounds for wool myiasis control. Pyrethroids also kill lice and keds (Hall 1978, Bayvel et al. 1981, Kettle et al. 1983). In addition, pyrethroids repel biting flies (Schmidt et al. 1976, Blackman and Hodson 1977, Shemanchuk 1981, Shemanchuk and Taylor 1983). Forsythe and Lehman (1979) stated that existing pyrethroids show little promise for preventing blow fly strike because of poor larvicidal activity and very limited persistence, though they do not specify particular pyrethroids. However, Hall (1978) found that dipping sheep in cypermethrin and permethrin could protect them against reinfestation by biting lice (B. ovis) for up to 19 weeks and 9 weeks respectively and Kettle et al. (1983) found that deltamethrin could protect against the same species for 10 to 15 weeks. The use of microencapsulated forms, or other slow release formulations may be of use if persistence is a problem. Nicholson *et al*. (1983) showed poor larvicidal activity of permethrin against *L. sericata* larvae. Nevertheless, if further experiments show pyrethroids to be effective and persistent oviposition deterrents, they would be attractive to sheep growers, because of the number of different ectoparasite groups affected, and to chemical companies, because of the size of their potential market.

Development of controlled-release formulations and the use of strategically placed controlled-release devices, could markedly improve the efficiency of repellents and insecticides in controlling wool myiasis flies.

7.4 Nasopharyngeal and oculovascular myiasis

As these flies do not contact the sheep for any substantial period of time to larviposit, vapour repellents, which interfere with the approach of flies to the sheep's nose, seem to offer the best possibility for preventing nose-bot infestation. Controlled-release formulations of repellents may be worth investigation. It seems that to be effective, applications would need to be constantly renewed.

In tests to determine how compounds could spread from controlled release devices, tapes incorporated in halters or attached to the legs, both transferred ink to the noses of cattle (Beadles *et al*. 1977). However, it seems unlikely that compounds volatile enough to provide vapour repellency, could be transferred onto the skin using such devices.

It is also unlikely that vapour repellents could keep bot flies at sufficient distances to prevent behavioural responses of sheep to the presence of the flies. If, as Cobbett (1956) suggests, these responses are the major source of loss in sheep flocks, there would be little point in developing repellents. Repellents to prevent larvae migrating into the nasal passages are another possibility, but the likelihood of such substances giving any long lasting protection seems remote.

Pyrethroid ear tags have been shown to repel face flies from near the eyes of cattle (Knapp and Herald 1981). This is the position in which Gedoelstia spp. oviposit. Though pyrethroids act mainly by contact repellency, investigation of ear tag formulations of repellents for protection against ocular myiasis may be worthwhile.

7.5 Sheep head flies

Many repellents have been shown to be effective against the sheep head fly (French et al. 1977, Appleyard 1982, Appleyard et al. 1984a). Ear tag formulations of permethrin and cypermethrin have given season-long protection (Appleyard 1984a,b). It is likely that there will be increased use of these tags for sheep head fly control.

7.6 Biting flies

Spraying pyrethroids on cattle has given short-lived control of biting flies (Blackman and Hodson 1977, Bailie and Morgan 1980, Shemanchuk 1981, Shemanchuk and Taylor 1983).

It is likely that similar control could be achieved on the non-woolled parts of sheep. When applied to wool, protection may be more persistent as the formulation will be less subject to loss by skin absorption and to dilution by sweat. The type of application necessary will depend on the feeding habits of the species to be controlled.

If the main area of attack is on the ears or around the face, as with biting midges in Australia (Muller and Murray 1977) and S. vittatum in Idaho (Jessen 1977), pyrethroid ear tags may give good control. Studies similar to that of Beadles et al. (1977) are needed to determine which parts of the face and body come into contact with pyrethroid ear tags attached to sheep. The pattern of contact may be quite different from cattle, especially after the wool has grown.

Biting flies, which attack mainly on the legs, such as mosquitoes and S. calcitrans, may be controlled by applications of pyrethroids through automatic sprayers similar to that used by Raun (1955) to prevent oviposition by H. lineatum on the legs of cattle. Polyvinyl-chloride strips containing pyrethroids may also be effective if attached to the legs of sheep. Hunt et al. (1980) note that similar strips were seldom lost from the legs of cattle even when they grazed in brushy range land.

A number of species of mosquitoes and Culicoides also feed on the bodies of sheep (Muller and Murray 1977, Schmidtmann et al. 1980). The possibility of using pyrethroids, applied to the fleece to deter oviposition by fleece myiasis flies, has previously been noted. This could also provide protection against biting flies which feed on the body.

8.0 Conclusions

Repellents have a number of advantages over insecticides for the control of insect pests of livestock. However, it is unlikely that they can be efficiently used to control resident ectoparasites of sheep. Repellents may slow the spread of resident ectoparasites, but do not treat the source of the infestation. Application of insecticides to sheep, which both eliminates the source of the infestation and protects clean sheep, seems to be a more rational approach.

In experiments to date the contact repellent GH74 has been effective and persistent in suppressing oviposition by L. cuprina and damage by H. irritans. The period of protection provided against blow fly strike by GH74 was much longer than that given by currently available larvicides. GH74 also has the advantage that persistent protection can be obtained from spray applications whereas larvicides must be applied by dipping, showering or jetting to give long-lasting effect. If final testing gives favourable results, it seems likely that GH74 will be used in practice in the near future. Examination of its effects on other ectoparasites would be worthwhile.

Laboratory studies have shown that cypermethrin, deltamethrin and permethrin supress oviposition by L. cuprina, but the persistence of protection provided when they are applied to the fleece of sheep has not been reported. Pyrethroids also repel biting flies and exert toxic effects on resident ectoparasites. The latter action is important as a compound which can control resident ectoparasites will gain access to the world sheep dip market. This increases the economic attraction of developing such compounds. Though presently available pyrethroids have poor activity against sheep blow fly larvae, new pyrethroid compounds are continually being synthesized and it is possible that one with persistent larvicidal activity will be found. In addition, new pyrethroids have been developed that are highly neuroactive but less toxic than those currently available (Ruzo et al. 1984). These may lead to a new generation of repellents. With their wide spectrum of activity, it is likely that pyrethroids will find increased use in sheep husbandry.

Vapour repellents may be of use for protecting against wound, nasopharyngeal and ocular myiasis. Formulations are needed which can prolong their repellency in wound dressings until wounds have healed. Whether vapour repellents can exert sufficient effect to prevent infestation by O. ovis or Gedoelstia spp., which do not alight to larviposit, is uncertain. Finding methods of application which can provide persistent protection may also be a problem.

To date there has been limited use of controlled release technology against veterinary ectoparasites. Ear-tag formulations of pyrethroids have given good control against sheep head flies. Their effectiveness in protecting against myiasis in the fighting wounds of rams, and against biting flies which attack the face and ears should also be investigated. In addition, the active ingredient could be transfered from ear tags to other sites on the sheep's body and may control ectoparasites which infest sheep at these sites. Formulating mosquito repellents with film-forming gels and fixatives has significantly prolonged their effect, and microencapsulation of pyrethrum markedly improves its persistence. Investigation of controlled-release formulations for protecting against sheep ectoparasites is needed.

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