POTENTIAL OF ACCELERATED ELECTRONS FOR INSECT CONTROL IN STORED GRAIN

F. L. WATTERS
Agriculture Canada Research Station
Winnipeg, Canada

INTRODUCTION: It is now apparent that the high expectations of the last 20 years regarding the use of ionizing radiation for the disinfestation of stored grain have not materialized. Although research in various countries (1, 2, 3) indicates that radiation is technically feasible for insect control, high installation and operating costs, reservations concerning the acceptability of irradiated foods, and lack of demonstrated need to substitute radiation in place of chemical pesticides, have precluded its use for the disinfestation of stored grain. Even the comparatively recent development of insect resistance to insecticides has failed to elicit a resurgence of interest in the application of ionizing radiation for the direct control of insects. Perhaps this is because most experimental applications have employed radioactive isotopes such as Cobalt-60 to produce the penetrating radiation required to treat bulk commodities such as stored grain. We are all aware that chemical and physical pest control agents are increasingly being subjected to public scrutiny, especially those products or processes that carry the slightest suspicion of causing carcinogenic effects either during or after treatment of the product. Thus, it appears that progress in the application of radioactive isotopes for the direct treatment of infested grain will continue at a slow pace.

Accelerated electrons is another form of ionizing radiation which has possibilities for the control of pests in stored foods. This form of radiation is characterized by low penetration, high power and high dose rate. Cornwell and Bull (4) added an addendum to their paper to describe the advantages of electron accelerators over Cobalt-60 gamma radiation for the disinfestation of stored grain. Few workers, however, have taken up the challenge of investigating electron machines for insect control. The main emphasis has been on investigations of radiation produced by Cobalt-60. It is only recently that workers at the University of Mexico modified a Van de Graaff electron accelerator and incorporated it into a small-scale pilot plant for the irradiation of infested maize (3). This paper describes further studies of the use of an electron accelerator for the control of insect pests of stored foods.

MATERIALS AND METHODS: The pilot plant was designed for irradiation of infested maize at a rate of 200 kg/hr. The radiation source was a Van de Graaff accelerator which produced electrons with energies up to 1.5 MeV; a beam current of 30 μa was used. The electrons were accelerated inside a vacuum line and emerged as a beam of electrons which were scanned or defocused by a coil system along the horn extension at frequencies of 1 to 50 Hz.

The flow of grain from the storage tank into the irradiation zone was regulated by valves adjusted to irradiate a single layer of grain. A sloping wire screen caused the maize to tumble during irradiation to facilitate uniform bombardment by electrons. Dose was determined by adjusting voltage and beam current at various flow rates. The maize was moderately infested (45-75 beetles per kilogram) with *Sitophilus oryzae*, *S. zeamais*, and *S. granarius*; *S. granarius* predominated. Samples were sifted at weekly intervals to determine survival of adults.

The pilot plant was modified to determine the susceptibility of three strains of the red flour beetle, *Tribolium castaneum* (Herbst), collected from a silo, a granary, and a laboratory culture. The insects were irradiated in groups of 25 enclosed in 3 mil polythene envelopes, 4 x 5 cm. Four replicates were used for each irradiation dose. They were introduced into the irradiation zone by means of a pulley system operated by remote control.

After irradiation, the insects were placed in vials, each containing 25 grams of whole wheat flour and corn flour (1:1) and stored in a cabinet at 27.5°C, 65% R.H.

Irradiated eggs of a laboratory strain of *T. castaneum* were retained in the envelopes to observe the date of hatching. The newly emerged larvae were then transferred to the flour medium. Larvae, pupae and adults were transferred to flour immediately after irradiation and stored at 27.5°C, 65% R.H. Controls were subjected to the same handling procedures. Insect development and survival were assessed at weekly intervals for 8 weeks.

RESULTS: Survival of adults from infested maize at various times after irradiation was a function of the applied dose (Fig. 1). The 3 krad dose was ineffective because larvae and pupae formed adults after 6 weeks. After 4 weeks, doses of 15 and 25 krad suppressed emergence in most samples but 6 weeks was required for complete control at both these doses.

