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Electronic Rodent Repellent Devices: A Review of Efficacy Test Protocols and Regulatory Actions

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ABSTRACT

A wide variety of sonic/ultrasonic, electromagnetic, mechanical/vibrational, and electrical barrier devices have been researched, developed, and marketed over the past 30 years. Although there are currently no Environmental Protection Agency (EPA) registration requirements, human safety and repellent efficacy test data for these devices may be requested whenever they are commercially manufactured, marketed, and retailed. This chapter reviews research reports and data sets for devices operating at selected frequency ranges, pulse rates, duty cycles, and intensity levels. It also describes examples of laboratory and field test protocols as well as recent EPA and Federal Trade Commission (FTC) regulatory actions in relation to the compliance requirements of the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) and provisions of the Federal Trade Commission Act (FTCA), respectively. State regulations may be imposed on manufacturers and retailers of repellent devices when they are carried as stock items through local stores or through mail-order service companies. Controlled efficacy test protocols have indicated only marginal repellency effects with six commercial ultrasonic devices (i.e., 30-50% reduction in movement activity), and rapid habituation (i.e., no significant repellency effects beyond 3 to 7 days of exposure). An analysis follows of research and development attempts to reduce habituation effects, to incorporate and integrate ultrasonic devices into traditional rodent control methods and to improve efficacy.

KEY WORDS

rodent repellent, electronic device, efficacy, regulations

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HISTORICAL BACKGROUND

Early civilizations including the ancient Chinese used a number of mechanically operated sensory repellent devices to ward off rodent infestations in agricultural crops and in buildings. Many were operated by wind and water power; and they generated movement, sound, and vibrational repellent mechanisms. Such devices have always appealed to homeowners and farmers as a way to safely and easily protect stored food from consumption and contamination by rodents.

The use of sonic and ultrasonic stimuli to repel or control rodents stems, in part, from a phenomenon known as the audiogenic seizure response. As first described by Donaldson (Lehmann and Busnel 1963) in 1914, the response involves physiological stressor signs shown by rats when stimulated by intense sonic and ultrasonic energy such as that generated by jangling keys. Several hundred reports have been published related to the effect which is characterized by (1) a latent period of an initial startlejump reaction followed by rapid movements of the rat around in a cage; (2) rapid, violent, and nondirected running; and (3) clonic-tonic convulsions, followed by (4) a complete recovery or death. The reaction has been observed in rats, mice, rabbits, chickens, dogs, and goats. Repeated seizures induced by these means can lead to cerebral hemorrhages with certain mouse strains being extremely susceptible to this lethal effect. In rats, age is a critical factor with the peak reaction sensitivity occurring at 3 weeks and almost no sensitivity at 20 months. In mice, maximal sensitivity to the reaction occurs at around 30 days, thereafter decreasing through 50 days of age.

Frings (1948) suggested the use of ultrasound as a means of repelling wild rodents based upon the audiogenic seizure phenomenon. Twenty years later, however, Greaves and Rowe (1969) noted that only two scientific papers had been published that were aimed at assessing sonic-acoustic or ultrasonic stimuli as a means of repelling rodents. Marsh et al. (1962), in one of these reports, described negative results with a 15-16 kilohertz (KHz) generator producing less than 100 decibels (dB) in three grain elevator structures. Likewise, Sproke et al. (1967) were unable to demonstrate consistent rodent repellency using sonic/ultrasonic generators in the 1.8-48 KHz range at 60-140 dB.

Herbert Frings and his wife, Mable, also had a strong interest in acoustic avian repellent devices and alarm/distress call recordings from birds (Frings and Frings 1963). They made several contributions to the science of bioacoustics in terms of evaluating a variety of distress and alarm call recordings as a means of repelling large congregations of bird flocks in roosts and in agricultural crops. The idea of using the recordings from distressed rodents, however, did not receive a corresponding degree of attention. Only Sprock et al. (1967) published an attempt to assess recorded distress calls of a rat killed by a skunk as a means of repelling other rats. This distress call recording was described as having more promise" than other generator systems for repelling rodents. On the negative side and in terms of practicality, however, human acceptance of rat sounds in work or home environments would probably be equally repellent to people! Also, in terms of human acceptance, some commercial manufacturers of electronic repellent devices have, in fact, developed multiuse devices that can be programmed to emit audible sonics for bird repellency outdoors and ultrasonics for rodent repellency in structures. Of course, avian species are not sensitive (Woronecki 1988) to the traditional ultrasonic range (i.e., > 20 KHz) and

rodents are insensitive to low frequency audible sounds (i.e., < 1 KHz) (Kelly and Masterton 1977).

