EXPERIENCE during the war demonstrated that we must concern ourselves with insect problems throughout the world, especially the control of insects that affect man.

Hundreds of species of insects, ticks, and mites annoy man. But of far greater importance is that they transmit dangerous diseases. During the war, when our men and women were stationed all over the world, we had to fight lice, which carry louse-borne typhus and relapsing fever; mosquitoes, vectors of malaria, filariasis, dengue fever, yellow fever, and encephalitis; flies, transmitters of typhoid, dysentery, and cholera; fleas, which spread plague and murine typhus; mites, carriers of a disease known as tsutsugamushi or scrub typhus; and ticks, which carry tularemia and spotted and relapsing fevers. There are other important disease carriers among the insects and arachnids (ticks and mites), but the ones mentioned are all of vital importance throughout the world, particularly in this age of fast and complicated transportation. All of them occur in this country. Fortunately, most of the diseases I listed are not present here, although malaria, encephalitis, relapsing fever, spotted fever, tularemia and murine typhus, and certain fly-borne diseases are a problem in the United States.

As a result of the research by entomologists, chemists, and engineers, new insecticides and more effective control methods were developed for every important pest that affects man’s health. The Army, Navy, United States Public Health Service, Tennessee Valley Authority, Rockefeller Foundation, National Defense Research Committee, and various other agencies and industrial concerns have made valuable contributions. The advances that have resulted will make this country and other parts of the world healthier and more pleasant places in which to live. They will
also be a tremendous factor in the economic development of many areas that are now handicapped because of insects and insect-borne diseases.

Among the thousands of chemicals tested by the entomologists, one material, DDT, proved outstanding. Most of my discussion is devoted to DDT, but other materials have been found useful for certain purposes, and studies on a number of promising insecticides are under way in efforts to determine their full potentialities.

The body louse (Pediculus humanus corporis Deg.) carries the dreaded typhus disease; often it is found in the clothing of destitute peoples, hidden in the seams and folds. Although a common and important parasite of man through the ages, control methods until recently were generally ineffective or unsatisfactory.

A colony of body lice was maintained under the direction of G. H. Culpepper in the Bureau of Entomology and Plant Quarantine Laboratory at Orlando, Fla. Human subjects, serving as guinea pigs, fed the lice and allowed themselves to be infested in order to test new insecticides. R. C. Bushland, Gaines W. Eddy, and associates in the same laboratory found that DDT was many times more effective than the best of the other materials known at that time. One ounce of a powder containing 10 percent of DDT, dusted on the inside of the underwear, killed all lice present at the time of treatment and killed any lice that hatched from eggs or that crawled on the person as long as a month after treatment.

Even though DDT in powder form was very good, research was continued in an effort to find even more effective ways to use the material. When clothing was dipped into a dry-cleaning solution (Stoddard solvent) containing from 1 to 2 percent of DDT, and all excess liquid wrung from the garments, Howard A. Jones, chemist, found that the treatment would prevent lice from living in the clothes for many months and it even continued to kill lice after four to six washings. A water-emulsion preparation containing 1 to 2 percent of DDT was also developed. This was made from a concentrate consisting of 25 percent of DDT, 65 percent of xylene, and 10 percent of Triton X-100.

After the value of DDT for louse control was fully established, the chemical was recommended for use by the armed services. The Army then developed simple methods of treating large numbers of people by using ordinary dust guns. The chemical has since been used in many parts of the world. The Army in Naples and the Rockefeller Foundation in Mexico demonstrated that typhus epidemics can be stopped almost immediately after the people are deloused. As a result, louse-borne typhus is now one of the diseases of man that can be easily and quickly brought under control; now we can hope that this disease, which has killed more people than all wars, will eventually be eradicated from the earth.

The head louse (Pediculus humanus humanus L.) is closely related
to the body louse. Its habits are different, however, in that the head louse lives in the hair of the head instead of in the clothing. It is common throughout the world and is a problem of considerable importance in this country, especially among school children.