Experiments on the susceptibility of three strains of *T. castaneum* to irradiation showed variable results at 7 krad and 15 krad (Fig. 2). At 7 krad, the silo strain was less affected by irradiation after 3 and 5 weeks than the granary strain or the laboratory strain. At 15 krad the granary strain was less susceptible than the other two strains at 3 and 5 weeks after irradiation. At 25 krad all 3 strains were equally susceptible.

T. castaneum eggs, 0-2 days old, were highly susceptible to irradiation. Only 34% hatched and formed adults at 1 krad; no eggs hatched at 3 krad or at higher doses. About 74% of eggs in the untreated controls hatched and formed adults.

T. castaneum larvae were less susceptible than eggs. 98% of those irradiated at 3 krad formed adults and survived

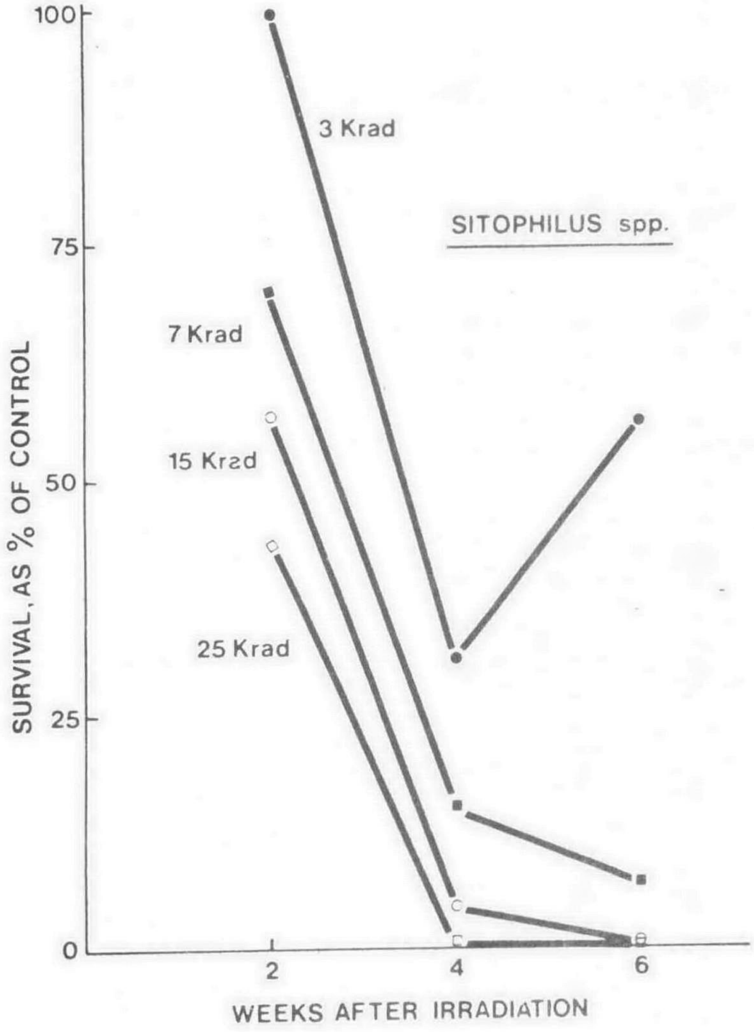

Figure 1.--Response of *Sitophilus* spp. to irradiation with accelerated electrons.