Putative mechanisms of action for ultrasonic rodent repellency with commercially manufactured devices have included pain, interference with communication, disorientation, or fear-inducing danger signals. Neither commercial bird control nor rodent control sonic/ultrasonic devices have been developed that are capable of delivering "supernormal" stimuli that could exceed natural repellency generated by conspecifics or predators (Bomford and O'Brien 1990). As indicated, audible rodent distress or alarm cries would most likely be rejected in the work or home environment. Ultrasonic devices capable of producing pain (i.e., > 140 dB), would (1) exceed the OSHA Standards for 8-hr workplace exposures in humans, (2) probably lead to deafness in short order in the rodent target species, (3) produce objections related to animal welfare and humaneness, and (4) be effective only over very limited areas due to the rapid decrement in intensity of ultrasound as the distance from the source is increased.

Several agencies have responsibility for regulation and control of the sales and marketing of commercially manufactured electronic pest control devices. Although the devices are not required to be registered or certified, they must conform to the requirements of the Federal Insecticide, Fungicide, and Rodenticide Act (40 CRF 162.10), as monitored by the EPA, and the Fair Trade Act, as monitored by the Federal Trade Commission (FTC). In addition, State Departments of Agriculture (e.g., as in Indiana and Colorado) may require efficacy data before electronic repellent devices are directly marketed or distributed for retail sale in stores.

TYPES OF DEVICES

Sonic

These units have been mainly manufactured and marketed to deal with bird problems in terms of crop damage and roost buildups. Devices are mainly designed to frighten birds with explosive charges, recorded distress/alarm bird sounds, or electronically mimicked bird sounds. Intensity levels that are sufficient to repel birds in the field from crop or roost sites are largely unknown (Bomford and O'Brien 1990). The explosive charge type of device, however, can be capable of producing pain-level sound intensities if birds are in reasonably close physical proximity to the source. The recorded or simulated bird sound devices are operated at levels designed to signal "danger" to the birds in order to generate a "contagious" exodus even though no predator or other threat is ever visually observed by the birds. Some devices have added visual cues and movement to enhance the "fright-inducing" stimulation for bird flocks (Stickley et al. 1995).

Ultrasonic

A vast array of devices that operate above the human-hearing frequency range have been manufactured and marketed as electronic pest control "tools" that can prevent rodent invasions, repel rodents in existing infestations, or enhance conventional rodent control methods (e.g.,

baiting and trapping) by influencing rodent movements to improve efficacy in an "integrated" approach. Almost all applications recommended for ultrasonic rodent control devices are in structures (e.g., homes, businesses, warehouses). Since the devices are practically inaudible to humans with their output frequencies above the 20-KHz range, they have been marketed as a Usilent sentry" to guard against rodent problems with no annoying noises in the home or workplace. Most devices generate ultrasonic output in the 70-140 dB range of intensity as measured 12 inches (30.5 cm) from the transducer. Similar to sound, ultrasound loses intensity rapidly as one moves farther from the source. The ainverse square law" defines this intensity drop as inversely proportional to the square of the relative distance. For example, a sound or ultrasound stimulus measured at a distance of 12 feet from the device is going to be only one-fourth as strong compared to the strength at a distance of 6 feet from the same device. Ultrasound also has the disadvantage of being rapidly absorbed in its energy level by soft-textured materials (e.g., cloth, insulation), minor obstacles in its path (e.g., paper, cardboard), and corners or angles out of the direct path of the device's output energy. Typical electrical power requirements for the devices are a few watts of 110 VAC, and they come packaged with mounting bracket hardware, modern integrated circuitry, and instruction manuals describing their use and proper installation procedures.

Electromagnetic

These units for controlling pest species including insects and rodents were offered for sale during the 1970's. These devices were advertized as capable of generating their own magnetic fields or distorting the earth's magnetic fields in such a manner that animal pest species (but not "beneficial species") stopped eating, drinking, and reproducing. As preposterous as this premise sounds, many units were sold to unsuspecting, trusting customers. Despite the fact that no efficacy data existed to support the electromagnetic pest control concept or theory, there were 30 manufacturer-distributors of these devices in 1977 with an annual sales volume of several million dollars. Laboratory efficacy tests on the control of Norway rats by Rex Marsh and Walter Howard at the University of California, Davis (Environmental Protection Agency 1980) and field efficacy tests on the control of pocket gophers in Nevada by John O'Brien (Environmental Protection Agency 1980) indicated definitively that such devices have no effect on feeding, drinking, mating, or infestation patterns. Legal actions by EPA resulted in fines to manufacturers for misbranding such products. In addition, court orders have been issued against manufacturers. Few, if any, electromagnetic pest control devices are marketed currently.

