SOME EFFECTS OF RADIANT ENERGY ON THE BEETLES, TRIBOLIUM CONFUSUM DUV., SITOPHILUS GRANARIUS (L), AND ACANTHOSCELIDES OBTECTUS (SAY)

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Oscar Taboada

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By

Oscar Taboada

AN ABSTRACT

Submitted to the School of Graduate Studies of Michigan State College of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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THESIS ABSTRACT

The purpose of this work was to investigate some effects of radiant energy on certain insects which infest stored products. Infrared, ultraviolet and x-rays, as well as accelerated electrons were used on the confused flour beetle. The granary weevil was subjected to infrared rays, ultraviolet rays and accelerated electrons and the common bean weevil was limited to only one test of accelerated electrons. The beetles were reared under laboratory conditions of 80° ± 2° F. and a relative humidity of about 66 percent. The manner of rearing was so arranged that a constant supply of adult beetles of a known age were produced.

The infrared energy tests indicated that both temperature and exposure time were important factors in obtaining effective results. A temperature of at least 138° F. and a maximum exposure time of 2.5 minutes was necessary to obtain lethal effects on the confused flour beetle, granary weevil and their eggs. The ultraviolet tests gave no clear indication of its effects on the beetles since the type of lamp used emitted four fifths of its energy as infrared energy.

No exposure time in the x-ray tests showed any effects on the confused flour beetle. After the tests the adults were not sterile and were able to reproduce normal progeny. However, the results of the accelerated electron tests were more promising. A dose of at least 500,000 rep would be necessary to kill completely a mixed population of adults and larvae of the con-

fused flour beetle, the adults of the granary weevil and common bean weevil. A dose of 10,000 rep prevented the eggs of the confused flour beetle and the granary weevil from hatching. This same dose sterilized the adult granary weevil, the adult confused flour beetle and prevented the larvae of the flour beetle, after reaching the adult stage, from reproducing.

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I INTRODUCTION

Insect pests of stored grain and milled cereal products have been a problem to man ever since he learned to keep grain for food or seed. Many of the insect pests of grains of ancient times are prevalent today and have been distributed throughout the world through commerce. Cotton (6) states,

> "Evidence indicates that many of the insects that trouble stores of grain today were prevalent in ancient times. Supplies of grain placed in the tombs of ancient Egyptians have been found destroyed by the same species with which we are familiar."

Experts have estimated that the annual insect damage in the United States, is about four billion dollars and about one fourth of this sum is caused by insect pests of grain in stored grain and grain products. According to Cotton (6), methods used to combat the pests of stored products, and their feeding activities cause an annual cost of at least $300,000,000 in this country.

Many methods have been used and are being used to control insects. Some of these methods include the use of dusts, sprays, fumigants and heat. Some of the chemicals which are now widely used for the control of insects may have a residue so high as to be poisonous when used on grain products used as food. An ideal method to control insects without any residual effect would be the use of radiant energy. Before a method is used to any degree of success in the field, a series of extensive experiments must be performed in the laboratory. Some methods return to the laboratory for further experimentation and others remain in

the laboratory for long periods of time before they can be put to practice.

The use of radiant energy for the control of insects has been limited, and, unfortunately, much of this work has remained in the experimental stages. With this in mind, this paper deals with tests conducted with radiant energy on insects. An infrared lamp, an ultraviolet lamp, x-ray machines and a Van de Graaff accelerated electron generator were used as sources of energy for the tests. The insects used in the tests were the granary weevil, Sitophilus granarius L., which is a serious pest of stored grain, the confused flour beetle, Tribolium confusum Duval, which is a serious pest of flour mills or where milled grain is stored, and the common bean weevil, Acanthoscelides obtectus (Say), which infests various kinds of beans in the field and in storage.

II REVIEW OF LITERATURE

Rearing

Pyenson and Menusan (17) reared cultures of bean weevils of known ages by placing 500 - 1000 eggs, at weekly intervals, in pint jars containing red kidney beans. The eggs were taken from special oviposition cages made of pint cardboard boxes with the bottoms replaced by a 20 - mesh wire screening. This allowed the eggs from the adults to drop through to a collecting tray. A few beans in the cage provided a stimulus for oviposition. The cages and the culture jars were kept in an incubator at 25° C and 75 - 80% R. H. The time taken for development from egg to egg stage was about 40 days.

Lindgren (12) used large-mouthed gallon capacity glass containers filled about one third full of wheat of a moisture content of 14%. He obtained grain weevils of a known age by placing adults in the wheat jars to oviposit for three or four days. Then the adults were sifted through a No. 10 wire sieve and placed in another jar of wheat. Adults from the eggs appeared in about five weeks when the jars were held at a temperature of 23° to 26° C. Robinson (19) did not consider age or temperature in rearing grain weevils for his experiments.

Collins (5) maintained a large colony of Tribolium confusum of known ages in an air-circulated incubator at 78° - 83° F. and a relative humidity of 69%. He established the colony by placing adult beetles to oviposit in flour jars. After four days the

beetles were sifted out with a No. 20 mesh sieve, and placed in another jar. Working with the same species, Park (15) used a mechanical device to separate the beetles. The automatic shaker consisted of a motor and a sieve connected to a belt wheel. The beetles were retained in the sieve and the flour fell through to a collecting tray.

Infrared

Headlee (10) testing a 260W incandescent therapeutic lamp, a white light Mazda lamp and a 450W quartz - mercury lamp, all at the same distance, found that the therapeutic lamp killed American roaches almost instantly. The other two lamps did not have the same promptness. He concluded that no matter the source, the insects were not killed until a lethal heat was reached. Wigglesworth (25) gives the fatal temperature for small insects at about 110 F. Cotton (6) states that a temperature of 140°F. for 10 minutes is fatal to all grain insects.

Blazer (3) using hot air blasts of 140°F. for 30 minutes did not get a satisfactory kill on several insects. The treatment raised the temperature of the rice to 122°F. only, which he stated was not high enough to kill the insects. Dean (7) obtained better results when he increased the temperature of a room in a flour mill to 133.5°F. All insects found in the open, and down to three inches in depth of flour sacks, were killed.

Ultraviolet

Ray (18) conducted tests on the eggs of Melanoplus differentialis, with an air-cooled Quartz mercury - vapor lamp at 110-115 V.A.C. and 3.7 amps. at 15 cm. distance. The irradiations varied from 5 seconds to 4 hours. There was no noticeable effect at 5 seconds, but effectiveness was obtained at 1 minute exposure by having 18% hatch only, and no egg hatch at 15 minutes exposure.

MacLeod (13) reported that the adults of the bean weevil, Ascanthocelides obtectus, showed no effects from light of wavelengths less than 3126A. However, the eggs and first instars were killed.

Ellis and Wells (9) exposed the eggs of the Ascaris roundworms to ultraviolet rays from six to eight hours. The test did not produce immediate kill.

X-Ray

Experimenting on the fruit flies, Dacus cucurbitae Cog., and D. dorsalis Hendel, Koidsumi (11) reported that these insects can be killed by certain amounts of x-ray radiations in all stages of their life cycle. Using a Coolidge tube without filtration, he showed, as Mavor (14) showed for Drosophila, that the resistance of the insects to x-rays becomes greater as development proceeds from egg to full grown larva.

Whiting (24) made studies on the effects of x-rays on

the parasitic wasp, Habrobracon juglans, Ashmead, Dunning (8) working with the same species, reported that the loss of fertility and viability of individuals receiving the maximum dosage of 8000r. units was transmitted for several generations. However, he was unable to determine whether this loss of fertility was due to less eggs laid, or failure of the eggs to hatch, since the number of eggs laid was not counted.

Electrons

Trump, Van de Graaff (22) and Burrill (4) were among the first to develop equipment for accelerated electrons. Proctor and Goldblith (16) were among the first investigators to treat various food products with accelerated electrons.

Probably the first to report on the use of electrons on insects is Yeomens (26), who reports on the use of a capacitron treatment on various insects. The electron dosages ranged from 180,000 rep to 900,000 rep. He obtained 100% kill from a dose of 800,000 rep on mosquito eggs. The same results were obtained from a dose of 310,000 rep on adult confused flour beetles, 48 hours after treatment. A higher dose was required to get 100% kill of adult bean weevils.

III PROCEDURES IN REARING AND HANDLING THE TEST INSECTS

Two incubators, as shown in Fig. 1 and 2, in which a relatively constant temperature could be maintained, were used to rear the confused flour beetle, Tribolium confusum Duval., the granary weevil, Sitophilus granarius L., and the common bean weevil, Ascanthoscelides obtectus (Say). The same incubators were used as recovery cabinets. Various investigators have found that a temperature of about 80°F. and a relative humidity of around 75% shortens the life cycles of most of the pests of stored products. The temperature in the incubators was set at 80°F. A periodic check by a thermograph (Fig. 2) indicated fluctuations between 78° - 82°F. Wexler and Brombacker (20) suggest the use of sodium chloride solution made up as a slushy mixture, to produce a relative humidity of around 75%. A commercial salt composed of 99.5 percent sodium chloride and 0.5 percent tri-calcium phosphate was readily available. The salt was used to make up the salt solutions and was mixed in two large enamel pans. A pan was placed at the bottom of each incubator. Every two or three days water had to be added to each pan to replenish the loss of water and thereby keep the salt at a constant slushy mixture.

At the onset of the project, the incubators were kept in a refrigerated room, but later were moved to a laboratory. It was found that the humidity was not being controlled in the incubators. An investigation revealed that the humidity in

the refrigerated room was about 97 percent, which more than likely, caused the abnormal humidity in the incubators. The humidity in the laboratory, during the winter months of 1952 - 53, was around 35 percent, and relatively higher during the following spring. The humidity readings made for the laboratory and the incubators were recorded from a wall-type hygrometer. However, towards the end of the rearing and testing project, a recording hygrothermograph was used to record the temperature and the relative humidity of the incubators. The recording was for a period of two weeks, and the readings indicated that the temperature fluctuated between 78°- 82°F. and the relative humidity was around 66 percent.

According to Shepard (20) and others, food materials that have been in storage are too low in moisture content to rear insects successfully. Whole wheat flour of fine grind, Cornell 595 wheat and Michigan navy beans were used as culture media for the confused flour beetle, the granary weevil and the common bean weevil respectively. A successful attempt was made to increase the moisture content of the materials as follows. The wheat and beans were spread over an area 30 x 18 inches and one layer in depth on pieces of paper. The flour was spread over a smaller area in boxes and one eighth of an inch in depth. The samples were placed in the refrigerated room previously mentioned. The moisture content of the wheat before being placed in the room was about 10 percent. At the end of three weeks the moisture in the wheat had increased to

Fig. 1. General view of incubators used for rearing the test insects.

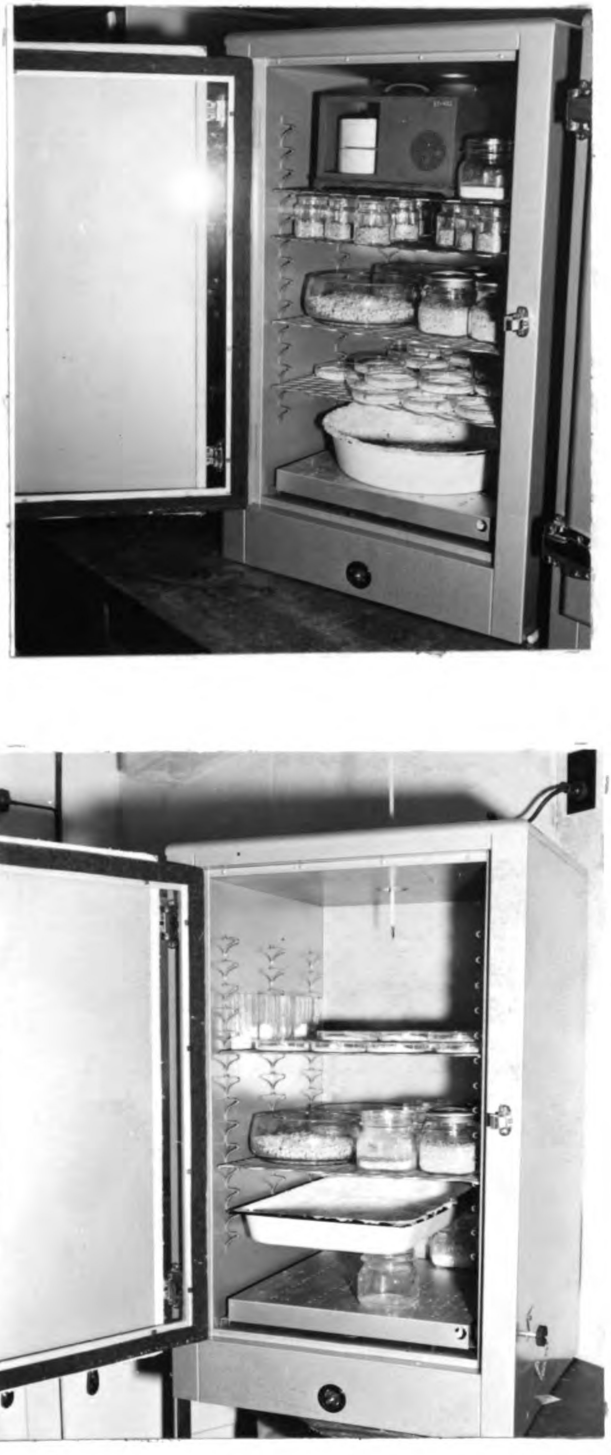

Fig. 2. Interior view of incubators used for rearing the test insects, and as recovery cabinets.

about 16 percent. Using the wheat as an index, it was assumed that the other materials had had an increase in moisture also. Then the practice was established whereby the food materials were placed in the refrigerated room three weeks before being used.

Four hundred adult confused flour beetles were obtained as a breeding colony. Basically, the procedure used by Collins (5) was employed, but with certain modifications. Flour was put in pint jars to a depth of about an inch. One hundred beetles were placed in each of four jars which were marked A_1, A_2, A_3, and A_4. The date, which was September 29, 1952, for the first series of jars, was also recorded on each jar. A week after the adults had been placed in the jars to oviposit were sifted from the flour. Beetles from jar A_1 were placed in jar B_1 and beetles from jar A_2 were placed in jar B_2 etc. The jars containing the flour and the eggs were returned to the cabinet along with the next jars that contained the adult beetles. The same procedure was used at weekly intervals and each time the date was recorded and a successive letter of the alphabet was used. By the mentioned method described, a rough estimate of the age of the adults was made and the use of old adults was avoided. A twenty-mesh sieve was used to separate the beetles from the flour (Figs. 3 & 5). The sieve was held in a vertical position over the jar and a camel's hair brush was used to push the beetles in the jar. Approximately thirty-nine days after incubation, beetles from series A jars appeared. Some of the new adult beetles were used to

Fig. 3. Background; constant temperature box used to transport insects between buildings and to the Upjohn Co., Kalamazoo, Michigan.

Foreground; at left is a ringstand with funnel used to place beetles in recovery vials. At the extreme right is an oviposition cage for the common bean weevils, and in the center are the sieves used to separate the test insects.

Fig. 4. Shown are; Petri dish carriers, recovery vial, Petri dish sample, breeding jars and lids.

maintain the breeding stock while the old breeding adults were discarded.

Essentially the same method was employed with the granary weevils, except that an eight-mesh screen (Figs. 3 & 6) was used to separate the weevils. The screen retained the wheat and the weevils would fall through to a glass vessel (Fig. 6). The vessel was held in a vertical position and the weevils were brushed off into the jar. Unlike the confused flour beetle, the granary weevil is able to crawl up the side of glass. This required the use of cloth covers for the jars in order to keep the weevils confined. A large colony of the granary weevil and the confused flour beetle was soon built up, however, the establishment of the common bean weevil colony proved more difficult. The same marking procedure used for the confused flour beetle and the granary weevil was used for the bean weevil. Small glass jars and four oviposition cages (Fig. 3), as that used by Pyenson and Menusan (17), were used. The eggs were collected in a petri dish at the botton of each cage. At weekly intervals, the eggs were reclaimed and placed in the jars which contained beans. According to Back (1), the usual length of life of the common bean weevil is about two weeks during the active season. It was noted that death occurred in about a week among the newly emerged adults. An investigation was made to find the cause of such high mortality, but unfortunately, the cause was not found. Nevertheless, the colony, although weak, was maintained and enough adults were obtained to use in at

least one test (Accelerated Electron Test 7).

