EVALUATION OF COMPOUNDS OF CADMIUM AND RELATED METALS AS REPRODUCTION INHIBITORS IN INSECTS

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IN INSECTS

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INTRODUCTION

The use of chemicals for controlling insects has caused considerable criticism and concern to be expressed in recent years. The possible and actual harmful effects to wildlife and human health that may result from insecticide residues have been over emphasized by critics. Public awareness coupled with the continuing problem of the development of insect-resistance to insecticides has stimulated workers to find new approaches to insect control. Entomologists have known for many years that insects could be sterilized by X-rays or gamma radiation. Little interest was generated in the practical usefulness of this procedure until 1938 when E. F. Knipling proposed the use of the male sterilization technique as a means of insect control.

The success of this imaginative approach was demonstrated by the eradication of the screw-worm fly, Callitroga hominivovax (Coquerel), from the southeastern United States. Currently a similar program is being conducted in southwestern United States in an attempt to eradicate this species from this area and Mexico. Many workers have been prompted to evaluate new processes and techniques for solving their particular insect problems.

The possibility of utilizing the irradiation technique for the control of many pest species is not feasible and it became apparent that other means of inducing sterility in insects were needed. In this effort several workers have demonstrated that sterility could be induced in a large segment of an insect population by administering certain chemicals.

Consequently, the chemical induction of sterility in insects has been widely investigated in recent years. Utilizing these methods, considerable promise has been shown to occur in the control of species not particularly adapted to gamma irradiation.

However, much more study is needed to define the various chemical groups which will induce sterility in insects without causing severe damage to longevity and mating vigor, a disadvantage attributed to irradiation. More research needs to be done to determine the mode of action of chemicals, their effects on different sexes, and the toxicity to both insects and other forms of life, including man.

The research data reported in this thesis resulted from studies to evaluate the effectiveness of some compounds of cadmium and related metals as potential insect chemosterilants on four different insect species. The relative effectiveness of these compounds in sterilizing males and females, the effective level of treatment, and the most effective method of treatment for each species are discussed.

REVIEW OF LITERATURE

A comprehensive review of literature was made to develop a good background and a better understanding of most of the research work pertaining to insect control by the sterility techniques.

Runner (1916) was the first to observe the effect of radiation on adult insects. Cigarette beetles, Lasioderma serricorne (Fabricius), after irradiation produced only infertile eggs. He indicated that larvae given the same treatment remained dormant for a prolonged period and died before reaching the pupal stage.

Alexander (1960) reviewed the history and discussed the similarities between high energy radiation and radiomimetic substances in producing the same apparent biological effects in organisms ranging from viruses to mammals. He stated that changes caused by radiation on living matter had been studied for over 50 years.

Muller (1927) determined, for the first time, that the treatment of the sperm of Drosophila melanogaster (Meigen) with relatively heavy doses of X-rays induced the occurrence of true gene mutations in a high proportion of the treated germ cells. Since that time many papers have been published on the biological effects of radiation on insects (Bushland 1960).

The discovery that X-rays render Drosophila incapable of reproduction received little attention among entomologists until 1938 when E. F. Knipling considered the practical use of sterility to control the screwworm fly (Bushland and Hopkins 1951).

Knipling (1955) discussed the possibilities of insect control through the use of sterile males. The successful eradication of screw-worm flies from the southeastern United States has been described by Knipling (1955) and (1960a), Lindquist (1955), and Baumhover et al. (1955).

The theoretical advantages of the sterile male technique were discussed by Knipling (1959) and (1960b). He indicated that the population decline should be more rapid when sterile males are continually present than when chemicals are employed to kill the insects and presented theoretical calculations to prove his theorem. Lindquist (1961b) considered the highly successful eradication of the screw-worm as one of the most outstanding entomological accomplishments of all times. Unfortunately, with certain pest species which maintain large numbers of individuals throughout the year, the introduction of equal or greater numbers of sterilized males is precluded. When such released insects may cause damage, even if temporary, irradiation is impractical (LaBrecque et al. 1960). Knipling (1962) indicated that the inability to rear certain insects under laboratory conditions, and when rearing is possible, the high cost of producing large numbers have directed attention towards the use of chemicals to induce sterility in natural populations.

Alexander (1960) stated that for many years geneticists looked for chemicals that would produce or induce gene mutations. P. C. Keller observed that mustard gas would produce permanent chromosome abnormalities that are indistinguishable from those produced by X-rays. Many other chemicals have since been found, that cause mutations and chromosome damage in certain cells.

One of the first reports on the induction of sterility in insects by chemicals was that of Goldsmith and Frank (1952). They found that

aminopterin when fed to adult Drosophila reduced oviposition and in many instances prevented females from laying eggs. Mitlin et al. (1954) confirmed the work of Goldsmith and Harnley (1950) who determined that the effect of aminopterin on Drosophila was reversed when aminopterin-treated larvae were fed folic acid. Their findings indicated that treatment of house fly larval food medium would prevent adult emergence at higher concentrations.

Wallace (1951) has shown that in Drosophila populations treated with nitrogen mustard, the proportion of viable fertilized eggs is decreased.

Konecky and Mitlin (1955) tested several mitotic poisons, antimetabolites, and compounds that had shown previously biological activity, such as repellent, insecticidal, synergistic, or bacteriocidal activity. They measured the indirect effects of these compounds rather than the direct kill. Impairment of larval development, delayed pupation, or decreased emergence of adults were used as criteria.

Mitlin et al. (1957) studied the effect of mitotic poisons on house fly oviposition and reported that aminopterin and colchicine prevented ovarian development and caused an irreversible sterility in females. The fertility of the male was not affected.

Twenty-six growth inhibiting compounds used in the study reported by Gellhorn and Hirschberg (1955) were tested by Mitlin and Baroody (1958b) on house flies, Musca domestica (Linnaeus), to determine whether house flies could be used for screening potential tumor-inhibiting drugs. Growth of the ovaries was used as a criterion. Fifteen chemicals caused inhibition of ovarian growth, and the house fly was recommended as one of the primary screening agents.

Evaluation of compounds as chemosterilants of house flies has been

conducted at the Orlando, Florida laboratory, U. S. D. A., since 1958 (Smith et al. 1964). Of the two hundred chemicals tested by LaBrecque et al. (1960) for their ability to sterilize or otherwise interfere with the normal development of house flies, 79 had deleterious effects when added to larval media and ten had an effect on development when added to adult food. Only one compound, amethopterin sterilized females, but not males, after a single feeding given in the initial meal and reduced subsequent oviposition when given in a later meal.

LaBrecque et al. (1960) and LaBrecque (1961) demonstrated that several compounds, including aziridinyl derivatives, induced sterility in house flies similar to that caused by radiation and coined the term "chemosterilants" for such compounds.

Borkovec (1962) defined a chemosterilant as, "a chemical compound which, when administered to an insect, will deprive it of its ability to reproduce." He conceded that his definition does not imply or specify the mechanism by which the compound operates, but that it simply classifies the compound by its final biological effect, which can be observed either in the laboratory or in the field. Smith (1963) defined a chemosterilant as, "a chemical capable of causing sexual sterility--that is, failure to reproduce--in insects or other organisms." Hall (1963) referred to a chemosterilant as "a coined name given to a chemical causing sexual sterility in an insect."

Lindquist (1961a) and (1961b), and Hall (1963) stressed the considerable promise that chemosterilants have for insect control and recommended the possibility of combining them with insecticides. Knipling (1962) discussed in detail the mechanics by which the induction of sterility in a large proportion of the natural population would result in a constant

diminution of the population greater than that which would be obtained by insecticidal action of similar intensity.

Sterilization of the screw-worm fly with apholate was accomplished by Chamberlain (1962) by treatment of the medium containing the larvae, by dusting the pupae, by topical application to adults, or by feeding apholate to the adults. In nearly all tests the females were affected more than the males, and higher mortality was encountered in larval and prepupal treatments than in adult treatment.

LaBrecque and Gouck (1963) stated that of the more than 1000 chemicals tested, 20 caused sterility in adult house flies when given in the food, but only 3 aziridinyl compounds induced sterility without apparent toxic effects when used in a broad range of concentrations. Later Gouck and LaBrecque (1964) reported that of the 970 chemicals tested only 27 caused sterility in adult house flies when given in adult food. Ethyl bis (1-aziridinyl) phosphelcarbamate induced sterility when used in a broad range of concentrations.

Morgan and LaBrecque (1962) found that apholate administered in the food of adult female house flies as a 1.0 % concentration for a period of 240 hours inhibited, but did not eliminate, ovarian development. Morgan and LaBrecque (1964) determined the effect of tepa and metepa on ovarian tissue to be identical except for its severity in tepa.

Lindquist (1961a) proposed the application of chemosterilants to the feeding or resting places as a possible method of application. Smith et al. (1965) induced sterility in male and female two-spotted mites, Tetranychus telarius (Linnaeus), by dipping them in 0.5 % and 2 % apholate, respectively. Females allowed to feed on plant foliage previously dipped in 1 % aqueous apholate ceased oviposition after a few days and

became sterile. Most of the males which fed for 24 hours on apholate-treated foliage were sterilized. Gouck et al. (1963) demonstrated that with house flies and screw-worm flies, the feeding technique provided a better method for evaluation of chemicals in screening programs than topical application or larval dipping. In comparing the techniques for screening chemosterilants, Gouck et al. (1963) found that rearing screw-worm larvae in 1 % aqueous solutions usually caused more toxicity than sterility.

Chamberlain (1962) stated that the fertility of screw-worm flies was greatly reduced when the larvae were reared in media containing 25 to 50 ppm of apholate, but the treatment had deleterious side effects. Weidhaas (1962) succeeded in inducing complete or partial sterility in Aedes aegypti (Linnaeus), by treating the rearing water with 10 PPM of tepa or apholate. Results obtained with some other species of mosquitoes have not been satisfactory.

Harris (1962) sterilized adult stable flies, Stomoxys calcitrans (Linnaeus), by exposing them for 48 hours on deposits of 10 mg of apholate in half-pint jars or for one hour on deposits of 100 mg. He indicated that the insects were completely sterilized even when the deposit was 24 weeks old.

Altman (1963) reported that the holding of mosquitoes on a tepa residue of 10 mg / square foot either immediately before or after they fed on chicks that were infected with Plasmodium gallinaceum (Brumpt), caused a reduction in the percentage of mosquitoes that became infected, a reduction in the mean oocyst count, and a reduction in malaria transmission rates.

Chang and Borkovec (1964) reported that injection of male house flies

with graded concentrations of aqueous solutions of tepa, metepa, or apholate induced sterility, but tepa was 4 times as effective as apholate and 12.5 times as effective as metepa.

Laboratory studies conducted by Lindquest et al. (1964) on sterilization of the boll weevil indicated that apholate was quite toxic, and effective sterilizing dosages resulted in high mortalities. Also, treated male weevils regained fertility from 10 - 20 days after treatment.

Shaw and Sanchez Riviello (1965) related that the immersion of larvae of Mexican fruit flies in apholate proved to be ineffective or deleterious. Nevertheless, they indicated that treatment of larvae should be one of the more useful methods of application and satisfactory techniques could be developed for some species. They further indicated that the Mexican fruit fly could be sterilized by dipping puparia in a 5 % solution of tepa in methanol, provided the adults were allowed to crawl on the treated puparia but not when the puparia were washed and dried. Presumably the flies were actually sterilized in the adult stage as ascertained by Smith et al. (1964). They thought the age of the pupae was very critical as the results were not entirely consistant.

Chamberlain (1962) achieved sterility by dipping prepupal stage of screw-worm fly in apholate but the pupal dipping resulted in only partial sterility. Piquett and Keller (1962) reported that oviposition was prevented in the emerging house flies when puparia containing pupae about 4 days old were immersed for 30 minutes in equal parts of acetone and water saturated with a known chemosterilant, (2, 2^{1}-dichloro - N - methyldiethylamine). Similarly, Chamberlain (1962) induced sterility in house flies by dipping puparia of different ages in apholate, tepa, and metepa. Apholate and metepa gave the most consistent sterility in flies emerging

from puparia dipped when pupae were two days old, and tepa in flies emerging from puparia dipped when pupae were one day old.

Hair and Adkins (1964) demonstrated that the fertility of the face fly was reduced when the pupae were submerged in apholate or the adults were fed either apholate or tepa.

Cressman (1963) reported that when recently emerged citrus red mites, Panonychus citri (McGregor), were sprayed with 0.03 to 0.1% formulations of tepa, apholate, or aphamide, the fecundity of the treated females and the viability of the eggs and larvae were reduced.

Henneberry et al. (1964) stated that adult male or female Mexican bean beetles, Epilachna varivestis (Mulsant), dipped in an aqueous solution of 0.5 % of apholate, or confined for 48 hours on foliage sprayed with the same concentration, were completely sterilized.

Topical application was thought not as adaptable as other treatments to large-scale sterilization programs by Smith et al. (1964), but they conceded that it may prove useful in obtaining more precise comparisons of compounds on the basis of the dosages required to produce sterility. Chamberlain (1962) found that topical application of 300 mg of apholate to the dorsum of the screw-worm fly was necessary to produce sterility in both males and females. In tests with the stable fly, Harris (1962) demonstrated that only 3.7 ug of Tepa or 1 ug of metepa or apholate per fly produced almost complete sterility, but males were apparently more sensitive to the chemicals than were females. Gouck et al. (1963) reported that when 10 % solutions of chemosterilants were applied topically to house flies and screw-worm flies at the rates of 1 and 2.2 to 2.4 ul, respectively, per fly, more compounds caused mortality and fewer caused sterility than when the same compounds were given in the adult food.

Collier and Downey (1965) outlined laboratory techniques to obtain preliminary data on the action of chemosterilants against various stages of gypsy moth, Porthetria disper (Linneaus). The authors tested tepa, metepa,and apholate against the eggs, pupae and adults. No reduction of hatch was observed in treated eggs. Dipping of pupae was ineffective except with tepa, which caused high pupal mortality. Topical application to both sexes was ineffective, while residual films of tepa and metepa caused significant sterilization of male moths. Apholate was shown to have sterilizing action only at high residual levels when both sexes were treated.

LaBrecque (1962a) conducted preliminary field tests by distributing chemosterilants periodically as baits in dumps and poultry houses. He reported reduced house fly fertility with a corresponding decrease in populations. However, he indicated that flies from other breeding sites infiltrated throughout the tests and prevented elimination of the insect. Corn meal bait containing 0.5 % of aphoxide was applied on an isolated refuse dump in the Florida Keys for the control of house flies by LaBrecque et al. (1962b). Applications were made each week for nine consecutive weeks, except during the second week. House fly populations were reduced from 47 per grid to 0 within four weeks, the proportion of egg masses, containing at least one viable egg was reduced from 100 % to 10 % within four weeks, and the percent hatch among all eggs laid was reduced to 1 % within five weeks.

The assay method of evaluating the potency of chemosterilants on house flies reported by Chang and Borkovec (1964) was simplified by Chang (1965b) by separating the feeding and egg-collecting devices without changing the overall reliability of the assay method. Howland et al. (1965)

showed that cabbage looper Trichopulsia ni (Hubner), can be sterilized with apholate, tepa, or metepa by feeding the chemical in sugar solutions or by exposure to residues of tepa or metepa. They demonstrated the practicability of combining the attractive properties of female sex pheromome and ultraviolet light to cabbage looper moths, with the use of chemosterilants as a practical control measure.

Shaw and Sanchez Riviello (1965) obtained substantial protection ofa ten acre mango grove from Mexican fruit fly by releasing 2.5 million tepa treated puparia of the Mexican fruit fly, Anastrepha ludens (Loew).

Lindquist (1961a) pointed out that much work of a more basic nature needs to be done before the full potential of treatment with chemosterilants as a practical control measure can be accurately assessed. He stressed the necessity of a thorough knowledge of the biology, mating behavior, dispersal of insects, and the physiological effects chemicals may have on life processes.

The metabolism of alkylating agents by large animals has been studied to a considerable extent and has been reviewed by Smith et al. (1958). The work of Craig et al. (1959) on the metabolism of thiotepa, which is closely related to metepa, by the mouse, rat, and dog indicated that the thiotepa was converted by the mouse to phosphoric acid, but in the rat and dog, the primary metabolite was tepa. Chamberlain and Hamilton (1964) conceded that the rate of absorption, excretion and metabolism of P^{32}-labeled metepa by the screw-worm fly and the stable fly explains to a considerable extent the differences noted between the dosages required to sterilize these two species since the screw-worm fly absorbed only half as much radio labeled material in proportion to its size as the stabel fly. The excretion by the screw-worm fly was twice that of the stable fly.

Kilgore and Painter (1962) found that when house flies were given C^{14}-labeled 5-fluorouracil in the diet for 36 hours after emergence, the antimetabolite or metabolic product was incorporated into the egg. The viability of the eggs was low during the first four days but increased later with decrease of detectable radioactivity.