Vibration and Shock

Other electrically operated devices that have been marketed for rodent control include vibrational devices designed to frighten pests from buildings or agricultural crops. Efficacy for such devices has yet to be demonstrated for any application. Electrical barriers and electrical shocking devices have been used to control rodent problems where baiting and trapping have

failed. These devices are considered to be safe and effective, but limited in area coverage due to relative cost of electrical barrier fencing materials.

PARAMETERS OF DEVICE OUTPUT

Frequency

Sonic versus ultrasonic devices are defined on the basis of human auditory sensitivity (i.e., audibility), with the normal frequency range of hearing for humans spanning 20 Hz to 20 KHz. Devices that produce frequencies of output that are predominantly above 20 KHz are therefore considered to be "ultrasonic." Many sources of sound, of course, also produce ultrasonics including human speech, movement, and mechanical/motorized equipment operation. Ultrasonic or sonic devices can be made to vary in an infinite variety of frequency patterns, and it is generally accepted, based on related physiological and behavioral data in rodents, that slower habituation/adaptation to the stimulus occurs with varied frequencies rather than pure, constant (sine wave frequency) pattems.

Pulse Rate

Automatic activation of the device in "on" and "off" cycles is a common feature with most generators. The number of stimulus pulses or "spikes" of sonic or ultrasonic energy can be made to vary over a given time period. For example, a device that produces 1-sec pulses once every 3-sec interval would have a pulse rate of 20 per min (i.e., 60 sec/ 3 sec = 20).

Duty Cycle

Devices vary in their proportion of activation versus nonactivation times. In the previous example, since the device is active for 1-sec over each 3-sec interval in a continuous pattern, the duty cycle is 0.33 (i.e., 1 sec/3 sec = 0.33). Duty cycles that are relatively low along with low pulse rates in this example would probably necessitate that intensity levels be detected using a "peak hold" type of sound pressure level dB meter. Otherwise, the meter movement would probably be too slow to track the "peak" output reading for each individual pulse.

Intensity

Electrical shocking devices or barriers are generally monitored or measured for intensity of stimulation using the parameter of electrical voltage with field operational devices. In laboratory tests with rodents, using foot shock, for example, current may be varied and measured to control shock intensity with voltage held relatively constant. The socalled "matched impedance" shock

devices accomplish this by placing a very high resistance in a circuit parallel with the animal to be shocked so that most of the voltage, which can vary drastically as the animal moves, is used in the impedance matching network. Voltage changes are thereby "swamped" or smoothed out so that current becomes the main parameter controlling shock intensity.

Sonic and ultrasonic device intensity is measured most commonly in decibels, an absolute reference level which can be related to the human audibility threshold at midfrequency range (i.e., 20 N/m at 1,000 Hz). The decibel or dB scale is a logarithmic measure (i.e., similar to the Richter scale for earthquake activity). When measuring dB levels with a sound pressure level (SPL) meter, care must be taken to point the microphone detector directly toward the sound/ultrasound source at animal ear level above the floor of the structure. The meter scale position as well as any frequency filtration that may have been imposed should be recorded along with the dB levels. For precise measures, a calibrating piston phone device should be used to check meter calibration before each series of readings is taken. Also, the detecting microphone, meter, and filter units should be calibrated and adjusted every year or two to assure accuracy of the readings. Internal laboratory standards are adequate to maintain calibrations between commercial service calibration intervals, and an independent check with a second SPL meter is desirable to assure that the instrument is stable and within sensitivity specifications at different frequencies.

As previously stated, point source stimulus energy level falls off rapidly in intensity over a relatively short distance according to the inverse square law. This becomes a major consideration when one attempts to cover large areas with commercial or experimental devices. Devices that generate alarm/distress signals will still remain effective with greatly reduced intensity as long as they are perceptible by the pest rodents. Devices that generate pain effects, however, will become ineffective over relatively short distances due to the inverse square law.

Directivity

The sound path becomes more linear as frequency is increased. In the ultrasonic range, the energy does not normally "bend" around comers. Energy at these ultrasonic frequencies, however, may be reflected around blind comers if hard (e.g., metal, concrete) surfaces are available on the walls and floor of the structure. Lower frequencies of sound, on the other hand, are more efficient at penetrating dense objects and bending around objects or corners. Directivity of sound is also related to sound localization by animals. More specifically, the more directive the sound signal at the higher sound frequencies, the easier it becomes for the animal to detect the position from which the sound came (i.e., sound localization). Hence, rodents can more quickly locate escape or avoidance routes away from ultrasonic as opposed to sonic stimuli. At high frequencies, the animal's head can serve to block or absorb some sound energy to create a disparity in intensity, time, and phase angle between the two ears. Sound localization reaches a pinnacle among the bat and porpoise echo-locating species, and it has become poorest among some burrowing rodent species such as the pocket gopher.