The insects were handled carefully at all times and no injured insects were used in the tests. In preparing test samples of the confused flour beetle, a 20 - mesh sieve was used. The flour from the breeding jars was sifted, with the adults remaining in the sieve. A card was placed in the sieve, and after a large number of beetles had climbed on the card, it was held over an empty petri dish. The beetles were counted as they were brushed off into the dish (Fig. 5). When the desired number was completed the card was placed back in the sieve while a recount was made of the beetles in the dish. The beetles were transferred from the petri dishes to flour samples to be used. This method of handling was repeated according to the number of samples to be treated. After each test, the beetles, where flour was used were sifted out, and the live ones were brushed off from the sieve into a vial containing fresh flour. A separate vial was used for each sample and was marked with the appropriate sample number. The use of vials, because of their smallness, provided easier handling in mortality counts and provided a means to conserve space in the incubators.

In preparing test samples of the granary weevil, an eight-mesh sieve was used. The wheat from the stock jars was put in the sieve and with a few gentle taps on the sieve the weevils would fall through to a large glass vessel (Fig. 6). The weevils were counted as they were brushed into small jars. When

Fig. 5. Apparatus used to count beetles.

the desired number was achieved the jar was immediately covered with a cloth in order to keep the weevils in the jar. Upon the completion of the sample counts, each jar was uncovered long enough to add the desired amount of wheat. During the tests the contents of each sample was placed in a petri dish just long enough for the treatment to be performed, then the weevils were placed in a jar. When all the testing was finished the weevils were sifted out, a mortality count was made and the weevils were placed in fresh wheat. The same method, sieve and jar size used for the granary weevil tests was used for the common bean weevil test.

Whenever an egg test was made of the confused flour beetle and the granary weevil, the adults were placed in the samples of food materials to oviposit for at least three days (except accelerated Electron Test 1 which was 2½ days). The tests, except Infrared Test 3, were made on both the adults and the eggs in the same sample. Immediately after the test, the adults were separated from the samples and placed in fresh material in the incubators. The samples containing the eggs were also placed back in the incubators and observations as to number of emerging adults were recorded.

Most of the insects used for the tests were about one month old. None were over a month and one half old, nor were they used more than once. However, before enough confused flour beetles were produced from the breeding colony for the tests, adults from a standing culture were used for the in-

Fig. 6. Apparatus and method used to prepare weevils for the tests.

frared tests. The amounts of food materials used, observations, special handling and the number of samples, including check samples, will be discussed in the tests.

IV TESTING EQUIPMENT AND PROCEDURE

Only a brief description of the equipment and dosages used will be presented. For a more detailed discussion of this subject, the reader is referred to the writer's colleague, Baker (2).

Infrared

A series of six tests was conducted and the major equipment used in the tests is shown in Fig. 7. A type R-40/250 - watt lamp was used as a source of energy. The lamp height for all tests was measured from the bottom of the lamp to the bottom of the petri dish. The lamp voltage was maintained at 117 volts, unless otherwise indicated. There were slight differences in the procedure of each test.

Test 1. The test was in two parts and was of a preliminary nature. The radiant energy was changed by varying the voltage to the lamp with a variable transformer, Fig. 7. A type DW-60 radiation meter was used to measure the energy. The various levels of infrared energy used and data collected for the test are shown in Table 1. Twenty adult confused floured beetles placed in each of twenty 9-cm plain petri dishes were used for the first part of the test and twenty-five adults placed in each of 5 petri dishes were used for the second part of the test.

Test 2. Twenty adult confused beetles were placed in each

Fig. 7. Equipment used for the infrared tests.
From left to right; variable transformer, inclined rod with a thermocouple, stop watch and a DW-60 radiation meter. In the center is the type R-40/250 W. lamp.

of 25 petri dishes. In addition a petri dish sample with the same number of beetles was used as a check. During the test the petri dish containing the insects was set on an aluminum foil insulated block. The energy was measured with a DW-60 radiation meter and the lamp height was measured from the bottom of the petri dish to the bottom of the 250 W type R-40 infrared bulb. The data collected for this test is shown in Table 2, and the apparatus used is shown in Fig. 7.

Test 3. This test was designed to determine the effects of infrared energy on confused flour beetle eggs. Fifty adult beetles were placed in each of 30 petri dishes containing 20 grams of whole wheat flour, which was sifted through a 20-mesh sieve before being used. The adults were left to oviposit in the samples for three and one half days. During this 76 hour period all the samples were kept in an incubator. Just before the testing period the adults were removed from the flour. The eggs and flour in each of the 25 samples were treated with various amounts of infrared energy. The flour in each sample was leveled evenly so that the depth of the flour was about one-fourth of an inch. Five samples were used as checks. The lamp was turned off at the end of each exposure time and the thermocouple attached to the inclined rod (Fig. 7) was inserted into the flour. The thermocouple junction touched the bottom of the petri dish and the readings, in millivolts, were measured in the Leeds and Northrup potentiometer (Fig. 8). After the testing period the samples were put back in an incubator for

about 36 days. The number of eggs hatched after incubation and other data for this test are shown in Table 3.

Test 4. This test was designed to determine the effects of infrared energy on adult confused flour beetles covered with flour. Twenty adult beetles were placed in each of thirty petri dishes containing 20 grams of whole wheat flour, which was sifted through a 20-mesh sieve before being used. Before exposing each test sample, the insects were covered with the flour and the flour leveled so that the depth was about $\frac{1}{4}$ inch. Immediately after each exposure, the thermocouple on the inclined rod, Fig. 7, was inserted in the flour so that the element touched the bottom of the petri dish. A Brown potentiometer was used to record the temperatures. After the test, the samples were placed in an incubator and observed at specified intervals. Mortality counts and other data for this test are shown in Table 4.

Test 5. In this test the time of exposure was increased and the adults together with the eggs were tested in the same samples. Forty adults were placed in each of 30 petri dishes containing 10 grams of whole wheat flour. The adults remained in the samples for four days before the testing period in order to allow sufficient time for the adults to oviposit. Twenty five samples containing the adults and eggs were treated. Five samples were used as checks. Before each test the flour was leveled in each dish, however, no effort was made to cover the insects with flour. At the end of each exposure, the thermocouple, Fig. 7, was inserted into the flour so that the

element touched the bottom of the petri dish. Immediately after the test the adults were separated from the samples and placed in fresh flour. The lamp heights, temperature, exposure times, mortality counts and eggs hatched are shown in Table 5, and Figs. 11 A and B.

Test 6. Test 6 was designed to determine the effects of infrared energy on granary weevil adults and eggs. Twenty five adult weevils were placed in each of twelve small jars containing 20 grams of wheat. The adults remained in the jars for four days before the test in order to allow sufficient time for oviposition to take place. Ten samples containing adults and eggs were treated in petri dishes. Two samples were used as checks. At the end of each exposure the contents of the dish were poured into the insulated thermocouple cavity (Shown in Fig. 8), and the temperature was recorded by a Brown potentiometer, after which the sample was returned to the jar. When the testing was completed the adults were separated from samples and placed in fresh wheat. The samples containing the adults and the samples containing the eggs were placed in an incubator. Mortality counts and number of eggs hatched, as well as other data are shown in Tables 6 and 7, and Figs. 16A and B.

Ultraviolet

Two ultraviolet tests were made and the major equipment used in the tests is shown in Fig. 8. A GE type UA-2 UVIARC 250 W mercury vapor lamp with a radiation wavelength shorter

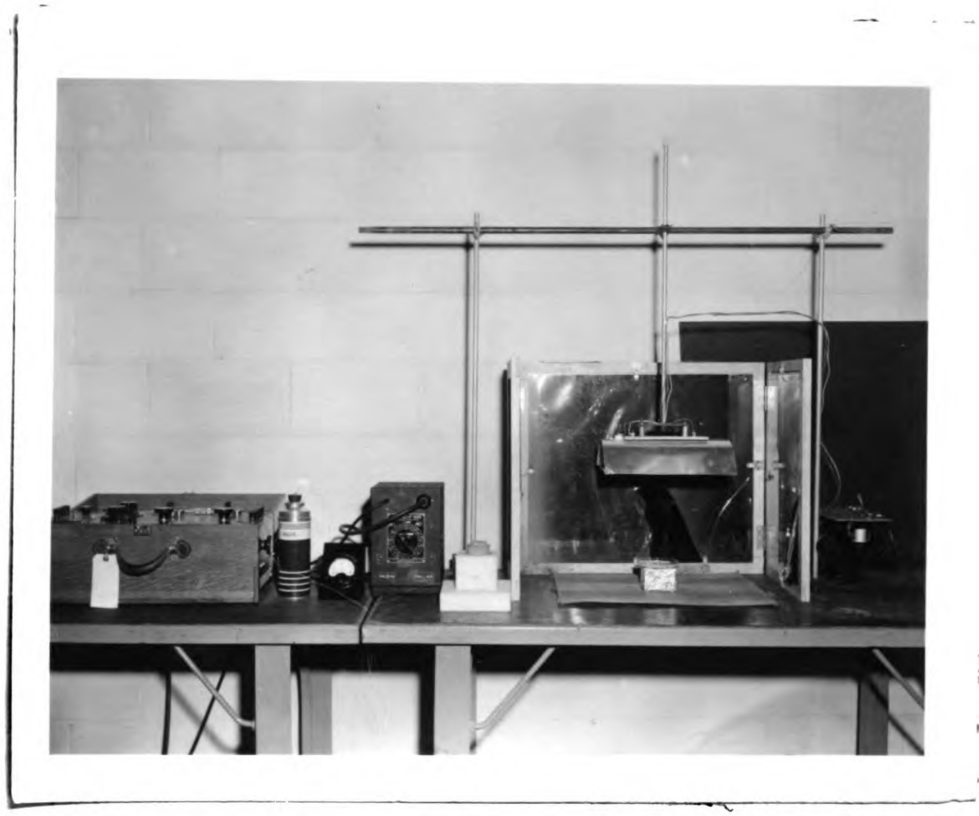

Fig. 8. Equipment used for the ultraviolet tests. From left to right; a Leeds and Northrup potentiometer, variable transformer, thermocouple and cavity, and a parabolic reflector containing the UA-2 lamp. Under the lamp is the aluminum foil block used to set the test samples.

than 2880A was used as a source of ultraviolet energy. The energy distribution of this lamp was computed by Baker (2). The lamp, mounted under a parabolic reflector, was used at different heights in the tests. The lamp was measured from the point of maximum curvature of the reflector to the bottom of the petri dish. The voltage was maintained at 117 throughout the tests.

Tests 1A and 1B. Forty adult confused flour beetles were placed in each of 18 petri dishes containing 5 grams of whole wheat flour to oviposit for four days before the test. Fifteen of the samples were tested and three samples were used as checks. At the end of each exposure a thermocouple was placed under the layer of flour and the temperature was recorded. Upon the completion of the test a mortality count was made and the live adults were placed in fresh flour. The samples containing the adults and the samples containing the eggs were placed in an incubator. The results and data for this test are shown in Tables 8 and 9.

Test 2A and 2B. Twenty-five adult granary weevils were placed in 12 small jars containing 20 grams of wheat. In order to allow enough time for ovipositing, the adults remained in the samples for four days before the test. Before each treatment the contents of the jar were placed in a petri dish. After the exposure the contents of the petri dish were poured into the thermocouple cavity (Fig. 8). The maximum temperature was recorded and the contents poured in the jar. At the com-

pletion of the testing period the weevils were separated, a mortality count was made and the live adults were placed in fresh wheat. The samples containing the live adults and the samples containing the eggs were placed in an incubator. The results and data for this test are shown in Tables 10 and 11.

X-Ray

Two x-ray tests were made. The test insect for these tests was the confused flour beetle only. A Hilger machine type 50 KV. was used for Test 1 and a GE Maximar 250 III, 250 KV was used for Test 2.

Test 1. The x-ray unit used for this test was a 50 KV Hilger machine of the Physics Department of Michigan State College (Figs. 9A and 9B). Forty adult confused flour beetles were placed in each of 15 petri dishes containing 13.5 grams of whole wheat flour. In order to allow sufficient time for ovipositing the adults remained in the flour for three days before the test. Just before the testing began, the samples were each placed in a cardboard box, 1.5 inches in diameter and .75 inch thick. The test samples were mounted 15.5 inches from the target in order to utilize the maximum beam area. At the time of this test, the dosimeter for the x-ray unit was out of order, therefore no dosages were calculated for this test. After the testing period the adults were separated from the samples and placed in fresh flour. One week later the adults were separated from these samples and again placed in

Fig. 9A. General view of the 50 KV Hilger machine used for the x-ray tests.

Fig. 9B. Close up view of controls for the Hilger machine. A test sample may be seen in the upper right part of the picture.

fresh flour. The flour was saved in order to check on the fertility of the adults irradiated with x-rays. A fertility check was made of the egg test adults also. Approximately 15 days after the appearance of the first adult in the irradiated egg samples, including the check samples, a count was made and the adults were placed in fresh flour. A week later the adults were discarded and the flour was saved for further observations. The exposure time and other observations are in Table 12.

Test 2. The x-ray unit used for this test was a GE Maximar 250 III, 250 KV of the School of Veterinary Medicine, Michigan State College. Thirty adult confused flour beetles were placed in each of 15 petri dishes containing 10 grams of whole wheat flour. The adults remained in the samples for three days in order to allow enough time for ovipositing. Twelve samples were irradiated and three samples were used as checks. Unlike Test 1 the treatment was made in the petri dishes. After the test the adults were separated from the samples and placed in fresh flour. The same methods used in Test 1 in checking the fertility of the treated adults and adults from the treated eggs, including all check samples, were used in this test. Observations, dosages and specifications of the x-ray unit used are shown in Table 13.

Accelerated Electrons

A series of seven tests were conducted with the Van de Graaff

generator (Figs. 10A and 10B) of the Upjohn Company at Kalamazoo, Michigan. These tests include irradiations made on the confused flour beetle larva and adults of the common bean weevil. The insects were transported to and from Kalamazoo by car in an insulated box. (Fig. 3)

Tests 1, 2A, 2B, and 4. Since this procedure for each of these tests was similar a general description of the procedure is presented under one heading.

Forty adult confused flour beetles were placed in each of twenty-four petri dishes containing 15 grams of whole wheat flour for Test 1, (Table 14). The adults remained in the flour for two and one-half days before the test, in order to allow time for the adults to oviposit. In Test 2, one hundred adults were placed in each of 12 petri dishes containing 30 grams of whole wheat flour. The adults remained in the flour for the three days in order to allow time for the adults to oviposit. In Test 4 fifty adults were placed in 24 petri dishes without flour. The samples were placed on the Van de Graaff generator conveyor belt and treated. The number of replicates, dosages and the number of check samples are shown in Tables 14, 15, 16, and 18. After the tests, the adults were separated from the samples and placed in fresh flour. The beetles from Test 4 were also placed in fresh flour. Observations were made at various intervals as shown in the tables. At the end of one week a final observation was made and the adults were discarded, but the flour was saved in order that a fertility check

Fig. 10A. View of conveyor belt, shielding blocks and vacuum pump for the Van de Graaff generator. Picture courtesy of the Upjohn Company.

Fig. 10B. General view of The Van de Graaff generator and controls. Picture courtesy of The Upjohn Company.