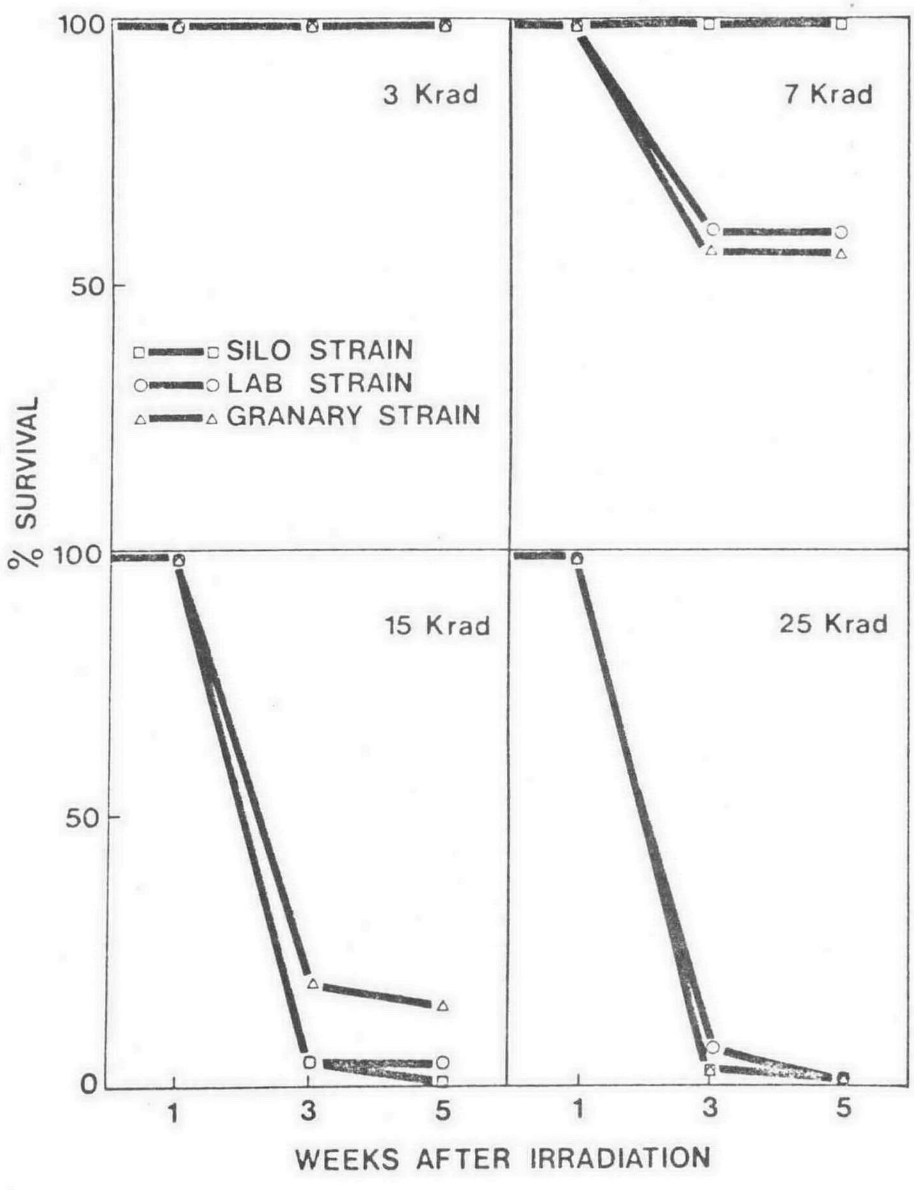

Figure 2.--Susceptibility of three strains of *T. castaneum* to irradiation with accelerated electrons.

(Fig. 3). The numbers that formed adults and survived at higher doses were inversely proportional to the applied dose. At 15 krad, larval development was completely suppressed. Studies with pupae indicate that they are more susceptible than adults to electron irradiation.

At 5 krad, 94% of irradiated *T. castaneum* adults survived for 8 weeks (Fig. 4); at 10 krad, 45% of the adults survived for 8 weeks; and at 15 krad only 2% survived for 8 weeks. Irradiation of adults at 25 krad resulted in complete mortality after 4 weeks. None of the adults irradiated at 5 krad to 100 krad produced viable eggs.

DISCUSSION: The pilot plant studies have shown that accelerated electrons are effective in controlling infestations of *Sitophilus* spp. in maize irradiated at a dose of 15 or 25 krad. However, a dose of 25 krad is required for complete control of *Tribolium castaneum* adults. Since *T. castaneum* adults are the most resistant stage, all other stages would also be controlled at 25 krad.