DDT powder dusted in the hair is effective in controlling the insects, but a powder is somewhat objectionable. Consequently, several liquid preparations containing DDT were developed by Dr. Eddy. The formula most widely used by the Army, which was known as the NBIN concentrate, consisted of 68 percent of benzyl benzoate, 6 percent of DDT, 12 percent of benzocaine (ethyl p-aminobenzoate), and 14 percent of a suitable wetting agent that makes the solution mix with water. One part of the concentrate must be diluted with 5 parts of water before it is applied. The resulting solution, which then contains 1 percent of DDT, kills the lice and prevents infestations for at least 2 weeks. The eggs of the lice are not affected by DDT but are killed by the benzocaine present in the formula. The benzyl benzoate, which I shall mention again later, is used because it will control the human itch mite and is a solvent for DDT and benzocaine.

The crab louse (Phthirus pubis (L.)) is not a disease carrier, but is one of the annoying parasites that must be dealt with. It can also be readily brought under control with either the 10-percent DDT powder or with the NBIN solution. The powder must be dusted thoroughly on all hairy portions of the body, and on individuals having much body hair it should be dusted over the entire body. Because DDT will not kill the eggs or nits, a second treatment must be given from 7 to 10 days after the first. The NBIN concentrate must be diluted with 5 parts of water, as described for use against the head louse, before it is applied. The liquid formula, well applied, will control crab lice in one treatment.

The development of DDT for the control of mosquitoes is one of the most important of all advances in the field of medical entomology. The insecticide is effective against larvae and adults of both the Anopheles (malaria carriers) and culicines (pest mosquitoes and transmitters of other diseases).

In carrying out the extensive investigations that were necessary to study the various aspects of mosquito control, a large colony of a malaria mosquito (Anopheles quadrimaculatus Say) was reared under laboratory conditions in order that insects would be available for test purposes. Several thousand new materials and special preparations of promising chemicals have been tried against the larvae and adults in the laboratory, and the more effective compounds and formulas were tested in natural breeding places.

Paris green and oil (kerosene, Diesel, and fuel oils) were widely used before DDT became available for controlling larvae of the malaria mosquitoes. Oil was also the standard method of controlling the various
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_Culex, Aedes, Psorophora_, and related mosquitoes. One to 2 pounds of paris green per acre of water surface was generally needed for adequate anopheline larvae control. C. C. Deonier and assistants of the Orlando laboratory demonstrated that DDT in dust form (using 1 to 2 percent of DDT in talc) was more effective when applied at the rate of 1 pound to 20 acres. For routine treatment, however, DDT in dust form is recommended at the rate of 1 pound to 10 acres.

Furthermore, when dissolved in kerosene or fuel oil and properly applied, 1 quart of oil containing 5 percent of DDT was shown to be equally as effective as 20 to 25 gallons of oil that did not contain DDT. The great savings in cost of materials, transportation, and labor for the DDT treatments are therefore readily apparent. For routine control operations against various kinds of mosquitoes 5 quarts of a 1-percent DDT solution of fuel oil applied as a fine mist is recommended for each acre of breeding area. Ordinary garden-type pressure sprayers and even hand pressure sprayers have been found satisfactory for the small breeding areas. Where large areas involving hundreds of acres are to be treated, and if the DDT is not applied by means of airplanes, power units may be employed.

DDT may be used in ways other than dusts or oil solutions. The DDT emulsion concentrate already mentioned in connection with the control of lice was found useful in mosquito control. This concentrate (or several modifications of this formula) when diluted with water so that the finished spray will contain 1 percent or less of DDT was found to be a very effective and satisfactory treatment. The recommended dosage of 0.1 pound of DDT per acre meant that less than one-half pint of material had to be transported for each acre of larval breeding area.

Airplanes, formerly used extensively for applying paris green dusts, are very useful for applying DDT sprays. Good control of the _Anopheles_ and most of the other kinds of mosquito larvae can be obtained with 1 to 2 quarts of fuel oil containing 5 percent DDT per acre applied with special spray equipment.

Studies by the Tennessee Valley Authority, the armed services, and the Bureau of Entomology and Plant Quarantine have shown that excellent control of _Anopheles_ mosquito larvae can also be obtained with fine mist sprays by applying as little as one-half pint per acre when a 20-percent DDT solution is employed. This means that an airplane that can carry 1,000 pounds can treat 2,000 acres with one load.