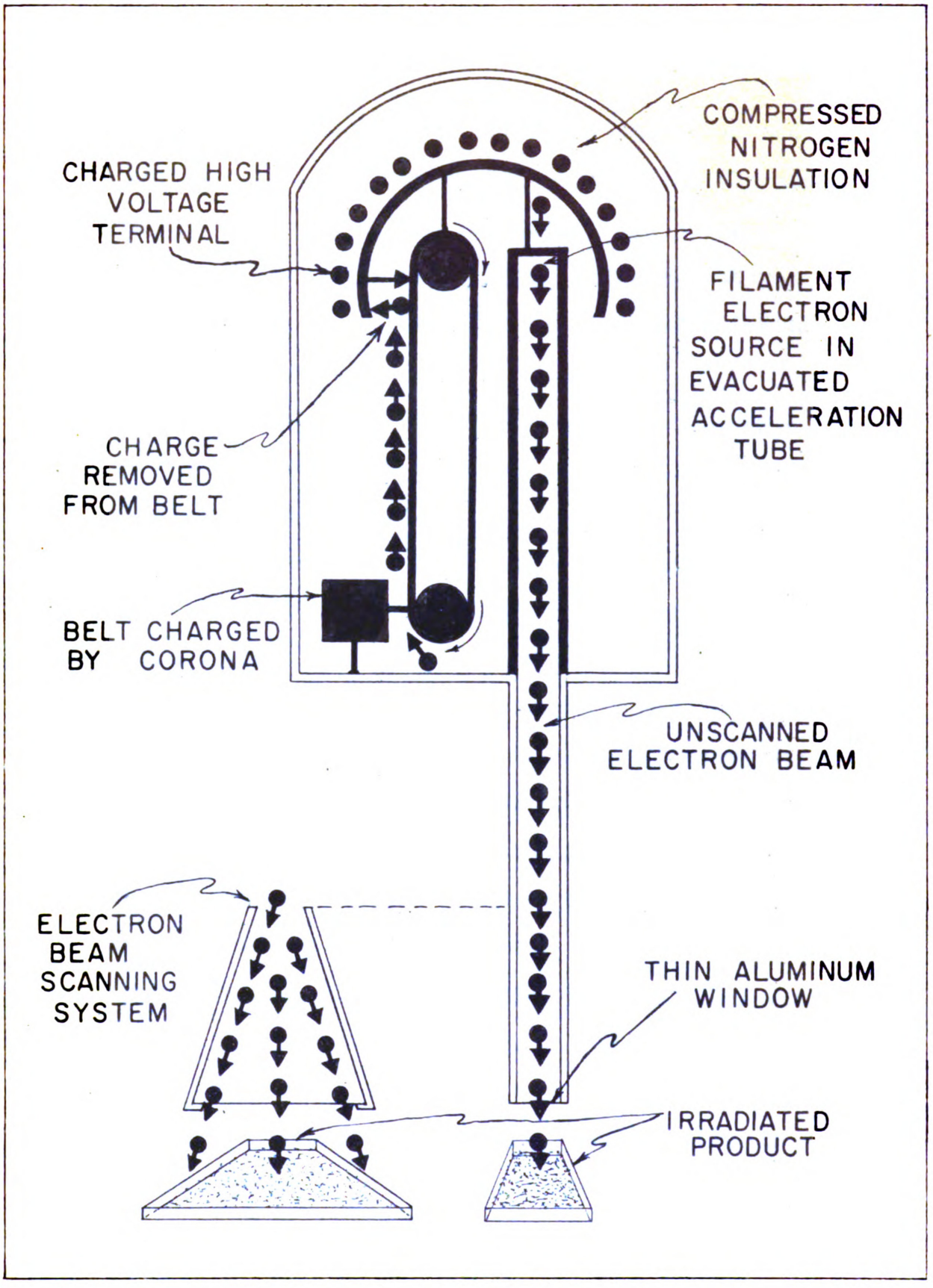

Fig 11 Schematic sketch of the Van de Graaff electron accelerator.

could be made of the adults. A fertility check was made of the egg test adults also. About two weeks after the appearance of the first adult in the irradiated and check samples, the beetles were placed in fresh flour. A week later, the adults were discarded and the flour was saved for further observations.

The dosages, observations, and the number of check samples used for each test are shown in Tables 14, 15, 16, 17, and Figs. 17AB and 18AB.

Test 5. This test was designed to determine the effects of accelerated electrons on the larvae of the confused flour beetle. Since the method of handling for this test was not discussed under the section, "Procedures In Rearing And Handling The Test Insects", a specific method is presented here.

Flour from the stock culture of the confused flour beetle was sifted through a 20-mesh wire screen. The screen separated the adults, the pupae and some of what appeared to be the last instar stage of the larvae. The flour then was sifted through a 40-mesh wire screen as shown in Fig. 3. The flour containing eggs, and possibly the first two instars of the larvae, fell through the sieve. The sieve retained the other instar stages and larger particles of flour. The wire screen with the larvae was inverted on a piece of paper and the method was repeated until it was assumed that enough larvae had been collected. The larvae were divided among twenty-four petri dishes, and flour was added to the petri dishes so that each

contained 13.5 grams of flour.

The confused flour beetle larva is very delicate and any repeated handling may injure the insect. In order to avoid the use of an injured larvae no attempt was made to count them. A visual criterion (Fig. 21) was used to determine the activity of the larvae. Several hours before the activity check was made, each sample was gently tapped on the side of the dish. The tunnels made at the bottom of the petri dish by the larvae would collapse and the flour was leveled. The activity was determined several hours later by the amount of tunneling made by the crawling larvae on the bottom of the petri dish. The activity check was made at weekly intervals as shown in Table 19. A sterility observation was made on the emerged adults.

Tests 3, 6 and 7. Since the procedure for each of these tests was similar, a general description of the procedure is presented under one heading.

Forty adult granary weevils were placed in each of 25 small jars containing 30 grams of wheat for Test 3. The adults remained in the wheat three days before the test in order to allow enough time for the weevils to oviposit. No egg tests were made in Tests 6 and 7. In Test 6, fifty adult granary weevils were placed in each of 24 empty small jars and in Test 7, fifteen adult common bean weevils were placed in each of ten small jars containing 20 grams of beans. The samples for tests 6 and 7 were prepared several hours before testing period.

Before each test was performed the contents of each jar were placed in petri dishes. Each dish was covered with a piece of aluminum foil in order to keep the weevils confined. The samples were then treated with various dosages. No wheat was used for Test 6. The number of replicates, dosages, and the number of check samples are shown in Tables 17, 20, and 21. The treated and untreated samples were observed immediately. The weevils were placed in jars containing fresh food materials.

The wheat containing the eggs of Test 3 was saved and observations as to the number of hatches were made. A sterility check was made on the adults of Test 6 and the adults of Test 3, including the adults from the irradiated eggs. No sterility check was made on the adults of the common bean weevils. The results of Tests 6 and 7 are shown in Tables 20, 21 and the results of Test 3 are shown in Table 17 and Figs. 20 AB.

Mortality Counts

The criterion for death was the inability of the adult beetle to crawl on a flat surface. This criterion was used by Collins (5). When mortality counts were made the beetles were sifted from the food material and placed on a piece of paper. The adults of the granary weevil were given longer time, because these weevils feign death whenever jarred or handled. The dead or moribund beetles, after given enough time to recover, were discarded. The live beetles were put back in the containers and returned to the incubators. Mor-

tality counts were made of each sample at various intervals as shown throughout the tables. However, only one mortality count was made of the confused flour beetle larvae (Test 5). The criterion for death in this test was easily established. The larvae that were dead appeared charred and motionless.

V EXPERIMENTAL RESULTS

INFRARED TEST 1

Tribolium confusum (Flour Beetle)

Sample Number	Time In Seconds	Volts	Gram Calories Per Square Centimeter Per Minute	Number Dead 48 Hours After
1	5	48	.5	0
2	10	48	.5	0
3	15	48	.5	0
4	20	48	.5	0
5	25	48	.5	0
6	5	67	1.0	1
7	10	67	1.0	0
8	15	67	1.0	0
9	20	67	1.0	0
10	25	67	1.0	0
11	5	86	1.5	0
12	10	86	1.5	0
13	15	86	1.5	0
14	20	86	1.5	0
15	25	86	1.5	0
16	5	101	2.0	0
17	10	101	2.0	0
18	15	101	2.0	0
19	20	101	2.0	0
20	25	101	2.0	0

Sample Number	Time In Minutes	Volts	Lamp Height	Dead After 48 Hours
1	1	117	10	0
2	2	117	10	7
3	3	117	10	13
4	.5	117	8	0
5	1	117	8	8

TABLE 1. Infrared Test with 25 Tribolium adults in 9 cm petri dishes.

INFRARED TEST 2

Tribolium confusum (Flour Beetle) Adults

Sample Number	Time In Seconds	Lamp Height In Inches	Gram Calories Per Square Centimeter Per Minute	Number Dead 48 Hours After	Additional Dead After 72 Hours	Additional Dead After 1 Week	Total	Per Cent Dead
1	15	12	1.83	0	0	1	1	5
2	30	12	1.83	0	0	0	0	0
3	45	12	1.83	0	1	0	1	5
4	60	12	1.83	0	1	0	1	5
5	75	12	1.83	0	2	0	2	10
6	15	10	2.20	0	0	0	0	0
7	30	10	2.20	0	0	0	0	0
8	45	10	2.20	0	0	0	0	0
9	60	10	2.20	4	6	0	10	50
10	75	10	2.20	16	1	1	18	90
11	15	8	2.60	0	4	0	4	20
12	30	8	2.60	2	5	0	7	35
13	45	8	2.60	4	6	3	13	65
14	60	8	2.60	12	3	0	15	75
15	75	8	2.60	18	1	1	20	100
16	15	6	3.25	12	7	0	19	95
17	30	6	3.25	10	3	1	14	70
18	45	6	3.25	19	0	0	19	95
19	60	6	3.25	20	0	0	20	100
20	75	6	3.25	20	0	0	20	100
21	15	4	4.00	9	4	0	13	65
22	30	4	4.00	17	3	0	20	100
23	45	4	4.00	20	0	0	20	100
24	60	4	4.00	20	0	0	20	100
25	75	4	4.00	20	0	0	20	100
26	Check	—	—	0	0	0	0	—

TABLE 2. Infrared Test 2 with 20 adult Tribolium confusum placed in 9 cm petri dishes with no flour.

INFRARED TEST 3

Tribolium confusum (Flour Beetle) Eggs

Sample Number	Time In Seconds	Lamp Height In Inches	Milli— Volts	Degrees F.	Hatched Nov. 10	Additional Hatched Nov. 11	Additional Hatched Nov. 12	Total	Per Cent of Check
1	Check	—	—	—	100	87	1	188	100
2	15	12	1.23	88	75	48	0	123	73
3	30	12	1.24	88	110	61	0	171	101
4	45	12	1.26	89	91	61	0	152	90
5	60	12	1.33	92	74	110	6	190	112
6	75	12	1.35	93	115	52	0	167	99
7	Check	—	—	—	101	60	0	161	100
8	15	10	1.23	88	79	54	0	133	79
9	30	10	1.33	92	93	31	4	128	76
10	45	10	1.39	94	60	71	10	141	84
11	60	10	1.45	97	85	39	1	125	74
12	75	10	1.58	103	147	75	0	222	130
13	Check	—	—	—	150	64	0	214	100
14	15	8	1.30	90	73	33	0	108	64
15	30	8	1.32	92	90	145	10	245	140
16	45	8	1.38	94	100	146	0	246	140
17	60	8	1.67	106	75	86	2	163	97
18	75	8	1.72	109	83	27	0	210	124
19	Check	—	—	—	71	52	0	123	100
20	15	6	1.32	92	65	67	1	133	79
21	30	6	1.48	98	103	89	1	193	114
22	45	6	1.57	102	98	52	1	151	89
23	60	6	1.60	104	105	72	0	177	105
24	75	6	1.92	117	90	31	0	127	75
25	Check	—	—	—	99	69	0	168	100
26	15	4	1.33	92	110	65	0	175	74
27	30	4	1.57	102	118	60	0	178	105
28	45	4	1.56	102	87	75	0	164	92
29	60	4	1.74	110	97	27	0	124	74
30	75	4	1.87	115	92	29	0	121	72

TABLE 3. Fifty adult Tribolium were left in 20 grams of whole wheat flour for 76 hours. Then the adults were removed and flour was treated in petri dishes under 250 watt infrared lamp, voltage 117 v. Depth of flour in petri dishes about ¼ inch. Treated October 4, 1952.

INFRARED TEST 4

Tribolium confusum (Flour Beetle) Adults Only

Sample Number	Time In Seconds	Lamp Height In Inches	Degrees F.	Number Dead 24 Hours After	2 Days After	4 Days After	1 Week After	Total	Per Cent Kill	Insects Came to Top During Test
1	Check	—	—	0	0	0	0	0	0	—
2	45	10	95	1	0	0	0	1	5	7
3	60	10	105	0	0	0	0	0	0	2
4	75	10	108	1	0	0	0	1	5	11
5	90	10	112	2	0	0	0	2	10	3
6	105	10	113	1	0	0	0	1	5	1
7	—	—	—	0	0	0	0	0	0	—
8	45	8	115	2	0	0	0	2	10	2
9	60	8	121	1	0	0	0	1	5	6
10	75	8	122	6	1	0	0	7	35	1
11	90	8	131	7	2	0	0	9	45	0
12	105	8	127	4	0	0	0	4	20	1
13	—	—	—	0	0	0	0	0	0	—
14	45	6	132	4	0	0	0	4	20	5
15	60	6	137	3	0	1	0	4	20	3
16	75	6	141	5	3	0	0	8	40	6
17	90	6	146	3	0	0	0	3	35	4
18	105	6	149	5	1	0	0	6	30	7
19	—	—	—	0	0	0	0	0	0	—
20	45	4	127	5	0	1	0	6	30	5
21	60	4	138	1	0	0	0	1	5	1
22	75	4	156	4	0	0	0	4	20	2
23	90	4	159	3	0	0	0	3	15	0
24	105	4	175	4	0	1	0	5	25	0
25	—	—	—	0	0	0	1	1	5	—
26	45	2	164	7	3	0	0	10	50	0
27	60	2	169	11	1	0	0	12	60	2
28	75	2	174	8	2	0	0	10	50	0
29	90	2	187	12	3	0	0	15	75	1
30	105	2	213	17	3	0	0	20	100	0

TABLE 4. Infrared Test 4. Twenty adult tribolium flour beetles were placed in 20 grams of whole wheat flour. The flour was sifted through 20 mesh screen. Depth of flour in dish about ¼ inch. When test was started, all insects were covered; however, during test some insects came to top of flour.

INFRARED TEST 5

Tribolium confusum (Flour Beetle) Adults and Eggs

Sample Number	Lamp Height In Inches	Time In Minutes	Degrees F.	Dead 1 Hour After	24 Hours After	1 Week After	Total	Per Cent Dead	Eggs Hatched 43 Days After	Per Cent Hatched
1	Check	—	--	0	0	0	0	0	150	—
2	10	.5	85	0	0	0	0	0	135	93
3	10	1.0	88	1	1	0	2	5	123	85
4	10	1.5	92	3	3	0	6	15	132	91
5	10	2.0	104	2	0	0	2	5	109	75
6	10	2.5	107	10	1	0	11	27	57	39
7	Check	—	--	0	0	0	0	0	140	—
8	8	.5	89	1	0	0	1	2.5	99	68
9	8	1.0	101	0	1	0	1	2.5	123	85
10	8	1.5	114	3	0	0	3	7.5	79	54
11	8	2.0	120	5	1	0	6	15	47	32
12	8	2.5	127	40	0	0	40	100	11	8
13	Check	—	--	0	0	0	0	0	134	—
14	6	.5	96	0	0	0	0	0	118	81
15	6	1.0	110	9	0	0	9	23	34	24
16	6	1.5	128	25	0	0	25	62	25	17
17	6	2.0	134	30	1	0	31	77	7	5
18	6	2.5	138	40	0	0	40	100	0	0
19	Check	--	--	0	0	0	0	0	157	—
20	4	.5	94	11	0	0	11	27	45	31
21	4	1.0	120	35	2	0	37	92	35	24
22	4	1.5	144	40	0	0	40	100	0	0
23	4	2.0	151	40	0	0	40	100	0	0
24	4	2.5	172	40	0	0	40	100	0	0
25	Check	—	--	0	0	0	0	0	143	—
26	2	.5	118	16	0	0	16	40	34	23
27	2	1.0	144	33	1	0	34	85	6	4
28	2	1.5	162	40	0	0	40	100	0	0
29	2	2.0	174	40	0	0	40	100	0	0
30	2	2.5	184	40	0	0	40	100	0	0

TABLE 5. Infrared Test 5. Forty adult tribolium were placed in 10 grams of whole wheat flour for 4 days in order to have eggs and adults in the same test. Samples were treated in 9 cm petri dishes.

