

POTENTIAL OF ULTRAVIOLET RADIATION FOR CONTROL OF AMERICAN COCKROACH POPULATIONS

BY

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Populations of *Periplaneta americana* (L.) were exposed for 8-20 week periods in specially designed rooms to 254 nm UV at low intensity (50-115 ergs sec⁻¹cm⁻²), high intensity (160-220 ergs sec⁻¹cm⁻²), or to white light. The rooms contained tables and chairs to simulate occupied space, with food and water placed in positions exposed to UV radiation. 'General' irradiation (where the whole room was exposed to UV) at 115 ergs sec⁻¹cm⁻² and above was effective in producing high mortality in all stages except 8-10th instar nymphs and adults. "Hot-spots" irradiation (where UV lamps were placed behind table and chair harborages) produced high mortality only in 1st-3rd instar nymphs which would result in slower elimination of a population. Crude aggregation pheromone was not successful in holding cockroaches close to radiation sources or substantially increasing mortality under the conditions of the experiments.

Although the lethality of ultraviolet (UV) radiation to insects has been well reported (Bertholf, 1933, Wells & Hamilton, 1953, Henzlik, 1964, Beard, 1972, & Cohen *et al.*, 1975), no practical control programs using UV as a lethal agent have been developed to date. However, UV has been widely used for various collection and killing traps (Buttolph, 1955, Hollingsworth *et al.*, 1963, Zhigal'tseva *et al.*, 1966). A study by Wharton (1971) showed that UV radiation from germicidal lamps was lethal to nearly all stages of American cockroaches and repellent at least to males. Cohen *et al.* (1973, 1975) extended Wharton's study to include five species of cockroaches and also found 254 nm UV to be the most lethal wavelength. Gingrich (1973) demonstrated increasing avoidance responses to UV in germicidal lamps by American cockroaches in successive instars. However, since the above studies were done under laboratory conditions, questions still remained about potential practical application of UV radiation in insect control. It was the objective of this research to explore the potential for practical application of 254 nm UV radiation in controlling populations of *P. americana*.

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MATERIALS AND METHODS

Three basic approaches were taken to evaluate UV's effectiveness: 1) lighting a whole room with UV (Test 1), 2) placing UV lights close to the floor near cockroach harborages or runways (Test 2), and 3) placing cockroach aggregation pheromone near UV lights to enhance exposure to UV (Tests 3 and 4).

Experimental rooms

Three large plywood rooms (2.4 × 3.7 × 2.1 m) were constructed contiguously (in line) so that the three doors opened into a common vestibule. Each room had five fluorescent light fixtures (46 cm long), one of which was mounted in the center of each wall and ceiling. Additionally, the ceiling of each room was divided into three equal areas by the placement of two fluorescent fixtures (92 cm long) for white lighting only. The rooms were painted with white semigloss latex and were carefully caulked around all doors, cracks, and fixtures. Galvanized steel baffles (7.5 cm wide) were mounted on the perimeter of both the inside and outside of each door and were coated with vaseline to prevent cockroach entrance or escape. The heating and circulation vent to each room was framed, caulked, and screened to prevent cockroach escape.

Environmental controls

Room conditions were 31°-33° and 40%-80% RH. During periods of low ambient humidity, 2.5 cm wide cotton cloth wicks were extended from the ceiling to a water container on the floor, thereby raising the humidity by 5%-10%.

Light regimens were controlled by time clocks to approach conditions occurring in a room occupied only during the day. The "normal" or control room was on a 12-h light, 12-h dark cycle. The UV exposure rooms received 12 h of white light followed by 12 h of UV in order to approach anticipated practical usage. Two sources of UV radiation were used: high-intensity 85-W Hanovia mercury lamps¹⁾, or low-intensity 15-W germicidal lamps²⁾. Daytime white lighting was provided by 40-W cool-white lamps from the two fixtures on each ceiling. Measurements of 254 nm energy were made before and after each test by use of an IL600 photometer (International Light, Newburyport, MA), calibrated to give readings in ergs sec⁻¹cm⁻². Measurements were made at five specific floor locations and one top corner of each room and from these values a weighted average was determined for each room over the course of the test.

Harborages, food, and water

To simulate real room conditions, each room was provided with identical furnishings including one table (0.76 × 1.2 m) and two single-armed wooden

¹⁾ Hanovia Lamp Division, Newark, NJ, Lamp No. 88A-45, rated 10.4 W at 254 nm.