DDT has provided new and strikingly effective means of controlling adult mosquitoes. There are three general methods of attack on adult mosquitoes with DDT. The methods were first investigated by A. W. Lindquist, J. B. Gahan, B. V. Travis, and others of the Orlando laboratory. First, and perhaps the most important, is the use of this insecticide as a residual or surface spray. Never before has an insecticide been em-
ployed in this way for controlling adult mosquitoes, although R. Wies-
mann of Switzerland had shown that flies could be controlled thus. The
spraying of the inside of buildings, under bridges, inside hollow logs, or
even the vegetation itself with DDT leaves a deposit of DDT that will
kill mosquitoes which rest in such places for weeks or even months later.

Many laboratory tests were run in 1943 with many types of DDT
sprays. Different rates of application were used on various surfaces. The
tests showed that some differences existed in regard to the effectiveness
of the DDT on different kinds of surfaces, but in general a single treat-
ment at the rate of 1 gallon of 5-percent spray for each 1,000 square
feet remained effective for many months. After the laboratory tests, field
experiments were run in Arkansas in 1943 and 1944. The inside walls
of barns, toilets, chicken houses, bridges, and other places where
Anopheles mosquitoes rest were treated with 5-percent DDT solutions.
Kerosene or the water emulsion already mentioned were tested. As long
as 5 months after one treatment there was a reduction of about 99 per-
cent in the number of mosquitoes resting in the buildings.

A mosquito cannot transmit malaria until about 2 weeks after it has
fed on a person having the disease. If the houses and other resting places
of mosquitoes in the vicinity of human habitations are treated, the mos-
quitos will be killed sometime during the 2-week period. This break in
the chain is the key to the success of DDT in the control of malaria and
other diseases transmitted by mosquitoes. It is sometimes difficult to
realize how important this one development is to people everywhere, but
the fact is that malaria and other important mosquito-borne diseases
cause more than 100 million cases of illness and many deaths each year.

Another new method of utilizing DDT involves spraying large areas
to kill the adult mosquitoes as well as the larvae. Airplane equipment
was used, and it was shown that adult mosquitoes as well as the larvae
could be controlled. When epidemics of mosquito-borne diseases occur,
this method permits immediate control of the disease by killing the
already infected mosquitoes in the area; the destruction of the larvae
prevents a rapid increase in the mosquito population.

Adult mosquitoes can also be controlled with equipment that can be
used on the ground. In fact, in the first tests with DDT for killing adult
mosquitoes outdoors, hand dusters and sprayers were used. Because of
the success of those early tests, investigations of various types of equip-
ment to disperse DDT fogs and sprays for mosquito control were under-
taken. V. K. LaMer of the National Defense Research Committee, work-
ing with Randall Latta, developed special fog machines, which are
proving effective and practical for controlling mosquitoes, sand flies,
gnats, and various other annoying insects.

A third way to use DDT against adult mosquitoes consists of sprays
and aerosols for use inside houses and other confined space to give im-
mediate but temporary control of the insects present. Pyrethrum has been widely used in household sprays. DDT added to such a spray was found to increase its killing power for flies and mosquitoes. Ordinary refined kerosene containing DDT and pyrethrum makes an effective space spray for mosquitoes and for general household use. The method is not to be confused with residual or surface application.

DDT was found useful in the pyrethrum aerosol bomb, which was developed by L. D. Goodhue and W. N. Sullivan. In order to add the 3-percent DDT to the Freon aerosol, the amount needed for general use, the formula had to be modified. After testing many preparations, the Orlando scientists and those at Beltsville developed formulas.

The common housefly carries filth and disease. Sanitary practices and the use of screens, sprays, and other methods give a fair degree of control against the insect. Too often, however, available control measures are not judiciously followed. Army and Navy personnel realized the danger of flies. Dysentery, a disease spread by flies, was a major problem in certain war theaters, and the presence of many flies lowered morale.

