Human Health Risks from Cockroaches and Cockroach Management: A Risk Analysis Approach

Robert K. D. Peterson and Bradley A. Shurdut

Most of the 4,000 species of cockroaches throughout the world are not associated with humans. However, about one percent of cockroach species are domestic and for centuries these organisms have been viewed as nuisance pests (Harwood and James 1979). Indeed their mere presence is objectionable almost universally.

Cockroaches are considered nuisance pests because most emit a repulsive odor, feed on anything edible to humans, hide in cracks and crevices of structures, and degrade the aesthetics of the household environment. However, cockroaches are not strictly nuisance pests; they also have been implicated in the transmission of human disease. Published data have implicated cockroaches in the mechanical transmission of *Salmonella, Aspergillus, Entamoeba*, and *Toxoplasma* species (Roth and Willis 1957, Cornwell 1968, Chinchilla and Ruiz 1976, Harwood and James 1979, Brenner et al. 1987). Additionally, in laboratory experiments, cockroaches have been shown to harbor the yellow fever virus and the bacterial agents of cholera, pneumonia, diptheria, anthrax, tetanus, and tuberculosis (Harwood and James 1979). Further, cockroach feces and body parts are well known allergens. In a sense, cockroaches "vector" the biological substances that cause allergies and asthma.

Clearly, the need to manage cockroaches extends beyond their status as nuisance pests. But what if the risks associated with managing cockroaches are greater than the risks from cockroach infestations? Health concerns about cockroaches are counterbalanced by health concerns related to control tactics, including insecticide use. Indeed, the risks presented by both cockroaches and their control need to be considered before designing any type of management program. In this paper, we highlight the health risks associated with cockroach allergens and the health risks associated with a specific type of insecticide application—chlorpyrifos applied as a crack-and-crevice treatment. To examine these risks, we employ the risk analysis paradigm as defined by the National Academy of Sciences (NRC 1983).

The Nature of Risk and Risk Assessment

The concept of risk extends well beyond the identification of hazards. Definitions of risk vary, but most would recognize risk as the product of the adverse consequences of an event multiplied by the probability of that event occurring (Lowrance 1980, Peterson and Higley 1993). Of course, the definition of an "adverse event" is subjective and represents a value judgement (Cooper 1996). In terms of chemical and biological substances, risk can be defined more narrowly as a function of toxicity and exposure. Given that definition, both toxicity and exposure for any substance need to be understood to assess risk and manage it properly.

Risk assessment is an analytic process involving four integrated steps: (1) hazard identification, (2) dose-response assessment, (3) exposure assessment, and (4) risk characterization (Fig. 1) (NRC 1983). In this article, we follow the risk assessment paradigm to better understand the risks posed by cockroaches and cockroach management.

Importance and Prevalence of Asthma in the United States

Asthma affects approximately 15 million people in the United States, nearly 5% of the total population; it resulted in more than 5,000 deaths in 1991 (Marwick 1997). The incidence of asthma is increasing in the U.S. population, especially among children (Evans et al. 1987, Gergen et al. 1988, Marwick

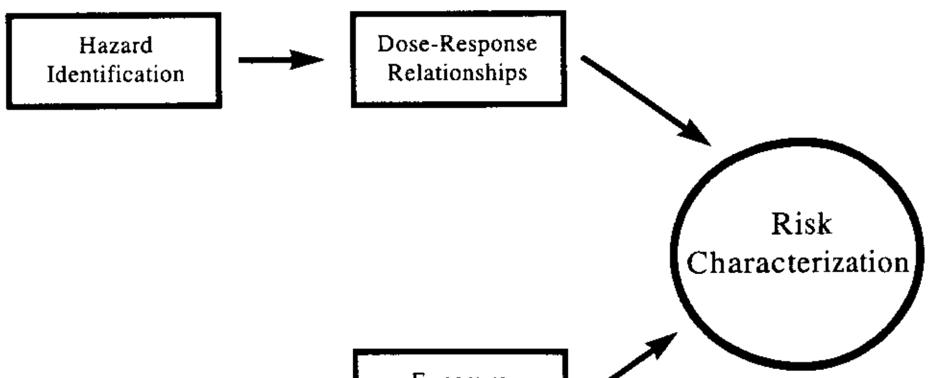

Fig. 1. The risk assessment paradigm.