²⁾ Sylvania Lighting Center, Danvers, MA, Lamp No. G15T8 rated 3.3 W at 254 nm.

school chairs. Spaces under each table and chair were covered with heavy shelving paper to provide additional dark harborages within each furniture piece. Food consisted of Purina Lab Chow¹⁾ scattered throughout the room and 7-8, 200-ml water tubes with cotton plugs were placed around the room perimeter and near harborages.

Test animals

American cockroaches from laboratory cultures were separated into four groups prior to introduction into the rooms, namely: 1) adults (equal number of male and female), 2) large nymphs (8-10th instar), 3) medium nymphs (5-6th instar), and 4) small nymphs (2nd-3rd instar). Pre-introductory anesthesia consisted of exposure to 4° for 10-25 min depending on size. Numbers of cockroaches introduced varied from one test to another, although a constant ratio of small, medium, large nymphs and adults of 4:2:1.5:1 was maintained. Cockroaches were introduced during daylight hours and allowed at least 24 h to adjust to their new surroundings prior to receiving their first UV exposure. Any moribund or dead cockroaches were replaced prior to starting the test.

Aggregation pheromone as an adjunct

Aggregation pheromone was used in some tests in an attempt to increase UV exposure of cockroaches. The source of the pheromone was either fouled filter papers (Bell *et al.*, 1972) or a crude extract of fouled filter papers similar to that used by Ishii (1970). The extract was obtained by soaking fouled filter papers in petroleum ether followed by rotary vacuum evaporation of solvent and redissolution in 10 ml of hexane. Activity was verified according to the technique of Roth & Cohen (1973).

Test 1. Four hundred and twenty-five *P. americana* (50 adults) in the ratios, indicated previously, were released in each of the three test rooms. The average 254 nm intensity was 115 ergs sec⁻¹cm⁻² in the low intensity room and 220 ergs sec⁻¹cm⁻² in the high intensity room. The test ran for 20 weeks during which periodic observations were made on aggregations. At the end of the test, the entire population was harvested and the increase or decline in each segment of the population was noted.

Test 2. Fifty-one *P. americana* (six adults), in the instar ratios indicated previously, were introduced in each room after clipping tegmina for identification of all but the small instars (2-3rd). The test duration was 8 weeks during which dead individuals were removed every 2-3 days and mortality counts tallied for each of the four 2-week periods. One room was irradiated as in Test 1 with germicidal lamps yielding an average room intensity of 115 ergs sec⁻¹cm⁻². The second UV room had three germicidal lamps situated 46 cm above the floor in "hot spots" (areas behind tables and chairs frequented by cockroaches) while a 4th lamp was

¹⁾ A registered trademark of the Ralston-Purina Co., Kansas City, MO.

behind the table 92 cm above the floor. Average room intensity was only 50 ergs $\text{sec}^{-1}\text{cm}^{-2}$ although directly under the three lower lamps and the one higher lamp it was 1130 and 370 ergs $\text{sec}^{-1}\text{cm}^{-2}$, respectively.

Test 3. One hundred and two *P. americana* (twelve adults), in the instar ratios indicated earlier, were introduced for a period of 8 weeks after marking as in Test 2. Lighting was as in Test 2 with one "hot spots" room and one generally irradiated room. UV intensities in the "hot spots" room were 905 and 280 ergs $\text{sec}^{-1}\text{cm}^{-2}$ directly under the lamps 46 cm and 92 cm above the floor, respectively. Average room intensity was 75 ergs $\text{sec}^{-1}\text{cm}^{-2}$ in both rooms although light distribution was better in the generally irradiated room. Paper towels (28×35 cm) treated with 1 ml of crude aggregation pheromone in hexane were stapled to the wall below the lights in such a way that the bottom 7.5 cm overlapped onto the floor along cockroach runways. This was expected to lure cockroaches away from their traditional harborages and increase UV exposure. Mortality was assessed as in Test 2.

Test 4. One hundred and two *P. americana* (twelve adults), in instar ratios previously indicated, were introduced for an 8-week period after marking as in Test 2. The generally irradiated room utilized Hanovia lamps⁴ with a resultant increase in average 254 nm intensity to 160 ergs $\text{sec}^{-1}\text{cm}^{-2}$. The "hot spots" room displayed an average intensity of 70 ergs $\text{sec}^{-1}\text{cm}^{-2}$ while directly under the lamps 46 cm and 92 cm off the floor the intensities were 1160 and 280 ergs $\text{sec}^{-1}\text{cm}^{-2}$, respectively. Aggregation pheromone was supplied from two sources, filter papers (15×35 cm) from laboratory cultures and sprayed Kraft papers (plastic-backed, 15×35 cm). Placement of papers was the same except that the Kraft papers were sprayed on the plastic side, which was placed towards the wall to prevent UV exposure.