Fortunately DDT is a powerful weapon. Early in 1943, even before we had heard that Wiesmann of Switzerland had previously employed DDT residual treatments for fly control, Mr. Lindquist had shown DDT treatments to be effective for several months when tested under laboratory conditions. Practical tests at dairies and military establishments in Florida showed that a 5-percent DDT-kerosene spray, thoroughly applied at the rate of 1 gallon for each 1,000 square feet of surface, would reduce flies by more than 95 percent as long as 4 months after treatment. Since that time DDT has been widely employed in oil solutions, emulsions, wettable powders, and dusts. The amount of DDT to apply varies with the length of the fly season, climate, and the type of surface to be treated, but it is generally recommended that \( \frac{1}{2} \) to 3 ounces for each 1,000 square feet of surface be used in solutions containing from 1 to 5 percent of DDT.

The treatment may be applied with garden-type pressure sprayers or with power equipment. The surfaces where flies concentrate (such as garbage cans, animal houses, and so on) should be thoroughly covered. The spray should also be applied on the inside of the establishment that is to be protected. It is preferable to paint the doors and window screens, because spraying them would be wasteful. Although DDT is an excellent control for flies, it is recommended that sanitary practices, such as the elimination of breeding places, the disposal of garbage, and screening, be continued. DDT is slow in its action, and several hours' exposure is frequently required to kill flies. So, if the fly population is high, a reduction as high as 95 percent may leave enough flies to create a problem.

The use of DDT in conjunction with pyrethrum in sprays and the aerosol bomb has already been discussed. The pyrethrum is included
mainly to increase the speed of knock-down, but the DDT is the principal killing agent.

Fleas are usually considered an occasional or accidental pest of man. In this country this is largely true, but in many parts of the world many houses are infested with the human flea (*Pulex irritans* L.), and they are found in the clothing and on the body of man much as they occur on our pets. Bubonic plague and endemic typhus are caused by fleas.

Our researchers found that DDT is highly effective for controlling fleas both on the person and in buildings. As a spray it may be employed as a residual treatment (in a manner similar to that already described for flies and mosquitoes), but dusts containing 10-percent DDT are also recommended. The DDT dust or spray should be thoroughly applied to the floor and furnishings or to the infested soil. If possible, the source of the infestation should be determined and eliminated. If pets cause the trouble, as they generally do, they and their bedding should be treated with a suitable flea powder. DDT can be used safely on dogs, but it should not be used on cats. When infestations occur on the person, the clothing should be thoroughly dusted the same as for body lice.

DDT destroys fleas on rats. Early work on this problem was undertaken by the Bureau of Entomology and Plant Quarantine station at Savannah, Ga., and by the Menard, Tex., station in cooperation with the Texas State Board of Health. The United States Public Health Service has also studied the problem extensively. The studies indicate that it may be possible to control murine typhus, which is transmitted by the rat flea (*Xenopsylla cheopis* (Rothsch.)).

Bedbugs fortunately do not carry disease but they are common and widespread pests. They are easily and effectively controlled with DDT.

After the usual preliminary laboratory tests procedures, A. H. Madden of the Orlando laboratory treated the bedstead, springs, and heavily infested mattress of a bed with about 3 ounces of a 5-percent DDT spray. For a year after the treatment he tried to reinfest the bed with bugs from the laboratory colony, but the efforts were unsuccessful—all the bugs died within 48 hours. While such experiments were still in progress, thousands of beds in military establishments at Orlando were treated by the Army as an experiment. For at least 6 months after the treatment, not a single bedbug was found alive in the beds.

The small insects called sand flies in the United States include the *Culicoides*. They are commonly referred to as punkies or, because of their small size, no-see-ums. The true sand flies (*Phlebotomus*) are of little importance in this country, but in many parts of the world they are major pests, mainly because of certain diseases that they transmit.

DDT can be employed as a residual treatment applied to the inside of buildings, stone fences, screens, and other favorite resting places for controlling the true sand flies. The method of treatment is essentially
the same as for mosquitoes. The number of sand flies and punkies in this country can be reduced by the use of airplane sprays, fog machines, and by treating the screens and the inside of houses.

Pyrethrum is not a new insecticide, but some new uses for it have been found, and its toxicity to insects has been increased by combining it with materials that by themselves are not toxic—an action that is termed activation or synergism. In 1940 C. W. Eagleson, of the Dallas, Tex., laboratory of this Bureau demonstrated that sesame oil used in pyrethrum fly sprays greatly increased the activity of this insecticide.