Safety

Human safety is a major consideration when utilizing any sound, electrical shock, or light source as a means of repelling pest rodents or other animal species. The Occupational Safety and Health Administration (OSHA) standards for exposure are based on an 8-hr work day and are in the 140-dB range for sonic and ultrasonic devices. It should be noted, however, that even an 80-dB sound of pure continuous frequency, such as those used to track wildlife with radiotelemetry equipment, can produce permanent tone deafness if exposures persist over several hours on each of several days. Variable frequency sound is much less damaging at the lower intensity levels.

Safety margins as well a species selectivity may be improved by selection of frequencies that are within the range of optimal sensitivity for the rodent species to be controlled. Attempts have been made to control bats in buildings using recorded ultrasonic echolocation cries from other bats, but they were unsuccessful at "jamming" the bats' navigational systems. The animals can change frequency modulation (FM) characteristics of their cries to avoid these interference attempts.

GENERAL APPLICATION OF EFFICACY PROTOCOLS

Laboratory

Despite the constraints and limitations of cage or test chamber confinement, laboratory evaluations of nonchemical repellents can serve as a very useful starting point for further development. Industrial chemists and physicists do not conduct large-scale experiments with new processes or products in manufacturing plants without a great deal of "bench testing" and parameter evaluations using small-scale models, test batches, and simulations. It can be argued that wild pest species are extremely variable in their responsiveness to the same stimuli and will show altered behavioral and physiological responses under confinement stress, either exaggerating or greatly diminishing their natural responsiveness. Nonetheless, many individual animal responses such as head movements, jumping, running, and escape can be examined in greater detail in the laboratory with extraneous factors controlled and stabilized. Some useful laboratory evaluation methods have involved studies of the audiogenic seizure response (Frings 1948), cued-escape-avoidance of ultrasonics (Belluzzi and Grossman 1969), and comparisons with "standard" laboratory pain stimuli such as electrical shock or thermal heating.

Heart rate acceleration and food-reinforced lever-pressing rate reduction are often used as dependent measures for "fear" or disturbance in laboratory experimental comparisons (e.g., Thomas et al. 1981, Thompson et al. 1979). Escape or avoidance responses can be monitored using treadle-switch chambers, proximity detectors, or photocell devices (e.g., Kent and Grossman 1968). A variety of other, individual animal test regimes can be of use to describe and define what constitutes an effective repellent stimulus within the laboratory test setting. Stimulus parameters are then varied systematically to optimize repellent effects. Of major importance in all laboratory studies are the choices of dependent measures and independent stimulus variables

to be evaluated or controlled. Area repellency, for example, needs to be examined within the context of species-typical territorial behavior, interspecific and intraspecific competition, and predator-prey interactions. More often than not, all of these influences cannot be simulated or adequately defined in laboratory or even enclosure situations. Social factors, such as rodent density and food or breeding competition, can greatly alter the outcomes in such evaluations and are more suitably studied under enclosure test conditions.

Enclosure

Large indoor test environments and outdoor pen facilities in the field or at research centers can be used as rodent test enclosures. Animals may be tested singly or in small groups to study social interaction effects on repellency. Repellent sounds that represent signals for a group of rodents may generate "contagious" effects not detectible in small laboratory test chambers or with individually tested animals. Interconnected enclosures (e.g., Sprock et al. 1967, Shumake et al. 1982) allow animals to escape from repellent stimuli or to totally avoid the area. Rodents usually start "reality" testing and move back into the previously experienced "repellent area" within a matter of days or weeks.

Some of the most frequently used measures of animal presence in enclosures include: general activity, food consumption, water consumption, animal tracking board activity, fecal pellet counts, urine spots, and nesting activity signs. An underutilized measure that may have applications to both attractant and repellent assessments, involves a simple count of the animals found in each enclosure after some period of elapsed time. The initial approach or avoidance into the enclosure containing an attractant (Jolly and Jolly 1992) or a repellent stimulus has been demonstrated to have greatly improved correlation with field data when compared to other measures (e.g., general activity or food consumption). In some instances, only a portion of a given local population may show repellency which may be related to sensory thresholds, individual differences in habituation, or previous exposure experiences.

Other difficulties that can cloud enclosure results include the problem of identifying which specific individual rodents were repelled. Extreme sensitivity or insensitivity among different individual rodents in enclosures could provide clues as to what controls adequate repellent efficacy as found in certain situations and lesser degrees of repellent efficacy in others.