1997, Platts-Mills and Carter 1997). From 1982 to 1992, asthma prevalence increased by 42%, hospitalization rates rose 6%, and annual mortality rates increased by 40% (Marwick 1997). Childhood asthma rates and hospitalizations also increased each year through the 1980s (Gergen et al. 1988). Children with asthma in the United States collectively lose more than 10 million more school days each year than children without asthma. Children who belong to racial or ethnic minorities and who live in economically depressed, urban areas are at highest risk for asthma (Weiss and Wagener 1990, Weiss et al. 1992). Indeed, African-American children are three to four times more likely than Caucasians to be hospitalized for asthma and four to six times more likely to die from asthma (Marwick 1997).

The Role of Cockroaches

The indoor environment seems to have a greater impact on the incidence of asthma than the outdoor environment (Solomon and Burge 1984; Spengler 1986; Kang et al. 1989, 1993). Domestic cockroaches are present in the indoor environments of many human dwellings and other buildings and long have been associated with allergies in humans (Kang 1990). Human and experimental animal sensitization to cockroach allergens has been associated with species such as the Asian cockroach, *Blatella asahinai* Mizukubo; German cockroach, *Blatella germanica* (L.); American cockroach, *Periplaneta americana* (L.); and Oriental cockroach, *Blatta orientalis* L. (Helm et al. 1990; Kang et al. 1991, 1995, 1996). Further, allergic reactions occur in response to the whole body, cast skin, oothecae, and feces (Kang 1990). Sensitization to cockroaches occurs by inhalation of airborne particles or by ingestion of contaminated food (Kang 1990).

Researchers have linked cockroaches and sensitization to cockroach allergens as direct causes of bronchial asthma (Kang 1990, Duffy et al. 1998). Although asthma is a disease with several potential causes, cockroach allergens in the indoor environment seem to be a key cause, especially among children residing in lower socioeconomic conditions. In poor, urban areas, cockroach densities typically are greater than in wealthier urban or suburban areas. Consequently, exposure to cockroach allergens and resulting asthma rates also are greater than in wealthier areas (Kang et al. 1993). In particular, the increased morbidity and mortality associated with asthma in adolescents in inner-city environments have been associated with increased exposure to cockroach allergens (Call et al. 1992, Christiansen et al. 1996, Rosenstreich et al. 1997, Togias et al. 1997).

Exposure to Cockroach Allergens

The precise relationship between human sensitization to cockroach allergens and cockroach infestation has been difficult to determine primarily because of the complexity in quantifying the number of cockroaches in dwellings. However, a relationship between sensitization and amount of cockroach allergens has been established. In the United States, sensitivity to cockroach allergens has been found in 23 to 60% of urban residents with asthma (Kang et al. 1989, Call et al. 1992) and has been observed in children as young as 10 months (Kang 1990). Among asthmatics who are allergic to cockroach allergens, 85 to 95% have had positive asthmatic reactions after a single inhalation of allergens (Kang et al. 1979).

Exposure and sensitization to cockroach allergens also have been assessed in countries other than the United States. In Hong Kong, eastern Malaysia, and southern China, 25 to 30% of schoolchildren (n = 1,438) were allergic to cockroach allergens, which were among the most common allergens found (Leung et al. 1997). In Singapore and Amsterdam, 53% of 603 homes and 44% of 96 homes contained German cockroach allergens, respectively (van Wijnen et al. 1997, Zhang et al. 1997).

In a comprehensive study of 476 children with asthma from eight inner city areas of the U.S., Rosenstreich et al. (1997) found that 36.8% of the children were allergic to cockroach allergens. Further, 85.3% of the children had detectable levels of cockroach allergens and 50.2% had high levels of cockroach allergens in their bedrooms (> 8 international units [U] per gram of dust). Children who were both allergic to cockroach allergen and exposed to the allergen at high levels had 0.37 hospitalizations per year compared with 0.11 for other children, and 2.56 had unscheduled medical visits for asthma per year compared with 1.43. Both parameters were statistically significant.

Kang et al. (1989) observed that asthmatics living in cockroach-infested dwellings in the United States had significantly higher incidences of cockroach sensitivity. Further, the number of cockroaches seen by residents per night was correlated closely with the level of cockroach sensitivity among asthmatics, as indicated by radioallergosorbent testing. This was documented further by positive allergic reactions in about 80% of 100 asthmatics when greater than 11 cockroaches were seen per night.