The biological activity and reactivity of aziridine compounds was indicated by Borkovec and Woods (1963) to vary with the number and properties of the ring substitutes. Borkovec (1962) reported that effective sterilants are found among the mono- and oligoaziridinyl compounds, but the proportion of active to inactive compounds was lower in monoaziridines than in the oligoaziridines. Crystal (1963) stated that of the six mono- and bifunctional aziridine compounds tested, only two behaved as sexual sterilants of screw-worm flies when both mating partners were treated. A much higher percentage of polyfunctional derivatives, 7 of 8, was found to be effective, but monoaziridinyl compounds had slight activity.

Parish and Arthur (1965) verified the findings of Crystal (1963) and demonstrated that only 1 of 4 monofunctional aziridines was effective as an insect chemosterilant. Bifunctional aziridines tend to be more effective than monofunctional compounds, but the activity was not greatly increased.

The mutagenic effects of alkylating agents have been under investigation for several years. Sublethal doses of nitrogen mustard, an aziridinyl derivatives or esters of methane sulfonic acid, administered by feeding or by injection, have been found to completely sterilize male Drosophila, as shown by Bird (1950), Fahmy and Fahmy (1955), and Fahmy and Fahmy (1961).

Beroza and Borkovec (1964) reported that some of the highly active insect chemosterilants containing aziridinyl groups were very sensitive to acidic media and that their solutions decomposed rapidly at low pH values. Borkovec et al. (1964) ascertained that in partially degraded solutions the sterilizing activity was proportional to the contents of intact tepa or metepa rather than to the total contents of the aziridine function. Contrary to the finding of Beroza and Borkovec (1964) they found no significant variation of activity with the pH of the solution.

Plapp et al. (1962) have investigated the metabolism of metepa by mosquitoes, house flies, and mice. They found that house flies injected with metepa rapidly converted it to inorganic phosphate. Cytological studies of the effect of apholate on house flies have been initiated by Morgan and LaBrecque (1962). Murvosh, LaBrecque, and Smith (1964) studied the relationship between concentrations of metepa, apholate, and tepa in the diet and the degree of sterility induced in adult house flies. Metepa and apholate were found to be similar but tepa had a greater sterilizing effect at a lower concentration. Metepa and apholate substantially shortened the life span, although a slight delay in initial male mortality occurred. It was indicated that more than 90 % of the males survived the first ten days, a time sufficient to allow mating with most of the females.

Knipling (1959) indicated that it is essential that sterility be produced in the organism without affecting the sexual vigor to realize the theoretical advantage in population control over that obtained by killing. Bushland and Hopkins (1953) stated that radiation sterilization somewhat shortened the life expectancy and perhaps affected the vigor of treated screw-worm flies. Similar observations were made by Lindquist (1961b).

In his study on chemosterilization and mating behavior Chang (1965a) demonstrated that male and female house flies reached sexual maturity in 20 to 40 hours, respectively, after emergence, and that insemination began as soon as copulation was physically established. His findings were consistent with those of Murvosh, Fye, and LaBrecque (1964). Chang (1965a) indicated that injection of 1 ug of tepa into male flies reached 50 % sterility effectiveness in 23 minutes and full effectiveness in about 3.5 hours. Male flies remained sterile for about one week. Tepa was found to be equally effective in sterilizing males of different ages.

The common malaria mosquito, Anopheles quadrimaculatus (Say) was sterilized by gamma radiation, with a resulting reduction in mating vigor (Davis et al. 1959), and by chemosterilants (Weidhaas et al. 1961).

Inability of Weidhaas et al. (1962) to control A. quadrimaculatus through release of males sterilized by gamma radiation was shown by Dame et al. (1964) to be due to behavioral deficiencies in the males of the colonized strain released.

LaBrecque et al. (1962a) reported that male house flies sterilized by feeding on a diet containing 1 % of apholate were as successful as normal males in competition for mates. The percentage of sterile eggs laid by females in cages containing normal and chemosterilized males was as high as, or higher than, would be expected from the ratio of sterile males present. Morlan et al. (1962) tried unsuccessfully to control A. aegypti by releasing irradiated males. Weidhaas and Schmidt (1963) reported that although the mating vigor of irradiated males of this species was severely reduced, the mating vigor of chemosterilized males appeared unaffected. The house fly, extensively used as a test organism for screening insect chemosterilants, was reported by LaBrecque et al. (1962a)

to have an apparent increase in the mating vigor following chemosterilants treatment.

Schmidt et al. (1964) compared the effect of chemosterilants and ionizing radiation on the house fly and the common malaria mosquito in terms of aggressiveness of the resulting sterile males. They indicated that results from chemosterilization equaled or surpassed those from radiosterilization. With mosquitoes, highly competitive, yet permanently sterile, males were more attainable with chemosterilants than radiosterilization. With house flies either method seemed adequate, but a slightly greater degree of recovery after irradiation than after chemosterilization was encountered.

Shaw and Sanchez Riviello (1965) found that males of the Mexican fruit fly that emerged from tepa-treated puparia were sterilized permanently with no deleterious effects on their sexual aggressiveness.

The effects of chemosterilants on the gonads of insects have been studied by several workers. Mitlin et al. (1957) reported that marked reduction of ovarian growth was exhibited when house flies were fed aminopterin and 2,2'-chloro-N-methyldiethylamine hydrochloride at rates of 0.2 mg/ml and 2 mg/ml, respectively, in 50 % skimmed milk. Chamberlain (1962) stated that when screw-worm larvae were exposed to apholate, the ovaries and testes of the mature adults were reduced to one-fourth or one-half of their normal size. Shaw and Sanchez Riviello (1962) indicated that when given in the food to Mexican fruit flies, chlorambucil inhibited the growth of the testes and 4-amino-1 H-pyrazolo-3, 4-d-pyrimidine sulfate the growth of the ovaries.

Cantwell and Henneberry (1963) reported that adults of Drosophila fed 1 % of apholate in sugar-yeast bait for 24 hours showed ceasation of

sperm development in the anterior portions of the testes after the eighth day and a general necrosis of the germinal epithelium of the area. Complete breakdown of the nurse cells, oocytes, and follicle cells occurred in the ovaries. Crystal and LaChance (1963) found that female screw-worm flies treated topically with 2 ul of solutions of five aziridinyl chemosterilants showed the greatest inhibition of oogenesis when the flies were 0 to 4 hours old.

In conjunction with their studies on the mode of action of chemosterilants Painter and Kilgore (1964) tested fifteen compounds on house flies by feeding the compounds 48 hours after emergence to determine their effect on eggs viability and whether the sterility induced would be permanent or only temporary. Their findings indicated that 9 compounds had little or no effect on sterility, 2 induced sterility with no oviposition, 3 were only temporary sterilants, and 2 induced permanent sterility with oviposition.

Kilgore and Painter (1962) reported that when house flies upon emergence were fed a diet containing 5-fluorouracil for 35 to 48 hours sterility was partial and only temporary. Morgan and LaBrecque (1964) indicated that ovarian development was inhibited in house flies when metepa, and tepa were administered in the food of adult females at 1 % concentration.

Crystal (1964b) induced antifertility effects in adult screw-worm flies by topical and oral treatments with four esters of bis (1-aziridinyl) phosphinyl carbamic acid. The compounds were much less active when administered topically than orally. He indicated that (ethyl[bis (1-aziridinyl) phosphinyl] carbamate) sterilized either sex orally and with little toxicity, but the sterilized males were half as competitive as normal or gamma-irradiated flies. The flies were effectively sterilized

and males at all ages tested, remained infertile for life. Inseminated females were rendered sterile when treated either before or after depositing eggs.

Dame and Schmidt (1964) in their attempt to correlate the uptake of the sterilant, metepa, with its effects on the male insects, reported that P^{32}-labeled metepa was rapidly absorbed from glass surfaces by both mosquitoes, A. aegypti and A. quadrimaculatus. This uptake resulted in severe reduction of mating ability in mosquitoes, coupled with 99 % sterility in house fly and A. aegypti. Excretion of the chemicals, however, was rapid. Insects exposed to treated larval medium and food retained a high percentage of their original radioactivity over prolonged periods.

Chamberlain and Barrett (1964) determined the differences in amounts of metepa required to produce the same effect on fertility of the screwworm fly and the stable fly. They indicated that the differences in susceptibility of the two species could possibly be due to differences in cuticle permeability, rate of excretion, or efficiency of the mechanism for breakdown of metepa, or the three together.

Borkovec (1962) recognized three main classes of chemosterilants: (1) Alkylating agents, (2) antimetabolites, and (3) miscellaneous agents which he referred to as those compounds which are neither alkylating agents nor obvious antimetabolites. Several unrelated compounds have been reported to have some carcinostatic effects on living organisms and/or to possess unique properties affecting insect growth and development.

Nenyukov and Tareeva (1931) in experiments relating to the problems of nitrogen exchange in insects found that incomplete arsenical poisoning affects the metabolic processes and probably the reproductive power of roaches. Their findings were confirmed by Pickett and Patterson (1963).

Grosch (1963) demonstrated that ingestion of arsenite by braconid wasps resulted in a non selective lowering of egg production with alteration of somatic tissue concerned with food assimilation and utilization.

In studies of possible effects of nutritional and hormone sprays, fungicides, and insecticides on orchard mites, Harries (1960) found that egg laying by two-spotted spider mites, Tetranychus telarius (Linnaeus), was strongly inhibited by cycloheximide and cytovirin. Both compounds were shown to have some toxicity to peach seedlings, apples, and pears by Harries (1961). Further studies by Harries (1963) on the effect of antibiotics and other compounds indicated that these mites were inhibited by low concentrations of a number of antibiotics. He concluded that the antibiotics seem to interfere with some process in the division and growth of the egg cells.

Hays and Cochran (1964) reported the effect of hormones and hormone-related compounds and certain other compounds on the fertility of plum Curculio, Contrachelus nenuphar (Herbst). Folic acid, colchicine, and progestrone diethylstilbestrol prevented reproduction when applied directly to adults, while only Enovid treated larvae failed to reproduce.

Simkover (1964) found that 2-imidazolidinone larval treatment of Drosophila prevented emergence of adults, although the larvae developed normally and pupated. This compound also affected growth and development of the immature stages of the house fly; the large milkweed bug, Oncopeltus fasciatus (Dallas); the corn earworm, Heliothis zea (Boddie); the mosquito, Anopheles albimanus (Wiedemann); the stable fly; and the western spotted cucumber beetle, Diabrotica undecipunctata (Mannerheim).

Ascher (1957) related that di-(p-chlorophenyl)-trifluoromethylcarbinol and di-(p-chlorophenyl-Penta-fluoroethycarbinol reduce, delay, or

prevent oviposition in house flies upon tarsal contact, when they are applied to females prior to feeding with milk. Thorpe and Ware (1963) were unsuccessful in inducing permanent sterility by feeding low concentrations of nitrofurans to larvae and adults of the red flour beetles, Tribolium castaneum (Herbst), the granary weevil, Sitophilus granarius (Linnaeus), and the Angoumois grain moth, Sitotroga cerealella (Oliver). Higher dosages, however, were either toxic or repellent.

Mitlin and Baroody (1958a) tested fifteen synthetics and three materials of biological origin for their effect on ovarian growth of the house fly and reported that only Coumarin 1-phenyl-2-thiourea, piperonyl butoxide, P-quinone, and thiourea completely inhibited ovarian growth.

Crystal (1964a) reported that 5 anthelminthics, out of the 12 which were known to inhibit reproduction in helminths, completely inhibited oviposition of viable eggs in screw-worm flies when applied topically. Antifertility effects usually occurred at levels which reduced survival 50-59 %. Effects of two aziridinyl compounds on saprophytic nematodes (Panagrella sp. and Rhaliditis sp.) were determined by Feldmesser et al. (1962). They demonstrated that reproduction systems of nematodes were affected after short exposures to high concentrations and extended exposures to low concentrations.

Kenaga (1963) listed several growth regulator compounds used as experimental insect sterilants. Adult house flies were sterilized successfully by Kenaga (1965) by feeding triphenyl tin compounds. He indicated that these compounds were superior to the conventional aziridine (ethylimine) for their wide margin of safety and persistence of sterility. Some degree of reproduction inhibition was encountered in German roaches, and confused floor beetles, Tribolium confusum (Jacquelin du Val).

The anthelmintic activity of cadmium salts was first reported by Guthrie (1954a, 1954b) and Burch (1955). The effect of cadmium on immature stages of Ascaris lumbricoides (Linnaeus), was demonstrated by Kelly et al. (1956) and Levine et al. (1956). The former indicated that cadmium anthranilate reduced egg counts while the latter indicated that cadmium salts killed or prevented the development of larvae. Levine and Ivens (1954) reported the effect of several cadmium compounds on horse strongyle larvae.

The toxicity and tissue content of cadmium following low level administration have been discussed by Wilson et al. (1941) and Decker (1956). Bunde et al. (1954) confirmed that cadmium was readily absorbed from the gut and firmly fixed by the tissues. Forny et al. (1955) reported the highest cadmium concentrations in the kidney, spleen and liver.

During their toxicity studies Parizek and Zahor (1956) found that cadmium chloride and cadmium lactate sterilized male laboratory rats. One ml of 0.03 mM/ aqueous solution of cadmium salt injected subcutaneously led to rapid destruction of all the testicular tissue, while no morphological lesions were detected in the ovaries of female rats.

Parizek (1957) observed that 0.03 mM of cadmium chloride / Kg body weight caused acute destruction of the seminiferous epithelium and interstitial tissue, while one-tenth of this dosage produced no change in ten days. These changes in turn evoked castration phenomena. The whole testis was replaced in ten days by masses of eosinophilic tissue. Administration of cadmium chloride, 150 ug/Kg body weight, was found by Kar and Das (1962) to cause acute and irreversible destruction of the germinal epithelium. Kar et al. (1962) determined that a lower dosage,

0.125 mg/100 g body weight, caused only partial degeneration of rat testes while the accessory genital organs were affected for a short period.

Testes of cadmium chloride treated mice were shown by Meek (1959) to be swollen in 12 hours and 24 hours, to exhibit extensive testicular damage in 48 hours, and complete destruction of the cells within the tubules in 96 hours. These organs were distinctly shrunken and yellow in three weeks, and occassionally some midzonal lesions in liver were seen.

Gunn et al. (1961b) reported that the subcutaneous administration of 0.03 mM/Kg to rats produced marked injury to the testes. Irreversible damage to the seminiferous tubules was indicated.

Kar and Pandoj (1963) sterilized male rats by scrotal inunction of 20 or 30 % cadmium chloride in aqueous or aqueous-glycerine medium. Irreversible destruction of seminiferous epithelium and temporary degeneration in the interstitial elements were observed. However, 5 % solution was ineffective.

Testicular changes due to cadmium chloride were reported in mice, rabbits, guinea-pigs and golden hamsters by Parizek (1960). Contrary to Gunn et al. (1961a), Kar, et al. (1959) induced powerful cellular and vascular changes in the ovaries of prepuberal rats. However, after 168 hours, the ovary presented normal features. Cadmium had no effect on utrine weight and failed to induce permanent damage to the endocrine potentialities of the ovary.

Male Rhesus monkeys were sterilized by a single intratesticular injection of cadmium chloride by Kar (1961). The seminiferous epithelium was permanently destroyed but the interstitial elements regenerated after the initial phase of disorganization. It was observed that these

effects could have been evoked by a considerably reduced dose if cadmium chloride was injected directly into the testis.

Testicular damage has not been described in man, although testes have been examined histologically in fatal chronic poisoning of cadmium (Smith et al. 1960).

Parizek (1965) observed that cadmium salts given in small amounts to pregnant rats, evoked progressive changes in the placenta, resulting in destruction of the pans faetalis. The high mortality among pregnant rats was striking. This intoxication with cadmium was associated with pathological changes which could not be evoked in non-pregnant animals.

Gunn et al. (1963 a) concluded that the testes and the proximal end of the caput epididymis were specifically damaged by cadmium by virtue of injury to their vascular supply. It was conceded that endothelium may have morphologic organ specifity, since blood vessels in other body areas were undamaged.

Mawson and Fischer (1951) showed that zinc was present in high concentrations in the dorsoventral prostate in the rat. The selective uptake of zinc by the accessory sex glands was demonstrated by Gunn et al. (1955). Gunn and Gould (1958) found that zinc traversed the entire female reproductive tract after ejaculation. The removal of large amounts of zinc from the ejaculate, by the dorsolateral prostate had no deleterious effect on either fertility or fecundity.

Powell et al. (1964) working with calves, reported that rate of growth, water intake, and testicular development decreased progressively as the concentration of cadmium in the diet increased. Addition of zinc partially offset the effects of cadmium in calf performance.

Turkey poults fed from one day old on a diet containing cadmium were reported by Supplee (1961) to have exhibited typical zinc deficiency at 2 - 3 weeks of age. The deficiency symptoms were less pronounced when zinc intake was increased, indicating a specific reversible effect between dietary cadmium and zinc.

Kar et al. (1960) prevented degenerative changes induced by cadmium in the rat gonads by zinc and selenium. It was pointed out that it was possible that cadmium was antagonized by zinc and selenium. Cameron and Foster (1963) indicated that the main line of evidence favours competition with zinc, rather than inhibition of sulphydryl enzymes, as an explanation of the distinctive effects of cadmium on testicular tissue.

