## Healthy Homes Issues:

# Pesticides in the Home

## Use, Hazards, and Integrated Pest Management

November 2011


U.S. Department of Housing and Urban Development
Office of Healthy Homes and Lead Hazard Control

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This and previous versions of the document were prepared by:
**Peter Ashley,** DrPH, HUD OHHLHC
**J. Kofi Berko,** PhD, HUD OHHLHC
**Joanna Gaitens,** PhD, Healthy Housing Solutions, Inc.
**Jackson Anderson, Jr.,** Healthy Housing Solutions, Inc.
**Marcia Nishioka,** MS, Battelle
**Maureen A. Wooton,** MS, Battelle
**Jennifer Zewatsky,** MS, MEn, Battelle

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John Adgate, PhD
University of Minnesota
School of Public Health

Thomas Brennan
U.S. Environmental Protection Agency
Office of Pesticide Programs

Deborah Hartman, JD
U.S. Environmental Protection Agency
Office of Pesticide Programs

John Menkedick, MS
Battelle

Kathy Seikel, MBA, BS
U.S. Environmental Protection Agency
Office of Pesticide Programs

Daniel M. Stout II, PhD
U.S. Environmental Protection Agency
ORD—North Carolina

Allison Taisey, MAT
Northeastern IPM Center

Changlu Wang, PhD
Purdue University
Center for Urban and Industrial Pest Management
Department of Entomology

# Preface

In 1998, Congress appropriated funds and directed the U.S. Department of Housing and Urban Development (HUD) to "develop and implement a program of research and demonstration projects that would address multiple housing-related problems affecting the health of children." In response, HUD solicited the advice of experts in several disciplines and developed a preliminary plan for the Healthy Homes Initiative (HHI). The primary goal of the HHI is to protect children from housing conditions that are responsible for multiple diseases and injuries. As part of this initiative, HUD has prepared a series of papers to provide background information to their current HHI grantees, as well as other programs considering adopting a healthy homes approach. This background paper focuses on pesticides and provides a brief overview of the current status of knowledge on:

- The extent and nature of pesticide uses and hazards in the home;
- Assessment methods for pesticide hazards in the home;
- Mitigation methods for pesticide hazards in the home, including preventive measures such as integrated pest management (IPM); and
- Research needs regarding residential pesticide hazards and IPM in the home.

Please send all comments to:
hhpgmfeedback@hud.gov

U.S. Department of Housing and Urban Development (HUD)
Office of Healthy Homes and Lead Hazard Control
Fax: 202–755–1000

# Contents

**Preface** ........ page v

**Summary and Relevance to Healthy Homes Programs** ........ page 1

**1.0 Overview of Pesticide Use in the Home** ........ page 3

**2.0 Hazards Associated with Pesticide Use in the Home** ........ page 7
- 2.1 Nature and Extent of Pesticide Hazards in the Home ........ page 7
- 2.2 Health Impacts and Toxicity ........ page 8
- 2.3 Methods Used To Assess Pesticide Hazards In The Home ........ page 10
- 2.4 Methods Used To Mitigate Pesticide Hazards In The Home ........ page 14

**3.0 Integrated Pest Management (IPM)** ........ page 16
- 3.1 Overview of Integrated Pest Management in the Home ........ page 16
- 3.2 General Guidelines for IPM in Homes ........ page 16
- 3.3 IPM for Specific Pests ........ page 19
  - *3.3.1 Cockroaches ........ page 19*
  - *3.3.2 Mice ........ page 21*
  - *3.3.3 Bed bugs ........ page 21*
  - *3.3.4 Other Pests ........ page 23*
- 3.4 IPM Programs and Their Effectiveness ........ page 24

**4.0 Research Needs and Information Gaps** ........ page 26

**References** ........ page 28

**Appendix A: Additional Internet Resources** ........ page 39

**Appendix B. Example IPM Programs** ........ page 41

## List of Tables

Table 1. Selected Major Chemical Classes of Pesticides ............ page 3

Table 2. Most Commonly Used Pesticide Active Ingredients in Home and Garden Market, 2001 (Ranked by Range in Millions of Pounds of Active Ingredient) ............ page 4

Table 3. Average Concentrations of Selected Pesticides Found in Clinical Specimens, NHANES 1999–2000, 2001–2002, and 2003–2004 ............ page 12

Table 4. Ten Elements of an Effective IPM Program ............ page 17

# Summary and Relevance to Healthy Homes Programs

Broadly defined, pesticides are substances or mixtures of substances used to control pests such as insects, rodents, weeds, fungi, or bacteria. The use of pesticides is widespread in the United States, particularly in agricultural settings, though use in home and garden applications is on the rise. Pesticides are generally classified by their target pest group and function, as well as by their formulation and chemical class. Use patterns for residential and agricultural insecticides have evolved over the last 50 years, during which time four major classes of compounds—the organochlorines, the organophosphates, the carbamates, and the pyrethroids—have been used.