Exposure to Cockroaches

Cockroaches are ubiquitous insect pests found in many human workplaces and dwellings. Infestations vary depending on geographic location and socioeconomic condition. In a study of 1,022 low-income apartments in Florida, more than 97% of apartment units were infested with German cockroaches (Koehler et al. 1987). Further, half of all the apartments were infested with more than 13,000 cockroaches per apartment. In a study of public housing, 100 residents each in Roanoke, VA; Norfolk, VA; and Baltimore, MD; observed an average of 8, 29, and 36 cockroaches per day, respectively (Zungoli and Robinson 1984). Thoms and Robinson (1986) surveyed 151 residents of the public housing apartments in Norfolk, VA, regarding Oriental cockroaches. Ninety percent of the residents indicated that they had seen Oriental cockroaches in or around their apartments.

Risk Characterization for Cockroaches

The toxicity of cockroach allergens to asthmatics, especially asthmatic children, has been well documented. There seems to be a positive dose-response relationship between the degree of sensitization to cockroach allergens and the amount of allergens in house dust (Rosenstreich et al. 1997). Further, there is a correlation between cockroach infestation in human housing and the degree of sensitization to cockroach allergens (Kang et al. 1989).

Only one study has determined a quantitative relationship between cockroach allergens and the density of cockroaches. Helm et al. (1993) found that living cultures of 10,800 German cockroaches and 700 American cockroaches produced 3.2 mg/m^3 and 3.7 mg/m^3 of aeroallergens, respectively, during a 48-hr period. Although Helm et al. (1993) did not measure cockroach allergens in a human dwelling and did not measure the bioavailability of allergens, the density of cockroaches in a dwelling that would be required to elicit an allergic reaction in asthmatics most likely would be low, especially given that cockroach allergens can remain in a dwelling after cockroaches are absent. Fifty percent of 100 residents who viewed only one to two cockroaches per night became sensitive to cockroach allergens (Kang et al. 1989). Consequently, in poor, inner-city areas where asthmatics frequently live in cockroach infested dwellings, allergen thresholds seem to be exceeded regularly.

Rethinking Management Thresholds for Cockroaches

Tolerance thresholds to cockroaches, and other nuisance pests, are based on an aesthetic value rather than an economic value. The economic injury level (EIL) is the level of injury, usually expressed in terms of pest density, in which the economic value of losses equals the economic costs of management (Pedigo et al. 1986). EILs have been determined for many pests that injure crops, but few attempts have been made to determine similar thresholds for pests of humans (Peterson 1996). This is because it is not practical to assess market value for human life, and some level of morbidity and mortality would need to be accepted before management action is initiated (Pedigo et al. 1986, Peterson 1996).Therefore, EILs for pests that impact human health are virtually impossible to calculate. Consquently, there are no EILs for disease vectors (Peterson 1996).

Despite the problems associated with determining EILs for medical pests, Zungoli and Robinson (1984) determined aesthetic injury thresholds for the German cockroach based on public tolerance of pest infestations. Residents of public housing (n = 300) in Virginia and Maryland were asked how many cockroaches they could tolerate seeing in a 24-hour period in their dwelling before they would attempt to control them. The majority of residents would control cockroaches after seeing only two to three in a 24-hr period. In a survey of 151 public housing residents in Roanoke, VA, Thoms and Robinson (1986) observed that 60, 82, and 96% of residents considered one, two, and five Oriental cockroaches an intolerable level of infestation, respectively.

Although aesthetic injury thresholds for cockroaches varied among housing location, they were low across all locations. Clearly, most residents would not tolerate seeing more than two cockroaches per day or evening. Aesthetic injury levels for cockroaches are really nuisance thresholds. However, nuisance thresholds most likely are not entirely adequate for domestic cockroaches because of their potential to produce allergens, promoting atopic disease and asthma. And, as discussed above, economic thresholds for cockroaches, or any pest, based on their medical impact are difficult to calculate given that it is impractical to ascertain economic value for human suffering. Instead, it may be possible to base treatment thresholds on the number of cockroaches that produce allergen levels necessary to induce disease. However, basing treatment thresholds on the number of cockroaches could be problematic given that reductions in cockroach numbers does not reduce allergen load necessarily (Gergen et al. 1999).