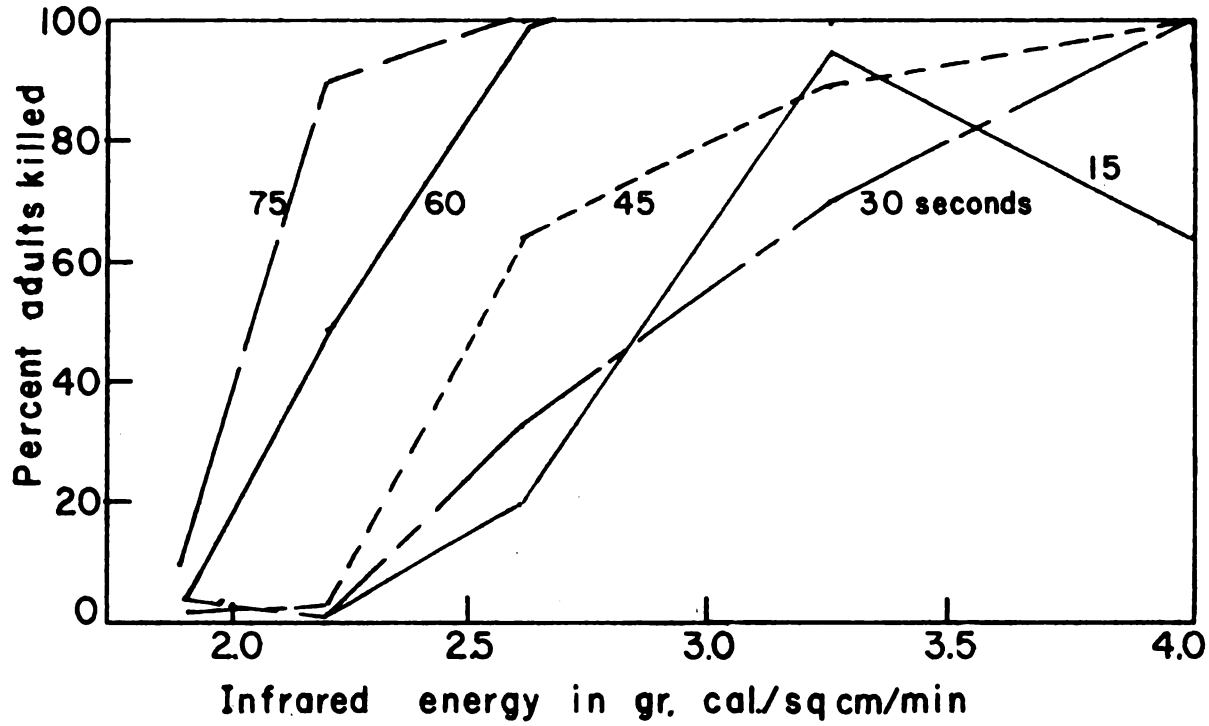

FIG A

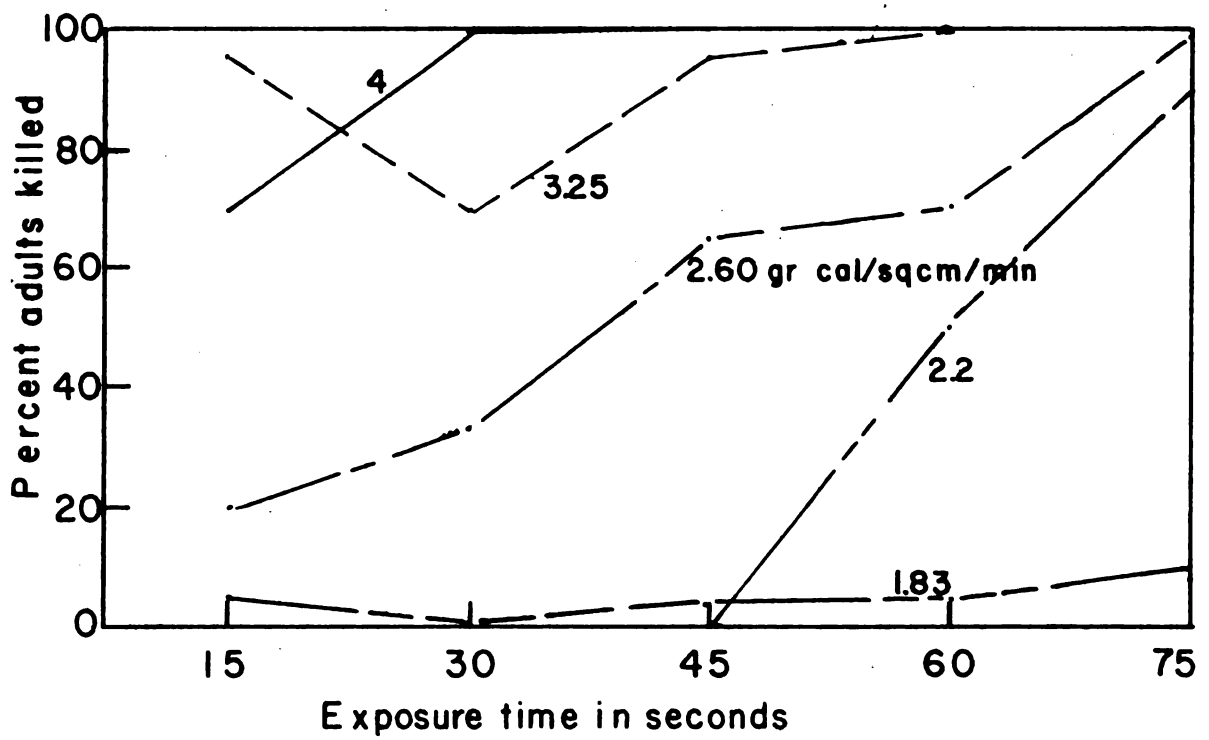

FIG B

FIG 12.A-B Percent Tribolium adults killed for infrared test 2 with 20 adults in plain petri dishes.

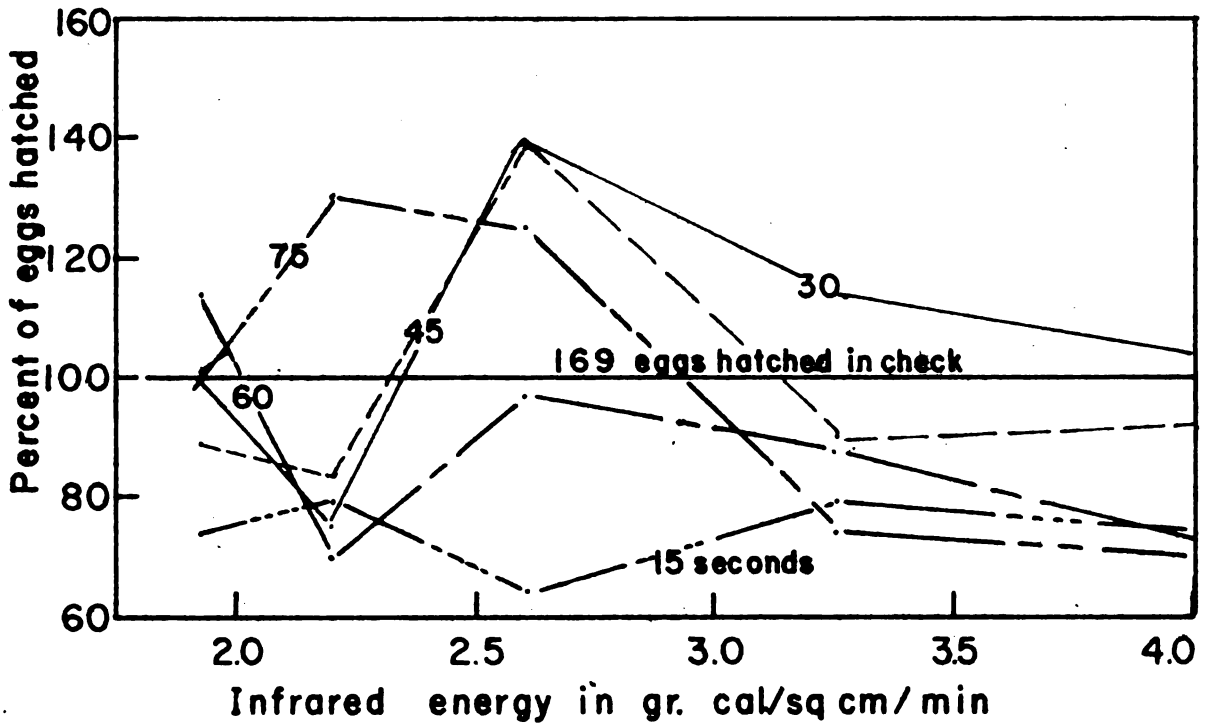

FIG 13 A Percent Tribolium eggs hatched for infrared test 3.

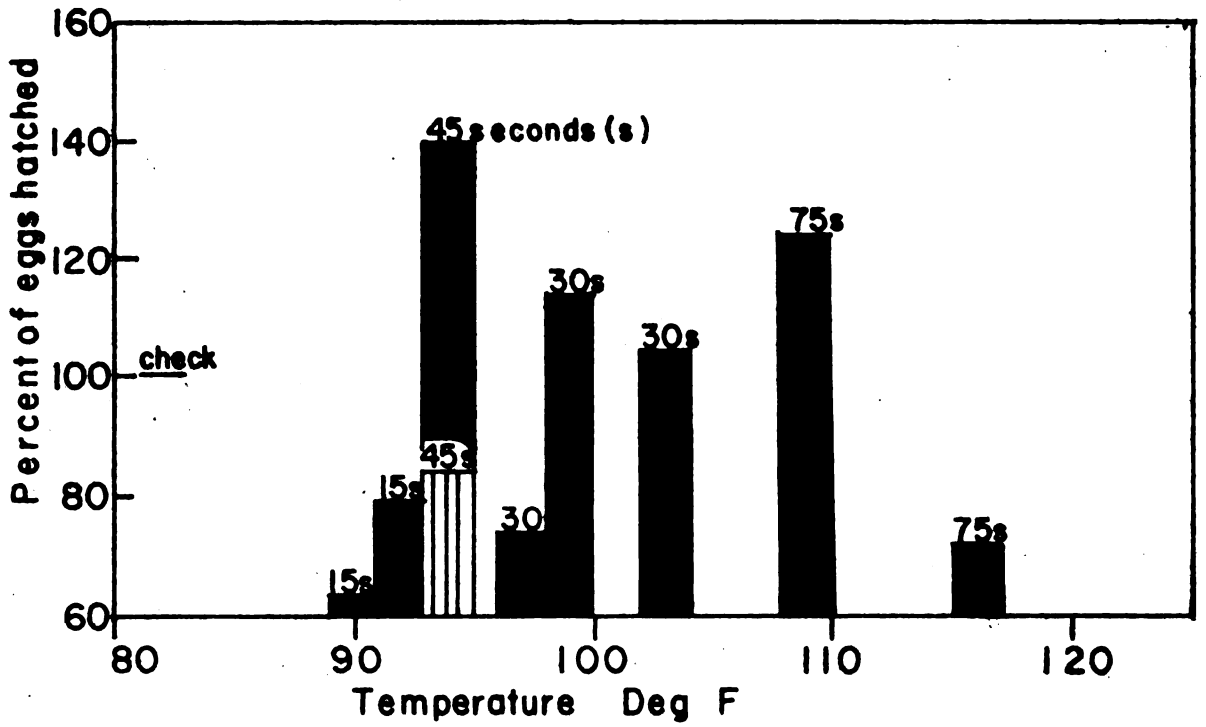

FIG 13 B Percent Tribolium eggs hatched bar chart for infrared test 3.

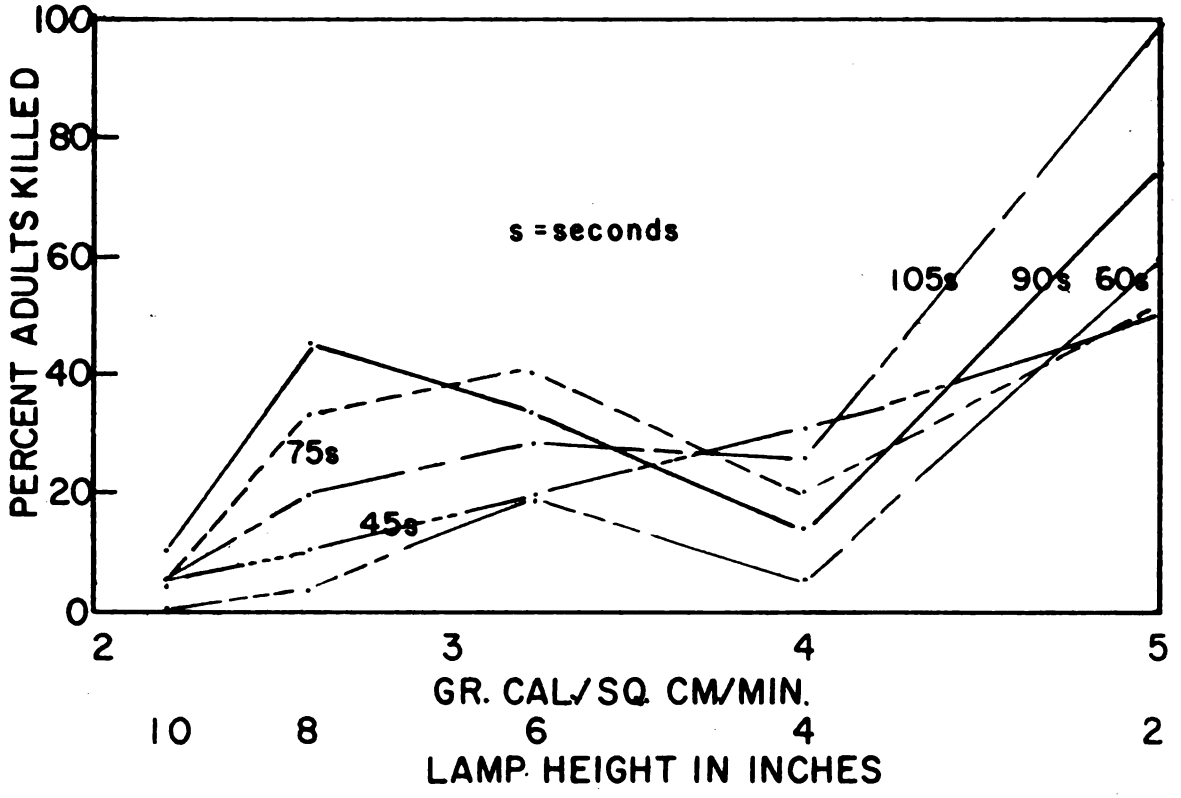

Fig 14 A Pecent adult Tribolium killed for infrared test 3

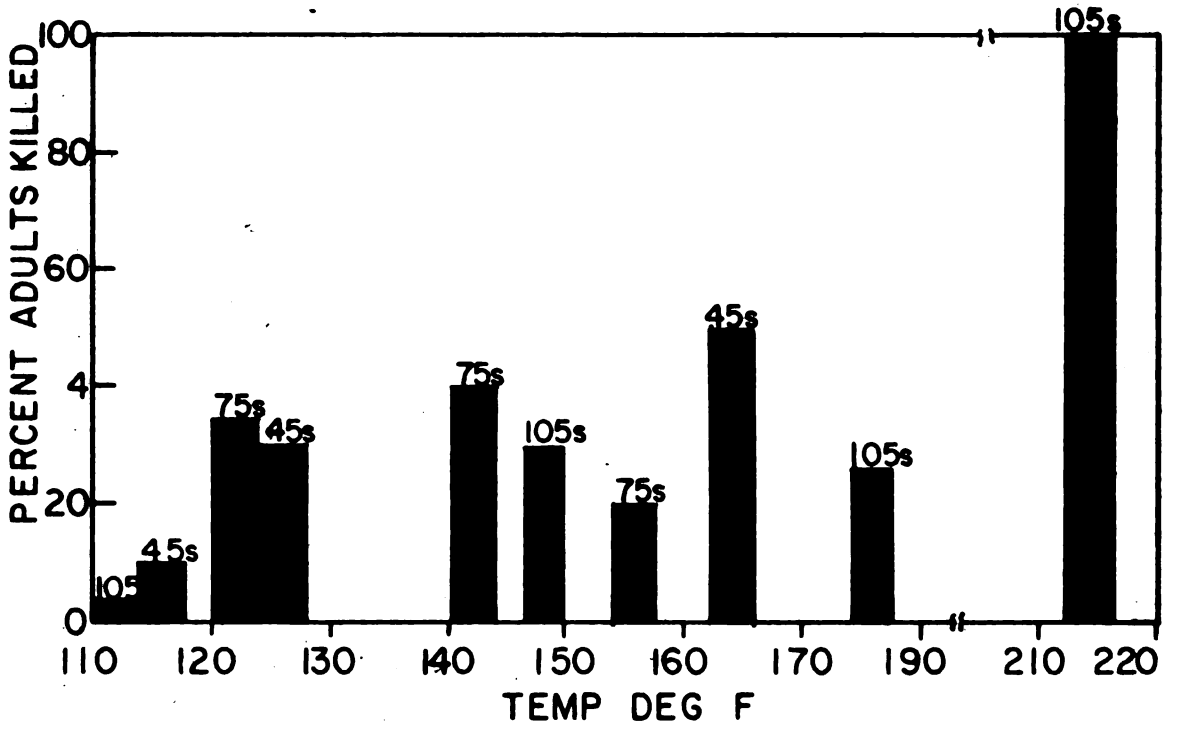

Fig 14 B Partial bar chart for percent Tribolium adults killed for infrared test 4.