The prevalence of pesticide use has raised significant concern over the potential health effects associated with both acute and chronic exposure to these compounds. Children, in particular, may be especially vulnerable as compared to adults to the toxicants present in many commercial pest control products due to differences in exposure, metabolism, and/or toxicity.

Risk of exposure varies as children grow (Firestone, 2010) due to both behavioral and physiological changes. In response to this finding, EPA developed "Guidance on Selecting Age Groups for Monitoring and Assessing Childhood Exposures to Environmental Contaminants" (EPA, 2005). Exposure differences are due to generally higher rates of chemical intake (on a body weight basis) as well as behaviors unique to young children such as crawling and hand/object-to-mouth activity. The following age groups were recommended by EPA for assessing exposure and risk for children and for future exposure data collection and analysis efforts:

- Less than 12 months old: birth to <1 month, 1 to <3 months, 3 to <6 months, and 6 to <12 months.
- Greater than 12 months old: 1 to <2 years, 2 to <3 years, 3 to <6 years, 6 to <11 years, 11 to <16 years, and 16 to <21 years.

This guidance has adopted the age group notation "X to <Y" (e.g., the age group 3 to <6 years is meant to span a 3-year time interval from a child's 3rd birthday up until the day before his or her 6th birthday).

Based on evidence of, or potential for serious and persistent toxic effects, the primary compounds used in the pesticide market have undergone a dramatic shift in recent years. Some of the more acutely toxic substances have been removed from commercial use. These have been replaced by alternative strategies for controlling pests in and around the home.

Multiple hazards are associated with pesticide use in the home. Low-dose, chronic exposure may negatively impact the nervous system, though long-term effects are still not thoroughly understood. Cases of poisoning resulting from accidental acute exposure to pesticides have been well documented in children. Some research suggests a possible link between pesticide exposure and neuro-developmental effects, potential asthma exacerbation, and leukemia. These risks may be amplified in low-income urban neighborhoods, where substandard housing conditions and resident behaviors increase the chances of pest infestation and pesticide usage. Efforts are underway to assess the degree of residential pesticide use in the U.S. and effects of exposure, particularly upon children and the offspring of pregnant women. Methods of quantifying pesticide use include home surveys and questionnaires, human biological sampling, and sampling of environmental media within the home.

Because of the potential health effects of pesticide exposure and the possibility of pesticide resistance, it is preferable to minimize pesticide use in residential situations. Techniques to mitigate pesticide hazards include the following:

- Public education to prevent improper pesticide use;
- Use of low exposure pesticides (e.g. child-proof baits rather than sprays or "foggers");

- Decontamination following inappropriate use of pest control substances; and
- Adoption of an integrated pest management (IPM) approach to pest control, which minimizes the reliance on and use of chemical pesticides.

Case studies on the use of IPM in schools and residential settings provide examples of promising results from the use of IPM in lieu of "traditional" pest control methods. Additional studies are needed to better characterize the risks of exposure to pest control products and to evaluate the effects of intervention strategies, such as those used in IPM, on health outcomes associated with pest infestation and pesticide use.

# Pesticides in the Home:
## Use, Hazards, and Integrated Pest Management

## 1.0 Overview of Pesticide Use in the Home

Today, there are a wide variety of tools available for pest control in residential environments, including the use of chemical pesticides as well as various non-chemical techniques. Broadly defined, a pesticide is any agent used to suppress pests such as insects, rodents, weeds, fungi, or bacteria. Although most people recognize that insecticides, which target pests, are a pesticide; not everyone recognizes that pesticides are also herbicides (plants), fungicides (fungi), rodenticides (rodents), acaricides (mites), and various other substances used to control pests. Many common household products are also considered pesticides, such as kitchen disinfectants and products that eliminate mold and mildew (Olkowski et al., 1991; EPA, 2002a). In addition to being classified by their target pest group and function, pesticides are often described according to their formulation and chemical class. Some of the major chemical classes of pesticides are shown in Table 1 below.