RESULTS

Test 1. Initially aggregations of 20-30 cockroaches (mostly 8-10th instar nymphs and adults) were formed in the upper corners of all rooms. Second - 6th instar nymphs tended to aggregate near or around the water tubes. Within 3 days, however, all aggregations had retreated to the furniture harborages except for two aggregations in the control room. The tremendous decline in population suffered by 2-3rd and 5-6th instars in both UV-exposure rooms is indicative of high mortality coupled with non-replacement by hatching and development of progeny (Table I). This suggests ultimate population elimination in spite of the increase in adult population (primarily due to maturation of 8-10th instars) in the germicidal room and only a slight decline in the Hanovia (high-intensity) room adult population (Table I).

Test 2. No aggregations were formed outside the harborages during the test other than one group of 2-3rd instars found around a control room water tube. The smaller population coupled with the marking procedure enabled collection of time-mortality data for each age group (Fig. 1). At 2 weeks, mortality in the "hot

TABLE I

Percent increase (+) or decrease (-) in cockroach populations of small, medium, large and adult instars after a 20-week exposure in experimental rooms to germicidal UV (115 ergs sec⁻¹cm⁻²), Hanovia UV (220 ergs sec⁻¹cm⁻²), or white light (control)

Size Group	No. Introduced	Room condition		
		Control	Germicidal	Hanovia
Small	200	+272	.96	.100
Medium	100	+586	.87	.99
Large	75	+183	.96	.97
Adults	50	+284	+206	.4
Total	425	+329	.70	.88

spots" and "general UV" rooms was about equal, but by the end of the test, mortality was higher in the "general UV" room. Mortality among 8-10th instars in the "hot spots" room was not much higher than that in the control room, suggesting their avoidance of or resistance to UV light.

Test 3. Several aggregations had formed on the pheromone-sprayed toweling in all rooms within a few hours after release. However, the aggregations in the UV rooms had largely dispersed after the first day except for a few 2-3rd instars which aggregated behind the toweling. Aggregations in the control room remained after the first day but moved behind the toweling. After the 1st week, only 2-3rd instars continued to aggregate behind the toweling in the control room. Also, 2-3rd and 8-10th instars rarely aggregated together, although 5-6th instars frequently aggregated with either group. As in other tests, 2-3rd instars were eliminated within 2 weeks in UV-irradiated rooms (Fig. 2). Total mortality was not significantly different between the two UV-exposure rooms over the test period.

Test 4. As in previous tests, 2-3rd instars were found around water tubes or fouled or pheromone-sprayed papers adjacent to the water tubes in all rooms. Such aggregations were rarely found in UV-irradiated rooms after the first or second day, although some 2-3rd instar aggregations persisted in the control room for the duration of the experiment. Fifth through 10th instars retreated to furniture harborages within a day or two. Fouled and pheromone-treated papers were not markedly different in their attractance to cockroaches. Second- and 3rd - instar mortality in UV-irradiated rooms was not complete during the first 2 weeks, perhaps because some aggregated behind water tubes away from the light source (Fig. 3). Mortality was predictably higher in the Hanovia than in the "hot spots" room. Interestingly, the first significant adult mortality was also witnessed in this test in the Hanovia (high-intensity) room.

DISCUSSION

Comparison of Figs 1-3 showed that general or localized UV irradiation of a room would eliminate 2-3rd instar nymphs from a population, while older instars