The concentrations of cockroach allergens necessary to induce disease have been proposed to be about 8 U and 2 U per gram of house dust for the German cockroach allergens, Bla g I and Bla g II, respectively. Togias et al. (1997) observed that Bla g I allergen levels of 6.3 U per gram produced excessive sensitization in adolescents with asthma. Treatment thresholds could be based on allergen thresholds. For example, if cockroach allergen sensitization occurs at ≥ 2 U per gram of house dust, curative treatment of cockroaches may need to be imposed below 2 U per gram to prevent allergen levels from reaching this threshold. Alternatively, it may be more practical to base treatment thresholds on numbers of cockroaches. Based on research by Helm et al. (1993), a mature colony of approximately 10,800 German cockroaches can produce 1.63 U of Bla gI over just 96 hours. Given that residents, especially those in poor, inner city dwellings, only see a small fraction of the total number of cockroaches in their houses, cockroach thresholds most likely would be low—perhaps lower than nuisance thresholds.

Regardless of the ability to develop thresholds for curative cockroach control, management of asthma is critical, especially in poor, inner-city environments. Based on recent research, a key component of asthma management is effective cockroach management. However, management of asthma requires a multicomponent approach that includes cockroach reduction, allergen reduction, education of patients, and appropriate health care such as access to proper medications and medical care. To date, asthma management that has included attempted reductions in densities of cockroaches and allergens has not been successful, especially in multifamily dwellings (Gergen et al. 1999).

Risks Associated with Cockroach Control

As discussed above, cockroach infestation in human housing entails a potentially significant risk of asthmatic sensitization. Therefore, proper management of cockroaches in the home seems to be critical for the management of asthma and allergies. Cockroaches should be managed within an Integrated Pest Management (IPM) framework. The IPM paradigm is a system for managing pests based on considerations of economics, environment, and ecology. The goals of IPM are relatively simple and revolve around the concept of sustainability. IPM should address sustainability through the following: economic sustainability through minimizing economic impacts of pests, ecological sustainability through minimizing resistance selection pressure on pests, and environmental sustainability through minimizing the impact of management tactics on the environment (Higley and Wintersteen 1996). An integration of management techniques typically is necessary to ensure that management is sustainable. Exclusive and overemployment of a single management tool may result in cockroach resistance development. Additionally, over use of a single tool may result in unacceptable risks to humans or the environment.

Integrated management of cockroaches has been shown to be effective. Techniques include preventing entry into residences through caulking and puttying crevices, cleaning residences regularly and thoroughly, disposing of food properly, trapping cockroaches, and treating with pesticide products (Kamble and Keith 1993). However, each technique or approach used in an integrated pest management program presents risks. Therefore, the risks associated with the various techniques need to be understood to design a management program that is sustainable and does not present unacceptable risks to humans or the environment.

Although all pest management techniques present some degree of risk, perceptions of risk are undoubtedly greatest with insecticides. Indeed, Rosenstreich et al. (1997) stated, "...implementation of cockroach-reduction strategies, including education of patients and the use of safe insecticides... should be evaluated as a method of reducing morbidity due to asthma...." The implicit assumption in their statement is that there are unsafe insecticides that are used for cockroach control. But what does "unsafe" mean? Does "unsafe" mean unacceptably risky?

The Crack and Crevice Insecticide Application and Risk

In addition to insecticidal baits, crack and crevice applications of insecticides represent an important tactic for the indoor control of crawling pests, including cockroaches. A common insecticide used for crack and crevice treatments is chlorpyrifos. The risk to humans incurred by treating cockroach infestations with a crack and crevice application of chlorpyrifos provides us with a case study to analyze cockroach management tactics using the risk assessment paradigm described above (also, see Fig. 1). Chlorpyrifos is used in this case study because considerable empirical studies have been conducted regarding its toxicity and exposure. Although other insecticides used for cockroach control may be used more frequently, to our knowledge chlorpyrifos is the only insecticide for which publicly available empirical human exposure data exist following a crack-and-crevice application.

Although termite and outdoor lawn treatments represent major residential uses for chlorpyrifos, crack and crevice or spot applications are the most important indoor use patterns for the product (Gibson et al. 1998).