Finally, the statistical analysis that can be applied to enclosure tests will be a function of the number of enclosures available, capabilities of obtaining individual-animal data within each enclosure, and replication capabilities of the test system. Often, only nonparametric tests of significance can be applied to enclosure data due to the relatively small number of observations made on a small number of enclosures.

Field

Efficacy of an electronic rodent repellent device as demonstrated or supported statistically in field structures or in open field plots is, of course, the ultimate requirement for identifying practical and useful products. All the laboratory and enclosure evaluations together may indicate

some high level of sustained repellency; but, if these effects do not appear consistently with free ranging rodents in actual rodent infestation conditions, the device should not be on the market.

Field test measures most often involve animal counts (e.g., using direct observation, video taping, etc.), tracking counts, food consumption or disturbance, fecal pellet counts, or rodent activity detection. Ramifications and detailed requirements for field efficacy evaluations are described in more detail in the next section in the context of regulatory agency protocol review and approaches to efficacy testing.

SPECIFIC PROTOCOLS

EPA/Fish and Wildlife Service (FWS) Enclosure Test Protocol

An enclosure test protocol designed to simulate some of the elements of a natural "field" rodent infestation, but in a temperature and light-cycle controlled structure, with confined groups of wild Norway rats has been reported previously (Shumake et al. 1984). The building had 69-m^2 floor space with a concrete floor and brick walls lined with sheet metal to prevent rat climbing. Two rooms each consisting of 32.5-m^2 floor space were separated within the building by a 3.5-m^2 central "harborage" area containing food, water, and wood shelter boxes. Twelve wild Norway rats (*Rattus norvegicus*, six males and six females) were released into the central area and allowed to adapt socially for a few days before adaptation to the two test rooms. Each room could then be entered by rats through sound/ultrasound baffling ports, and each room was "baited" with 30-32 small paper packets each containing 14.5 g of whole rolled oats at a density of 1/m^2. Rat activity in each room was monitored with photocell sensors, infrared closed circuit television, and packet damage or removal for several days until activity and damage stabilized in each room. Measures were taken every 3- to 4-day interval over 1-4 weeks. Each device was mounted above the floor in one of the rooms. Sound level meter readings were taken above each oat packet location with a type 4135 free field condenser microphone connected to a Bruel and Kjaer type 2209 sound level meter at rat ear level (5 cm) above the concrete floor. Fresh ground food (No. 5001 Purina Laboratory Rat Chow) in the central area and freshly prepared oat packets in each test room were made available to the animals at 3- to 4-day intervals throughout the test. Data were collected midday (1200 to 1400 MST) and consisted of (1) photocell counts (2) counts of destroyed/removed packets (3) oat groat consumption at each packet location, and (4) ground laboratory chow consumption. After a 1-week baseline period and then activation of a sample ultrasonic device for 2.5 weeks, the animals were confined to the central area for 4 days. The procedure (after a second 1-week baseline with no ultrasound and free access allowed into both rooms) was repeated but with the device mounted on the far wall in the other room. A direct replication of the above entire procedure was then conducted with a new group of wild Norway rats. Packet oat consumption data for the baseline versus weeks 1 and 2 of ultrasound activation were analyzed using repeated measures analysis of variance. Other data sets were evaluated graphically and with summary tables.

Enclosure efficacy test results for individual rat groups are shown as an example in Table 1. The main dependent measure, rolled oat consumption, for each packet location at the 3- to 4-day intervals indicated a possible marginal effect with the "Pest Free" device on week 2, but there was no consistency through week 3, and a drop in food consumption also occurred for the control room on this last week of the test. Other devices showed no consistent effects either on a weekly basis or in comparison to control consumption levels. Photocell activity effects were similar with some indications of reduced activity in the ultrasonically treated room (30-50%) for the first 3 days during the first week. Overall, the enclosure test results indicated partial repellent effects that were not sustainable. One could argue that the lack of repellent effect stemmed from the rats having insufficient alternate space to escape from the "painful" or "fear-inducing" properties from these six commercial devices. This criticism, however, is not valid when the field data on these same devices are considered in the next section.

EPA/FWS Field Test Efficacy Protocol

Each of the six devices tested in the enclosure protocol underwent efficacy testing in at least four minimally disturbed field test structures (Shumake et al. 1984) that were naturally infested with rodents. These structures were of metal or wood construction, with concrete, metal, wood, or earthen floors, and varied in size from 8.9 to 196.5 m^2. Efficacy was assessed using three successive 3-week (baseline, ultrasound activation, return-to-baseline) periods. For some devices, when weather patterns were stable, a second 3-week ultrasound activation period was conducted. Most of the test evaluations consisted of placing 4-14 vinyl floor tiles (12 in or 929 cm^2) coated with sifted baking flour on the floors of the structures, and monitoring the extent of rodent tracking two times per week. A wire grid template that divided the tiles into nine sectors (103 cm^2 each) was used to roughly quantify the extent of tracking on each tile. Ultrasound levels were measured at each tile location within the buildings before devices were activated. Resulting data were analyzed with tabular presentations, and where feasible, by nonparametric statistical analyses (Chi-square, Wilcoxon-ranked sum).