The prevention of cadmium-induced-degeneration by use of selenium was shown by Kar and Das (1963) to be of a permanent nature. It was indicated that cadmium possibly is promptly removed from the body by selenium and the testes are spared.

Parizek (1957) and Kar et al. (1960) reported that testis injury following subcutaneous injection of cadmium can be prevented by similar injection of 80 x equimolar amounts of zinc acetate within 19 hours after cadmium treatment. Mason et al. (1964) found that doses up to 160 x equimolar amounts of zinc acetate given subcutaneously after cadmium injection were ineffective but that 20 x equimolar amounts of zinc acetate administered over 3 to 6 days or a single dose one day prior to cadmium approximated the minimal protective level.

Gunn et al. (1961a) determined that cadmium-zinc injection did not protect animals if they were bred immediately following injection, since these animals were attempting to rid themselves of near toxic

levels of zinc.

Parizek (1960) recognized two possibilities in the pathogenesis of testicular necrosis: (1) that either cadmium salts evoked circulatory failure in testis resulting in secondary destruction of the tubules, or (2) the circulatory changes were sequelae of primary tubular damage.

Parizek (1964) concluded that it appeared that cadmium cations caused selective circulatory damage, not only in the testis, but in other oestrogen producing organs. Complete necrosis followed by interstitial cell tumor formation in rats injected with cadmium chloride was reported by Gunn et al. (1963b). They observed that sarcomata arose at the site of repeated subcutaneous injections of cadmium chloride. Atrophy of seminiferous tubules, leydig-cells hyperplasia- and leydig-cell neoplasia, and pituitary changes also occurred in response to cadmium treatment. The carcinogenic nature of cadmium was confirmed by Cameron and Foster (1963). Interstitial cell tumor formation was also reported by Gunn et al. (1963b).

The empirical relations between compounds affecting mitosis and compounds effective in cancer chemotherapy (carcinostatic), antineoplastics or antitumor agents were established by Biessele (1958) between 1950 and 1960.

MATERIALS AND METHODS

TEST INSECTS.--The following insect species were used in this study: (1) House Fly, Musca domestica (Linnaeus), (2) Fruit Fly, Drosophila melanogaster (Linnaeus), (3) American roach Periplaneta americana (Linnaeus), and (4) German roach Blattella germanica (Linnaeus).

Musca domestica.--Wild house flies were collected from the Experimental Swine Barn at Oklahoma State University. A colony was established in the spring of 1965, and the culture was maintained in the Entomology insectary. Adult flies were held in 24 by 18 by 24 inches plastic screened cages. The flies were sustained on a diet of equal parts of granulated sugar and powdered dry skim milk solids.

Adult flies 2 to 4 days old were offered oviposition medium which consisted of water moistened paper towels wrapped around portions of Chemical Specialities Manufactuers Association (CSMA) rearing medium manufactured by Ralston Purina Company. The towels were moistened frequently until the eggs were laid and collected. The eggs were removed from the paper by means of a small, soft brush, placed in a 20-ml graduated cylinder and washed with 15 ml of water. The procedure of Peterson (1959) was followed for obtaining an adequate number of eggs for seeding larval rearing jars. The larval and adult rearing room was maintained at a constant temperature of 80 F $\pm$ 5 and a relative humidity of 50 to 60 %.

The CSMA medium which was first formulated by Richardson (1932)

and later standardized by the Chemical Specialties Manufacturers Association. It consists of a mixture of bran, alfalfa meal, yeast, and Diamalt. Only the dry parts of the medium, bran and alfalfa meal, mixed at the rate of 340 g to 800 ml of water, were used throughout the experiment. No apparent adverse effects on the flies were encountered. Three or four days after seeding rearing jars with house fly eggs, about two inches of expanded vermiculite were placed on the surface of the medium. By the fourth day most of the larvae had reached maximum growth and were in the drier, cooler, upper part of the rearing medium. The mature larvae rapidly migrated into the vermiculite over layer to pupate, for this material provided a relatively drier environment with a lower temperature than that of the upper layers of the rearing medium. The pupae were separated from the vermiculite by sifting in a metal pan 12 by 8 inches. Peet (1928) and Incho (1954) used an air blast from a fan, while Goodhue and Linnard (1950) used a cyclone separator to collect clean pupae.

Periplaneta americana and Blattella germanica.--The American and German cockroach cultures were originally established in 1963 by Dr. M. D. Miesch, former graduate student at Oklahoma State University. He obtained the roaches from the Thuron Industries, Inc., of Dallas, Texas where the colonies had been maintained for four years.

The cockroaches were maintained in 20-gallon garbage cans each of which had several shelves added to provide additional surface area for the insects (Fig. 1). Purina Dog Chow was the only food offered. The cockroach colonies were maintained at a temperature of 80 F. $\pm$ 5 and a relative humidity of 50 to 60 %.

Drosophila melanogaster.--Two laboratory strains of Drosophila

fly: Stephenville and Oregon, were obtained from the Genetics Foundation, University of Texas, through the courtesy of Dr. L. H. Bruneau of the Oklahoma State University, Zoology Department. The flies were reared on modified University of Texas banana medium, and included the following ingredients:

Water	1250 ml
Agar (powdered)	19 g
Brewer's yeast (no sulfur)	33 g
White Karo	28 ml
Molasses	28 ml
$2\frac{1}{2}$ ripe bananas (approximately)	250 g
Propionic acid	7.5 ml

Agar was dissolved in gently boiling water, then transferred to a blender. The other ingredients were added and mixed in the above proportions in the order listed. The medium, while still thin, was poured into previously autoclaved half-pint milk bottles or 3-inch 0.5 inch diameter shell vials. The bottles and vials were allowed to cool at room temperature, plugged with cotton, and then used or stored in a refrigerator until needed.

METHODS OF INACTIVATION.--Adult D. melanogaster was inactivated by using ethyl ether or carbon dioxide. However, ice-cold water was found as effective, but flies inactivated by this method recovered faster and the procedure was more time consuming. When using ethyl ether the flies were shaken from the culture bottle into the etherizer. The technique adopted by Demerec and Kaufmann (1962) was followed in the construction of the etherizer and other handling procedures. Carbon dioxide was used to inactivate cockroaches.

CHEMICALS TESTED.--Twenty nine chemicals were evaluated for repro-

duction inhibition, including cadmium chloride, cadmium acetate, cadmium sulfate, cadmium nitrate, cadmium oxide, cadmium lactate, cadmium sulfide, cadmium carbonate, zinc chloride, and Cadminate (cadmium succinate 60 % [cadmium 29 %] a product of Mallinchrodt Chemical Works, St. Louis 2, Mo. used widely as a fungicide), and seven cadmium mercaptides and six miscellaneous cadmium compounds. The seven mercaptides were supplied through the courtesy of Phillips Petroleum Company, Bartlesville, Oklahoma. These included 2,9-p menthane mercaptide, cadmium pinanyl mercaptide, cadmium 2-hydroxyethyl mercaptide, cadmium n-octyl mercaptide, cadmium tert-octyl mercaptide, cadmium tert-dodecyl mercaptide, and cadmium n-dodecyl mercaptide. The six miscellaneous cadmium compounds were also supplied by Phillips Petroleum Company and included cadmium stearate, cadmium laurate, cadmium phosphate, cadmium hydrogen hydroxyethyl ethylenediamine triacetate, cadmium cyclopentamethylene dithiocarbamate, and cadmium 2-ethylhexoate. The compounds of mercury, antimony, and indium were supplied by Aldrich Chemical Company, Organic Research Chemicals, Milwaukee, Wisconsin.

LABORATORY PROCEDURES.--The following tests were conducted with each insect species to evaluate the activity of the different chemicals.

TREATED FOOD.--Several techniques were used in developing a convenient technique for food treatment, since the feeding habits, resting habits, and mouth parts of the test insects were variable.

Semisolid food.--The semisolid food technique was primarily used for D. melanogaster, then modified for P. americana. The required concentration of chemical was added to the standard Drosophila medium, after all the ingredients were blended but before cooling occurred.

The concentrations of chemicals used ranged from 1.0 % to 0.0001 %.

The treated medium was poured into 3-inch shell vials 0.5 inch in diameter, allowed to cool, and the vials were plugged with cotton and used immediately or stored in a refrigerator.

Fifteen adult flies, less than 12 hours old, were placed in each vial for treatment, or the same numbers of pupae were caused to adhere to the sides of the vials. Six replications and two controls were used for each adult and pupae treatment. The vials with flies were placed in an incubator at an optimum temperature of 23 C and a relative humidity varying from 72 - 100 % (Fig. 2). The vials were checked for mortality, oviposition, and hatchability at intervals of 6, 12, 24, and 48 hours.

Semisolid formulations of cockroach food were made by mixing dehydrated potato with water till a paste-like consistency was attained. The chemicals tested were dissolved in water or in a volume/volume mixture of water and acetone, and then mixed with the food in concentrations ranging from 0.001 to 1.0 %. The food was then placed in metal containers 1.5 inches in diameter and 0.38 inches deep. Two replications were used for each chemical and four controls for the whole test.

Two batches of the controls were offered water and untreated food, while the other two batches were offered only water. In each treatment two of the six metal containers were used to determine sample weight loss due to evaporation. These were covered with 40 mesh screen wire to keep cockroaches from eating the food. The weight losses in the covered containers were subtracted from the weight loss in the feeding containers to correct for the loss of weight due to evaporation. The food containers were placed at random on a plywood board and a clean plastic open ended cylinder was placed over them. These then were

Figure 1. The Containers Used for Rearing Roaches

Figure 2. The Incubator used for Maintaining Drosophila

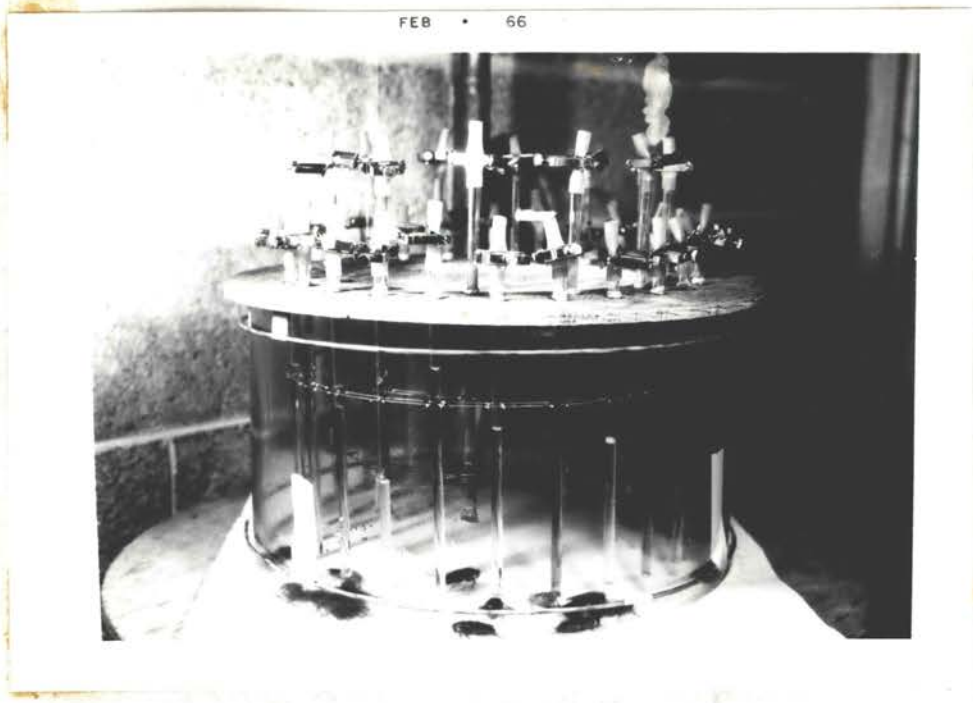

Figure 3. The Liquid Food Experimental Unit Used for American Roaches

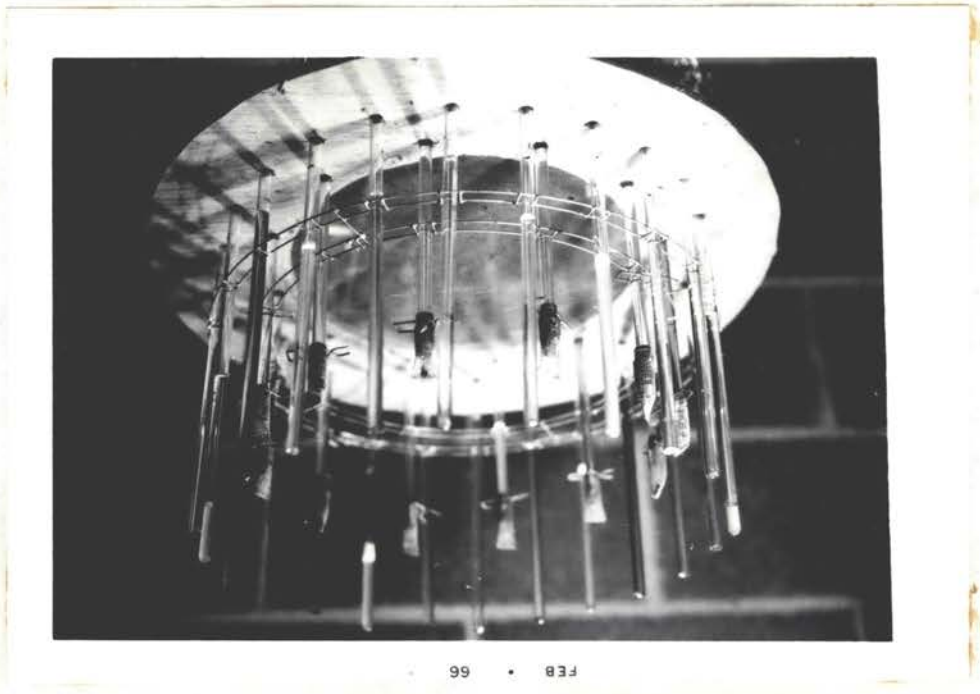

Figure 4. The bottom View of Liquid Food Experimental Unit Showing Consumption and Evaporation Check Tubes

covered with a lid of plywood having a 9-inch circular ventilation hole in the center covered with nylon tulle.

Liquid food.--The design shown in Figs. 3 and 4 was used for liquid food tests. It consisted of a circular arrangement of glass tubes suspended vertically from a lid placed on top of a clear plastic cylinder. This container was 16 inches in diameter, and was covered by a circular plywood lid with a 9.75 inch circular hole in the center covered by nylon tulle to facilitate ventilation.

In the plywood lid 8-millimeter glass tubes with an inner diameter of 6 ml were arranged in two rings: an outer ring 13.25 inches in diameter consisting of 24 consumption tubes, and an inner ring 11 inches in diameter consisting of 12 evaporation check tubes. A wire frame was used to stabilize the tubes approximately three inches below the lid.

The tops of the glass tubes were closed by short lengths of rubber tubing and screw-type clamps. The glass tubes were filled by sucking the liquid above a uniform height on each tube and adjusted by manipulating the screw clamp. The tubes were adjusted with a rubber band to a height of 0.8 inch of the base. Thirty American roaches were used in each treatment.

The consumption of treated liquid was arrived at by subtracting the evaporation measurement from the consumption measurement to obtain the amount of liquid consumed. Twenty percent sucrose solution was used in both consumption and evaporation check tubes to eliminate any possible difference in evaporation due to difference in density of water and cadmium sugar solution.

Solid food.--The adult house flies were given the candidate chemi-

cals in a food mixture consisting of 1 part powdered sugar and 1 part nonfat dry skim milk. The chemicals that were soluble in acetone were dissolved in 25 to 30 ml. of acetone and added to 30 g of the food. The food was allowed to dry for 24 to 36 hours, repulverized, and placed in emergence cages. Cages containing untreated food were used as checks. Two replicates were made for each treatment.

Zinc chloride was simultaneously fed with 1, 2, 5, or 10 times as much cadmium chloride and cadmium acetate to determine possible competition between zinc and cadmium as reported by Parizek (1957) and others. Chemicals that were insoluble in acetone were thoroughly mixed with the food in a mortar, then transferred into tightly sealed bottles and blended in a ball mill for 30 minutes. In each test cage, pupae weighing the equivalent of 120 counted control pupae were placed in a Petrie dish. The weighed pupae numbered 120 $\pm$ 3. Emergence was always within 3 days. No sexing of pupae was tried, but the sex ratio ranged between 60 - 40 and mostly approached 50:50 ratio. Each cage was examined daily to check the number of flies that emerged. Since the females reached sexual maturity in about three days and the males in approximately one day oviposition medium (CSMA) was placed in Dixie paper cups and put in cages three days after emergence. The medium was checked for eggs 6 and 12 hours later. If no eggs were laid the medium was moistened and examined daily until oviposition occurred or all the adults were dead. Egg and larval counts were made three days after the egg-laying medium was introduced. The medium was washed from the Dixie cups into a Petrie dish with lukewarm water, then more water was added in the Petrie dish till the medium was covered. This forced the larvae to float to avoid drowning. Larvae were reared and adults emerging were

observed for any abnormalities, fertility, fecundity and longevity.