Other materials have been developed for use in fly sprays and for other types of insecticide materials that contain pyrethrum. Among these is N-isobutylundecylenamide, which, when tested in combination with pyrethrum, was found to increase the effectiveness of the insecticides from 10 to 100 times. This development was the basis for the first louse powder recommended for use by the armed services. The powder, known as MYL formula, contained 0.2 percent of pyrethrins (the active principle of pyrethrum extract), 2 percent of N-isobutylundecylenamide, 2 percent of 2,4-dinitroanisole (for killing louse eggs), 0.25 percent of Phenol S (a pyrethrum stabilizer or antioxidant) in pyrophyllite dust.

The MYL powder, the most effective treatment known at the time, was widely used by the armed services for the control of lice attacking man, and as a general-purpose insecticide. Although it was replaced by DDT, the research leading to the development of the pyrethrum-synergist combination insect powder was important and further emphasizes the potential value of synergists for pyrethrum. A number of other promising synergists have been tested for possible use in fly sprays and other treatments involving the use of pyrethrum. Among these, two of the most effective are piperonyl cyclohexenone, and piperonyl butoxide.

Experiments with pyrethrum, even before DDT was available, had shown that this insecticide has good residual killing properties. Excellent control of bedbugs for several weeks after treatment was demonstrated by making residual treatments of pyrethrum sprays. The use of N-isobutylundecylenamide increased the activity of the residual treatment against this insect. Investigations also showed that pyrethrum applied as a residual treatment is effective against other insects including adult mosquitoes, houseflies, and cockroaches; and certain synergists greatly increase the effectiveness and lasting properties of such treatments.

**Benzene Hexachloride**

This material, investigated by the French and British before it was tested in this country, is equal to DDT in many respects. Research at Orlando in 1943 and 1944 showed that the crude product containing 12 percent of the gamma isomer (the gamma isomer is the most toxic
form of this material) was about as effective as DDT on body lice when used at a concentration of 10 percent in pyrophylUte. When applied as a residual spray against flies and mosquitoes, its properties resembled that of DDT, but it generally was more rapid in its action. It was also found to be quite effective as a mosquito larvicide but less so than DDT. E. R. McGovran, in work at Beltsville, found that the gamma isomer is actually about eight times more toxic than DDT to flies when used as a space spray.

The insecticide is effective against chiggers when dusted or sprayed on infested soil or vegetation. As little as 5 pounds to the acre of the crude material will give practically complete control of the mites for several weeks after treatment. Sulfur, which was formerly recommended for this purpose, requires at least 100 pounds an acre to produce the same results. DDT was found to be relatively ineffective.

Benzene hexachloride is also effective against fly maggots, for which DDT is generally unsatisfactory. When prepared as a benzene emulsion containing 0.1 to 0.25 percent of benzene hexachloride and sprayed on animal carcasses, it completely destroyed the maggots present.

These brief accounts of results with benzene hexachloride show that it is a potent insecticide. It has, however, an undesirable and persistent odor, a serious draw-back in controlling insect pests of man.

**Benzyl Benzoate and Other Mite Killers**

Among the most annoying pests of man in the United States are small mites (*Eutrombicula* and related genera), commonly known as chiggers or red bugs. The first or larval stage will attach itself to man in a manner somewhat similar to a tick and cause extreme local irritation and, sometimes, secondary infections. In certain parts of the world, especially in Burma and some of the Pacific islands, similar mites transmit a serious disease called tsutsugamushi disease.

Early in 1942 A. H. Madden, of the Orlando laboratory, investigated materials and methods of protecting individuals from chiggers. He found that dimethyl phthalate, one of the insect repellents, applied as a barrier about 1 inch wide to all openings in the clothing, was an effective treatment. The chemical was utilized effectively by our military personnel through further research by the United States of America Typhus Commission, United States Army. The only objection to dimethyl phthalate was its lack of persistence when treated clothing got wet. Dibutyl phthalate, first tested by the Australians, was also a good mite treatment, but results with this were somewhat erratic against the chiggers in this country.