Results for the six sample devices described previously are presented for steel-sidewall constructed structures varying in size from 16.4 to 196.6 m^2 in Table 2. As indicated, only the Transonic II device operating with a sawtooth sweep of frequencies between 20 and 100 KHz showed some possible effect on rodent (field mouse) activity during the ultrasound period with the mean number of sectors per tile disturbed being reduced from 7.8 to 2.5 and then returning to 7.2 during the recovery interval. The field mice (*Peromyscus maniculatus*) were not, however, eliminated from the structure during the ultrasound activation period, and 75% of the tiles continued to be tracked during this 3-week interval. One can argue that, with a small sample size, this "effect" was also not necessarily related to ultrasound. No change was noted for four other wood structures instrumented with the Transonic II device.

Based on these and other field test data, the six commercial ultrasonic devices were found to have insufficient repellency to merit any usefulness in rodent pest control applications. This conclusion holds for both preventive and corrective applications, and for those applications that include combining ultrasonic rodent repellent devices with baits, traps, or glue boards. A wide

Table 1. Simulated Field Test Results for Rolled Oat Consumption (g/packet) with Six Commercial Ultrasonic Rodent Repellent Devices Tested under Controlled Conditions with Groups of 12 Wild Norway Rats

Device Brand Name	Ultrasonic[a] Output Characteristic	Ultrasound (U) vs. Control (C) Room Data	Baseline[b] (Week 1)	Ultrasound Activation (Week 2)	Ultrasound Activation (Week 3)
Pest Free	90–95 dB	U	9.10 ± 5.09	6.28 ± 5.07	13.48 ± 2.92
	30–62 KHz	C	11.51 ± 3.51	12.48 ± 3.12	8.78 ± 4.17
	Random sweep generated				
Sonitron	110–111 dB	U	11.20 ± 3.51	8.20 ± 4.52	11.80 ± 1.83
	Peak output at 20 Khz	C	11.70 ± 2.62	14.20 ± 1.27	12.80 ± 1.21
Rat-I-Cator	120–122 dB	U	13.50 ± 2.33	11.90 ± 3.84	13.70 ± 2.15
	3-ultrasonic frequencies (not identified)	C	13.60 ± 1.86	12.10 ± 2.81	11.80 ± 2.84
Sonaray	109–114 dB	U	14.40 ± 0.02	13.80 ± 1.80	14.10 ± 1.40
	Peak output at 25 KHz; 40% duty cycle	C	12.00 ± 3.39	13.70 ± 1.93	13.10 ± 2.66
Ultra*Shield	103–105 dB	U	11.00 ± 3.72	12.90 ± 2.62	14.50 ± 0.00
	26–60 KHz With sweep rate of 3 Hz	C	12.50 ± 3.16	14.50 ± 0.00	14.50 ± 0.00
Transonic II	78–81 dB	U	14.35 ± 0.53	14.17 ± 1.19	14.16 ± 1.29
	20–100 KHz Continuous sweep	C	13.65 ± 2.22	14.20 ± 1.35	14.19 ± 1.35

[a] Measured at 30.5 cm from the devices with a Bruel and Kjaer type 2209 sound level meter with a 6.3 mm free-field condenser microphone.

[b] Values are $\bar{x}$ ± SD for the 2 values taken each week for 30 to 32 packets located in ultrasound and control rooms.

range of dB levels and frequencies were evaluated with the efficacy protocols; and strong, sustained repellent effects were never detected. The EPA has pursued legal actions in terms of FIFRA violations of misbranding and false advertising/efficacy claims against manufacturers of these listed devices. None have been currently marketed since fines were levied and a court order was issued by EPA.

Canadian Pest Control (CPC) Field Efficacy Test Protocol

Electronic devices for use in rodent and insect control in Canada must be registered (PCP Certified) as part of the Canadian Pest Control Products Act and Regulations (Laidlaw 1984). A minimum of 10 field test sites that contain existing rodent infestation is required. Due to unpredicted events such as a change in property owners or the initiation of other rodent control methods, it is advisable to select a few extra sites so that ultrasonic evaluations are obtained with unconfounded data for at least 10 sites. Baseline monitoring of each building site is to be conducted for 7 days with rodent tracking boards. Other acceptable measures of rodent activity include food consumption, fecal dropping counts, counts of tunnel openings after closure, and candy drop removal. Two measures are required for each location. For a 3- to 6-week period, ultrasonic (or other electronic) devices are installed and operated with the monitoring measures continued each day. The devices are then turned off so that daily activity measures can be taken for another 2-week period (return-to-baseline).