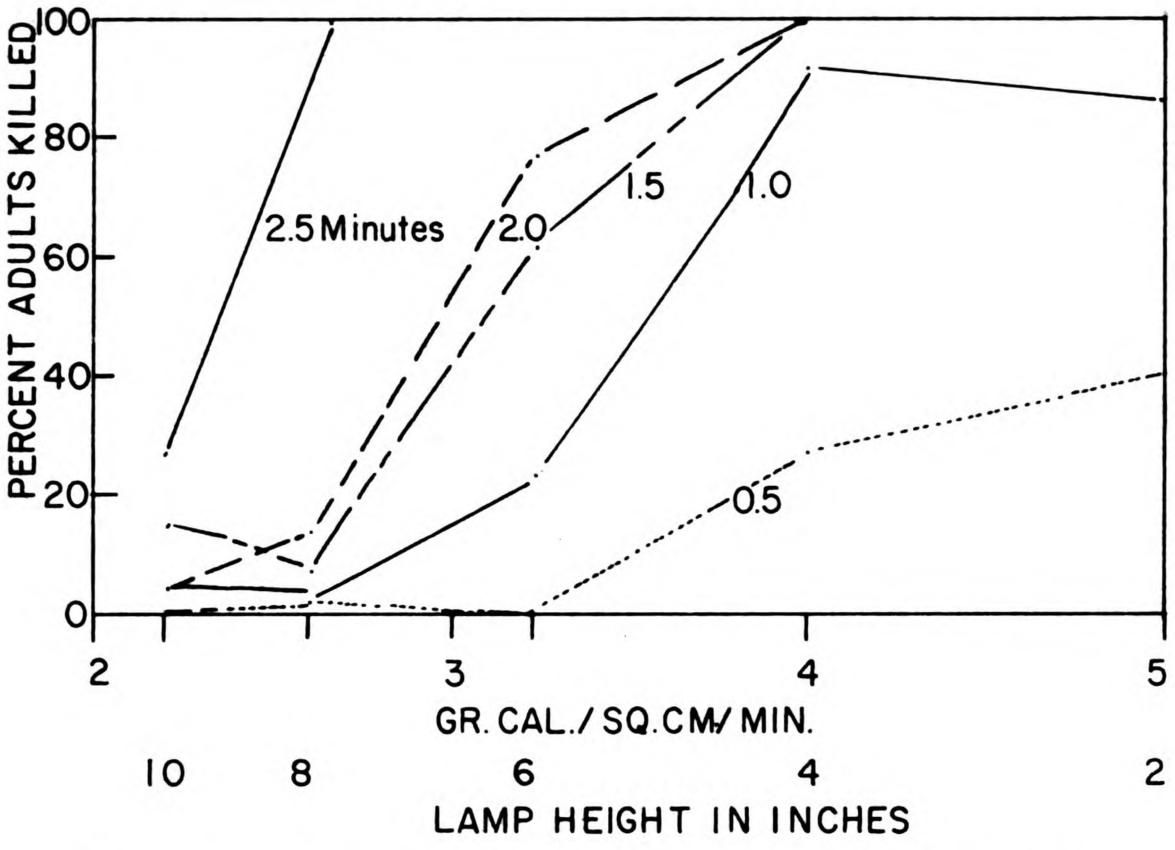

Fig 15 A Percent Tribolium killed for infrared test 5.

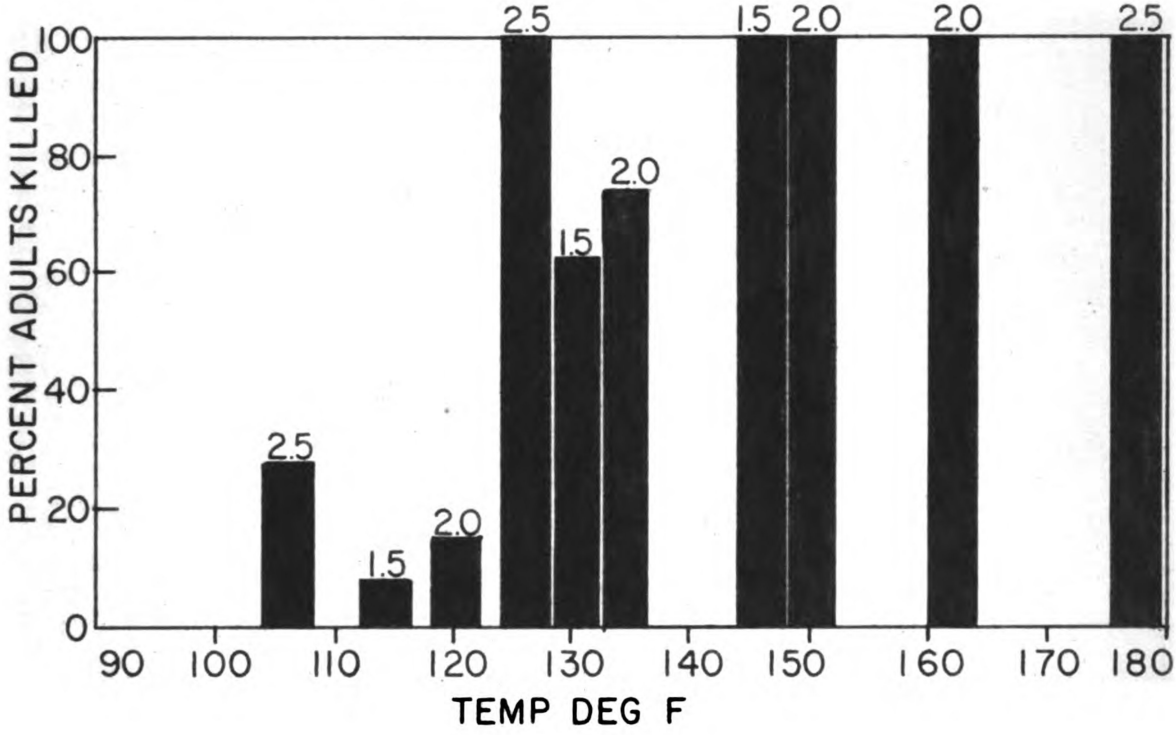

Fig 15 B Partial bar chart for percent Tribolium adults killed for infrared test 5.

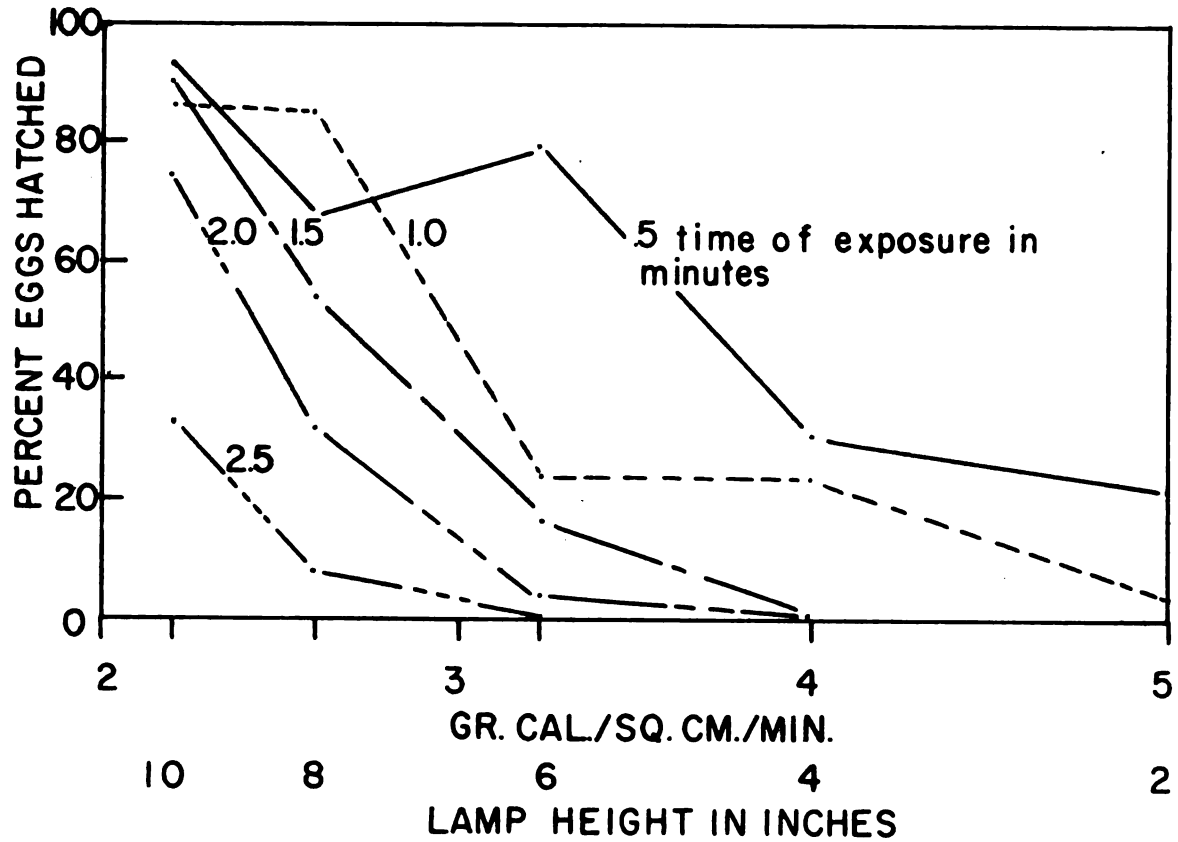

FIG 16 A Percent Tribolium eggs hatched for infrared test 5.

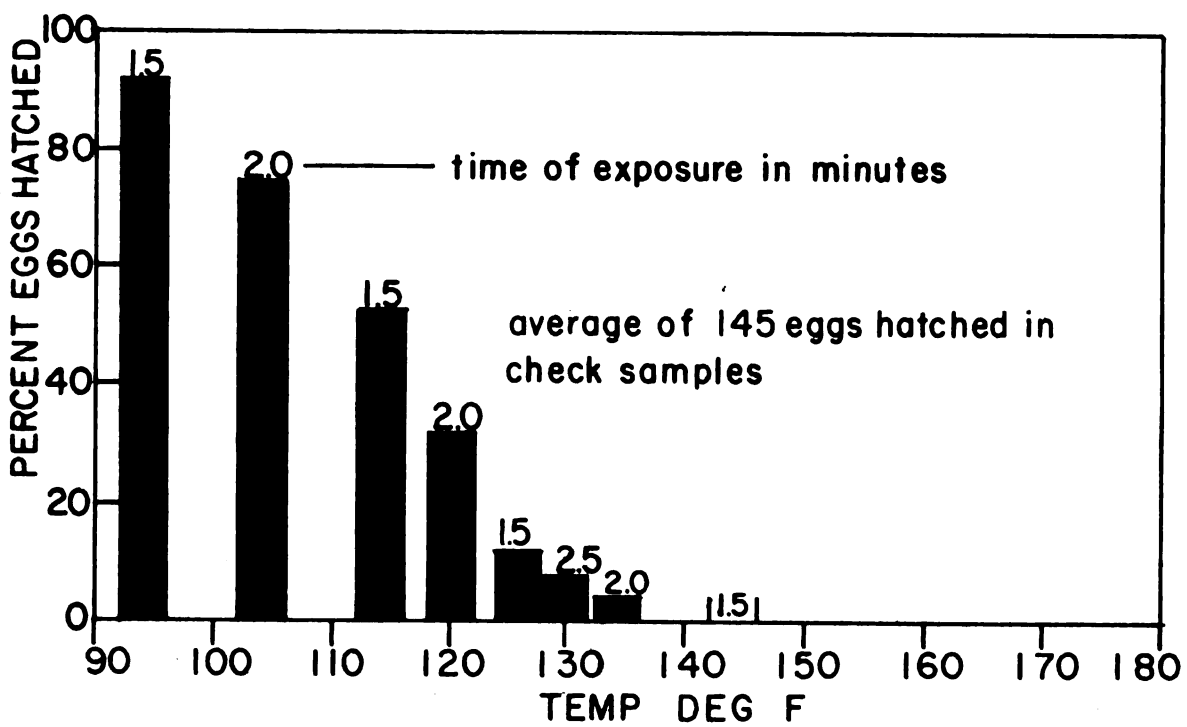

FIG 16 B Partial bar chart for percent Tribolium eggs hatched for infrared test 5.

INFRARED TEST 6A

Sitophilus granarius (Granary Weevil) Adults

Sample Number	Lamp Height In Inches	Time in Minutes	Milli— Volts	Degrees F.	Dead 1 Hour After	Additional Dead After 24 Hours	Additional Dead After 1 Week	Total	Per Cent Dead
1	Check	—	—	—	0	0	1	1	98
2	8	1.0	1.39	95	0	0	0	0	0
3	8	1.5	1.60	104	3	2	0	5	18
4	8	2.0	1.82	113	10	1	0	11	43
5	8	2.5	1.92	117	13	2	0	15	59
6	8	3.0	2.10	125	20	0	0	20	80
7	Check	—	—	—	0	0	0	0	98
8	4	1.0	1.93	118	18	1	0	19	75
9	4	1.5	2.19	128	25	0	0	25	100
10	4	2.0	2.53	142	25	0	0	25	100
11	4	2.5	2.70	150	25	0	0	25	100
12	4	3.0	3.10	166	25	0	0	25	100

TABLE 6. Infrared Test 6A, with 25 adult Granary Weevils placed in 9 cm petri dishes containing 20 grams of Cornell wheat.

INFRARED TEST 6B

Sitophilus granarius (Granary Weevil) Eggs

Sample Number	Lamp Height In Inches	Time In Minutes	Milli— Volts	Degrees F.	Hatched 41 Days After	Hatched 49 Days After	Hatched 56 Days After	Total	Per Cent Hatched
1	Check	—	—	—	35	41	0	76	100
2	8	1.0	1.39	95	25	28	0	53	81
3	8	1.5	1.60	104	10	19	0	29	45
4	8	2.0	1.82	113	7	3	0	10	15
5	8	2.5	1.92	117	10	4	0	14	22
6	8	3.0	2.10	125	1	0	0	1	1.5
7	Check	—	—	—	20	34	0	54	100
8	4	1.0	1.93	118	8	2	0	10	15
9	4	1.5	2.19	128	0	0	0	0	0
10	4	2.0	2.53	142	0	0	0	0	0
11	4	2.5	2.70	150	0	0	0	0	0
12	4	3.0	3.10	166	0	0	0	0	0

TABLE 7. Infrared Test 6B, with eggs laid by 25 adult Granary Weevils in 20 grams of Cornell wheat in 3 days.