German or American roaches were offered Purina Dog Chow food treated at rates of 5 % and 2.5 %. The dog chow was ground in a mortar, then mixed with the candidate chemical at the concentration required. The mixture was then blended and weighed. Amounts of treated food were placed in Petrie dishes 4 inches in diameter and 1 inch deep. Fifteen late instar nymphs were used in each test with American roaches, while fifteen pairs were used with German roaches. Quarter and half-gallon cartons were used for holding German and American, roaches respectively (Fig. 5). Check procedures followed in semisolid food tests were adopted.

Compounds that were highly toxic or caused sterility at high concentrations were tested at lower concentrations to establish the lowest concentration which would induce sterility without causing excessive mortality. Other tests included continuous feeding of treated food, and feeding treated food for five days then replacing it by untreated food.

PUPAL DIPPING.--The pupal dipping treatment was tested with house flies and Drosophila flies. Approximately 120 house fly pupae were placed in a 50-ml beaker and immersed for 5, 10, 20 or 30 minutes in 10 ml of saturated chemical in acetone in preliminary studies, but results indicated that this treatment was detrimental. The mixture which gave the most consistent results consisted of one part acetone and one part water plus lower concentrations of the chemical.

After decanting the liquid from the beaker, the pupae were dried with filter paper, placed in Petrie dishes and held for emergence in screen-wire fly cages at a temperture of 80 F $\pm$ 5 and a relative hu-

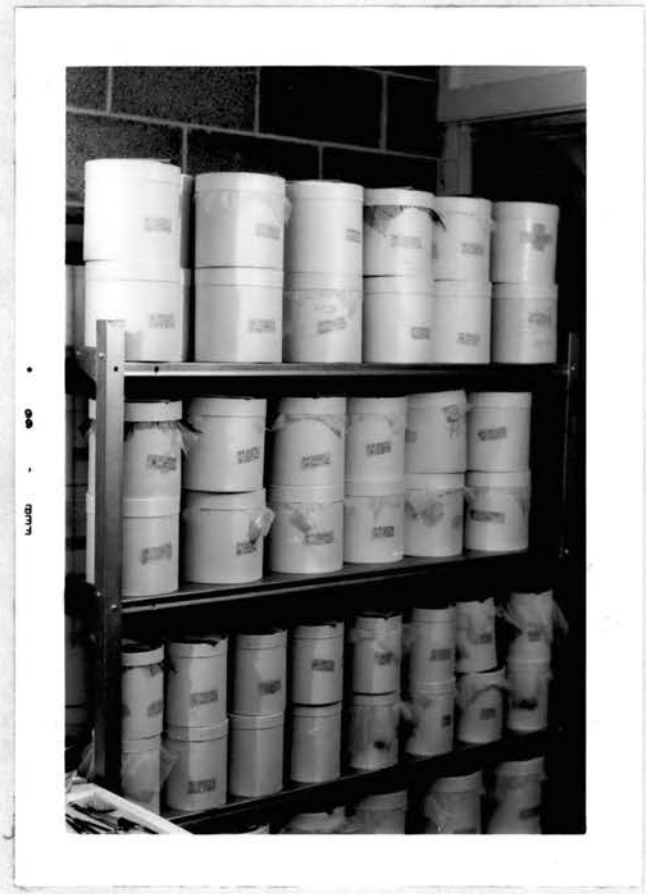

Figure 5. The Arrangement of Quarter- and Half-Gallon Cartons Used for Maintaining German and American Roaches, Respectively, on Treated Food

midity of 50 to 60 %. The wooden cages used for this purpose measured 12 by 18 by 12 inches, with a shelf at one end and two sides of screen wire 16 mesh. These were arranged in a box shape with four cages on each side. The floor of the cages was covered with paper towels to facilitate cleaning. Untreated food and water were put in the cages simultaneously with the treated pupae. Two controls were used for each three treatments. One control group of pupae was acetone-water dipped for an equivalent period of time to that of the treated batch and the other control group not dipped. Oviposition medium (CSMA) was presented to the flies 3-4 days after adult emergence. Daily observations were made for eggs. Larval counts were made four days after the medium was supplied. The same procedure was followed with Drosophila flies, except that the pupae were caused to adhere to the sides of the culture vials.

LARVAL DIPPING.--Larval dipping treatment was used only with Drosophila flies and on a limited scale. Late instar larvae, mostly in the third instar, were dipped in saturated acetone-water (v/v) solutions for 10, 15, or 30 minutes. The same procedure as described above for pupal dipping was followed. However, toxicity to house flies reared in a larval medium containing 5 or 1 % of cadmium chloride, cadmium nitrate, cadmium pinanyl mercaptide, cadmium 2-hydroxyethyl mercaptide and cadmium n-octyl mercaptide was very high.

DUSTING.--Dust treatments were applied by allowing newly emerged 6 to 12-hour old Drosophila flies to walk on undiluted thin dust layers of candidate chemicals applied to the sides of half-pint milk bottles. After the flies were exposed to these chamicals for 5 - 30 minutes, excess dust from the flies was removed by allowing the flies to walk

around clean bottles. The flies were then held in a holding bottle with moistened filter papers to further remove the dust. They were then transferred to culture vials. This procedure cut down the possibility of chemical contamination of the culture surface.

The treated flies were transferred to culture vials, were kept at incubator temperature of 23 C, and were checked for oviposition, mortality and hatchability at 6, 12, 24, 72 hour intervals. After which the culture vials were examined every 24 hours. Larval feeding, growth, and time of pupation were observed and recorded. No effort was made to dilute chemicals that caused high mortality, but the exposure time to treated surfaces was reduced to five minutes to cut down the mortality rate with chemicals which caused high mortality.

TOPICAL APPLICATION.--Topical application was tried in a limited number of tests with P. americana. Late instar nymphs were treated with acetone and water (v/v) solutions of 5 - 10 % cadmium chlorides, cadmium acetate, cadmium nitrate, and cadmium sulfate were topically applied on the dorsum of the mesothorax, metathorax, and the first abdominal segment with a microapplicator. However, the waxy nature of the cuticle caused the liquid to run off. The treated roaches were sexed and seven pairs were kept in one-gallon paper cartons with water and food. Weekly checks were made to determine mortality and molting. The organic cadmium compounds were insufficiently soluble in acetone, carbon tetrachloride, sulfone, sulfolane, dimethylsulfoxide, dioxane, chlorobenzene, or pyridine. The addition of surfactants atlox 1045A, and Triton did not provide stable mixtures. Hence, these compounds could not be tested topically or by injection and, therefore, they were only tested by offering them in solid foods.

INJECTION.--Concentrations of cadmium chloride, cadmium nitrate, and cadmium acetate ranging from 5 to 10 % in acetone were injected into the coxo-trochanteral joint at the right metathoracic leg of male and female P. americana. The injections were made with a microapplicator. (Figs. 6 and 7). Although the dose was originally inserted in the coxo-trochanteral joint and adjacent structures, part of the dosage was translocated.

Treatment was also tried by injection of the appropriate dose by inserting the delivery needle of a Hamilton 50 ul syringe between the third and fourth abdominal intersegmental membrane. The coxo-trochanteral injection was found more practical than injection through abdominal intersegmental membrane, since more mortality resulted from the latter treatment. This mortality might have been due to accidental damage to the viscera by the needle, and/or higher concentration of chemical in close approximation to sensitive organs.

INUNCTION.--Rubbing medicated ointment into the cuticle was tested on American roaches. Lanolin extract containing 25 - 30 % water was used as a basis for the ointment. The candidate chemical and the lanolin were weighed separately, then thoroughly mixed in a mortar. The concentrations used were 5 % and 2.5 %. A toothpick was used to apply the ointment on the mesothorax, metathorax, and the first abdominal tergite (Fig. 8). The Toothpick was carefully weighed in a Mettler balance after it was dipped into the treated ointment and again after the ointment was applied on the test insect. The difference between the two weights gave the amount of ointment used on each cockroach. An average of twenty weighings was made, and the amount of ointment applied on each roach was approximately 1.7 mg, which was

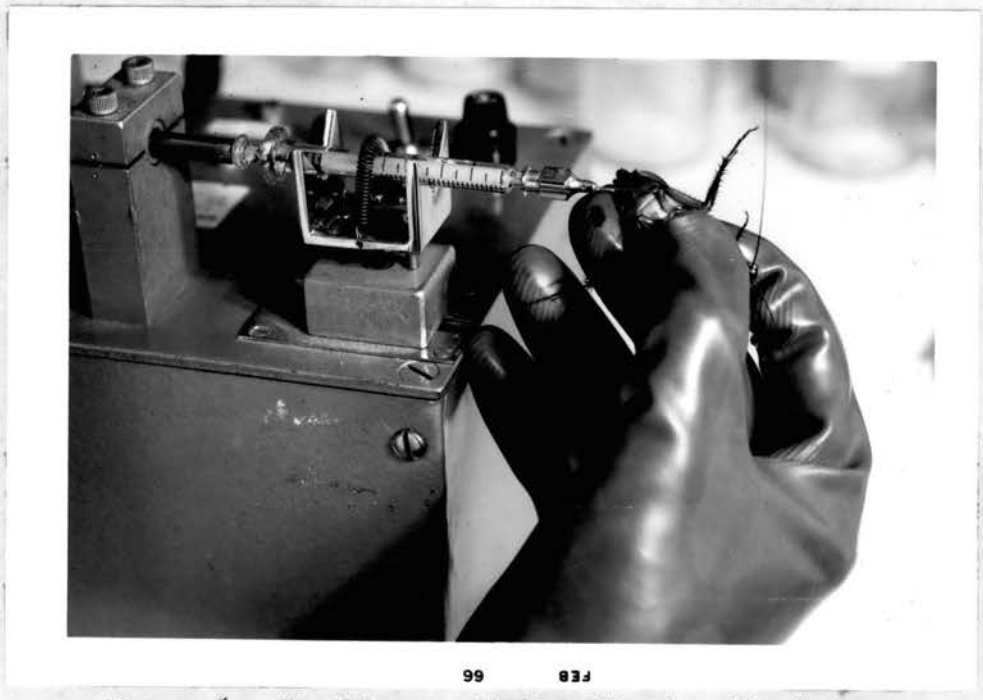

Figure 6. The Microapplicator Showing the Coxo-trochanteral Injection

Figure 7. Close-up View Showing Insertion of Needle into the Coxo-trochanteral Joint

Figure 8. The Inunction Treatment Showing the Meso- and Metathoracic Application

equivalent to 0.075 mg/roach. The average weight of the late instar nymphs used was approximately 1 gm. ± 0.05.

Fifteen late instar nymphs were used for each test chemical, and each test consisted of two replicates. One control was used for each three tests. Checks were made every other week, and molting, mortality, oothecal production, and hatching were recorded.

TEST VERTEBRATES.--To gain familiarity with the activity of cadmium in vertebrates preliminary tests were conducted with 12 yearling hereford steers, and 16 one-month-old Yorkshire boar hogs. The steer experiment was conducted at the Oklahoma State University Animal Science Experimental Range located on the north side of Lake Carl Blackwell. The herd was kept under range conditions. The hogs were kept in the Swine Barn of the Oklahoma State University Experiment Station.

Cadmium chloride was administered to both species of test animals by the following methods: (1) Subcutaneous injection, (2) intramuscular injection, (3) intratesticular injection, and (4) scrotal inunction.

The same dose (0.03 mM/Kg body weight) was used with each method. The stock solution was prepared by dissolving cadmium chloride in distilled water for 1, 2, and 3 treatments. Lanolin was used as a base for the inunction treatment which was uniformly rubbed on the scrotal sac.

In the hog experiment four replicates were made with each treatment with four controls for the whole test. The animals were divided into two groups. Two replicates for each method of administration with two controls were done first and the same procedure was followed

with the second group a week later. The animals were weighed before the test to determine the dosage, and weight gains or losses were recorded every two weeks. When the hogs were above 200 pounds, they were castrated, the testes were weighed, and necropsy findings were recorded. Sections of both testes were fixed in Allen's fluid for 24 hours, then transferred to Lenion's fluid for 48 hours and stored in 70 % alcohol for later sectioning.

The steer experiment was done under range conditions. Two replicates were used for each treatment, except four were used with the intratesticular treatment, two in which only one testis was injected, and two with both testes injected. Periodic checks were made, the steers were slaughtered 12 months after treatment and the testes sectioned. Macroscopic examination results of the testes were recorded.

The possibility of protection of cadmium-treated animals from biting flies by the repellant properties of cadmium chloride was also investigated.

RESULTS AND DISCUSSION

The effectiveness of chemosterilants is generally thought to be greatest when both sexes are treated (LaBrecque 1961). The screening program undertaken in this research, therefore, did not involve any appreciable effort to determine the effect of the chemicals tested on the individual sex. However, in preliminary tests where American cockroaches topically treated as late instar male nymphs were mated with untreated females, and vice versa, results indicated no sterility was produced.

TREATED FOOD

Semisolid Food.--Virgin Drosophila flies held on medium treated respectively with each of the cadmium compounds at 1.0 and 0.1 % indicated that these chemicals were strongly repellent and somewhat toxic at the above concentrations. Although there was no indication that the flies ever fed, evidenced by the fact that the smooth shiny surface of the medium was unbroken, 70 % died within 48 hours, and 100 % mortality occurred in 72 hours. The control group, with no medium, starved in approximately 96 hours, indicating that the flies must have picked up toxicant by contact to produce more rapid mortality. The control group, with untreated medium, fed and oviposited viable eggs and no adult mortality was observed. If the treated medium was not toxic or did not repel the flies, they would have fed and laid eggs or at least would have tried to do so. They then would have picked up enough of the chemical to cause death in a shorter time than that of the controls with no medium.

Results obtained with the lower concentrations, 0.01, 0.001, and 0.0001 %, did not exhibit the same degree of repellancy to adult flies, since these concentrations protected the medium from contamination by Drosophila eggs for only 12, 20, and 50 hours, respectively. Fewer eggs were laid in all treatments, as compared to the controls with untreated medium, and fewer eggs were laid in the higher treatment than in the lower treatments. The decrease was proportional to the increase in dosage. Hatchability also was concentration dependent. Rate of growth and pupation in the 0.001 % treatment approached that of the checks. The larvae in 0.01, 0.001 and 0.0001 % treatments were smaller in size, and sluggish. Only 55 - 85 % of the last instar larvae in the treated vials could crawl out of the medium to pupate on the drier sides of the vial. The results indicate that this may have resulted from the toxic effects of these chemicals.

Adults emerging from the pupae of adults reared on medium treated with 0.01, 0.001, or 0.0001 % cadmium salts, when held on untreated medium, oviposited viable eggs which produced fertile adults. The F_1 generation however, was smaller in size than the untreated controls. The F_2 flies were normal in size, and no differences in fecundity and fertility were observed.

The results obtained from tests using semisolid cockroach food are shown in Table I. The data indicated that even at the lowest concentrations cadmium chloride, cadmium nitrate, and cadmium acetate were highly repellant to American roaches. The difference in weight between the food in the covered food containers and the food in the uncovered food containers averaged 2.511 g per test. This was equivalent to 0.0837 g/roach in three weeks, while the roaches in the controls consumed 0.208

g/roach during the same period. The loss of weight in the uncovered food resulted from the roaches walking over the food and carrying parts of it on their legs and other appendages. All roaches given 0.001, 0.005, 0.01, 0.025 % treated food died in about the same time as the controls that were offered water only. Those in the three higher concentrations (0.05, 0.1 and 1.0 %), however, died 10, 18, and 25 days, respectively, before the controls. This eliminates the possibliity of death resulting from ingestion of the treated food in the lower concentrations. However, it is possible that starvation was the main factor responsible for mortality in lower concentrations, while starvation and, to a lesser extent, toxicity through contact were responsible in the higher concentrations. This is further supported by the absence of molting of roach nymphs to adults in the higher concentration and presence of 10-15 % molting to adults in lower concentrations. The chemicals must have gained entrance to the body through contact with tarsi, mouth parts or integument or by all three routes.

TABLE I

AVERAGE CONSUPMTION PER AMERICAN COCKROACH OF SEMISOLID FOOD CONTAINING DIFFERENT CONCENTRATIONS OF CADMIUM CHLORIDE IN THREE WEEKS

Concentration	Total Consumption g	Consumption/Roach g
0.001	2.916	0.0972
0.005	2.658	0.0886
0.01	2.285	0.0795
0.025	2.682	0.0894
0.05	2.706	0.0902
0.1	2.127	0.0709
1.0	2.103	0.0701
Controls	6.240	0.2080

Liquid Food.--Cadmium chloride, cadmium acetate, cadmium lactate or cadmium carbonate repelled the roaches when fed to American roaches in a 20 % sucrose solution at 1.0, 0.1, 0.05, 0.025, or 0.01 % concentrations. The two lowest concentrations, 0.005 and 0.001 %, were the least repellent of all the solutions fed. Data are presented in Table II, to indicate the average amount of cadmium chloride solution consumed for each concentration. These data when compared with that of the other cadmium salts were similar or identical. The results with liquid food, however, were inconsistent with results obtained with treated solid food, since compounds that were highly repellent when included in liquid food were readily ingested by the insects when it was included in solid food.