Raw data are submitted to the Pesticide Division for a review by the evaluation officer. If it is determined that sufficient and consistent repellency has been verified at the field test sites, the evaluation office will issue a registration number with the stipulation that the device must be labeled for restricted use (i.e., "For use with, and in conjunction with normal control practice"). Several devices have been registered for sale in Canada under the PCP Field Protocol, after manufacturers provided their own field efficacy data. As long as device buyers are satisfied with the product and/or are unaware of a problem that develops with efficacy, the devices remain registered throughout the Canadian Provinces.

Modified EPA/FWS and PCP Field Test Protocol (ASTM STP 1055)

An alternate field test protocol Jackson et al. 1989) has been designed to verify that ultrasonic devices can alter rodent behavioral patterns to "enhance" efficacies of other rodent control methods and to prevent them from entering "protected areas" in structures. This design requires that the individual structures be large enough to allow for some locations (rooms or areas) to be ultrasound-treated while other locations are left without ultrasound treatment. This is analogous to the EPA/FWS Enclosure Test Protocol previously described, but with a natural rodent infestation in a structure. The two kinds of conditions operating simultaneously could involve two separate buildings, but both should contain comparable resources (i.e., food, water, shelter).

The Modified Protocol, basically in agreement with both of the other Field Protocols described previously, requires either food consumption measures or tracking tile measures of rodent activity,

Table 2. Field Test Results for Tracking Tile Indices of Rodent Activity in Metal Buildings

Device Brand Name	Ultrasonic[a] Output Characteristic	Baseline[b] (Week 1–3)	Ultrasound Activation (Week 4–6)	Recovery (Week 7–9)
Pest Free[c]	90–95 dB	22.66 ± 4.72	21.33 ± 1.52	23.66 ± 0.57
	30–62 Khz	(4.33 ± 0.92)	(5.03 ± 0.66)	(5.41 ± 0.20)
	Random sweep generated			
Sonitron[d]	110–111 dB	4.00 ± 0.00	4.00 ± 0.00	4.00 ± 0.00
	Peak output at 20 Khz	(9.00 ± 0.00)	(9.00 ± 0.00)	(9.00 ± 0.00)
Rat-I-Cator[e]	120–122 dB	12.00 ± 0.00	12.00 ± 0.00	12.00 ± 0.00
	3-ultrasonic frequencies (not identified)	(8.78 ± 0.30)	(8.67 ± 0.47)	(8.97 ± 0.05)
Sonaray[e]	109–114 dB	11.66 ± 0.57	11.66 ± 0.57	11.66 ± 0.57
	Peak output at 25 Khz; 40% duty cycle	(6.49 ± 0.36)	(7.37 ± 0.64)	(7.52 ± 0.70)
Ultra® Shield[e]	103–105 dB	12.00 ± 0.00	12.00 ± 0.00	12.00 ± 0.00
	26–60 KHz With sweep rate of 3 Hz	(8.90 ± 0.10)	(8.80 ± 0.20)	(8.70 ± 0.10)
Transonic II[f]	78–81 dB	8.00 ± 0.00	6.00 ± 1.63	7.66 ± 0.47
	20–100 KHz Continuous sweep	(7.83 ± 1.65)	(2.50 ± 0.88)	(7.21 ± 1.43)

- [a] Measured at 30.5 cm from the devices with a Bruel and Kjaer type 2209 sound level meter with a 6.3-mm, free-field condenser microphone.
- [b] First values are $\bar{x}$ ± SD number of tiles tracked per week, and second values in parentheses are $\bar{x}$ ± SD number of sectors per tile tracked per week.
- [c] Field test site was a 196.6-m^2 steel storage building.
- [d] Field test site was a 16.4-m^2 steel grain storage structure.
- [e] Field test site was a 183.9-m^2 steel farm equipment storage building.

but chalk dust has been recommended rather than baking flour. Other suggested dependent measures include movement detectors or fecal pellet counts. In agreement with assumptions of the PCP Protocol, the Modified Protocol supports testing devices for their potential to enhance the action of toxic baits, traps, or glue boards. The Modified Protocol is designed for a temporary use of devices to improve efficacy of traditional rodent control tools. It does not, however, measure improved efficacy (i.e., increases in trapping counts and/or bait consumption levels). Without direct measures, the degree of increased efficacy can not be estimated.