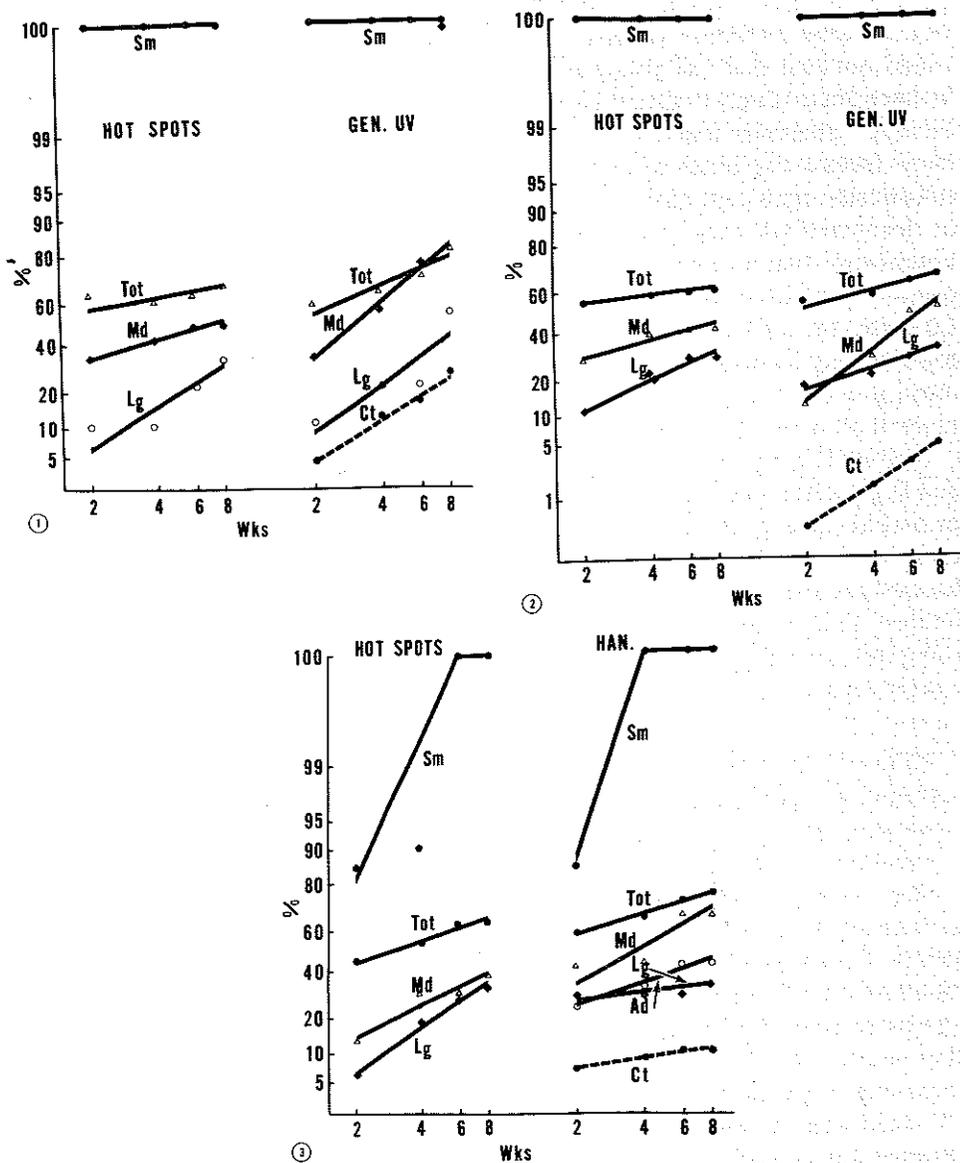


Fig. 1. Log/probability plots of mortality (%) in American cockroach population exposed in control rooms (white light), "hot spots" (\bar{x} = 50 ergs sec⁻¹cm⁻² of 254 nm UV), or general germicidal rooms (\bar{x} = 115 ergs sec⁻¹cm⁻² of 254 nm UV) for 8 weeks. Sm = small = 24, 2-3rd instars initially; Md = medium = 12, 5-6th instars initially; Lg = large = 9, 8-10th instars initially; adults numbered 6 initially; Tot = total mortality of all instars; Ct = total control mortality. Adult mortality insignificant. Fig. 2. UV intensity in "hot spots" and germicidal rooms \bar{x} = 75 ergs sec⁻¹cm⁻². Initial numbers of small; medium, large and adult instars were 48, 24, 18, and 12, respectively. Adult mortality insignificant. Fig. 3. UV intensity in "hot spots" room \bar{x} = 70 ergs sec⁻¹cm⁻², in Hanovia (HAN.) room 160 ergs sec⁻¹cm⁻². Ad = adult mortality. Initial numbers introduced were 48, 24, 18, and 12 of small, medium, large, and adult instars, respectively.

would suffer moderate to high mortality. Table I indicated that new progeny would not replenish the young instars of the population. However, cockroaches become increasingly resistant to UV with successive instars (Cohen *et al.*, 1973), thereby apparently explaining the high initial mortality of small nymphs while large instars exhibited a delayed and slow increase in mortality. Although statistically significant differences in mortality were not obtained between general or localized UV irradiation due to lack of replication, nevertheless, it is noteworthy that in nearly every case general UV exposure resulted in higher overall mortality among 5-10th instar cockroaches than localized UV irradiation. Likewise, the higher mortality caused by high-intensity UV lamps as compared to low-intensity lamps should be of obvious importance, although cost-effectiveness might preclude an increase in irradiation much above $115 \text{ ergs sec}^{-1} \text{ cm}^{-2}$ (near the upper limit of the low-intensity lamps under conditions of this test).