A crack and crevice or spot treatment consists of a direct, low volume spray targeted at relatively inaccessible areas within a home such as cracks, baseboards, and under and behind appliances.

Hazard Identification and Dose Response of Chlorpyrifos

The toxicology of chlorpyrifos has been studied extensively for more than 35 years. Chlorpyrifos is an organophosphate (OP) insecticide and, like other OP insecticides, its insecticidal action in the insect is due to the inhibition of acetylcholinesterase in the nerves and subsequent accumulation of acetylcholine in the nerve endings, which results in excessive transmission of nerve impulses (Matsumura 1985). This mode of action also is the mechanism that produces OP insecticide toxicity in mammals. Chlorpyrifos is of moderate toxicity to humans by acute oral and dermal routes of exposure, as indicated by numerous animal studies.

Other potential toxic effects of chlorpyrifos have been evaluated. There is no evidence that chlorpyrifos is mutagenic (Gollapudi et al. 1995), carcinogenic (Warner et al. 1980, Young and Grandjean 1988), or teratogenic (Deacon et al. 1980, Breslin et al. 1996) according to tests conforming to EPA guidelines. Further, evidence suggests that chlorpyrifos does not induce respiratory hypersensitivity or adversely affect reproduction (Breslin et al. 1996).

Research conducted to date supports the hypothesis that toxicity to chlorpyrifos does not occur in the absence of significant cholinesterase inhibition in the nervous system. If exposures are less than those that cause significant cholinesterase depression, then there are no signs or symptoms related to chlorpyrifos exposure. Consequently, the U.S. Environmental Protection Agency (EPA) regulates exposure to chlorpyrifos based on a "No-Observed-Effect-Level" (NOEL) for plasma cholinesterase. Plasma cholinesterase generally is most sensitive to commonly used organophosphate insecticides. It is a different enzyme than acetylcholinesterase and can be depressed without adverse effect. Because of this preferential inhibition of plasma cholinesterase, it is possible to detect exposures to chlorpyrifos that are not sufficient to cause subsequent acetylcholinesterase depression and toxicity.

Currently, EPA regulates pesticide exposure in the United States based on clearly defined studies that establish regulatory toxicological endpoints used to evaluate risks. Both acute and repeated durations of exposure always are considered. Acute risk assessments reflect short-term exposures to the pesticide whereas chronic risk assessments reflect longer exposure durations, from several months to a lifetime.

To ensure that health risks from pesticide exposure are acceptable, EPA requires that potential exposures to pesticides are well below relevant toxicological levels. After toxicological effects and NOELs have been determined, EPA generally divides the NOEL by an uncertainty factor (typically 100 or more) to determine the Reference Dose (RfD). The RfD is a level at or below which daily aggregate exposure over a lifetime will not pose appreciable risks to human health. An uncertainty factor, often termed a "safety factor," of 100 is commonly used because of the assumption that people may be as much as 10 times more sensitive to pesticides than the test animals, and that one person or subgroup of the population (such as infants and children) could be up to 10 times more sensitive to a pesticide than another (therefore, 10 X 10 = 100). In addition, EPA assesses the potential risks to infants and children based on the weight of the evidence of the toxicology studies and determines whether a further uncertainty factor should be removed or reduced.

Human data describing both acute and chronic exposures are used in chlorpyrifos risk assessments; therefore, an uncertainty factor of 10 for interspecific variation (test animals to humans) is not needed and not applied to the NOEL. However, an uncertainty factor of 10 for intraspecific variation is applied to the NOELs to account for potential subgroup sensitivity. The NOELs for chlorpyrifos are 100 μg/kg-body weight (BW) for short-term exposures and 30 μg/kg-BW/day for longer-term exposures (EPA 1996). Consequently, short-term exposures must be below the RfDs of 10 μg/kg-BW and the longer-term, repeated exposures below 3 μg/kg-BW/day (EPA 1996).