Differences were observed at 7 krad between a silo strain of *T. castaneum* as compared to a laboratory and a granary strain, both of which were equally susceptible at 3 and 5 weeks after irradiation. At 25 krad all strains responded similarly. Shipp (5) found that wild strains of *T. castaneum* were more susceptible to gamma irradiation than laboratory strains but he did not consider that this would result in any serious control problems at dosages that would be used for control purposes. Brower (6) reported that the response to gamma radiation of a DDT-malathion resistant strain of *T. castaneum* was similar to that of a susceptible strain. Our results showed that although differences among strains may be apparent at low doses, such differences may be of no practical consequence at doses of 25 krad which have been suggested as being suitable for control of stored product insects in wheat and flour (7).

Two factors have limited the use of ionizing radiation for insect control. First is the apparent high cost of installation and operation; secondly, are restrictions that may be imposed due to possible quality changes in the irradiated product. Both of these factors have adversely influenced the widespread acceptance of irradiation for the direct control of stored grain infestations.

Comparisons have been made between Cobalt-60 and electron radiation (4). Although various authors have reported little difference in the biological effects of radiation produced by gamma rays, x-rays and electrons (8), we have, in fact, found that up to 4 weeks after irradiation at doses of 7 and 15 krad, electrons are less effective than gamma rays against *Sitophilus* spp. (3). However, at 25 krad both types of radiation were equally effective 6 weeks after treatment.

It would appear that a commercially viable operation using a Cobalt-60 installation would require the use of an

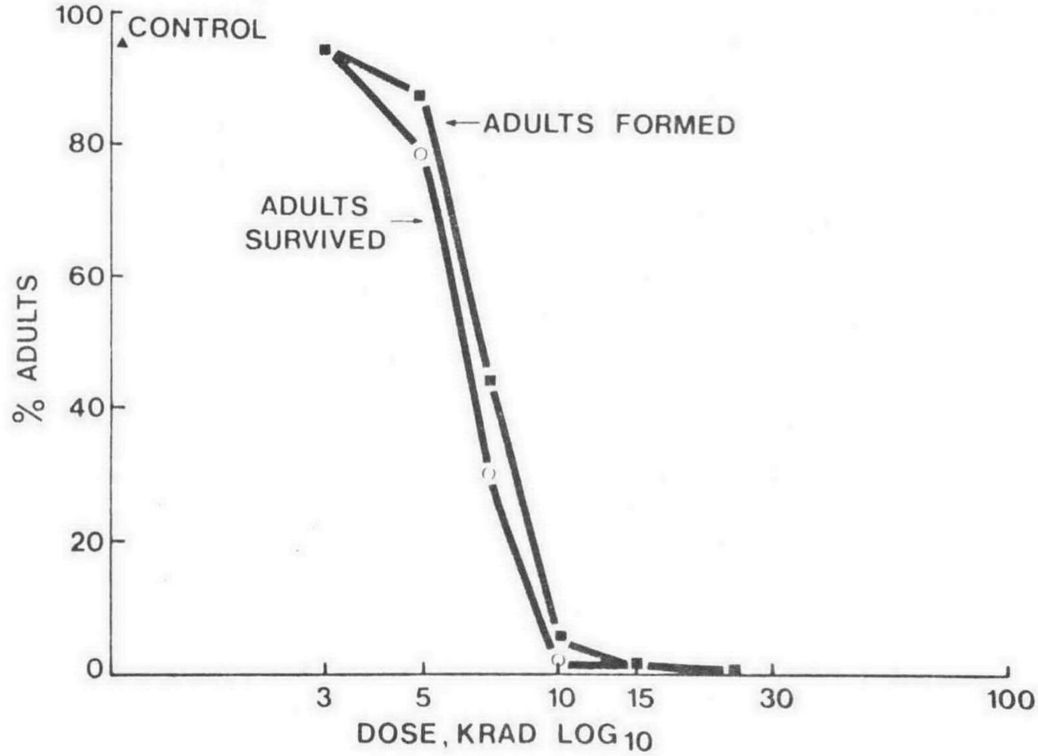

Figure 3.--Formation and survival of *T. castaneum* adults from irradiated larvae.