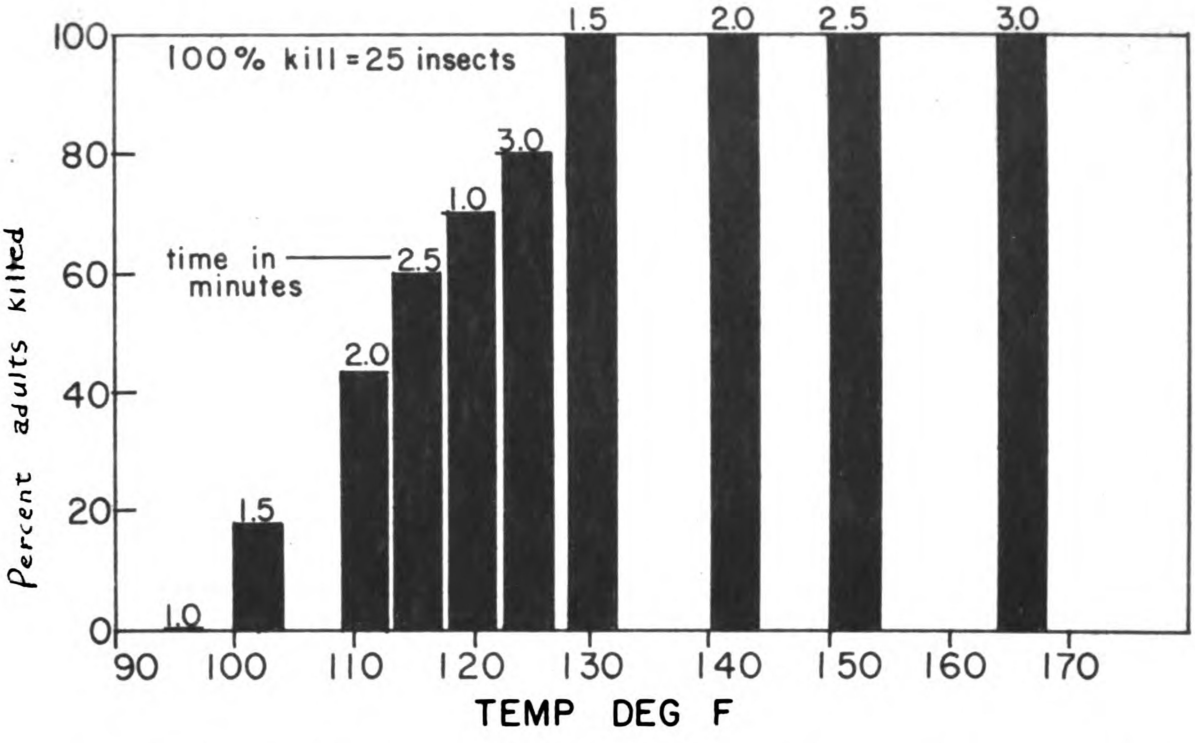

FIG 17 A Percent adult granary weevil killed for infrared test 6A.

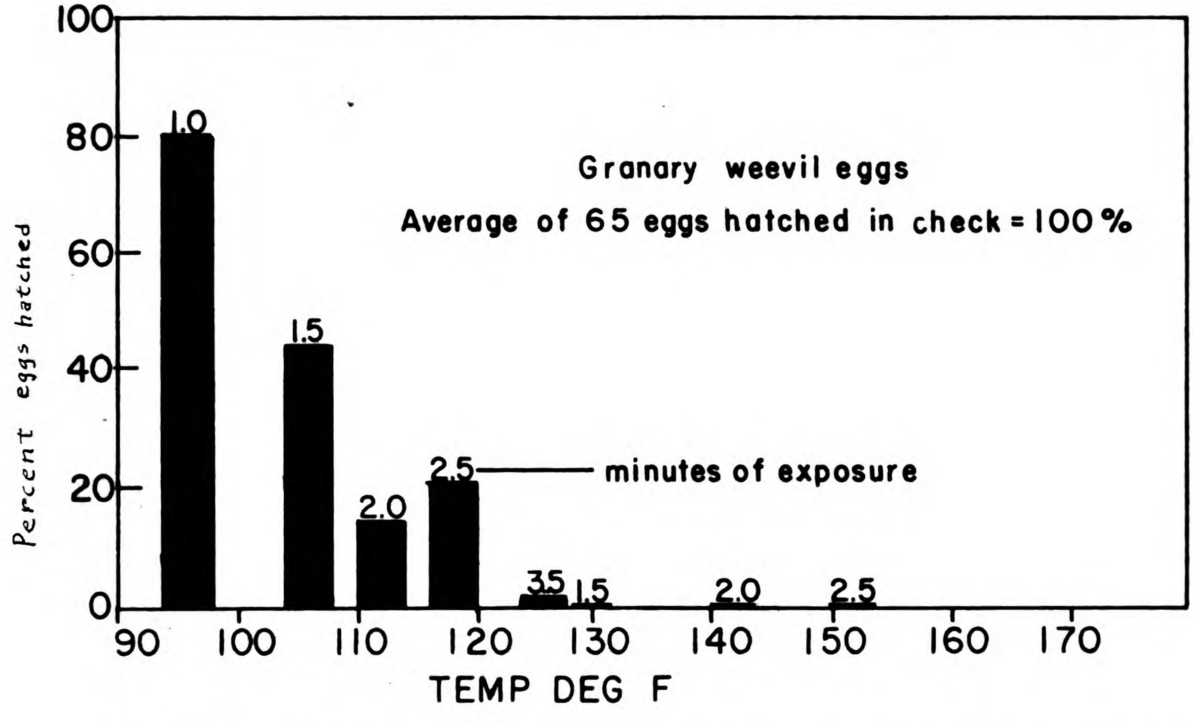

FIG 17 B Percent granary weevil eggs hatched for infrared test 6B.

ULTRAVIOLET TEST 1A

Tribolium confusum Adults (Flour Beetle)

Sample Number	Lamp Height In Inches	Time In Minutes	Milli— Volts	Degrees F.	Number Dead 1 Hour After	Number Dead 24 Hours After	Number Dead 1 Week After	Total	Per Cent of Check
1	Check	--	—	—	0	0	0	0	0
2	10	2	1.22	87	0	0	0	0	0
3	10	4	1.40	95	34	0	0	34	85
4	10	6	1.51	100	37	0	0	37	93
5	10	8	1.70	108	40	0	0	40	100
6	10	10	1.82	113	40	0	0	40	100
7	Check	--	--	--	0	0	0	0	0
8	7	2	1.40	95	37	1	0	38	95
9	7	4	1.78	112	40	0	0	40	100
10	7	6	2.15	127	40	0	0	40	100
11	7	8	2.20	129	40	0	0	40	100
12	7	10	2.42	138	40	0	0	40	100
13	Check	--	--	--	40	0	0	0	0
14	4	2	2.44	139	40	0	0	40	100
15	4	4	3.12	166	40	0	0	40	100
16	4	6	3.32	175	40	0	0	40	100
17	4	8	4.08	204	40	0	0	40	100
18	4	10	4.20	209	40	0	0	40	100

TABLE 8. Ultraviolet Test 1A. Forty adult Tribolium confusum were placed in 9 cm petri dishes containing 5 grams of whole wheat flour 4 days before test in order to allow time for adults to oviposit.

ULTRAVICLET TEST 1B

Tribolium confusum Eggs (Flour Beetle)

Sample Number	Lamp Height In Inches	Time In Minutes	Milli— Volts	Degrees F.	Number of Eggs Hatched After 47 Days	Per Cent of Check
1	Check	—	—	—	73	—
2	10	2	1.22	87	14	22
3	10	4	1.40	95	14	22
4	10	6	1.51	100	7	11
5	10	8	1.70	108	1	1.6
6	10	10	1.82	113	1	1.6
7	Check	—	—	--	54	—
8	7	2	1.40	95	13	21
9	7	4	1.78	112	0	0
10	7	6	2.15	127	0	0
11	7	8	2.20	129	0	0
12	7	10	2.42	138	0	0
13	Check	—	--	—	63	0
14	4	2	2.44	139	0	0
15	4	4	3.12	166	0	0
16	4	6	3.32	175	0	0
17	4	8	4.08	204	0	0
18	4	10	4.20	209	0	0

TABLE 9. Ultraviolet Test 1B. Forty tribolium confusum placed in 5 grams of whole wheat flour 4 days before test in order to allow time for adults to oviposit.

ULTRAVIOLET TEST 2A

Sitophilus granarius (Granary Weevil) Adults

Sample Number	Lamp Height In Inches	Time In Minutes	Milli— Volts	Degrees F.	Number Dead 1 Hour After	Number Dead 24 Hours After	Number Dead 1 Week After	Total	Per Cent of Check
1	Check	—	—	—	0	0	0	—	—
2	7	1	1.70	108	6	0	0	6	24
3	7	2	1.95	118	9	1	0	10	40
4	7	4	2.46	140	25	0	0	25	100
5	7	6	2.75	152	25	0	0	25	100
6	7	8	3.40	178	25	0	0	25	100
7	Check	—	—	—	0	0	0	0	0
8	10	1	1.30	90	3	0	0	3	12
9	10	2	1.69	108	6	1	0	7	28
10	10	4	1.82	113	11	0	0	11	44
11	10	6	2.10	125	20	0	0	20	80
12	10	8	2.35	135	25	0	0	25	100

TABLE 10. Ultraviolet Test 2A. Twenty-five adult Granary Weevils were placed in 9 cm petri dishes containing 20 grams Cornell wheat.

ULTRAVIOLET TEST 2B

Sitophilus granarius (Granary Weevil) Eggs

Sample Number	Lamp Height In Inches	Time In Minutes	Milli-volts	Degrees F.	Number of Eggs Hatched After 49 Days	Per Cent of Check
1	Check	—	—	—	123	—
2	7	1	1.70	108	80	57
3	7	2	1.95	118	59	42
4	7	4	2.46	140	0	0
5	7	6	2.75	152	0	0
6	7	8	3.40	178	0	0
7	Check	—	—	—	158	—
8	10	1	1.30	90	162	110
9	10	2	1.69	108	133	95
10	10	4	1.82	113	43	31
11	10	6	2.10	125	12	9
12	10	8	2.35	135	0	0

TABLE II. Ultraviolet Test 2B. Twenty-five adult Granary Weevils were placed in 9 cm petri dishes containing 20 grams of Cornell wheat. Adults remained in samples 4 days before treatment.

X-RAY TEST 1

Tribolium confusum Adults and Eggs

Sample Number	Time of Exposure In Minutes	Dead After Test		Eggs Hatched After 36 Days	Offspring from Adults 40 Days After Treatment	Adult Offspring From Treated Eggs
		1 Hour	1 Week			
1	Check	0	0	151	99	44
2	1	0	0	81	67	32
3	5	0	0	97	54	31
4	10	0	0	103	37	19
5	20	0	0	87	55	6
6	Check	0	0	120	121	53
7	1	0	0	131	21	63
8	5	0	0	90	72	42
9	10	0	0	101	60	32
10	20	0	0	105	65	54
11	Check	0	0	87	92	37
12	1	0	0	123	56	14
13	5	0	0	93	37	48
14	10	0	0	115	36	35
15	20	0	0	90	43	30

TABLE 12. X-Ray Test 1, with 40 adult tribolium and eggs in 13.5 grams of whole wheat flour, 40 kv, 20 ma strength. Insects placed in round cardboard box 1.5 inches in diameter, .75 inches deep. Box was placed 15.75 inches from copper target.

X Ray Test 2

Tribolium confusum (flour beetle) adults and eggs

Sample Number	Time in Minutes	$r/_{air}$	Total Roentgens	Dead after 24 hours	Dead after 1 week	Total dead after 2 weeks	Offspring from adults	Irradiated eggs hatched	Offspring from irradiated eggs
1	2	100	148	0	0	1	31	17	73
2	2	100	148	0	0	0	50	20	65
3	4	200	296	0	0	1	61	27	89
4	4	200	296	0	0	1	40	23	62
5	6	300	444	0	0	0	29	25	93
6	6	300	444	0	0	2	47	43	59
7	8	400	592	0	0	0	35	56	85
8	8	400	592	0	0	2	32	38	73
9	10	500	740	0	0	0	45	53	90
10	10	500	740	0	0	0	39	19	75
11	12	600	880	0	0	0	55	62	60
12	12	600	880	0	0	0	42	45	81
13	Check	-	-	0	0	0	62	42	68
14	Check	-	-	0	0	0	41	33	79
15	Check	-	-	0	0	1	46	35	95

Table 13. X-Ray test 2 using the G. E. Maximar 250 III, 250 KV X-Ray unit at the School of Veterinary Medicine of Michigan State College, April 14, 1953. Calibrated physical factors - - - total filtration @.25 cu, 1 al; hvl .78 cu; 15 ma, 200 KV, beam size 400 sq cm; fsd 50 cm; r/min air 50.

ACCELERATED ELECTRON TEST 1

Tribolium confusum (Flour Beetle) Adults and Eggs

Sample Number	reps	Number Dead 3 Hours After	Additional Dead After 24 Hours	Additional Dead After 1 Week	Total	Per Cent Dead	Eggs Hatched	Per Cent of Check	Offspring from Treated Adults
1	Check	0	0	0	0	0	112	—	34
2	1.45×10^6	40	0	0	40	100	0	0	0
3	1.45×10^6	40	0	0	40	100	0	0	0
4	1.45×10^6	40	0	0	40	100	0	0	0
5	1.45×10^6	40	0	0	40	100	0	0	0
6	720,000	40	0	0	40	100	0	0	0
7	Check	0	0	0	0	0	16	—	41
8	720,000	40	0	0	40	100	0	0	0
9	720,000	40	0	0	40	100	0	0	0
10	720,000	40	0	0	40	100	0	0	0
11	72,000	0	0	0	0	0	0	0	0
12	72,000	0	1	0	1	2.5	0	0	0
13	Check	0	0	0	0	0	33	—	20
14	72,000	0	2	0	2	5	0	0	0
15	72,000	5	3	0	8	12.5	0	0	0
16	10,000	0	0	0	0	0	0	0	0
17	10,000	0	0	0	0	0	0	0	0
18	10,000	0	1	0	1	2.5	0	0	0
19	Check	0	0	0	0	0	25	—	18
20	10,000	0	0	0	0	0	0	0	0
21	1,000	0	0	0	0	0	13	28	29
22	1,000	0	1	0	1	2.5	16	35	21
23	1,000	0	0	0	0	0	19	41	23
24	1,000	0	0	0	0	0	11	25	19

TABLE 14. Accelerated electron test 1 using Van de Graaff generator at Upjohn Company February 6, 1953. Forty adult Tribolium were placed in 9 cm petri dishes containing 15 grams whole wheat flour on February 3, 1953, which allowed about 2⅓ days for the adults to oviposit.

ACCELERATED ELECTRON TEST 2A

Tribolium confusum Adults

Sample Number	reps	Beam Current Microamperes*	Belt Speed Feet Per Minute	Number Dead 1 Hour After	Additional Dead After 24 Hours	Additional Dead After 48 Hours	Additional Dead After 1 Week	Total	Corrected Per Cent
1	1 x 10^6	26.0	1	100	0	0	0	100	100
2	1 x 10^6	26.0	1	100	0	0	0	100	100
3	.5 x 10^6	26.0	1	100	0	0	0	100	100
4	.5 x 10^6	26.0	1	100	0	0	0	100	100
5	.25 x 10^6	13.0	1	32	6	30	23	91	90.5
6	.25 x 10^6	13.0	1	19	9	40	27	95	95.0
7	100,000	5.2	8.3	1	0	0	3	4	9.5
8	100,000	5.2	8.3	0	0	1	1	2	9.8
9	50,000	2.6	8.3	0	0	1	0	1	1
10	50,000	2.6	8.3	0	0	0	0	0	0
11	Check	--	--	0	0	1	0	1	1
12	Check	--	--	0	0	0	0	0	0

*Samples 1 and 2 through beam twice to make total beam current 52 microamperes.