TABLE II

AVERAGE CONSUMPTION PER AMERICAN COCKROACH OF 20 % SUCROSE SOLUTION CONTAINING DIFFERENT CONCENTRATIONS OF CADMIUM CHLORIDE IN THREE WEEKS

% Concentration	Total Consumption ml	Consumption /roach ml
0.001	0.8	0.0266
0.005	0.9	0.0300
0.01	0.7	0.0233
0.025	0.8	0.0266
0.05	1.0	0.0330
0.1	0.9	0.0300
1.0	0.7	0.0233
Controls	10.5	0.350

The results of the liquid food tests were similar to the results given under the semisolid food tests, except that no molting occurred in any of the treated roaches. The relative toxicity obtained with the use

of liquid food was higher than that of the other two treatments. The difference in time required to reach 100 % mortality was 10 to 15 days shorter in all liquid food treatments when compared to the time required for semisolid food treatments. The absorption rate of the chemicals through the exoskeloton after contact have been higher when offered in liquid than in semisolid forms.

Observations of the testes and ovaries of the roaches exposed to treated liquid food, semisolid food, and the starved controls indicated no difference in size. The size and weight of roaches in the starved controls were similar to the size and weight of the treated roaches but the size and weight of the controls with water and untreated food or sucrose were larger and heavier, respectively.

Solid Food.--Data showing the effect of continuous feeding of cadmium mercaptides and other cadmium compounds on newly emerged house flies are presented in Tables III and IV.

The interpretation of data in Table III indicates that all the mercaptides tested caused some dalay in oviposition, except 2,9-p-Menthane mercaptide. With those flies treated, there was a substantial reduction in the number of eggs laid. The greatest reduction was observed to occur with the use of cadmium 2-hydroxyethyl mercaptide, followed by cadmium n-octyl mercaptide, cadmium tert-dodecyl mercaptide, and cadmium tert-octyl mercaptide. Cadmium n-dodecyl mercaptide and cadmium pinanyl mercaptide caused very little effect. This reduction in egg laying persisted in those flies exposed to cadmium 2-hydroxyethyl mercaptide and cadmium n-octyl mercaptide through the seventeenth day after emergence, and no eggs were observed to be oviposited thereafter. However, there was an increase in the percent of oviposition during these two treatments after emergence, but followed by a decrease for both on the fifteenth day.

TABLE III

EFFECT ON OVIPOSITION, HATCHING, AND ADULT MORTALITY WHEN NEWLY EMERGED HOUSE FLIES WERE EXPOSED TO FOOD CONTAINING 5.0 % CADMIUM MERCAPTIDES

Cadmium Compound	% Oviposition Reduction Compared with Control				% Hatching Reduction				% Adult Mortality			
	Days After Emergence				Days After Emergence				Days After Emergence			
	7	12	17	21	7	12	17	21	7	12	17	21
Cadmium pinanyl mercaptide	10	0	0	0	0	0	0	0	0	0	40	85
Cadmium 2-hydroxyethyl mercaptide	90	70	80	100	0	0	0	100	0	40	100	100
Cadmium n-octyl mercaptide	75	10	95	100	0	0	0	100	0	50	85	98
Cadmium tert-octyl mercaptide	50	0	0	0	0	0	0	0	0	0	60	90
Cadmium tert-dodecyl mercaptide	55	0	0	0	0	0	0	0	0	0	10	30
Cadmium n-dodecyl mercaptide	05	0	0	0	0	0	0	0	0	0	5	20
2,9-p-Menthane mercaptide	0	0	0	0	0	0	0	0	0	0	0	5

TABLE IV

EFFECT ON OVIPOSITION, HATCHING, AND ADULT MORTALITY WHEN NEWLY EMERGED HOUSE FLIES WERE EXPOSED TO FOOD CONTAINING 2.5, 5.0, and 10 % CADMIUM COMPOUND

Chemical	% Concentration	% Oviposition Reduction Compared with Control			% Hatching Reduction			% Adult Mortality		
		Days After Emergence			Days After Emergence			Days After Emergence		
		6	12	17	6	12	17	6	12	17
Cadmium stearate	5.0	0	55	0	0	0	0	15	50	95
Cadmium laurate	5.0	0	75	100	0	0	100	20	40	80
Cadmium phosphate	5.0	0	25	0	0	0	0	0	30	75
Cadmium hydrogen hydroxy-ethyl triacetate	2.5	95	90	100	0	0	100	30	80	98
Cadmium cyclopentamethylene dithiocarbamate	10.0	25	0	0	0	0	0	10	30	50

The 5.0 % cadmium mercaptides concentration in solid food was the optimum dose to induce some reproduction inhibition in house flies without excessive mortality.

All flies that were fed treated food for 5 days and then fed an untreated food, resumed their normal egg laying in 6 to 7 days; an indication that the partial reproduction inhibition was temporary. However, these flies were slower in reaching full egg laying capacity when compared to those fed untreated food continuously. A few flies seemed to have developed what appeared to be normal egg laying capability after they were fed untreated food for 10-15 days. As a consequence of this observation, it is uncertain whether or not these mercaptides can be referred to as chemosterilants as previously defined by Borkovec (1962), and Smith (1963).

From the above observations, it appears that these mercaptides seem to reduce oviposition as long as the house flies continue to feed on treated food. The two most effective mercaptides, cadmium 2-hydorxyethyl mercaptide and cadmium n-octyl mercaptide, appreciably shortened the life span of adult flies.

The dosages indicated in Table IV were based on preliminary tests. Four of the five compounds tested were ineffective at the 2.5 % level of treatment. Cadmium hydrogen hydroxyethyl ethylenediamine triacetate was the only chemical in this group that caused some reproduction inhibition at 2.5 % concentration. Cadmium cyclopentamethylene dithiocarbamate was found to be ineffective at levels to 5.0 % concentration and was tested at 10 % concentration. Cadmium hydrogen hydroxyethyl ethylenediamine triacetate reduced the number of eggs laid to 5.0 %, while cadmium cyclopentamethylene dithiocarbamate reduced it to 75 %. The number of

Eggs laid was normal with the three other chemicals. No delay in oviposition was observed in trials when all other chemicals were used. Cadmium cyclopentamethylene dithiocarbamate did not delay oviposition nor did it affect the number of eggs laid even on the seventeenth day after emergence, however, oviposition was 75 % of normal on the sixth day.

Adult house fly mortality was 15, 20, and 0 % in the three 5.0 % treatments six days after exposure, but adult mortality was 50, 40, 30 % twelve days and seventeen days after exposure, respectively, for the same treatments. There was no correlation between the oviposition and mortality rates. The interpretation of these data indicate that cadmium hydrogen hydroxyethyl ethylenediamine triacetate is an effective reproduction inhibitor. The effects of this chemical reduced the number of eggs laid 5, 10, and 0 % on the 6th, 12th, and 17th day after exposure, while adult mortality was 30, 80 and 98 %, respectively. It is also evident that cadmium hydrogen hydroxyethyl ethylenediamine triacetate when used at 2.5 % concentration appreciably reduced the fecundity of females but did not affect the viability of the eggs laid. All five chemicals tested shortened the life span of adult flies, and the percent mortality increased with time of exposure. Cadmium hydrogen hydroxyethyl ethylenediamine triacetate caused relatively higher toxicity than the other four chemicals.

Cadminate delayed oviposition at the two lower levels of treatment (0.25 and 0.5 %) to the 8th and 12th day, respectively, as indicated in Table V. These dosages caused a significant reduction in both the number of egg batches oviposited and the percent hatching as compared to controls. There was an appreciable increase in fecundity and an equivalent increase in fertility on and after the tenth day after exposure for the 0.25 % treatment. Increase in fecundity and fertility was

TABLE V

EFFECT ON OVIPOSITION, HATCHING, AND ADULT MORTALITY WHEN NEWLY EMERGED HOUSE FLIES WERE EXPOSED TO FOOD CONTAINING 0.25, 0.5, 1.0, and 5.0 % CADMINATE

Days After Emergence	0.25 %			0.5 %			1.0 %			5.0 %		
	% Oviposition Compared with Control	% Hatching	% Adult Mortality	% Oviposition Compared with Control	% Hatching	% Adult Mortality	% Oviposition Compared with Control	% Hatching	% Adult Mortality	% Oviposition Compared with Control	% Hatching	% Adult Mortality
6	0	0	2	20	0	7.5	0	0	15	0	0	95
9	35	12.5	5	25	0	10	0	0	65	0	0	100
13	65	10	5	32.5	5	15	0	0	85	-	-	-
17	85	45	10	37.5	12.5	40	0	0	90	-	-	-
24	70	40	25	15	5	85	0	0	100	-	-	-
28	20	10	65	0	0	98.5	-	-	-	-	-	-

moderate in the 0.5 % treatment up to the 17th day, then there was a sharp decrease in both, and flies exposed to both concentrations laid no eggs after the 26th day. The 0.5 % dosage, therefore, significantly decreased fecundity and fertility up to the 20th day without causing excessive adult mortality. Higher dosages of cadminate, 1.0, and 5.0 %, completely eliminated oviposition.

The increase in adult mortality and decrease in fecundity and fertility for the lower concentrations of Cadminate were dosage dependent. The gradual increase in fecundity and fertility, especially within the 0.25 % treatment, may be due to the gradual adjustments of the detoxification mechanisms of the flies with longer exposure to the chemical. If this assumption is acceptable the subsequent decrease in fecundity and fertility may have resulted from higher residues leading to interference with general metabolism, including that of the somatic cells, as indicated by the higher mortality rates.

Replacement of Cadminate treated food by untreated food five days after exposure to treated food decreased adult mortality and partially restored reproductive capacity. The increase in oviposition was 5, 30, and 80 % for the 1.0, 0.5, and 0.25 % treatments, respectively, 8 days after replacement of food. Interpretation of these results indicated that the reproduction inhibition was temporary, as well as partial.

Zinc chloride had no adverse effect on the fertility of house flies when fed at 1.0, 0.5, and 0.25 % concentrations in the adult food. Higher concentrations, 2.0 - 10 %, were moderately to highly toxic. The toxicity observed was dosage dependent. Oviposition was completely inhibited at 2.0, 5.0, and 10 % levels of treatment and 100 % mortality was encountered in 12, 8, and 5 days, respectively. The 0.25, 0.5 and

1.0 % treatments delayed oviposition for 2 days and fewer eggs were observed in each egg batch up to the 5th day after treatment. There was a slight increase in both the number of batches laid and the number of eggs in each batch after the 5th day. No mortality was observed in flies exposed to these concentrations. The fecundity and fertility of these flies exceeded that of the control. It is reasonable, therefore, to assume that zinc chloride is a trace element which does not occur in the CSMA larval medium that has some function in oogenesis and/or spermatogenesis.

Feeding a mixture of 10 % zinc chloride and 2.0 % cadmium chloride in food delayed adult mortality in house flies. Percent adult mortality on the 5, 7, 9, 11, 12, and 15th day after exposure was 2, 3, 20, 80, 90, 97.5, and 100 %, respectively, in flies fed zinc and cadmium chlorides while adult mortality on the 5, 7, 9, and 10th day after exposure was 10, 15, 60, and 100 %, respectively, in flies fed only cadmium chloride treated food.

The results of data presented in Table VI indicate that house flies did not oviposit when maintained on food with 2.0 % cadmium chloride or 2.0 % cadmium chloride with 10 % zinc chloride. It appears that zinc chloride is a cumulative poison but is less toxic to adult flies when compared to cadmium chloride as indicated by the mortality rates. It is apparent that zinc chloride will counteract the toxic effects of cadmium chloride but does not restore the reproductive ability of the flies.

Since zinc alone, at the same concentration, caused a higher mortality rate than when fed with cadmium, it is reasonable to assume that an antagonistic action can be ascribed to zinc and cadmium. Zinc appears to accumulate in the body to near toxic levels by the tenth day

TABLE VI

EFFECT ON OVIPOSITION, HATCHING, AND ADULT MORTALITY WHEN NEWLY EMERGED HOUSE FLIES WERE EXPOSED TO FOOD CONTAINING CADMIUM CHLORIDE OR A MIXTURE OF CADMIUM CHLORIDE AND ZINC CHLORIDE AT DIFFERENT CONCENTRATIONS

Days After Exposure	2.0 % Cadmium Chloride			2.0 % Cadmium Chloride + 10 % Zinc Chloride		
	% Oviposition Compared With Control	% Hatching	% Adult Mortality	% Oviposition Compared With Control	% Hatching	% Adult Mortality
5	0	0	10	0	0	2
7	0	0	15	0	0	3
9	0	0	60	0	0	20
10	0	0	100	0	0	80
11	-	-	-	-	-	90
12	-	-	-	0	0	97.5
15	-	-	-	0	0	100

when mortality reached 80 %, as compared to 100 % mortality in the cadmium chloride treated.

The effect of continuous exposure of newly emerged house flies to 0.5 % cadmium acetate or a mixture of 0.5% cadmium acetate and 0.5 % zinc chloride is shown in Table VII. The data presented indicate that toxic action as well as the partial reproduction inhibition of cadmium acetate were counteracted by feeding a mixture of equal amounts of zinc chloride and cadmium acetate. The cadmium acetate treated flies did not oviposit until the 17th day after exposure, and fecundity, fertility, and mortality were 5, 25, 98 %, respectively. Both fecundity and fertility appeared to remain normal while a mortality of 15 % occurred in flies exposed to cadmium acetate - zinc chloride treated food. The life span of cadmium acetate treated flies when compared to the controls was appreciably shorter, and approximated the normal in the cadmium acetate-zinc chloride treated flies.

The physio-chemical relation characteristics of cadmium and zinc have been found to be closely related by Parizek (1956). Many authors have noted a higher concentration of zinc compounds within the sperm cells and prostate gland (Mawson and Fischer 1953). However, its physiological significance is not yet known. Patton (1963) indicated that cold inactivated insect spermatozoa can not move into the micropyle of the egg. The release of zinc in small quantities from the spermatozoa of starfish was shown by Fujii (1955) to be responsible for sperm activities both as regards motility and respiration, and liberation of large amounts of zinc which caused stress. If this is applicable with insects, the competition of cadmium with zinc may explain the decrease in fecundity and fertility in house flies fed cadmium chloride with no zinc

TABLE VII

EFFECT ON OVIPOSITION, HATCHING, AND ADULT MORTALITY WHEN NEWLY EMERGED HOUSE FLIES WERE EXPOSED TO FOOD CONTAINING 0.5 % CADMIUM ACETATE OR A MIXTURE OF 0.5 % CADMIUM ACETATE AND 0.5 % ZINC CHLORIDE

Days After Emergence	0.5 % Cadmium Acetate			0.5 % Cadmium Acetate + 0.5 Zinc Chloride		
	% Oviposition Reduction Compared With Control	% Hatching Reduction	% Adult Mortality	% Oviposition Reduction Compared With Control	% Hatching Reduction	% Adult Mortality
6	100	100	3	100	100	0
9	95	100	12	80	20	0
12	-	-	70	0	0	0
15	-	-	98	0	0	15
18	95	75	100	0	0	15
25	-	-	-	0	0	25
30	-	-	-	0	0	60

chloride. If cadmium affects spermatogenesis as suggested by Parizek (1957) this effect can be counteracted with equal portion of zinc chloride, suggesting competitive inhibition between these two elements.

Indium trichloride, indium nitrate, indium sulfate, and phenylmercuric acetate when continuously fed to newly emerged house flies at 0.5 and 1.0 % concentrations did not produce any toxicity or in any way interfere with reproduction. Phenylmercuric nitrate at 1.0 % concentration was moderately toxic and partially inhibited oviposition, but the fertility of the eggs that were laid was normal. Oviposition returned to normal six days after treated food was replaced by untreated food.

Triphenylantimony continuously fed to adult flies at 1.0, 2.0, and 5.0 % concentrations increased both fecundity and fertility. The flies held on 2.0 % treated food produced 30 % higher egg and larval counts than the controls. No mortality was encountered even in the highest concentration tested. The life span also was observed to be normal. The interpretations given in the discussion under zinc chloride with respect to increase in fecundity and fertility following exposure to food containing zinc chloride could be applied here regarding fecundity and fertility, but not for mortality.