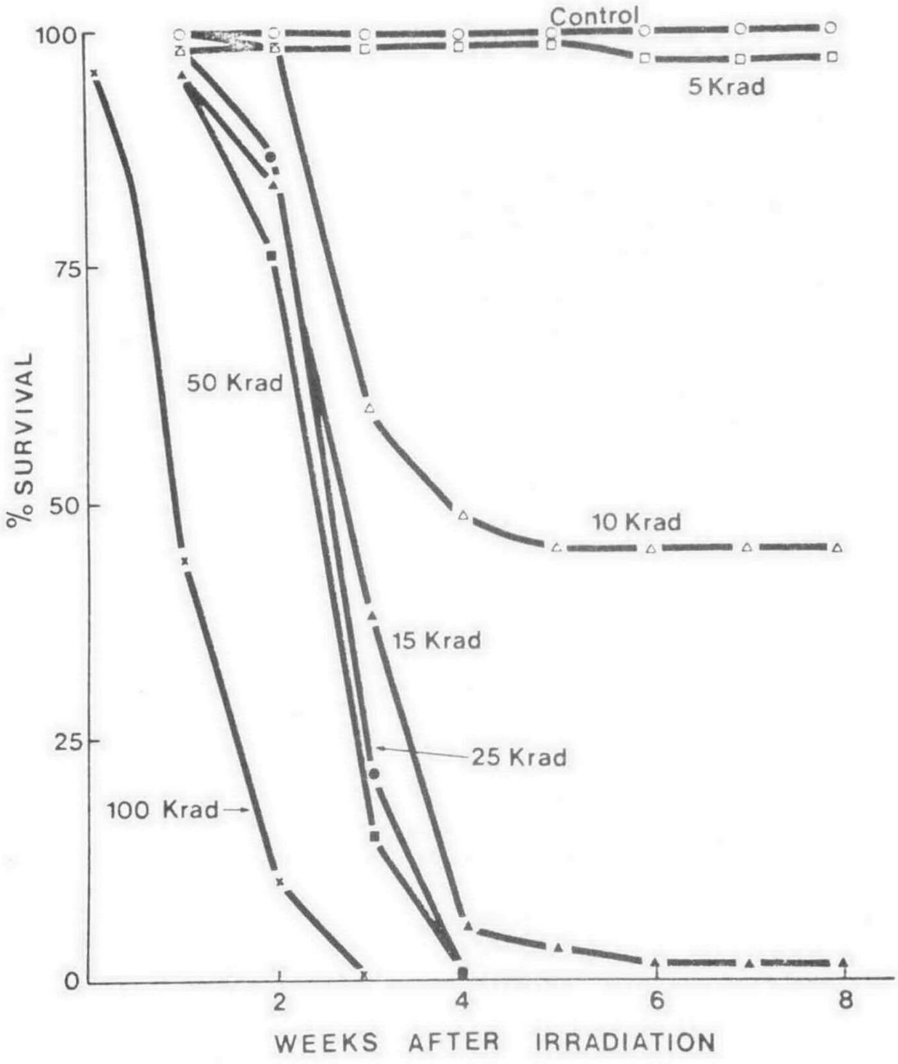

Figure 4.--Survival of *T. castaneum* adults exposed to various irradiation doses.

irradiation facility on a continuous basis (4). Furthermore, since the half-life of Cobalt-60 is 5.3 years, the source would have to be brought up to strength about every 10 months to maintain a satisfactory throughput (4). Since gamma radiation is attenuated in the grain medium according to the inverse square law, a lattice system or a series of baffles is usually employed to provide a uniform dose to the grain as it passes near the source to prevent either underdosing or overdosing. Alternatively, a conveyor system must be used with the object of exposing all parts of the grain to the radiation source.