TABLE 15. Accelerated electron test 2 using Van de Graaff generator at Upjohn Company, March 13, 1953. One hundred Tribolium adults were placed in 9 cm petri dishes containing 30 grams of whole wheat flour 3 days before test date.

ACCELERATED ELECTRON TEST 2B

Tribolium confusum Eggs

Sample Number	reps	Beam Current Microamperes	Belt Speed Feet Per Minute	Trips Through	Total Beam Current Microamperes	Eggs Hatched After 43 Days	Per Cent of Check
1	1 x 10^6	26	1	2	52	0	0
2	1 x 10^6	26	1	2	52	0	0
3	.5 x 10^6	26	1	1	26	0	0
4	.5 x 10^6	26	1	1	26	0	0
5	.25 x 10^6	13	1	1	13	0	0
6	.25 x 10^6	13	1	1	13	0	0
7	100,000	5.2	8.3	1	5.2	0	0
8	100,000	5.2	8.3	1	5.2	0	0
9	50,000	2.6	8.3	1	2.6	0	0
10	50,000	2.6	8.3	1	2.6	0	0
11	Check	--	--	--	--	69	--
12	Check	--	--	--	--	81	--

TABLE 16. Accelerated electron test 2 using Van de Graaff generator at Upjohn Company, March 13, 1953. One hundred adult Tribolium were placed in 9 cm petri dishes containing 30 grams of whole wheat flour 3 days before test date.

ACCELERATED ELECTRON TEST 3

Sitophilus granarus (Granary Weevil) Adults and Eggs

Sample Number	rep.	Beam Current Microamperes	Number dead 1 hour after	Additional dead after 24 hours	Additional dead after 48 hours	Additional dead after 1 week	Total Dead	Corrected percent dead	Eggs Hatched	Percent of check
1	1×10^6	79*	40	0	0	0	40	100	0	0
2	1×10^6	79*	40	0	0	0	40	100	0	0
3	1×10^6	79*	40	0	0	0	40	100	0	0
4	1×10^6	79*	40	0	0	0	40	100	0	0
5	$.5 \times 10^6$	79	40	0	0	0	40	100	0	0
6	$.5 \times 10^6$	79	37	2	1	0	40	100	0	0
7	$.5 \times 10^6$	79	40	0	0	0	40	100	0	0
8	$.5 \times 10^6$	79	40	0	0	0	40	100	0	0
9	$.25 \times 10^6$	40	0	2	25	13	40	100	0	0
10	$.25 \times 10^6$	40	2	5	30	3	40	100	0	0
11	$.25 \times 10^6$	40	0	7	24	9	40	100	0	0
12	$.25 \times 10^6$	40	0	3	27	10	40	100	0	0
13	$.10 \times 10^6$	16	0	0	20	7	27	68	0	0
14	$.10 \times 10^6$	16	0	0	27	12	39	97.4	0	0
15	$.10 \times 10^6$	16	0	0	15	20	35	87.4	0	0
16	$.10 \times 10^6$	16	0	0	10	23	33	82.0	0	0
17	$.50 \times 10^5$	8	0	0	2	5	7	16.5	0	0
18	$.50 \times 10^5$	8	0	0	7	3	10	27.6	0	0
19	$.50 \times 10^5$	8	0	0	3	2	5	11.4	0	0
20	$.50 \times 10^5$	8	0	1	1	2	4	8.8	0	0
21	Check	--	0	0	0	1	1	2.5	91	--
22	Check	--	0	0	0	0	0	0	157	--
23	Check	--	0	0	0	1	1	2.5	106	--
24	Check	--	0	0	0	0	0	0	96	--
25	Check	--	0	0	0	0	0	0	98	--

* Samples 1-4 through beam twice.

Table 17. Accelerated electron test 3 using Van de Graaff generator at Upjohn Company, March 13, 1953. Forty adult **Sitophilus granarus** placed in 2 cm petri dishes containing 50 grams of Cornell wheat on March 10, 1953. This allowed about 3 days for the adults to oviposit.

Accelerated Electron Test 4

Tribolium confusum (flour beetle)

Sample Number	Dose in reps	No. dead immediately after test	Additional dead 24 hours after test	Additional dead 48 hours after test	Additional dead 1 week after test	Total dead	Offspring from adults after 30 days
1	500,000	50	-	-	-	50	0
2	500,000	50	-	-	-	50	0
3	500,000	50	-	-	-	50	0
4	500,000	50	-	-	-	50	0
5	400,000	50	-	-	-	50	0
6	400,000	50	-	-	-	50	0
7	400,000	50	-	-	-	50	0
8	400,000	50	-	-	-	50	0
9	300,000	50	-	-	-	50	0
10	300,000	50	-	-	-	50	0
11	300,000	50	-	-	-	50	0
12	300,000	50	-	-	-	50	0
13	200,000	50	-	-	-	50	0
14	200,000	50	-	-	-	50	0
15	200,000	50	-	-	-	50	0
16	200,000	50	-	-	-	50	0
17	100,000	19	1	1	28	50	0
18	100,000	18	0	0	28	46	0
19	100,000	11	0	0	37	48	0
20	100,000	16	2	2	30	50	0
21	Check	0	0	0	0	0	61
22	Check	0	0	0	0	0	53
23	Check	0	0	0	1	1	65
24	Check	0	0	0	0	0	54

Table 18. Accelerated electron test 4 using the Van de Graaff generator at Upjohn Co. April 20, 1953. Fifty adult Tribolium confusum were irradiated in 9 cm petri dishes with no flour.

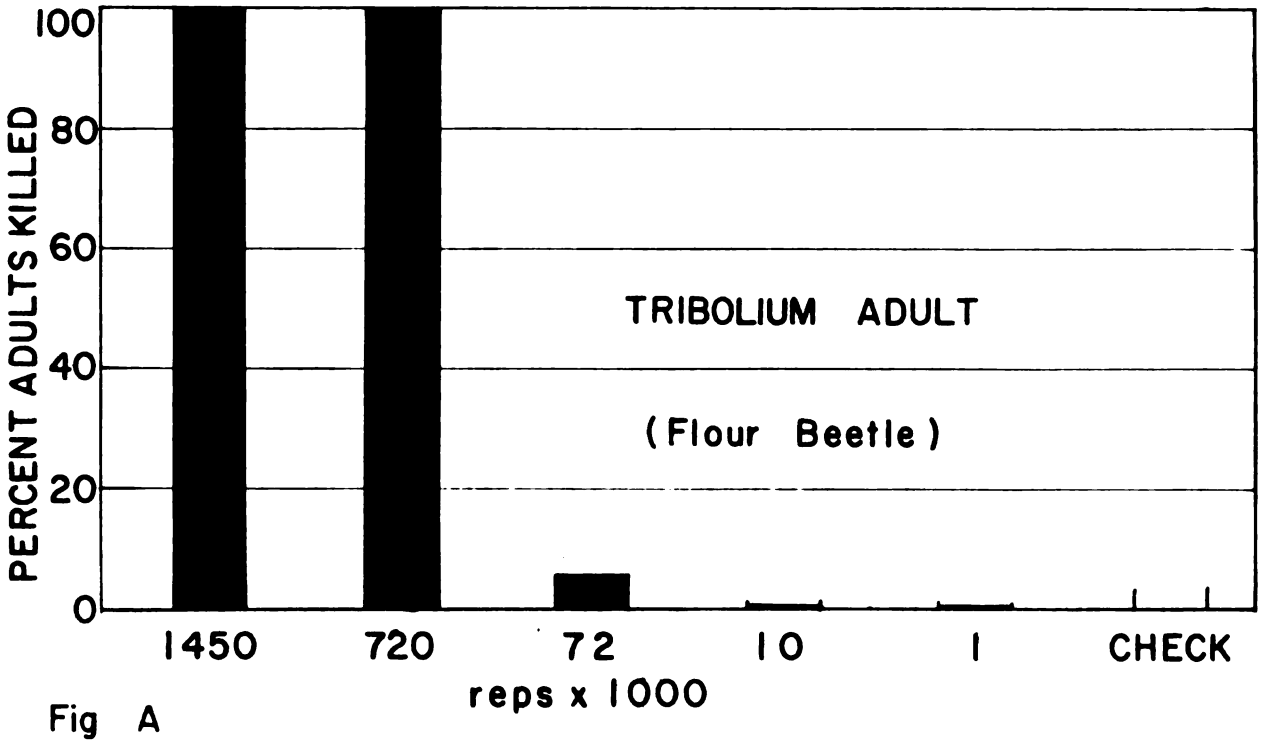

Fig A

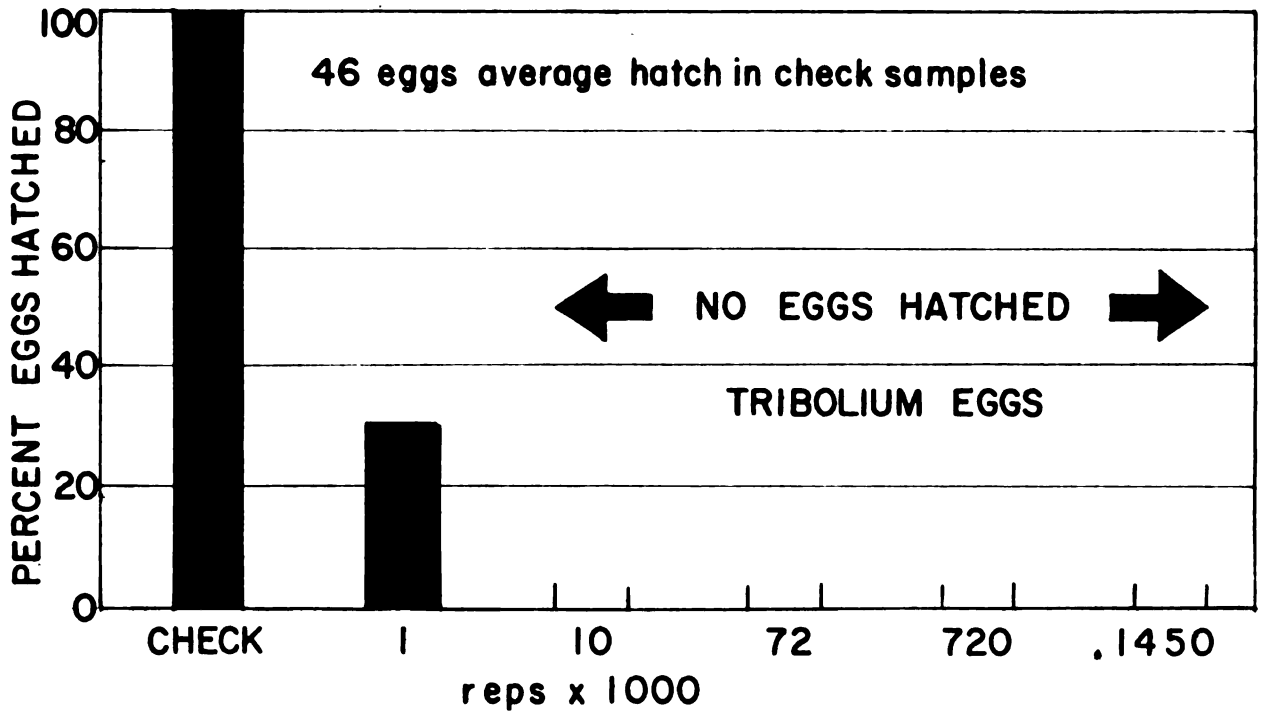

Fig B

Fig 18 A-B Percent Tribolium confusum adults killed and eggs hatched for accelerated electron test 1 using Van de Graaff generator at UPJOHN CO. Feb 5, 1953 - Data in table

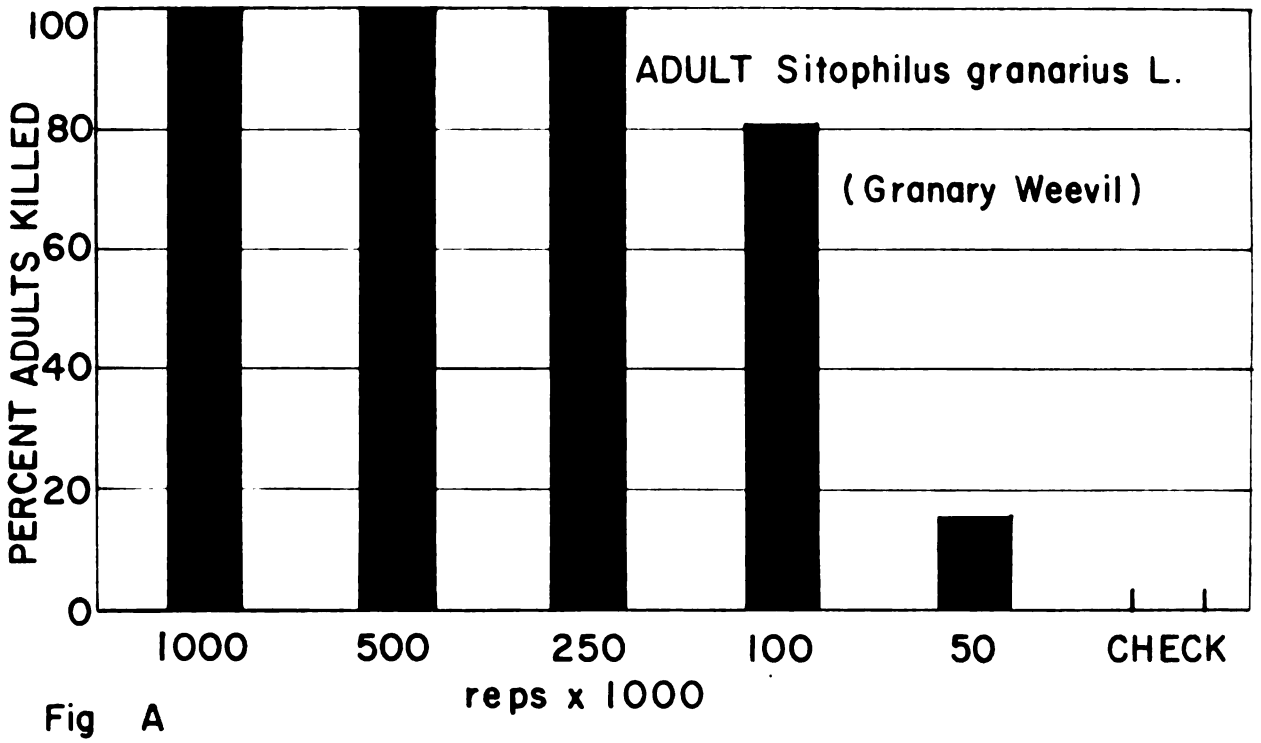

Fig A

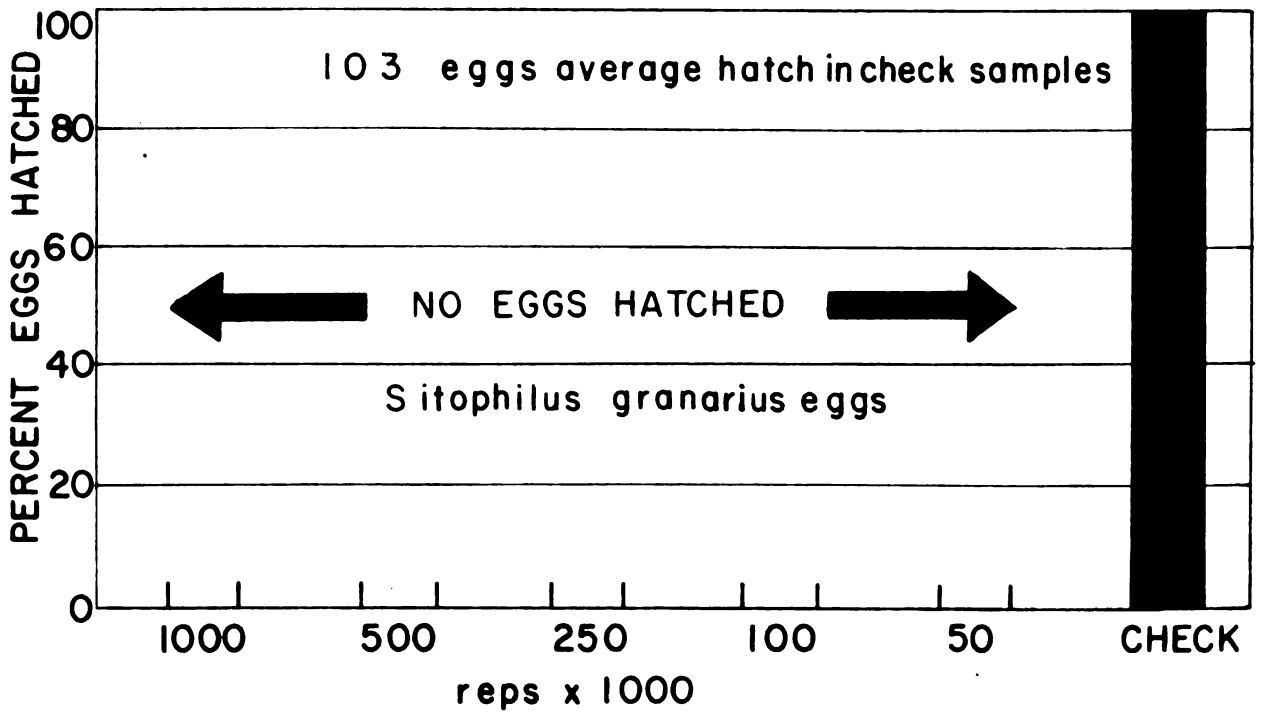

Fig B

Fig 20.A-B Percent Sitophilus granarius adults killed and eggs hatched for accelerated electron test 3 using the Van de Graaff generator at UPJOHN CO. March 13, 1953 - Data in table