The results of feeding 5.0 % cadmium mercaptides treated food to late instar German roaches are presented in Table VIII. These data indicate that four of the six mercaptides when continuously fed delayed and reduced oothecal production. One mercaptide, cadmium 2-hydroxyethyl mercaptide, prevented oothecal production, but caused very high mortality. The percent mortality has been corrected by Abbott's formula (1925). Cadmium n-dodecyl mercaptide was the only other mercaptide

TABLE VIII

EFFECT ON OOTHECAL PRODUCTION, HATCHING AND MORTALITY WHEN LATE INSTAR BLATTELLA GERMANICA NYMPHS WERE EXPOSED TO FOOD CONTAINING 2.5 % CADMIUM MERCAPTIDES

Chemical	No. of Roaches		Mortality of Roaches		No. of oothecae	
	Adults	Nymphs	%	% Corrected [1]	Carried	Hatched
6 Weeks after Exposure						
Cadmium pinanyl mercaptide	44	16	26.7	15.4	10	0
Cadmium 2-hydroxyethyl mercaptide	29	31	83.3	80.8	0	0
Cadmium n-octyl mercaptide	52	8	15.0	1.9	11	0
Cadmium tert-octyl mercaptide	40	20	31.7	21.2	5	2
Cadmium tert-dodecyl mercaptide	41	19	21.7	9.7	5	3
Cadmium n-dodecyl mercaptide	34	26	43.3	34.6	0	0
Control	52	8	13.3	-	15	5
8 Weeks after Exposure						
Cadmium pinanyl mercaptide	44	16	26.7	15.4	6	6
Cadmium 2-hydroxyethyl mercaptide	29	31	93.3	92.3	0	0
Cadmium n-octyl mercaptide	53	7	15.0	1.9	5	10
Cadmium tert-octyl mercaptide	40	20	58.1	51.9	0	8
Cadmium tert-dodecyl mercaptide	44	16	21.7	9.7	1	7
Cadmium n-dodecyl mercaptide	37	23	43.3	34.6	6	10
Control	52	8	13.3	-	9	19
12 Weeks after Exposure						
Cadmium pinanyl mercaptide	44	16	58.3	40.5	6	22
Cadmium 2-hydroxyethyl mercaptide	29	31	100.0	100	0	0
Cadmium n-octyl mercaptide	53	7	50.0	28.6	5	15
Cadmium tert-octyl mercaptide	40	20	66.7	52.3	0	13
Cadmium tert-dodecyl mercaptide	44	16	75.0	64.3	0	8
Cadmium n-dodecyl mercaptide	37	23	50.0	28.6	11	15
Control	52	8	60.0	-	12	34

[1] % mortality corrected by Abbott's formula (Abbott 1925).

which prevented oothecal production in the first four weeks after exposure. However, this delay did not affect the total number of oothecae laid nor did it shorten the life span, since the adults in this treatment outlived the controls. There was no correlation between the reproduction inhibition and percent mortality based on the 8th week counts, but the correlation was evident in the 4th and 12th weeks counts. Cadmium 2-hydroxyethyl mercaptide seems to exert similar adverse effects on both house flies and German roaches. Cadmium pinanyl mercaptide and cadmium n-dodecyl mercaptide were the least effective, followed by cadmium n-octyl mercaptide, cadmium tert-octyl mercaptide, and cadmium tert-dodecyl mercaptide. Their effectiveness was based on reduction of oothecal production. The order of effectiveness in the last three chemicals was reversed when compared to their effects on reproduction in house flies. The mortality among males was 10-25 % higher in all treatments as compared to females. Whether this higher mortality was due to the general inherent tolerance of females or to specific effects related to affinity or selective absorption of these chemicals by male gonads is not clear.

Data showing the effect of continuous feeding of miscellaneous cadmium compounds to late instar German roaches is presented in Table XIV. Cadmium laurate was the most effective reproduction inhibitor, followed by cadmium hydrogen hydroxyethyl ethylenediamine triacetate and cadmium stearate, respectively, however, the first two chemicals induced the highest mortality. Results obtained with treatments of cadmium phosphate and cadmium cyclopentamethylene dithiocarbamate indicated little reproduction inhibition in roaches. Cadmium laurate and cadmium hydrogen hydroxyethyl ethylenediamine triacetate were the least

TABLE IX

EFFECT ON OOTHECAL PRODUCTION, HATCHING, AND MORTALITY WHEN LATE INSTAR BLATTELLA GERMANICA NYMPHS WERE EXPOSED TO FOOD CONTAINING 2.5 % CADMIUM COMPOUNDS

Chemical	No. of Roaches		Mortality of Roaches		No. of oothecae	
	Adults	Nymphs	%	% Corrected	Carried	Hatched
4 Weeks after Exposure						
Cadmium stearate	40	20	25	16.7	7	0
Cadmium laurate	35	25	15	5.6	2	0
Cadmium phosphate	33	27	30	22.2	8	0
Cadmium hydrogen hydroxyethyl ethylenediamine triacetate	37	23	13.3	3.7	7	0
Cadmium cyclopentamethylene dithiocarbamate	47	14	20	11.1	10	0
Control	52	8	10	-	16	0
6 Weeks after Exposure						
Cadmium stearate	45	15	40	29.4	4	7
Cadmium laurate	40	20	45	35.3	0	2
Cadmium phosphate	43	17	41.7	31.4	5	13
Cadmium hydrogen hydroxyethyl ethylenediamine triacetate	47	13	50	41.2	4	7
Cadmium cyclopentamethylene dithiocarbamate	53	17	40	29.4	6	14
Control	54	6	15	-	8	16
12 Weeks after Exposure						
Cadmium stearate	45	15	50	33.3	5	13
Cadmium laurate	40	20	70	60	0	2
Cadmium phosphate	43	17	50	33.3	5	23
Cadmium hydrogen hydroxyethyl ethylenediamine triacetate	47	13	80	73.3	0	11
Cadmium cyclopentamethylene dithiocarbamate	53	17	50	33.3	10	20
Control	54	6	25	-	11	23

toxic to roaches four weeks after treatment, while these compounds were the most toxic 5, and 12 weeks after treatment. The laurate was more toxic than the triacetate in the first 4 weeks, but was less toxic after 5 and 8 weeks, respectively. Delay in toxicity among the laurate and triacetate treated roaches could be related to the higher toxicity of these chemicals to the adult stages of the roaches.

The effect of continuous exposure of late instar American roaches to 5.0 % Cadminate and cadmium related metals is shown in Table X. The data indicate that triphenylantimony was very toxic and prevented growth and molting to adults. Indium compounds produced no deleterious effects and both molting and oothecal production were normal. However, a 5.0 % mortality was observed in indium trichloride treated roaches. This observation coincides with those reported on the effects of this chemical on house flies, while those data obtained from the use of triphenylantimony do not.

Phenylmercuric nitrate prevented molting and consequently oothecal production in American roaches. The effects of phenylmercuric acetate caused 94 % inhibition in molting, and 70 % mortality as compared to 30 % mortality caused by phenylmercuric nitrate in ten weeks after exposure. No observations were made after the 10th week. Again reproduction inhibition was correlated with higher mortality. Similarly the molting process was linked with toxicity and hence mortality. The percent of roaches that molted ranged from 0 in roaches sustained on triphenylantimony treated food, the most toxic, to 55 in roaches on indium nitrate, the least toxic.

PUPAL DIPPING.--Drosophila pupae dipped in 5-10 % acetone-water (v/v) solutions of cadmium chloride, cadmium nitrate, cadmium acetate,

cadmium sulfate, or cadmium lactate showed a 5-25 % reduction in emergence, and adults that emerged laid eggs. The highest reduction in emergence was observed in flies dipped in 10 % cadmium chloride and cadmium nitrate solutions. There was no delay in oviposition with any of the chemicals tested by pupal dipping at lower concentrations. The age of pupae at dipping had no significant effect on fecundity and fertility of those adults that eventually emerged. However, emergence was reduced by 20 % when 1-day old pupae were dipped. This decrease in emergence was probably due to the higher permeability of the softer puparium. No adverse effects were observed in adults emerging from acetone-water dipped controls.

When pupae of all ages were dipped in saturated solutions of the above chemicals, development to the adult stage was reduced to 10-30 %. Mortality of the flies emerging from this treatment ranged from 20-100 % within 24-72 hours. However, those that survived completed development, adults emerged and eggs were laid, and no morphological abnormalities were observed. Based on the above observation it appears that these cadmium compounds penetrated the puparium and caused high toxicity but did not affect reproduction. The age of pupae, considered critical by Smith et al. (1964), did not appear to have an effect in inhibiting reproduction, but did appear to contribute to a slightly increased toxicity, indicating that more penetration of the chemicals occurs in younger than in older pupae.

The use of the cadmium mercaptides and the miscellaneous cadmium compounds was limited due to the lack of a suitable solvent. Few of these were soluble in methanol, but development to the adult stage was prevented when pupae were dipped in methanol solutions of these chemi-

TABLE X

EFFECT ON OOTHECAL PRODUCTION, HATCHING, AND MORTALITY WHEN LATE INSTAR PERIPLANETA AMERICANA NYMPHS WERE EXPOSED TO FOOD CONTAINING 5.0 % CADMINATE OR DIFFERENT CADMIUM RELATED METALS

Chemical	6 Weeks after Exposure					10 Weeks after Exposure				
	No. of Roaches		Mortality of Roaches %	No. of oothecae		No. of Roaches		Mortality of Roaches %	No. of oothecae	
	Adults	Nymphs		Carried	Hatched	Adults	Nymphs		Carried	Hatched
Triphenylantimony	0	1	95	0	0	0	0	100	0	0
Phenylmercuric nitrate	0	17	15	0	0	0	6	70	0	0
Phenylmercuric acetate	1	18	5	0	0	1	14	30	0	0
Idium trichloride	1	19	0	0	0	8	11	5	2	2
Indium sulfate	4	16	0	0	0	10	10	0	0	1
Indium nitrate	8	12	0	0	0	11	9	0	1	6
Cadminate	2	17	5	0	0	4	13	20	0	0
Control	10	10	0	0	0	12	8	0	3	12

cals. Since the checks dipped in methanol failed to emerge, the toxic effects must have been due to methanol rather than to the chemicals.

LARVAL DIPPING.--Dipping of the late instar Drosophila larvae, mostly the third, in saturated solutions of all the chemicals tested in the pupal dipping resulted in 90 to 100 % mortality. Of the 250 larvae dipped for 10 minutes in a saturated solution of cadmium nitrate, 200 survived the treatment. Of these only 20 pupated but did not emerge. Dipping larvae in 1.0-5.0 % concentrations was less toxic; 90 % of the treated larvae pupated and 80 % emerged. No reduction in either fecundity or fertility was observed in those flies that emerged. Since gonadal development and division of chromosomes in Drosophila take place mostly in the pupal state (Bodenstein (1950), it would seem logical to expect greater reproduction inhibition by pupal than by larval treatment. No reproduction inhibition was demonstrated by treatments with cadmium salts on Drosophila.

DUSTING.--Results of data showing the effect of dust treatments on recently emerged Drosophila flies are shown in Table XI. These data indicate that cadmium 2-hydroxyethyl mercaptide was the most toxic compound used and cadmium n-octyl mercaptide the second most toxic. The mortality rates observed for cadmium 2-hydroxyethyl mercaptide 1, 2, 3, days after treatment were 12.5, 60, 80 % and for cadmium n-octyl mercaptide 1, 2, 3 days after treatment were 1.4, 5, 10 %, respectively. There was no adult mortality observed in groups of flies treated with the other three mercaptides. Reduction in oviposition was toxicity independent. Cadmium n-octyl mercaptide treated flies laid more eggs than the cadmium 2-hydroxyethyl mercaptide treated flies. There was a delay in oviposition and a reduction in the number of eggs laid in all

TABLE XI

EFFECT ON OVIPOSITION, HATCHING, AND ADULT MORTALITY OF *DROSOPHILA* WHEN HELD FOR 5 MINUTES IN VIALS TREATED WITH CADMIUM MERCAPTIDE DUSTS WITHIN 12 HOURS AFTER EMERGENCE

Chemical	No. of Eggs Laid	No. of Larvae	% Hatching	% Adult Mortality
1 Day after Treatment				
Cadmium pinanyl mercaptide	10	0	0	0
Cadmium 2-hydroxyethyl mercaptide	4	0	0	12.5
Cadmium n-octyl mercaptide	0	0	0	1.4
Cadmium tert-octyl mercaptide	3	0	0	0
Cadmium tert-dodecyl mercaptide	9	0	0	0
Cadmium n-dodecyl mercaptide	10	0	0	0
Control	75	0	0	0
3 Days after Treatment				
Cadmium pinanyl mercaptide	35	10	28.6	0
Cadmium 2-hydroxyethyl mercaptide	50	12	24	60
Cadmium n-octyl mercaptide	15	3	20	5
Cadmium tert-octyl mercaptide	30	6	20	0
Cadmium tert-dodecyl mercaptide	150	50	33.3	0
Cadmium n-dodecyl mercaptide	210	70	33.3	0
Control	300	140	47.7	0
6 Days after Treatment				
Cadmium pinanyl mercaptide	120	40	33.3	0
Cadmium 2-hydroxyethyl mercaptide	15	3	20	80
Cadmium n-octyl mercaptide	75	30	40	10
Cadmium tert-octyl mercaptide	100	40	40	0
Cadmium tert-dodecyl mercaptide	160	70	43.8	0
Cadmium n-dodecyl mercaptide	360	150	41.7	0
Control	400	200	50	0

treated vials as compared to the untreated controls. Flies in all treatments, except those dusted with cadmium n-octyl mercaptide, laid eggs within 24 hours. Cadmium n-dodecyl mercaptide had very little effect on oviposition, but hatchability was 20 % on the third day after dusting. The percent hatching in cadmium tert-octyl mercaptide was identical to that of cadmium n-dodecyl mercaptide, and for cadmium 2-hydroxyethyl mercaptide 24 % on the third day, and 20 % on the sixth day. Hence, higher toxicity to adults did not affect fertility for three days after treatment but it did on the sixth day.

The results obtained for oviposition and hatchability were similar to those of the untreated controls on the tenth day after dusting for all the mercaptides, except cadmium 2, hydroxyethyl mercaptide for which a 95 % adult mortality was observed along with a decrease in both the number and fertility of eggs laid. These findings indicate that dusting of recently emerged Drosophila flies was not a very satisfactory method for inducing reproduction inhibition with cadmium mercaptides, since all treated flies laid some viable eggs. However, cadmium n-octyl mercaptide, cadmium 2-hydroxyethyl mercaptide, and cadmium tert-octyl mercaptide did reduce fecundity and fertility effectively. Cadmium 2-hydroxyethyl mercaptide caused high mortality. Better results could have been achieved if adult flies were repeatedly dusted, as the effects of some of the chemicals seem to decrease gradually with time.

Results of data presented in Table XII show the effect on oviposition, hatching, and adult mortality on recently emerged Drosophila flies when treated with Cadminate dust. The data indicate that the effects of Cadminate dusting prevented oviposition for over 24 hours with a significant reduction to 0.82, 0.75, 10 and 20 % after 72, 96,

TABLE XII

EFFECT ON OVIPOSITION, HATCHING, AND ADULT MORTALITY OF DROSOPHILA WHEN HELD FOR 5 MINUTES IN VIALS TREATED WITH CADMINATE DUST WITHIN 12 HOURS AFTER EMERGENCE

Hours After Treatment	Cadminate				Control			
	No. of Eggs	No. of Larvae	% Hatching	% Adult Mortality	No. of Eggs	No. of Larvae	% Hatching	% Adult Mortality
6	0	0	0	5	4	0	0	0
12	0	0	0	20	24	0	0	0
24	0	0	0	33.3	50	0	0	0
72	5	0	0	35	350	140	40	0
96	15	0	0	40	400	180	45	0
120	75	6	8	40	400	180	45	0
168	150	25	17	40	400	200	50	0

120, and 168 hours, respectively. Egg hatchability also was prevented for over 100 hours. The percent hatchability in the treated groups was 8, and 17 % after 120, and 168 hours, respectively, as compared to 40, 45, 45 and 50 % in the controls after 72, 96, 120 and 168 hours, respectively.

It is evident from the foregoing discussion and from the data presented that Cadminate was the most effective chemical tested as a reproduction inhibitor. Although the flies recovered partially their egg laying potential (20 %) the percent hatchability was only 17 %. Even after 168 hours, the flies did not regain their reproductive potential as was the case with the other chemicals tested by this method. These results were further supported by the relatively wider margin of safety to the treated adults. A factor which is a vital characteristic of ideal chemosterilants. An ideal chemosterilant should have a wide margin of safety between the killing and the sterilizing dose since treated insects must maintain normal habits in order to effectively compete with the untreated males in the natural population.

TOPICAL APPLICATION.--Topical application of the water-acetone (v/v) soluble chemicals tested at 5-10 % concentrations did not produce a detectable reproduction inhibition when applied to late instar American roaches. No mortality was observed during these trials and molting, oothecal production, and fertility percentages were in the normal range. Based on these observations it was concluded that cuticular penetration by these compounds was minimal. The waxy nature of the cuticle may have been a limiting factor to penetration.

INJECTION.--Cadmium chloride, cadmium nitrate, and cadmiun acetate when injected into the coxo-trochanteral joint were ineffective as re-

production inhibitors. Similarly, results obtained by injection of equivalent doses of these compounds through an abdominal intersegmetal membrane were ineffective. Mortality, high in the latter treatment, was attributed to the accidental damage to the viscera and/or to the higher concentration of chemical in close approximation to sensitive organs. The mortality was not related to sex, since the mortality ratio among treated males and females was approximately 50:50.