By contrast, an electron accelerator produces a beam of high energy electrons which are magnetically scanned and diffused in a scan horn before emergence into the air or material to be irradiated. Because electrons have weaker penetrating powers than gamma rays, the material to be irradiated must be passed in front of the scanning horn in a thin layer that is no greater than 0.4 to 1.26 cm thick, for beam current energies of 1 to 3 MeV (9). Taking into consideration the power losses, the utilization efficiency is estimated at 45-55% (9).

Electron machines such as the Radio Dynamics Incorporated Dynamitron have throughputs of the order of 200 to 400 metric tons per hour which compares with the handling rates of commercial elevators. The unit requires less shielding than a Cobalt-60 source and installation is therefore less expensive. An important advantage of an electron accelerator over Cobalt-60 is that the equipment can be switched off when not in use to reduce radiation hazard and permit maintenance.

Operating costs of the Dynamitron for 7,000 hours per year are calculated at 17 cents per ton as opposed to 25 cents per ton for Cobalt-60 for a throughput of 200 tons per hour (10).

If it is assumed that corn is worth $100 per ton, a daily throughput of 3200 tons per day (i.e., 16 hr/day operation at 200 tons/hr) would move $320,000 worth of corn. Assuming losses of 2% without treatment, a fairly conservative overall figure, the daily losses would be $6,400 or $1,664,000 per year (for 260 days operation per year). The total annual cost of operation of the accelerator including depreciation, for 1975 was calculated at $235,000. If this is adjusted to $300,000 for 1978, the cost/benefit advantage would be about 5 to 1.

With regard to possible quality changes in grain caused by irradiation, there is a great deal of evidence already available to suggest that there are no deleterious effects (11). Scientists at the Institute of Physics, National Autonomous University of Mexico are presently collaborating with nutritionists at the University to determine possible changes in vitamins and amino acids of irradiated grain.

We are also mindful that the irradiation of infested grain does not solve all problems. Th grain must be stored in uninfested bins, ships' holds or containers to protect it from further infestation until it reaches its final destination. This implies that insecticides and good sanitary practices must be employed to supplement radiation disinfestation of the grain. We are confident that in identifying and recognizing the limitations of ionizing radiation, we may be in a better position to determine its proper role for the control of insects in stored grains.

REFERENCES:

(1) Cornwell, P. B., The entomology of radiation disinfestation of grain. Pergamon Press (1966) 236 pp.

(2) Tilton, E. W., Brower, J. H., Status of U.S. Department of Agriculture research on irradiation disinfestation of grain and grain products. In Radiation Preservation of Food. Int. Atomic Energy Ag. Symp. 166/49. Bombay, India (1972).

(3) Adem., E., Watters, F. L., Uribe-Rendon, R., De la Piedad, A., Comparison of ^{60}Co gamma radiation and accelerated electrons for suppressing emergence of *Sitophilus* spp. in stored maize. J. Stored Prod. Res. 14 (1978) 135.

(4) Cornwell, P. B., Bull, J. O., Insect control by gamma-irradition: An appraisal of the potentialities and problems involved. J. Sci. Food Agric. 11 (1960) 754.

(5) Shipp, E., Susceptibility of Australian strains of *Sitophilus* and *Tribolium* species to gamma radiation. In The entomology of radiation disinfestation of grain. (Ed. Cornwell, P. B.) Pergamon Press (1966), 131.

(6) Brower, J. H., Radio-sensitivity of an insecticide-resistant strain of *Tribolium castaneum* (Herbst). J. Stored Prod. Res. 10 (1974) 129.

(7) Brower, J. H., Tilton, E. W., Comparative gamma radiation sensitivity of *Tribolium madens* (Charpentier) and *T. castaneum* (Herbst). J. Stored Prod. Res. 9 (1973) 93.

(8) O'Brien, R. D., Wolfe, L. S., Radiation, radioactivity, and insects. Academic Press, New York (1964) 211 pp.

(9) Brynjolfsson, A., Factors influencing economic evaluation of radiation processing, FAO/IAEA (1971) 13.

(10) Radiation Dynamics Incorporated, Technical Report, T15 75-9 (1975).

(11) Vas, K., Food irradiation technical and legal aspects. Food and Nutrition 3 (1977) 2.