Accelerated Electron Test 5

Tribolium confusum (flour beetle) larvae

Sample Number	Dose in reps	Activity after test	1 week after	2 weeks after	3 weeks after	4 weeks after	dead larvae after 5 wks.	alive adults after 5 weeks	offspring from adults
1	75,000	—	—	—	—	—	14	0	0
2	75,000	—	—	—	—	—	30	0	0
3	75,000	—	—	—	—	—	40	0	0
4	75,000	—	—	—	—	—	58	0	0
5	50,000	—	—	—	—	—	50	0	0
6	50,000	—	A	—	A	A	67	8	0
7	50,000	—	—	—	—	—	19	0	0
8	50,000	A	A	A	—	—	81	0	0
9	25,000	—	—	—	—	—	39	0	0
10	25,000	—	A	A	A	A	20	4	0
11	25,000	—	A	—	—	—	31	0	0
12	25,000	A	AA	A	AA	A	52	18	0
13	10,000	A	A	—	A	A	28	2	0
14	10,000	A	A	—	—	—	17	0	0
15	10,000	A	A	A	—	—	26	0	0
16	10,000	A	A	—	—	—	42	0	0
17	1,000	AA	AA	AA	A	—	61	0	0
18	1,000	AA	AA	AA	A	A	48	2	7
19	1,000	A	AA	A	A	A	28	2	0
20	1,000	AA	AA	A*	A	A	33	6	31
21	Check	AAA	AAA	AAA*	AAA	AAA	0	80**	80
22	Check	AAA	AAA	AAA*	AAA	AAA	0	32	97
23	Check	AAA	AAA	AAA*	AAA	AAA	0	49	91
24	Check	AAA	AAA	AAA*	AAA	AAA	0	60	102

Legend: —.....No Activity A.....Little Activity
AAA.....Very active *.....Adults began to appear
AA.....Active **.....Only 30 adults tested

Table 11. Accelerated electron test 5 using the Van de Graaff generator at Upjohn Co. April 20, 1953. Tribolium larvae were irradiated in 9 cm petri dishes containing 13.5 grams of whole wheat flour.

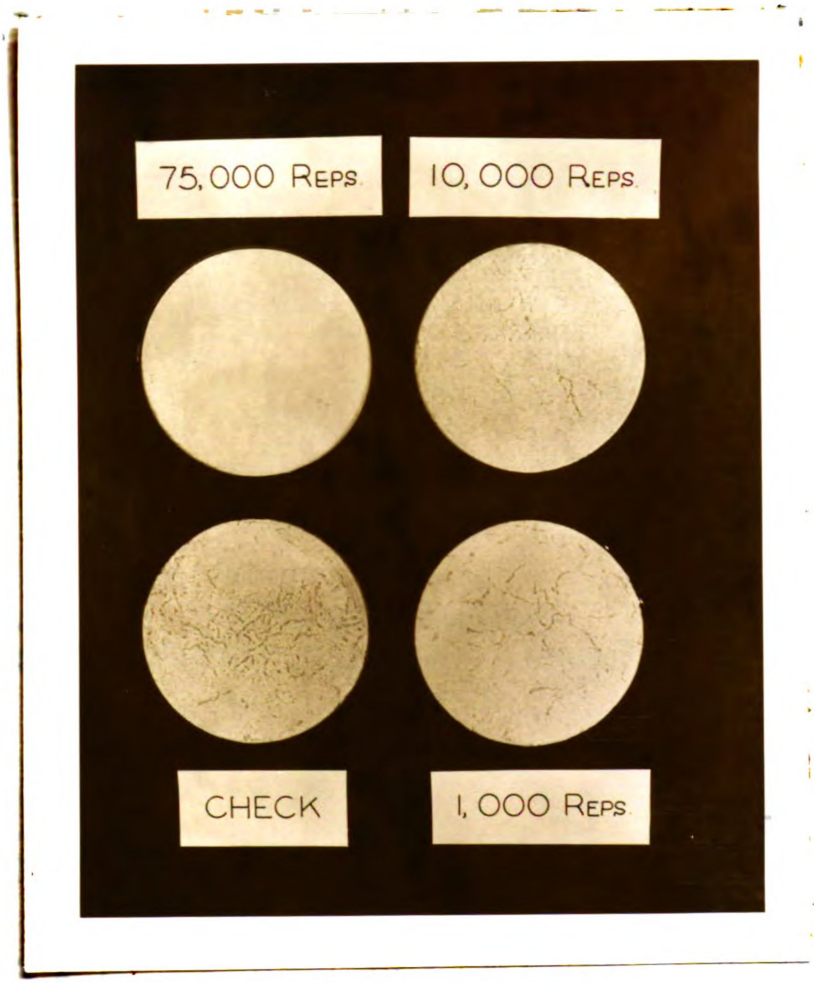

Fig. 21. An example of the visual criteria used to determine the activity of the confused flour beetle larvae test.

ACCELERATED ELECTRON TEST 6

Sitophilus granarius adults (granary weevils)

Sample Number	Dose in reps	No. dead immediately after test	No. dead 24 hours after test	No. dead 48 hours after test	No. dead 1 week after test	Total
1	250,000	50	-	-	-	50
2	250,000	50	-	-	-	50
3	250,000	50	-	-	-	50
4	250,000	50	-	-	-	50
5	125,000	0	8	4	38	50
6	125,000	0	6	9	35	50
7	125,000	0	9	2	39	50
8	125,000	0	10	8	32	50
9	75,000	0	6	4	40	50
10	75,000	0	2	3	45	50
11	75,000	0	5	2	43	50
12	75,000	0	1	5	44	50
13	50,000	0	2	0	36	38
14	50,000	0	0	1	41	42
15	50,000	0	0	0	30	30
16	50,000	0	0	1	33	34
17	10,000	0	0	0	13	13
18	10,000	0	0	0	7	7
19	10,000	0	0	0	8	8
20	10,000	0	0	0	9	9
21	-	0	0	0	2	2
22	-	0	0	0	1	1
23	-	0	0	0	1	1
24	-	0	0	0	0	0

Table 20. Accelerated electron test 6 using the Van de Graaff generator at Upjohn Company April 20, 1953. Fifty adult granary weevils were irradiated in 9 cm petri dishes containing no wheat. There were no offspring from the adults that survived except for the check samples.

Accelerated Electron Test 7

Acanthoscelides obtectus Say (bean weevil) adults

Sample Number	Dose in rep	No. dead immediately after test	No. dead 24 hours after test	No. dead 48 hours after test	No. dead 1 week after test	Total dead after one week
1	500,000	15	-	-	-	15
2	500,000	15	-	-	-	15
3	250,000	13	2	0	0	15
4	250,000	10	4	0	0	14
5	100,000	1	9	4	1	15
6	100,000	2	5	4	4	15
7	10,000	1	5	1	8	15
8	10,000	0	4	8	3	15
9	Check	0	0	2	1	3
10	Check	0	0	1	3	4

Table 21. Accelerated electron test 6 using the Van de Graaff generator at Upjohn Company April 20, 1953. Fifteen adult bean weevils were irradiated in 9 cm diameter petri dishes containing 20 grams of Michigan navy beans.

VI DISCUSSION OF RESULTS

Infrared

The procedure for this series of tests is described in sections III and IV. The results of these tests are recorded in Tables 1, 2, 3, 4, 5, 6 and 7. The results of Tests 2, 3, 4, 5, and 6, appear in graphic form in Figs. 12, 13, 14, 15, 16, and 17.

As can be seen from Table 1, first part of Test 1, only one beetle was dead 48 hours after the test. However, better results were obtained in the second part of the test. Thirteen out of a total of twenty five adults were dead 48 hours after the test with a lamp height of 10 inches. In test 3, no treatment used indicated 100 percent kill of eggs. However, in Test 4, a 100 percent kill of adults was obtained one week after treatment using an exposure time of 105 seconds and a maximum temperature of 213°F., with the height of the lamp at two inches. During this test a number of insects came to the top and there does not appear to be any relationship between the number of insects killed and the number that came to the top of the sample.

The results of Test 5 and 6 were more promising. In Test 5, the minimum time required to kill 100 percent adult confused flour beetles, one hour after the test, was 2.5 minutes at a lamp height of eight inches. The maximum temperature at the end of the test was 127°F. The minimum time required to kill 100 percent of the eggs was 2.5 minutes at a lamp height of 6 inches

with a maximum temperature of 138°F. This temperature more or less conforms to that of Cotton (6). He states that a temperature of 140°F. is fatal to all grain insects in 10 minutes time.

In test 6, 100 percent kill of adult granary weevils and eggs was obtained with an exposure time of 1.5 minutes at a lamp height of 4 inches and a maximum temperature of 128°F. at the end of the test. In reviewing the exposure times in the tables of these two tests, it was noted that a longer exposure time was required to increase the temperature of the wheat. The granary weevil lays its eggs inside the wheat kernel and the confused flour beetle deposits its eggs at random in the flour. Apparently the wheat provided a better insulation for the granary weevil eggs.

Ultraviolet

The results of these tests are recorded in Tables 8, 9, 10 and 11. The procedure for these tests is described in sections III and IV.

One hundred percent kill of the adult confused flour beetles was obtained at an exposure time of 8 minutes with a lamp height of 10 inches one hour after treatment. The maximum temperature recorded was 108°F. At this same temperature, lamp height and exposure time, only 1.6 percent of the eggs hatched, and no eggs hatched at an exposure time of 4 minutes with a lamp height of 7 inches. No adults or eggs survived

one hour after treatment with the lamp height of 7 inches and an exposure time of 4 minutes. The maximum temperature recorded was 140°F.

The confused flour beetle eggs, which are laid at random in the flour, were effected at a lower temperature than the eggs of the granary weevil. Since ultraviolet energy has poor penetration into the wheat kernel, and the fact that the granary weevil deposits its eggs inside the wheat kernel, more energy would be required to kill the egg. However, a temperature of 135°F. was fatal to the adults and eggs.

The ultraviolet energy radiated from the lamp used in these tests was about one fifth of the total energy, and the other four fifths was infrared energy. Under these conditions it would be difficult to separate the effects of ultraviolet energy from the effects of infrared energy.

X-ray

The data recorded for these tests are shown in Tables 12 and 13. The procedure, including the sterility checking method, is described in sections III and IV.

No exposure time used in Test 1 for the confused flour beetle adults showed any effects at one hour, or at one week after treatment. The eggs in the egg samples hatched normally as compared to the check samples. In Test 2, one adult died with a dose of 148r units, two adults died with a dose of

296r units and two adults died with a dose of 592r units, two weeks after the treatment. These results may be considered negligible since no adults died with the higher treatments and one died in the check sample two weeks after the test. There was no noticeable external effects on the progeny of the irradiated adults nor on the progeny of the irradiated eggs.

Accelerated Electrons

The results for these tests are presented in Tables 14 through 21 inclusive. Bar charts for Tests 1, 2 and 3, are presented in Figs. 18, 19 and 20. The procedure is given in sections III and IV.

Table 14, and bar chart Fig. 18, show that an electron dose of 720,000 rep* will kill 100 percent of the adult flour beetles in flour after treatment, whereas as electron dose of 500,000 rep will kill 100 percent of the adult granary weevils in wheat after treatment (Table 17, bar chart Fig. 20). The results for these two Tables (14 and 17) indicate that with a dose of 100,000 rep about 90 percent of the granary weevil adults were killed one week after treatment and a dose of 72,000 rep about 10 percent of the confused flour beetles were killed one week after treatment.

In Tests 4 and 6 (Tables 18 and 20) no flour or wheat was used. The results indicate that a dose of 200,000 rep

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*One rep represents a very minute quantity of energy. One rep (Roentgen-equivalent-physical) = 1 roentgen: 1 roentgen = 93 ergs/gram water or tissue.

will kill 100 percent of the adult flour beetle after treatment, whereas a dose of 250,000 rep will kill 100 percent of the adult granary weevils after treatment. A dose of 100,000 rep will kill about 95 percent of the adult flour beetle and a dose of 50,000 will kill about 40 percent of the adult granary weevils. An electron dose of 10,000 rep was lethal to 100 percent of the adult bean weevils one week after treatment (Test 7, Table 21). A dose of 75,000 rep killed 100 percent of the confused flour beetle larvae one week after treatment (Test 5, Table 20).

The results shown in Tables 14 and 17, indicate that an electron dose of 10,000 rep prevented the hatching of eggs of the flour beetles and the eggs of the granary weevils. This same dose prevented the adult granary weevil, the adult confused flour beetle and the larvae of the flour beetles, after reaching the adult stage, from reproducing. There were no noticeable external effects on the progeny of the irradiated adults, larvae or eggs.

VII SUMMARY

Infrared, ultraviolet and x-rays, as well as accelerated electrons were used on the confused flour beetle. The granary weevil was subjected to infrared rays, ultraviolet rays and accelerated electrons and the common bean weevil was limited to only one test of accelerated electrons. The beetles were reared under laboratory conditions of 80° ± 2° F. and a relative humidity of about 66 percent. The manner of rearing was so arranged that a constant supply of adult beetles of a known age were produced.

The infrared energy tests indicated that both temperature and exposure time were important factors in obtaining effective results. A temperature of at least 138° F. and a maximum exposure time of 2.5 minutes was necessary to obtain lethal effects on the confused flour beetle, granary weevil and their eggs. The ultraviolet tests gave no clear indication of its effects on the beetles since the type of lamp used emitted four fifths of its energy as infrared energy.

No exposure time in the x-ray tests showed any effects on the confused flour beetle. After the tests the adults were not sterilized and were able to reproduce normal progeny. However, the results of the accelerated electron tests were more promising. A dose of at least 500,000 rep would be necessary to kill completely a mixed population of adults and larvae of the confused flour beetle, the adults of the granary weevil and common bean weevil. A dose of 10,000 rep prevented the eggs of the

confused flour beetle and the granary weevil from hatching. This same dose sterilized the adult granary weevil, the adult confused flour beetle and prevented the larvae of the flour beetle, after reaching the adult stage, from reproducing.

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