Aggregation behavior suggests further reasons for differences observed in small and large instar mortality. Small instars frequently aggregated around water tubes or on pheromone-treated papers and were therefore prone to UV exposure. This contrasted with the larger instars which usually stayed within the chair and table harborages and were less likely to receive UV exposure. It is perhaps of academic interest that 2-3rd and 8-10th instars did not aggregate together, which corroborates Ehrlich's theory (1943) that this is a natural mechanism to preclude cannibalism.

Although small nymphs were more likely to frequent areas treated with crude aggregation pheromone, mortality was not noticeably improved by its use. However, since UV irradiation quickly eliminates small nymphs from the population, it is difficult to assess its adjunctive value for their control. It appears certain, however, that large nymphs were not lured from their traditional harborages by the pheromone, regardless of whether the source was fouled filter papers or crude pheromone extracts. It would appear that the positive pheromone stimulus is more than overcome by negative tactile auditory, and visual stimuli, especially since the harborages themselves contain an abundance of natural pheromone and UV from germicidal lamps is known to be repellent to cockroaches (Wharton, 1971, Gingrich, 1973). An alternative explanation is that UV inactivates the pheromone, although aggregations around pheromone-treated papers in the control room were also very limited both in terms of occurrence and numbers of individuals involved. Under the conditions of this test, at least, use of aggregation pheromone would be of marginal value.

Individual behavior and appearance was also of interest. UV-exposed large nymphs lacked the waxy sheen of normal animals and the cuticle was often blackened (see Gingrich, 1975). Such nymphs also often exhibited limited, sporadic, and uncoordinated movements which could only be elicited by sharp prodding. It is suggested that damaged cuticular attachments of muscles as shown by Gingrich (1975a) in newly molted cockroaches, were a factor in this behavior.

UV light would appear to have potential application in integrated control

programs of food handling areas, hospitals, or animal rearing laboratories, where only limited chemical control methods may be applied. One approach would be to irradiate with UV for control of young instars while eliminating the UV-resistant older instars with insecticides. Once control was established further outbreaks should be precluded by continued UV irradiation. Background research to date strongly suggests the need and value of continued field testing to further establish the potential of UV as part of integrated cockroach control programs.

ZUSAMMENFASSUNG

LEISTUNGSFÄHIGKEIT VON UV - BESTRAHLUNG ZUR BEKÄMPFUNG VON POPULATIONEN DER AMERIKANISCHEN SCHABE

Populationen von *Periplaneta americana* (L.), die hinsichtlich ihrer Alterszusammensetzung (2.—3.; 5.—6.; 8.—10. und adultes Stadium) und der Anzahlen in jedem Stadium festgelegt waren, wurden für 8—20 Wochenperioden in speziell dafür entworfenen Räumen einer 254 nm UV-Bestrahlung mit geringer (50—115 erg sec⁻¹cm⁻²) oder hoher (160—220 erg sec⁻¹cm⁻²) Intensität oder weißem Licht (als Kontrolle) ausgesetzt. Die Räume enthielten Tische und Stühle, um bewohnten Raum mit natürlichen Zufluchtsstätten mit Nahrung und Wasser an Stellen, die der UV-Bestrahlung unterlagen, zu simulieren. Ganzraumbestrahlung mit 115 erg sec⁻¹cm⁻² und darüber erzeugte hohe Mortalität bei 1.—3. und 5.—6.-Larvenstadien, örtliche Bestrahlung (UV-Lampen hinter Tisch- und Stuhl-Zufluchtsstätten) dagegen nur beim 1.—3.-Stadium, was zu einer langsameren Ausrottung einer Population führen würde. Ungereinigtes Aggregationspheromon als Zusatz, um Schaben dicht an die UV-Quellen zu locken und sie hier zu halten, war offenbar unwirksam, da eben die Mortalität nicht signifikant zunahm. Dieses Versagen war in erster Linie auf die Konkurrenz mit der Fülle von natürlichem Pheromon, das von den gewohnten Zufluchtsstätten ausging, zurückzuführen, verbunden mit der dem UV-Licht innewohnenden Abschreckung. Dennoch darf man annehmen, daß UV-Bestrahlung einen bedeutsamen Wert für die Verhinderung eines Populationswachstums (durch Ausschalten junger Larvenstadien) besitzt, besonders dort, wo chemische Bekämpfung aus Gesundheits- und Sicherheitsgründen oder wegen gesetzlichen Einschränkungen nur begrenzt möglich ist.

We acknowledge the technical assistance of Mr. Charles D. Roche, Mr. Samuel H. Cohen and Dr. Louis M. Roth for suggestions, and all the people of the former Pioneering Research Lab that created a climate dedicated to scientific research.

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