INUNCTION.--The effects of inunction treatment of six cadmium mercaptides on oothecal production and hatching in American roaches are summarized in the data of Table XIII. Alteration of integument was observed on the mesothorax and metathorax at the site of inunction 2-3 weeks after treatment in 40-80 % of the roaches treated with cadmium pinanyl mercaptide, cadmium n-octyl mercaptide, cadmium tert-octyl mercaptide, and cadmium tert-dodecyl mercaptide but no alteration was noted on the cadmium n-dodecyl mercaptide treated roaches. Dissection of roaches showing alterations in integument revealed hyperplasia of the tissue with excessive connective tissue formation under the integument. Over 30 % of the roaches having the integumental alterations died in the process of molting, since the exuviae would not come loose at the site of inunction. Those which molted to adults had deformed wings and the integument under the wings was hard, light gray, and pitted (Figs. 9 and 10). Dissection of adults 12 weeks after molting showed very little hyperplasia and the integument was softer but with the light gray pitted appearance. More males were affected than females, and the males affected were smaller in size than the females. No such changes were detected in controls treated with lanolin alone. Cadmium chloride has been reported by Miesch (1964) to destroy germa-

Figure 9. American Roach Numph Showing Alteration of Integument at Inunction Site

Figure 10. American Roach Adult Showing Wing Deformation Following Inunction Treatment

TABLE XIII

EFFECT ON OOTHECAL PRODUCTION, HATCHING, AND MORTALITY WHEN LAST INSTAR PERIPLANETA AMERICAN NYMPHS WERE TREATED BY INUNCTION WITH LANOLIN CONTAINING 2.5 % CADMIUM MERCAPTIDES

Chamical	No. of Roaches		Mortality of Roaches		No. of oothecae	
	Adults	Nymphs	%	% Corrected	Carried	Hatched
4 Weeks After Treatment						
Cadmium pinanyl mercaptide	-	24	20	14.3	0	0
Cadmium 2-hydroxyethyl mercaptide	2	21	23.3	17.8	0	0
Cadmium n-octyl mercaptide	3	21	20	14.3	0	0
Cadmium tert-octyl mercaptide	1	22	23.3	17.8	0	0
Cadmium tert-dodecyl mercaptide	7	20	20	14.3	3	0
Cadmium n-dodecyl mercaptide	4	24	6.7	-	2	0
Control	17	11	6.7	-	5	0
8 Weeks After Treatment						
Cadmium pinanyl mercaptide	8	11	36.7	26.9	1	0
Cadmium 2-hydroxyethyl mercaptide	6	11	43	34.6	4	0
Cadmium n-octyl mercaptide	9	11	33.3	22.7	1	0
Cadmium tert-octyl mercaptide	5	12	43.3	34.6	0	0
Cadmium tert-dodecyl mercaptide	11	7	40	30.8	11	1
Cadmium n-dodecyl mercaptide	8	14	26.7	15.6	6	0
Control	17	9	13.3	-	15	8
12 Weeks After Treatment						
Cadmium pinanyl mercaptide	12	4	46.7	36	29	8
Cadmium 2-hydroxyethyl mercaptide	12	3	50	39.9	8	6
Cadmium n-octyl mercaptide	6	5	63.3	55.9	12	5
Cadmium tert-octyl mercaptide	10	7	43.3	31.9	11	0
Cadmium tertOdodecyl mercaptide	14	1	50	39.9	20	8
Cadmium n-dodecyl mercaptide	13	7	33.3	19.9	12	7
Control	25	0	16.7	-	45	28

nial tissue of male American roaches and to cause hyperplasia in the ovaries of females when injected subcutaneously into the coxa or fed in a bait.

Necrotic changes at the site of injection, interstitial cell tumor formation, and the carcinogenic nature of cadmium following intratesticular injections of aqueous solutions of cadmium salts have been reported by Parizek (1964), Gunn et al. (1963b), and Cameron and Foster (1963), respectively.

The effects of the inunction treatment delayed molting, and consequently, oothecal production in all the treated roaches. No molting occurred during the first four weeks after treatment in cadmium pinanyl mercaptide treated roaches. The mortality rate increased during the molting period due to inability of the adults to shed their exuviae, thus dying of fatigue and starvation. Since the mortality rate varied considerably in the two sexes due to the effect of the different chemicals, and the subsequent imbalance in male and female ratio, no effort was made to evaluate these effects on oothecal production.

VERTEBRATES.--Post treatment observation of hogs showed slightly different reactions with the different methods of application. There was marked swelling around the site of injection in both the subcutaneous and intratesticular injections 24 hours after treatment. Swelling following the intratesticular treatment involved all the inguinal region by the fifth day and was subsided by the tenth day. The degree of inflamation was less profound in the subcutaneous injection and was completely subsided by the seventh day. Necrotic tissue was formed at the site of injection in both treatments. The testes were hard and not freely movable in the scrotal sac in the intratesticularly treated

hogs while they were normal in the subcutaneously treated. The scrotal sac was soft and reddish in the inunction treated hogs, but no other changes were observed. There was less weight gain in all treated animals as compared to the untreated controls.

Necropsy findings in animals treated by injection generally agreed with those of Parizek and Zahor (1956) and others. The castration phenomenon was considered to be temporary, since at necropsy the testicular parenchyma looked normal. In one hog that died four weeks after intratesticular treatment, the testes were smaller than normal, and the right testis was almost black. Adhesions between common and proper tunica were more pronounced in the intratesticular treatment than in the subcutaneous treatment and were absent in the inunction treatment. There was a focus of local necrosis with peripheral calcification under the tunica albugineous (1 cm in diameter) which appeared to consist of coagulated testicular tissue. These changes were observed to occur in the intratesticular treatment, but not in the other treatments.

Observations of the steers treated with cadmium chloride showed that the results were very similar in all the treatments. The testes and the inguinal region were swollen. There was a generalized reaction, the animals were restless, off food, and reluctant to stand on their feet or move about. The swelling started 12 hours after treatment and continued for over two weeks. Necropsy findings 12 months after treatment indicated normal testicular tissue. However, there was necrotic tissue under the tunica albugineous identical to that found in the intratesticular treated hog testis.

The steers seemed to be more sensitive to cadmium chloride than the hogs since their reaction to all treatments of this compound was

more pronounced. Only in the intratesticularly treated hogs was a similar reaction observed. The fly counts, on both steers and hogs, to determine any possible repellent properties of cadmium chloride were inconclusive. However, a very slight reduction in number of flies was observed settling on the treated hogs 24 hours after treatment. This is probably due to restlessness of treated animals, as compared to the untreated controls, rather than to any specific effect of cadmium chloride.

SUMMARY AND CONCLUSIONS

Laboratory experiments utilizing nine techniques including: semi-solid, liquid, and solid foods; pupal and larval dipping; dusting; topical application; injection; and inunction were conducted to evaluate the effect of cadmium compounds and cadmium related metals on the mortality and reproduction of the following insect species; Musca domestica, Blattella germanica, and Periplaneta americana.

Results of experiments with house flies and American cockroaches indicated that the adult solid food technique was the most effective method of evaluation, while dusting was the only method of treatment that induced partial reproduction inhibition in Drosophila. Semisolid and liquid treatments strongly repelled American roaches and Drosophila. Both pupal and larval dipping treatments used for Drosophila manifested higher toxicity but did not affect fecundity or fertility.

The effects of cadmium compounds tested were observed to delay, reduce or prevent oviposition in house flies when fed continuously at different concentrations in the adult food. Higher dosages (1.0-5.0 %) of Cadminate were observed to prevent oviposition, but a lower dosage (0.5 %) decreased fecundity and fertility without causing excessive mortality.

Of the six cadmium mercaptides screened, only cadmium 2-hydroxyethyl mercaptide and n-octyl mercaptide completely inhibited reproduction in house flies when given in adult food at a dose of 5.0 %. Cad-

mium hydrogen hydroxyethyl ethylenediamine was the only effective miscellaneous cadmium compound which decreased fecundity without affecting fertility.

Generally the cadmium compounds delay, reduce, or prevent oviposition as long as the flies continued to feed on treated food. House flies fed treated food for five days, then fed untreated food, partially resumed their normal oviposition. The life span of treated flies was appreciably shorter than it was for flies reared on the controls. The percent adult mortality was dosage dependent and increased with time of exposure.

Reproduction inhibition in house flies possibly was thought to be correlated with interference with the general cell metabolism including that of the somatic cells.

The closely related physio-chemical relation characteristics of cadmium and zinc suggest that the effect of cadmium on house flies could be counteracted by feeding a mixture of equal parts of zinc and cadmium, suggesting competitive inhibition between the two elements, or at least antagonistic action between zinc and cadmium.

Cadmium related metals, indium, mercury antimony, and zinc did not cause reproduction inhibition in house flies or roaches at 0.5-1.0 and 5.0 %, respectively, but phenylmercuric nitrate fed to house flies at 1.0 % produced partial reproduction inhibition and was toxic. Triphenylantimony or zinc chloride fed to newly emerged house flies at 0.25, 1.0, 2.0 and 5.0 % concentrations, respectively, increased both fecundity and fertility without adversely affecting longevity. It is concluded that antimony and zinc either are trace elements which do not occur in CSMA larval medium and have a function in oogenesis and/or

spermatogenesis. However, triphenylantimony was highly toxic to American roach nymphs at 5.0 % concentration.

Cadmium 2-hydroxyethyl mercaptide prevented oothecal production when fed to American roaches at 5.0 % concentration but caused high adult mortality at this level. Cadmium n-dodecyl mercaptide fed at 5.0 % concentration prevented oothecal production temporarily. Mortality in adult roaches was higher in males than in females in all chemicals tested. Whether this mortality is related to sex specificity or inherent tolerance of females was not clear.

Cadmium laurate, cadmiun hydrogen hydroxyethyl ethylenediamine triacetate and cadmium stearate fed at 2.5 % concentrations caused moderate degrees of reproduction inhibition in German roaches.

The response of the steers and hogs to cadmium chloride treatments was generally similar to the findings reported by other workers. The steers, however, reacted more severely than the hogs as indicated by the generalized reaction. The castration phenomenon was temporary in both species. No definite repellent action to flies was observed in animals treated with cadmium chloride.

The data presented in this thesis clearly indicate that some cadmium compounds effectively inhibit reproduction in house flies without seriously affecting longevity. The physio-chemical relations of cadmium and related metals may further be explored by the techniques expressed in this thesis.

LITERATURE CITED

Abbott, W. S. 1925. A method of computing the effectiveness of an insecticide. J. Econ. Entomol. 18 (2):265-267.

Alexander, P. 1960. Radiation imitating chemicals. Sci. Amer. 202 (1):99-108.

Altman, R. M. 1963. The effect of tepa on Plasmodium gallinaceum in Aedes aegypti Amer. J. Hyg. 77:221-227.

Ascher, K. R. S. 1957. Prevention of oviposition in the house fly through tarsal contact agents. Science 125:938-939.

Baumhover, A. H., A. J. Graham, B. A. Bitter, D. E. Hopkins, W. D. New, F. H. Dudley, and R. C. Bushland. 1955. Screw-worm control through release of sterilized flies. J. Econ. Entomol. 48 (4): 462-466.

Beroza, M. and A. B. Borkovec. 1964. The sterility of tepa and other aziridine chemosterilants. J. Med. Pharmacol. Chem. 7:44-49.

Biessele, J. J. 1958. Mitotic poisons and the cancer problem. Elsevier, New York. 214 p.

Bird, M. J. 1950. Production of mutations in Drosophila using four aryl-halogenoalkylamines. Nature 165:419.

Bodenstein, D. 1950. The postembryonic development of Drosophila. Biology of Drosophila. N. Y. John Wiley. P. 275-265.

Borkovec, A. B. 1962. Sexual sterilization of insects by chemicals. Science 137:1034-1037.

Borkovec, A. B. and C. W. Woods. 1963. Aziridine chemosterilants. Sulfur-containing aziridines. New approaches to pest control and eradication. Advances Chem. Ser. 41:47-55.

Borkovec, A. B., S. C. Chang, and H. M. Limbing. 1964. Effect of pH on sterilizing activity of tepa and metepa on male house flies. J. Econ. Entomol. 57 (16):815-817.

Bunde, C. A., H. E. Blair, G. R. Burch, and J. E. Lee. 1954. Ascarid action of cadmium. Proc. Soc. Exp. Biol. 87:549-550.

Burch, G. E. and H. E. Blair. 1955. A new ascaricide for swine. J. Amer. Vet. Assoc. 126:304-308.

Bushland, R. C. 1960. Male sterilization for the control of insects. Advances Pest Control Res. Vol. III:1-25.

Bushland, R. C. and D. E. Hopkins. 1951. Experiments with screw-worm flies sterilized by X-rays. J. Econ. Entomol. 44 (55):725-731.

_____. 1953. Sterilization of screw-worm flies with X-rays and gamma-rays. J. Econ. Entomol. 46 (4):648-656.

Cameron, E. and C. L. Foster. 1963. Observations on the histological effects of sublethal doses of cadmium chloride in the rabbit. 1. The effect on the testis. J. Anat. 97 (2):269-280.

Cantwell, G. E. and T. J. Henneberry. 1963. The effects of gamma radiation and apholate on the reproductive tissues of Drosophila melanogaster. J. Insect Pathol. 5:251-264.

Chamberlain, W. F. 1962. Chemical sterilization of screw-worm. J. Econ. Entomol. 55(2):242-248.

Chamberlain, W. F. and C. C. Barrett. 1964. A comparison of the amounts of metepa required to sterilize the screw-worm fly and the stable fly. J. Econ. Entomol. 57(2):267-269.

Chamberlain, W. F. and E. W. Hamilton. 1964. Absorption, excretion, and metabolism of P^{32}-labeled metepa by screw-worm and stable flies. J. Econ. Entomol. 57(6):800-803.

Chang, S. C. 1965a. Chemosterilization and mating behavior of male house flies. J. Econ. Entomol. 58(4):669-672.

_____. 1965b. Improved bioassay method of evaluating the potency of chemosterilants against house flies. J. Econ. Entomol. 58(4): 796.

Chang, S. C. and A. B. Borkovec. 1964. Quantitative effects of tepa, metepa and apholate on sterilization of male house flies. J. Econ. Entomol. 57(4):488-490.

Collier, C. W. and J. E. Downey. 1965. Laboratory evaluation of certain chemosterilants against the gypsy moth. J. Econ. Entomol. 58(4):649-651.

Craig, A. W., B. W. Fox, and H. Jackson. 1959. Metabolic studies of ^{32}P-labeled triethylenethiophosphoramide. Biochem. Pharmacol. 3:42-50.

Cressman, A. W. 1963. Response of citrus red mites to chemical sterilants. J. Econ. Entomol. 56(1):111-112.

Crystal, M. M. 1963. The induction of sexual sterility in the screw-worm fly by antimetabolites and alkylating agents. J. Econ. Entomol. 56(4):468-473.

Crystal, M. M. 1965a. Antifertility effects of anthelminthics in insects. J. Econ. Entomol. 57(4):606-607.

_____. 1964b. Chemosterilants efficiency of Bis (1-Aziridinyl) phosphinyl carbamates in screw-worm flies. J. Econ. Entomol. 57 (5):726-731.

Crystal, M. M. and L. E. LaChance. 1963. The modification of reproduction in insects treated with alkylating agents. 1. Inhibition of ovarian growth and egg production. Biol. Bull. 125(2):270-279.

Dame, D. A. and C. H. Schmidt. 1964. Uptake of metepa and its effect on two species of mosquitoes (Anopheles quadrimaculatus, Aedes aegypti) and house flies (Musca domestica). J. Econ. Entomol. 57(1):77-81.

Dame, D. A., D. B. Woodard, H. R. Ford, and D. E. Weidhaas. 1964. Field behavior of sexually sterile Anopheles quadrimaculatus males. Mosquito News 24(1):6-14.

Davis, D. A., J. B. Gahan, D. E. Weidhaas, and C. N. Smith. Exploratory studies on gamma radiation for the sterilization and control of Anopheles quadrimaculatus. J. Econ. Entomol. 52(5):868-870.

Decker, L. E. 1965. Tissue cadmium content following administration of low concentrations of cadmium in drinking water. Fed. Proc. 15:240.

Demerec, M. and B. P. Kaufmann. 1962. Drosophila guide. Carnegie Inst. Washington 47 p.

Fahmy, O. G. and M. J. Fahmy. 1955. Cytogenetic analysis of the action of carcigogens and tumor inhibitors in Drosophila melanogaster. IV. The cell stage during spermatogenesis and induction of intra- and inter-genic mutations by 2:4:6 tri (ethyleneimino)-1:3:5-triazine. J. Genetics 53:563-584.

_____. 1961. Cytogenetic analysis of the action of carcinogens and tumor inhibitors in Drosophila melanogaster. IX. The cell-stage response of the male germ line to the mesyloxy esters. Genetics 46:361-372.

Feldmesser, J., M. Beroza, and R. V. Rebois. 1962. Effects of chemosterilants on saprophytic nematodes. J. Parasitol. 48(2):44.

Forny, R. B., C. A. Bunde, and G. R. Burch. 1955. Tissue storage in cadmium treated pigs. Proc. Soc. Exp. Biol. (New York) 90:13-14.

Fujii, T., S. Utida, and T. Mizuno. 1955. Reaction of starfish spermatozoa to histidine and certain other substances considered in relation to zinc. Nature 176:1068-1069.