Exposure Assessment

Air, surface residue, and biological monitoring measurements have been made following crack and crevice applications to characterize potential multipathway exposures to adults and children living in homes treated in a crack and crevice manner (Wright and Jackson 1975, Wright and Leidy 1978, Byrne et al. 1998). In these studies, airborne residues measured in the child's breathing zone were low and dissipated shortly after application. In addition, dislodgeable residues on household surfaces and in surfaces representing children's toys were negligible. Byrne et al. (1998) conservatively estimated total exposures of chlorpyrifos to children after a crack and crevice application. To estimate potential respiratory exposures, the highest air concentration value (2.3 μg/m^3), not the daily average (1.6 μg/m^3), was used. Additionally, it was assumed that 100% of the inhaled dose was absorbed. The estimated oral dose for a child also was calculated by assuming that 100% of the residue found on the toys actually was absorbed

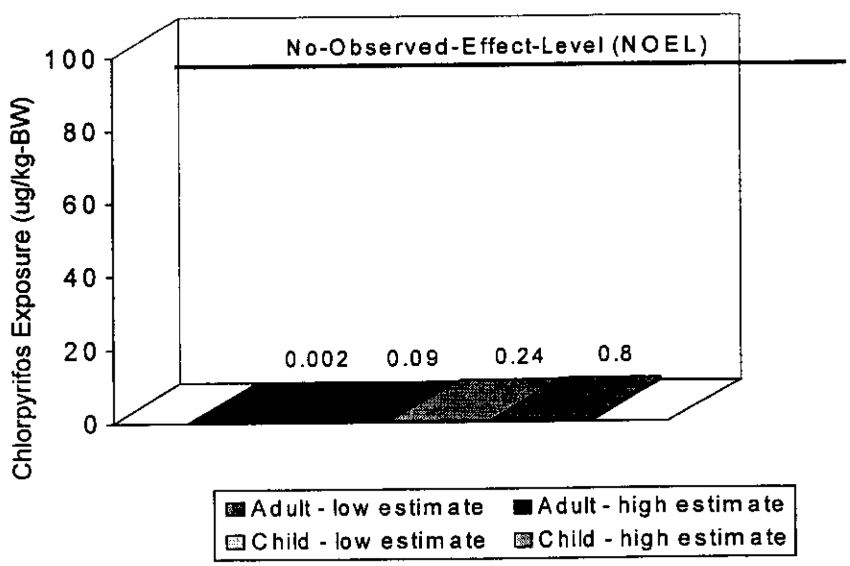

Fig. 2. Estimated exposures of adults and children to chlorpyrifos following a crack and crevice application. Exposures to adults were based on biomonitoring of urine. Exposures to children were estimated based on conservative assumptions. These assumptions were that the child was exposed to the highest peak short-term air concentrations over 24 hr, 100% of the inhaled dose was absorbed, and that all the residues found on the surface of a toy were dislodged and absorbed systemically. The NOEL is based on an acute, short-term toxicological endpoint. Consequently, estimated exposures were substantially below any exposure that would produce an observed effect. The figure is based on data from Byrne et al. (1998).

systemically. Therefore, these conservative exposure estimates most likely overestimated actual exposures. Byrne et al. (1998) determined that maximum daily total exposures to chlorpyrifos for children ranged from 0.24 to 0.8 μg/kg-BW/day.

In addition to estimating exposures to children, biological monitoring of urine samples collected from adult residents before and after application quantified the primary metabolite of chlorpyrifos, 3,5,6-trichloropyridinol (TCP), as a reliable measure of chlorpyrifos absorbed. The daily average amount of chlorpyrifos absorbed by each adult resident after application ranged from 0.002 to 0.09 μg/kg-BW/day, which was consistent with baseline exposures measured before treatment. These levels also were consistent with TCP concentrations reflecting adult aggregate exposures (dietary and non-dietary sources of chlorpyrifos) reported by Hill et al. (1995).

Risk Characterization

To characterize the risk to adults and children in a residence, the total estimated exposures to children need to be compared to an appropriate toxicological endpoint. The appropriate regulatory endpoint following short-term exposure to chlorpyrifos is the RfD of 10 μg/kg-BW/day (EPA 1996). Assuming that occupants were exposed to the highest peak short-term air concentrations measured in the Byrne et al. (1998) study for an entire 24-hour day, total estimated absorbed doses for a 20-kg child would be 2.4% and 8% of the RfD. Because exposures associated with a crack and crevice application are transient and decrease over a 7-day period after application, and any actual absorbed dose of chlorpyrifos is metabolized rapidly, it is unlikely that there would be any cumulative effects from subsequent crack and crevice treatments separated by the minimum 7-day application interval (Shurdut 1997).