Consequently, further research was undertaken at the request of the Typhus Commission of the Army to find more persistent materials.
F. M. Snyder, another colleague, tested more than 5,000 materials; among them he found a number of effective miticides. One of the most practical was a commercially available product, benzyl benzoate. Clothing dipped into a 5-percent water emulsion of benzyl benzoate gave complete protection when freshly treated and was effective even after two or three launderings. The treatment became standard.

A skin disease known as scabies and sometimes as 7-year itch is caused by the human itch mite (Scarcoptes scabiei Deg.). It is a common ailment, especially among school children; but under wartime conditions, when people are often closely crowded, epidemics may break out among adults. Various forms of sulfur have been used for it, without much success.

Benzyl benzoate was known to be a good treatment for scabies and was rather widely used in Europe even before the war. In the development of louse control preparations, as previously discussed, benzyl benzoate was included. The preparation, when diluted at the rate of one part of concentrate to five parts of water and thoroughly applied (1 to 3 ounces) to the entire body, has given complete control of the itch mite infestation in a single treatment. The treatment is indicated to be more effective than other types of preparations containing 10-percent benzyl benzoate possibly because the benzocaine aids in destroying the mites and eggs.

Ticks cause severe local irritation, and transmit certain diseases, among them relapsing fever and spotted fever. Methods of protecting the individual from ticks are not entirely satisfactory, but some progress has been made on this problem. H. O. Schroeder of the Orlando laboratory and C. N. Smith of the Savannah, Ga., laboratory found that clothing sprayed with dimethyl phthalate, Indalone, Rutgers 612, or benzyl benzoate at the rate of about 6 to 7 ounces per suit would provide almost complete protection from the "seed" ticks—the first stage. Against the nymphal stage, the control was about 90 percent, but only about 60 percent reduction in attachment was obtained against grown ticks.

**Other Promising Insecticides**

After the potentialities of DDT as an insecticide were fully recognized, chemists began to make related materials in an effort to find more effective insecticides. Although DDT is still outstanding, certain close relatives show some promise. TDE (1,1-dichloro-2,2-bis(p-chlorophenyl)ethane) was found to equal or perhaps slightly excel DDT against Anopheles larvae. It is less effective, however, against lice, flies, and mosquitoes.

Chemical 1068 is a recent material known only as 1068 (mixed isomers of C_{16}H_{6}Cl_{8}), which was developed by the Velsicol Corpora-
tion and first reported upon by W. C. Kearns and associates of the University of Illinois. In preliminary tests it proved more toxic than DDT to the body louse, *Anopheles* larvae, houseflies, adult mosquitoes, and certain household pests. This chemical shows great promise, but further practical tests under a variety of conditions must first be made and information as to its toxicological effects on man and animals must be obtained before its value can be fully established.

A chlorinated camphene (3956), developed by the Hercules Powder Co., warrants further consideration, because preliminary tests show it to equal DDT in effectiveness against the body louse; it approaches DDT in its toxicity to mosquito larvae and adults and to the housefly. It also shows promise for use against ticks and mites.

Sabadilla is an old insecticide and a plant product that is said to be used by natives in South America to control lice on man. It has recently been investigated by T. C. Allen of the University of Wisconsin, and methods of handling the product have been developed that increase its effectiveness. It is a powerful toxicant for flies and mosquitoes, according to tests made by Allen and by E. R. McGovran at Beltsville. It is also one of the more effective materials that have been tested against the body louse.

Chloromethyl-\(p\)-chlorophenylsulfone, known as Lausceto Neu, was one of the most effective insecticides used by the Germans. It was tested against several pests after the war. It was found to be a good insecticide, but less effective against lice, flies, and mosquitoes than DDT. It is, however, one of the best chemicals tested against louse eggs.

Hydroxypentamethylflavan, developed by E. I. du Pont de Nemours & Co., Inc., was found by W. G. Bruce and C. N. Smith of the Savannah laboratory to be an excellent chemical for controlling chiggers in the ground. In comparative tests it proved more effective than benzene hexachloride. Since it does not possess the disagreeable odor of the latter compound, it will no doubt be the preferred treatment.

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FOR FURTHER READING

Laboratory of the Bureau of Entomology and Plant Quarantine, Orlando, Fla.: *DDT and Other Insecticides and Repellents Developed for the Armed Forces*, U. S. D. A. Miscellaneous Publication 606, 1946.