COMPARISON OF PROTOCOLS

As indicated in Table 3, each of the three Field Test Protocols (EPA/FWS, PCP, and ASTM STP 1055) is similar in terms of measures of rodent activity and the overall strategy for assessment (pre-, during, and post-ultrasonic device activation periods). A second activation test period gains an advantage in terms of testing the question of whether or not the rodents will be consistently repelled on a second occasion in the same structures. None of the proposed or accepted Test Protocols provides a direct assessment of efficacy when devices are used in conjunction with conventional trapping or rodenticide baiting. There are too many variables to consider when lethal and nonlethal control methods are to be assessed simultaneously in a confounded design. Studies could be run to assess a nontoxic bait consumption increase and increases in live trap success rates in an attempt to indicate whether or not there are any short-term gains to be expected with conventional control methods when ultrasonic repellent devices are added to an "integrated pest management" program. Data from the EPA/FWS Enclosure Protocol, designed to simulate some aspects of field test conditions, did not indicate any major increases in rolled oat bait packet consumption with the six tested devices, and only 1 week increases in rat activlty (photocell breaks) in the nonultrasound-treated room were observed.

For all Field Test Protocols, it can be a major task to locate property owners who are willing to have rodents continuously present in their homes, businesses, or other properties for an extended period. Another uncontrolled factor that makes assessment quite variable is the wide range of rat or mouse infestation densities that can increase, stabilize, or decline in a given location due to unstable rates of reproduction, mortality, immigration, and emigration. Densities are particularly prone to instability when the animals are relying on food and/or water sources that may be external to the structure. These other uncontrolled factors are, of course, often a problem for efficacy assessment of any rodent control method in field test structures.

CONCLUSIONS AND FUTURE RESEARCH

Research and development on ultrasonic and other electronic rodent pest control devices are generally considered low priority endeavors. Research mainly consists of testing commercially available products (Bomford and O'Brien 1990) and is generally only initiated after consumer complaints to regulatory agencies begin to mount. There appears to be a high level of agreement among agencies, manufacturers, and individuals on what needs to be measured for tests of device

Table 3. Summary of Available Protocols to Evaluate Ultrasonic Rodent Repellent Devices in Structures

Type	Agency/ Organization References	Rodent Activity Measures	Baseline Period (Days)	Test Period (Days)	Recovery Period (Days)	Re-test Period (Days)	Size of Structure (m^2)
Simulated Field	EPA/FWS Shumake, LaVoie, Crane (1984)	Rolled oat consumption; paper packet damage; photocell break counts	7	17	7	17	69
Field	EPA/FWS Shumake, LaVoie, Crane (1984)	Tracking tile counts; number of sectors disturbed per tile; fecal dropping counts; packet damage; photocell break counts	21	21	21	21	8.9–196.5
Field	PCP Laidlaw (1984)	Tracking boards; feed consumption; fecal dropping counts; tunnel openings after closure; candy drop removal counts	7	21–42	14	–	Not Specified
Field	ASTM STP 1055 Jackson, McCartney, Ashton (1989)	Tracking tile counts; feed consumption; movement detector counts; fecal dropping counts	7	28	14	28	Large enough to accommodate both ultrasound and control areas; or separate buildings as control areas

efficacy; however, no specific criterion level or industry standard level of repellency has been proposed in terms of "pass/fail" limits (e.g., 70% reduced activity for 3 weeks at 80% of sites) by any agency or consortia of manufacturing firms. From a quality control standpoint, no standards have been developed to demonstrate statistically consistent repellency at or above a given criterion level measured over a period of days, weeks, or months.

Since electronic devices do not generally pose health or safety hazards to the public, there is a tendency to only require efficacy data for "approval for sale" or "registration." There are, of course, economic considerations that should be calculated in rodent control programs. One can estimate the cost of conventional control efforts including labor for baiting, trapping, glue boards, and structural barrier materials. The cost of purchasing commercial devices can also be estimated for the same structure. If both means of control had the capability of reducing the rodent infestation in terms of number of individual rodents per unit area by 50% within a 1-month interval, would the ultrasonic devices offer any advantages over maintaining traditional control methods? Would anyone ever be able to detect synergistic effects when attempting to use devices in concert with conventional methods?

A more productive research approach could involve an assessment of natural rodent alarm or distress calls as repellent stimuli. The capabilities of digitally recorded or synthesized critical frequencies have continued to improve at a rapid pace within industry. It is also possible that sonic/ultrasonic stimuli could be used in combination with other sensory modalities (e.g., alarm pheromones, predator odors) to enhance repellency in terms of potency and duration. With the recent increased interest in and emphasis on repellency in general in the field of animal damage control, such questions involving cross-modal repellents could have increased priority in future rodent control research.

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