Given the toxicity of pesticides, the fact that approximately 1.1 billion pounds of pesticides are used in and around homes each year in the U.S. (EPA, 2011) is cause for concern. The U.S. Environmental Protection Agency (EPA) uses information from a variety of annual surveys to publish estimates on the production and use of pesticides in the United States. The most recent report (EPA, 2011) includes data on 2006–2007 market estimates. Table 2 presents the most common active ingredients in home and garden pesticides in 2005–2007. The inventory generally indicates that most pesticides are used in agriculture, with home and garden use accounting for less than ten percent of the total. The latest

**Table 1.** Selected Major Chemical Classes of Pesticides

| Category | Examples |
|---|---|
| Organochlorines* | Aldrin, chlordane, DDT, heptachlor |
| Organophosphates | chlorpyrifos (Dursban), diazinon, acephate (Orthene), malathion |
| Carbamates | carbaryl (Sevin), propoxur (Baygon) |
| Synthetic pyrethroids | allethrin, cypermethrin, cyflutherin, permethrin, resmethrin |
| Inorganic | boric acid, chlorates, cryolite, diatomaceous earth, silica aerogel, chromated copper arsenate (CCA) |
| Organic (botanical) | garlic, limonene, neem, nicotine, pyrethrum, rotenone, ryania, sabadilla |
| Organic (microbial) | Bacillus thuringiensis, B. popillae, Cephalasporium, lecanii, Morrenia odorata, Nosema locustae |
| Miscellaneous | Horticultural oils, insect growth regulators, insecticidal soaps, insect pheromones |

*Source: Olkowski et al., 1991. Table 6.3*
**Aldrin, chlordane, heptachlor and DDT are no longer available in the U.S.*
*Note: The names in parentheses are trade names that have become so common that the chemical or generic name is less known.*

**Table 2.** Most Commonly Used Pesticide Active Ingredients in Home and Garden[1] Market, 2007 and 2005 (Ranked by Range in Millions of Pounds of Active Ingredient)[2]

| 2007–2005 Rank | Active Ingredient | Type | Million pounds active ingredient | Chemical class |
|---|---|---|---|---|
| 1 | 2,4-D | Herbicide | 8–11 | Chlorinated phenoxy compound |
| 2 | Glyphosate | Herbicide | 5–8 | Plant hormone-type |
| 3 | Carbaryl | Insecticide | 4–6 | Carbamate |
| 4 | MCPP | Herbicide | 4–6 | Hormone-type phenoxy |
| 5 | Pendimethalin | Herbicide | 3–6 | Dinitroaniline |
| 6 | Pyrethroids | Insecticide | 2–4 | Pyrethroids |
| 7 | Malathion | Insecticide | 2–4 | Organophosphate |
| 8 | Dicamba | Herbicide | 2–4 | Benzoic acid type |
| 9 | Trifluralin | Herbicide | 1–3 | Dinitroaniline compound |
| 10 | Pelarganoic Acid | Herbicide | <1 | Nonanoic acid |

*Note: Includes applications to homes and gardens by professional applicators and excludes pesticides used for agriculture. Does not include moth controls: Paradiclorobenzene (3–35 million pounds per year) and naphthalene (2–4 million pounds per year). Also does not include insect repellent N,N-diethyl-meta-toluamide (5–7 million pounds per year). Source: EPA proprietary data (EPA, 2011).*

*[1]Garden herbicides would not be expected to have as much impact on home exposure as the insecticides used inside the house.*

*[2]Due to lack of data, the same estimates are used for both 2005–2007.*

market estimate compilations from EPA are presented online and available at: http://www.epa.gov/opp00001/pestsales/07pestsales/market_estimates2007.pdf.

Home and garden pesticide use has been increasing since 1995, reversing the trend of the last two decade. In 2007, EPA estimated the number of households using insecticides and herbicides totaled 59 million (about 56%) and 41 million (about 39%), respectively (EPA, 2011). Seventy-four percent of American households used some type of pesticide in 2007 (EPA, 2011). Herbicides used to kill lawn weeds are used more than other pesticides; seven of the 10 most commonly used pesticides around the home are herbicides, and approximately 43 million pounds of herbicide active ingredients were used for home and gardens in 2007 (EPA, 2011). While some research has been conducted on the intrusion of lawn chemicals into the home via track-in or spray drift (Nishioka et al., 1997), in general, insecticides used in the home would be expected to represent most of the exposure. Exposure may also occur outside the residence, such as at school or the work place.

In recent years, the compounds used in the pesticide market have undergone a dramatic shift. Use patterns for residential and agricultural insecticides have evolved over the last 50 years, during which time four major classes of compounds—the organochlorines, the organophosphates, the carbamates, and the pyrethroids—have been used. The following discussion and the accompanying role in current human exposure patterns will be based on representative compounds of each class: DDT (dichlorodiphenyltrichloroethane) and chlordane for the organochlorine class, carbaryl for the carbamate class, diazinon and chlorpyrifos for the organophosphate class, and permethrin and cypermethrin for the pyrethroid class.