Gellhorn, A. and E. Hirschberg. 1955. Investigation of diverse systems for cancer chemotherapy screening. Cancer Res. Suppl. No. 3, 1955.

Goldsmith, E. D. and I. Frank. 1952. Sterility in the female fruit fly, Drosophila melanogaster, produced by the feeding of a folic-acid antagonist. Amer. J. Physiol. 171:726-727.

Goldsmith, E. D. and Morris H. Harnley. 1950. Reversal of action of folic acid antagonist 4-aminopteroylglutamic acid in Drosophila melanogaster. Cancer Res. 10(4):220.

Goodhue, L. D. and C. E. Linnard. 1950. Air separation apparatus for cleaning fly pupae. J. Econ. Entomol. 43(2):228.

Gouck, H. K. 1964. Chemosterilization of house flies by treatment of the pupal stage. J. Econ. Entomol. 57(2):239-241.

Gouck, H. K. and G. C. LaBrecque. 1964. Chemicals affecting fertility in adult house flies. J. Econ. Entomol. 57(5):663-664.

Gouck, H. K., M. M. Crystal, A. B. Borkovec, and A. W. Meifert. 1963. A comparison of techniques for screening chemosterilants of house flies and screw-worm flies. J. Econ. Entomol. 56(4):506-509.

Grosch, D. S. 1963. Insect fecundity and fertility: Chemical induced decrease. Science 141:732-733.

Gunn, S. A. and T. C. Gould. 1958. Role of zinc in fertility and fecundity in the rat. Amer. J. Physiol. 193:505-508.

Gunn, S. A., T. C. Gould, and W. A. D. Anderson. 1961a. Zinc protection against cadmium injury to rat testis. Arch. Pathol. 71:274-281.

_____. 1961b. Competition of cadmium for zinc in rat testis and dorsolateral prostate. Acta Endocrin. Copenhagen 37:24-30.

_____. 1963a. The selective injurious response of testicular and epididymal blood vessels to cadmium and its prevention by zinc. Amer. J. Pathol. 42(6):685-702.

_____. 1963b. Cadmium-induced interstitial cell tumors in rats and mice and their prevention by zinc. J. Natl. Cancer Inst. 31 (4):745-759.

Gunn, S. A., T. C. Gould, S. S. Ginori, and J. G. Morse. 1955. Selective uptake of Zn^{65} by dorsolateral prostate of rat. Proc. Soc. Exp. Biol. Med. 88:556-558.

Guthrie, J. E. 1954a. Critical tests with anthranilate as an ascaricide in swine. Vet. Med. 49:413-418.

_____. 1954b. Further observations on the efficiency of cadmium anthranilate as an ascaricide in swine. Vet. Med. 49:500.

Hall, S. A. 1964. New approaches to pest control and eradication. Advances Chem. Ser. 41: p. vii-xi.

Hair, J. A. and T. R. Adkins, Jr. 1964. Sterilization of the face fly, Musca autumnalis, with apholate and tepa. J. Econ. Entomol. 57(4):586-589.

Harris, R. L. 1962. Chemical induction of sterility in the stable fly. J. Econ. Entomol. 55(6):882-885.

Harries, F. H. 1960. Laboratory studies on orchard mites with emphasis on their development and control. Proc. Washington State Hort. Assoc. 1959 Meeting, p. 165.

_____. 1961. Effect of certain antibiotics and other compounds on the two-spotted spider mite. J. Econ. Entomol. 54(1):122-124.

_____. 1963. Effects of some antibiotics and other compounds on the fertility of orchard mite. J. Econ. Entomol. 56(4):438-441.

Hays, S. B. and J. H. Cochran. 1964. Evaluation of compounds affecting the reproductive potential of the plum curculio. J. Econ. Entomol. 57(2):217-219.

Henneberry, T. J., F. F. Smith, and W. L. McGovern. 1964. Some effects of gamma radiation and chemosterilants on the Mexican bean beetle. J. Econ. Entomol. 57(6):813-815.

Howland, A. F., P. Vail, and T. J. Henneberry. 1965. Effects of chemosterilants on fertility of cabbage loopers. J. Econ. Entomol. 58 (4):635-637.

Incho, H. H. 1954. A rapid method for obtaining clean house fly pupae. J. Econ. Entomol. 47(5):938-939.

Kar, A. B. 1961. Chemical sterilization of male Rhesus monkey. Endocrimology 69(6):1116-1119.

Kar A. B. and R. P. Das. 1962. Sterilization of males by intratesticular administration of cadmium chloride. Acta Endocrinol. 40: 321-331.

_____. 1963. The nature of protective action of selenium on cadmium induced degeneration of the rat testis. Proc. Nat. Sci. India Part B. Biol. Sci. 29(3):797-305.

Kar, A. B. and V. P. Pandoj. 1963. Sterilization of males by scrotal inunction of cadmium chloride. 7th International Congress on Planned Parenthood, 1963. J. Reprod. Fert. 5(3):461.

Kar, A. B., R. P. Das, and J. N. Karkun. 1959. Ovarian changes in prepuberal rats after treatment with cadmium chloride. Acta Biol. et Med. Germ. 3:372-399. (Biol. Abst. 36:75714. 1961).

Kar, A. B., R. P. Das, and B. Mukirji. 1960. Prevention of cadmium-induced changes in the gonads of rat by zinc and selenium. A study in antagonism between metals in the biological system. Proc. Natl.

Inst. Sci. India. Sec. B:Biol. Sci. 25 (Suppl.):40-50. (Biol. Abst. 27:5231. 1962).

Kar, A. B., P. R. Desgupta, and R. P. Das. 1962. Effect of low dose of cadmium chloride on the genital organs and fertility of male rats. J. Sci. Indust. Res. 20 C (II). 322-326. (Biol. Abst. 39: 1952. 1962).

Kelley, G. E., L. S. Oslon, and V. Garwood. 1956. Afield evaluation of ascaricides in swine. Vet. Med. 51:97-101.

Kenaga, E. E. 1963. Commercial and experimental organic insecticides (1963 revision) Bull. Entomol. Soc. Amer. 9(2):67:103.

_____. 1965. Triphenyl tin compounds as insect reproduction inhibitors. J. Econ. Entomol. 58(1):4-8.

Kilgore, W. W. and R. R. Painter. 1962. The effect of 5-fluorouracil on the viability of house fly eggs. J. Econ. Entomol. 55(5): 710-712.

Knipling, E. F. 1955. Possibilities of insect control or eradication through the use of sexually sterile males. J. Econ. Entomol. 48 (4):459-462.

_____. 1959. Sterile male method of population control. Science 139(3380):902-904.

_____. 1960a. The eradication of screw-worm fly. Sci. Amer. 203 (4):54-61.

_____. 1960b. Use of insects for their own destruction. J. Econ. Entomol. 53(3):415-420.

_____. 1962. Potentialities and progress in the development of chemosterilants for insect control. J. Econ. Entomol. 55(5)782-786.

Konecky, M. S. and N. Mitlin. 1955. Chemical impairment of development in house flies. J. Econ. Entomol. 48(2):219-220.

LaBrecque, G. C. 1961. Studies with three alkylating agents as house fly sterilants. J. Econ. Entomol. 54(4):684-688.

_____. 1962a. Chemosterilants for the control of house flies. New approaches in pest control and eradication. Advances Chem. Ser. 41:42-46.

_____. 1962b. Chemosterilants, their future looks bright. Farm Chemicals 125(8):30-31.

LaBrecque, G. C. and H. K. Gouck. 1963. Compounds affecting fertility in adult house flies. J. Econ. Entomol. 56(4):476.

LaBrecque, G. C., P. H. Adcock, and C. N. Smith. 1960. Tests with compounds affecting house fly metabolism. J. Econ. Entomol. 53 (5):802-805.

LaBrecque, G. C., D. W. Meifert, and C. N. Smith. 1962a. Mating competitiveness of chemosterilized and normal male house flies. Science 136 (3514):388-389.

_____. 1962b. A field experiment in the control of house flies with chemosterilant biats. J. Econ. Entomol. 55(4):449-451.

Levine, N. D. and I. Ivens. 1954. Nematocidal screening tests of cadmium compounds against horse strongyle larvae. J. Parasitol. (Suppl.) 40:15.

Levine, N. D., V. Ivens, M. D. Kleckner, and J. K. Sonder. 1956. Nematocidal screening tests of organic phosphorus, nitrofuran, cadmium and other compounds against horse strongyle larvae in Vitro. Amer. J. Vet. Res. 17:117-120.

Lindquist, A. W. 1955. The use of gamma radiation for control or eradication of the screw-worm. J. Econ. Entomol. 48(4):467.

_____. 196la. New ways to control insects. Pest Control 29(6): 8, 11-12, 14, 16, 18-19, 36, 38, 40.

_____. 196lb. Chemicals to sterilize insects. J. Wash. Acad. Sci. 51(7):109-114.

Lindquist, D. A., L. J. Gozyeki, M. S. Mayer, A. L. Scales and T. B. Davich. 1964. Laboratory studies on sterilization of the boll weevil with apholate. J. Econ. Entomol. 57(5):745-750.

Mason, K. E., James O. Young, and James E. Brown. 1964. Effectiveness of selenium and zinc in protecting against cadmium-induced injury of the rat testis. 77th Session of the American Anatomists, Denver, 1964. Anat. Rec. 148(2):309.

Mawson, C. A., and M. I. Fischer. 1951. Content of the genital organs of the rat. Nature (London) 167:4256):859.

_____. 1953. Zinc and Carbonic anhydrase in human semen. Bioch. J. 55:696-699.

Meek. E. S. 1959. Cellular changes induced by cadmium in mouse testis and liver. Brit. J. Exptl. Pathol. 40:503-506.

Miesch, M. D., Jr. 1964. Ecological and physiological mechanisms influencing food finding in Blattaria. Ph. D. Thesis. Oklahoma State Univ., Stillwater, Oklahoma.

Mitlin, N. B. and A. M. Baroody. 1958a. The effect of some biologically active compounds on growth of house fly ovaries. J. Econ. Entomol. 51(3):384-385.

Mitlin, N. B. and A. M. Baroody. 1958b. Use of the house fly as a screening agent for tumor-inhibiting agents. Cancer Res. 18(6): 708-710.

Mitlin, N. B., B. A. Butt, and T. J. Shortino. 1957. Effct of mitotic poisons on house fly oviposition. Physiol. Zool. 30(2):133-136.

Mitlin, N. B., M. S. Konecky, and P. G. Piquett. 1954. The effect of folic acid antagonist on the house fly. J. Econ. Entomol. 47(5): 932-933.

Morgan, P. B. and G. C. LaBrecque. 1962. The effect of apholate on the ovarian development of house flies. J. Econ. Entomol. 55(5): 626-628.

_____. 1964. Effect of tepa and metepa on ovarian development of house flies. J. Econ. Entomol. 57(6) 896-899.

Morlan, H. B., E. M. McCray, Jr., and J. W. Kilpatrick. 1962. Field tests with sexuallv sterile males for control of Aedes aegypti. Mosquito News 22(3):295-300.

Muller, H. S. 1927. Artificial transmutation of the gene. Science 66:84-87.

Murvosh, C. M., R. F. Fye, and G. C. LaBrecque. 1964. Studies on the mating behavior of the house fly, Musca domestica L. Ohio J. Sci. 64(4) 264-271.

Murvosh, C. M., G. C. LaBrecque, and C. N. Smith. 1964. Effect of three chemosterilants on house fly longevity and sterility. J. Econ. Entomol. 57(1):89-93.

Nenyukov, D. V. and A. I. Tareeva. 1931. The non-protein nitrogen of insect blood; its variations with diet and arsenic poisoning (in Russian with summary in English). Bull. Plant Prot. Leningrad. 3(1):33-38. (Abst. Rev. Appl. Entomol. Ser. A, 20:196. 1932).

Painter, R. P. and W. W. Kilgore. 1964. Temporary and permanent sterilization of house flies with chemosterilants. J. Econ. Entomol. 57(1):154-157.

Parish, J. C. and B. W. Arthur. 1965. Chemosterilization of house flies fed certain ethylenimine derivitives. J. Econ. Entomol. 58(4) 699-702.

Parizek, J. 1957. The destructive effect of cadmium ion on testicular tissue and its prevention by zinc. J. Endocrinol. 15:56-63.

_____. 1960. Sterilization of male by cadmium salts. J. Reprod. Fert. 1:294-309.

_____. 1964. Vascular changes at sites of oestrogen biosynthesis produced by parenteral injection of cadmium salts: The destruction of placenta by cadmium salts. J. Reprod. Fert. 7:263.

Parizek, J. 1965. The peculiar toxicity of cadmium during pregnancy. An experimental toxemia of pregnancy induced by cadmium salts. J. Reprod. Fert. 9:111-112.

Parizek, J. and Z. Zahor. 1956. Effect of cadmium salts on testicular tissue. Nature (London) 177:1036.

Patton, R. L. 1963. Introductory insect physiology. Phila. London. Saunders. p. 154-187.

Peet, C. H. and A. G. Grady. 1928. Studies in insecticidal activity. I. Testing insecticides against flies. J. Econ. Entomol. 21(4): 612-617.

Peterson, A. 1959. Entomological techniques--How to work with insects. Edwards Bros. Inc., Ann Arbor, Michigan. 455 p.

Pickett, A. D. and N. A. Patterson. 1963. Arsenates: Effect on fecundity in some Diptera. Science 140:493-494.

Piquett, P. G. and J. C. Keller. 1962. A screening method for chemosterilants of the house fly. J. Econ. Entomol. 55(2):261-262.

Plapp, F. W., Jr., W. S. Bigley, G. A. Chapman, and G. W. Eddy. 1962. Metabolism of methaphoxide in mosquitoes, house flies, and mice. J. Econ. Entomol. 55(5):607-613.

Powell, G. W., W. J. Miller, J. D. Morton, and C. M. Clifton. 1964. Influence of dietary cadmium level and supplemental zinc on cadmium toxicity in bovine. J. Nutr. 84(4):205-214.

Richardson, H. H. 1932. An efficient medium for rearing house flies throughout the year. Science 76:350-351.

Runner, G. A. 1916. Effects of Rontgen rays on the tobacco, or cigarette beetle and the results of experiments with a new form of Rontgen tube. J. Agr. Res. 6(11):383-388.

Schmidt, C. H., D. A. Dame, and D. E. Weidhaas. 1964. Radiosterilization vs. chemosterilization in house flies and mosquitoes. J. Econ. Entomol. 57(5):753-756.

Shaw, J. G. and M. Sanchez Riviello. 1962. Sterility in the Mexican fruit fly caused by chemicals. Science 137:754-755.

_____. 1965. Effectiveness of tepa-sterilized Mexican fruit flies released in mango grove. J. Econ. Entomol. 58(1):26-28.

Simkover, H. G. 1964. 2-Imidazolidinone as an insect growth inhibitor and chemosterilant. J. Econ. Entomol. 57(4):574-579.

Smith, C. N. 1963. Chemosterilants as a potential weapon for insect control. New approaches to pest control and eradication. Advances Chem. Ser. 41:36-41.

Smith, C. S., G. C. LaBrecque, and A. B. Borkovec. 1954. Insect chemosterilants. Ann. Rev. Entomol. 9:269-284.

Smith, F. F., A. L. Boswell, and T. J. Henneberry. 1965. Chemosterilant treatment of two greenhouse spider mites. J. Econ. Entomol. 58(1):98-103.

Smith, J. P., J. C. Smith, and A. J. MacCall. 1960. Chronic poisoning from cadmium fume. J. Pathol. Bacteriol. 80:287-296.

Smith, P. K., M. V. Nadkarni, E. G. Trams, and Clarke Davison. 1958. Distribution and fate of alkylating agents. Ann. New York Acad. Sci. 68:834-850.

Supple, W. C. 1961. Production of zinc deficiency in turkey poults by dietary cadmium. Poultry Sci. 40(3):827-828.

Thorpe, D. R. and G. W. Ware. 1963. Nitrofurans as chemosterilants of stored grain insects. J. Econ. Entomol. 56(3):404-407.

Wallace, B. 1951. Dominant lethals and sex linked lethals induced by nitrogen mustard. Genetics 36:364-373.

Weidhaas, D. E. 1962. Chemical sterilization of mosquitoes. Nature 195:786-787.

Weidhaas, D. E. and C. H. Schmidt. 1963. Mating ability of male mosquitoes, Aedes aegypti L., sterilized chemically or by gamma radiation. Mosquito News 23(1):32-34.

Weidhaas, D. E., C. H. Schmidt, and E. L. Seabrook. 1962. Field studies on the release of sterile males for the control of Anopheles quadrimaculatus. Mosquito News 22(3):283-291.

Weidhaas, D. E., H. R. Ford, J. B. Gahan, and C. N. Smith. 1961. Preliminary observations on chemosterilization of mosquitoes. New Jersey Mosq. Extermin. Ass. Proc. 48:106-109.

Wilson, R. H., F. De Eds, and Levin J. Cox, Jr. 1941. The effect of continued cadmium feeding. J. Pharmacol. 71:222.

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