Absorbed doses of chlorpyrifos for adult residents, as indicated by biomonitoring, corresponded to less than 1% of the RfD. Therefore, based on toxicological studies, exposure studies, and current regulatory guidelines, crack and crevice applications with chlorpyrifos-containing products do not present an unacceptable risk to residents (Fig. 2).

Risks to Pesticide Operators

In addition to exposure to the residents of treated dwellings, applicators of pesticides also are exposed during crack and crevice treatments. The exposure of pest control operators to chlorpyrifos performing crack and crevice applications recently was assessed (Vacarro et al. 1997). During a routine crack and crevice application with a 0.5% chlorpyrifos-based water mixture, 10 professional pest control company volunteers were monitored using whole body dosimetry techniques. The average total dose from both inhalation and dermal routes of exposure was 0.17 μg/kg-BW. The regulatory toxicological endpoint for this type of exposure was based on chronic, repeated exposure to chlorpyrifos because pesticide applicators apply pesticides on a daily basis (EPA 1996). Consequently, the NOEL was 30 μg/kg-BW/day and the RfD was 3 μg/kg-BW/day. The exposure corresponded to less than 5.7% of the RfD, indicating that crack and crevice applications of chlorpyrifos-containing products do not present unacceptable risks to pest control applicators. Similarly, risks have been assessed to homeowners who intermittently apply pesticides for the control of indoor pests. Estimated exposures indicated that homeowner applications do not present unacceptable risks when compared to the short-term NOEL and corresponding RfD (Jaquith 1995).

Risks From Other Management Tactics

Unfortunately, the risks from other cockroach management tactics have not been established with the same level of detail as the risk presented by crack and crevice applications containing chlorpyrifos. However, it is important to understand the risks from all management tactics so that informed decisions about cockroach and asthma management can be made. For example, what is the risk from using pyrethroids considering that some members of this insecticide class are known respiratory irritants? What are the health risks associated with vacuuming and using home cleaning products to reduce allergens? Also, the risks presented by insecticide-containing cockroach baits most likely would be low, and well within acceptable levels, given that the insecticide is concentrated in a protected bait station, precluding exposure to residents. However, what is the risk if the bait station was consumed accidentally by a child. Clearly, additional research is needed to understand the risks associated with all aspects of a multicomponent approach to allergen management.

Conclusions

Research conducted over several years has identified cockroach allergens as a human health hazard, contributing to allergic reactions and asthma development. Recently, dose-response relationships and exposures to cockroach allergens have been assessed. To date, the information has allowed us to begin to characterize the asthma risk associated with cockroaches. Once the risks are better understood, then tactics can be formulated to manage those risks.

Managing cockroach populations is critical to managing cockroach allergens and asthma effectively. However, risks associated with cockroach control need to be understood so that costs and benefits can be assessed. As we have shown, research conducted to date indicates that residential and applicator risk from a crack and crevice application containing chlorpyrifos is extremely low. Indeed, the risk of allergic reaction or asthma associated with a cockroach-infested dwelling, even where infestations are low, may be much higher than the risks from chlorpyrifos.

Is it possible to utilize tactics with lower risks? Perhaps, but the necessity to seek tactics with lower health risks in this case is questionable. Exposures to chlorpyrifos as a result of crack and crevice applications are at least two to three orders of magnitude below conservative regulatory endpoints that already include safety factors. Additionally, a variety of tactics is necessary given the need to have efficacious control, manage cockroach resistance to insecticides, and sustain control. Therefore, management tactics that present acceptable risks, such as the example presented in this paper, are necessary components for effective cockroach management within a multicomponent approach.

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Robert K. D. Peterson is a Senior Research Biologist at Dow AgroSciences and Adjunct Assistant Professor in the Department of Entomology at the University of Nebraska-Lincoln. He currently is a Regulatory Manager in the Regulatory Success-Americas group at Dow AgroSciences. Bradley A. Shurdet currently is a Risk Assessment Leader in the Global Exposure and Risk Assessment group at Dow AgroSciences. Corresponding address: Dow AgroSciences, 9330 Zionsville Rd., Indianapolis, In 46268, rkpeterson@dowagro.com