The insecticidal properties of DDT were discovered in 1939. Its greatest use in the U.S. occurred in the 1940s and 1950s. Its use was phased out in the 1960s, and all crop application uses were canceled in 1972 (EPA, 2002b). From 1948 to 1978, chlordane was used in the United States as a pesticide on agricultural crops, lawns, and gardens and as a fumigating agent. In 1978, the EPA canceled the use of chlordane on food crops and phased out other above-ground uses over the next five years. From 1983 to 1988, the only approved use of chlordane was to control subterranean termites in wooden structures. Indoor residential use appears to have been limited. In 1988, all approved uses of chlordane in the United States were terminated; however manufacture for export continued until 1997 (EPA, 2005c).

Even though approved uses of chlordane were terminated in 1988, residues of this pesticide can be found in homes years after use. For example, prior to their cancellation, organochlorine termiticides (particularly chlordane) were used to treat many homes, soils, and building structures. During demolition or other disturbances, these reservoirs have the potential to be significant sources of exposure. Research shows that indoor air and house dust in structures previously treated with these persistent organochlorines can have residual pesticide levels as much as 10–100 times higher than in outdoor air and surface soil (Lewis et al., 1988; Whitmore et al., 1994; EPA, 2000d; Wilson et al., 2003).

The introduction or use of any semi-volatile chemical in the home results in a residue being deposited in sorptive reservoirs of the home—dust, fabric, and furnishings (Cohen Hubal et al., 2000). Part of the reason for the persistence of these pesticides is that factors for environmental degradation and dispersion (e.g., sunlight, wind, rain and microbes) are not readily available for completely dissipating indoor pesticide levels. This persistence in the indoor environment is further exacerbated by the presence of household materials such as carpets, upholstered furniture, and draperies. These materials act as sorbents or reservoirs resulting in subsequent slow release of the pesticides over time (Cohen Hubal et al., 2000; Hore et al., 2005). As an example, carpets can have significantly higher levels of pesticides compared to other surfaces due to its fibrous nature that provides large surface area for particles to adsorb. Its overall structure retains particles by macro- and micro-inclusion in the fiber interstices and irregularities (Obendorf et al., 2006). These chemical residues, if persistent, will continually cycle through the home either by virtue of volatilization and reabsorption, or as a result of reservoirs being disturbed by activities such as cleaning or active play. For these reasons, dermal, inhalation and non-dietary ingestion exposures to organochlorines and deregistered insecticides can continue to occur on a chronic basis.

The insecticidal properties of organophosphates were discovered in 1932; however, they did not achieve widespread use for agricultural and residential pest control until lower cost organochlorines were deregistered. While the organophosphates are less persistent in the environment, they are more acutely toxic to humans than organochlorines.

During the latter half of 1990s, it was estimated that two to four million pounds each of diazinon and chlorpyrifos (on the basis of active ingredients) were used annually by homeowners in the U.S. home and garden market (Aspelin and Grobe, 1999). Prior to their deregistration for applications inside homes, the EPA estimated that approximately 75% of U.S. diazinon and 50% of U.S. chlorpyrifos was used for residential pest control (EPA, 2000c; EPA, 2001). In 2000, EPA obtained agreements with manufacturers of diazinon and chlorpyrifos to begin phasing out these chemicals from formulations used for indoor pest control (and diazinon from lawn and garden applications). The sale of diazinon for all home lawn and garden use ended on December 31, 2004. The sale and use of chlorpyrifos for residential use ended on December 31, 2005. These agreements were in response to neuro-developmental toxicity studies that found chlorpyrifos, and by implication possibly the entire class of organophosphate pesticides, more toxic to infants, children, and the offspring of pregnant or nursing women than was previously understood (Avakian, 2001).

Similar to the organochlorines, organophosphate residues have been found in homes years after use. For example, over a 6–8 week period relatively stable air concentrations of chlorpyrifos have been found in homes two and a half years after chlorpyrifos was banned (Whyatt et al., 2007). In another study, diazinon and chloripyrifos were found in more than 90% of surface wipe and vacuum dust samples taken from public housing units years after these pesticides were banned (Julien et al, 2008).

Carbamates were first used as a pesticide in the 1950's. They have mechanism of action similar to organophosphates which has raised concerns about their use. Carbaryl, a carbamate, was once widely used for residential lawns and gardens and in pet flea collars, powders and dips. Due to growing concern over residential exposure and potential health effects for children, registrants of the pesticide agreed to limit residential exposure by eliminating the product in pet flea powders and dips and limiting the amount of active ingredient found in home garden products (EPA, 2007). The overall decrease in use of carbamates and organophosphates, has led to a rapid introduction of pyrethroids for indoor pest control.

The market is quite diverse with up to 10 different pyrethroids being used in common products. These insecticides are widely viewed as "less toxic," although this assumption is based on the earliest pyrethrins that were botanicals derived from chrysanthemum flowers and had the advantage of low mammalian toxicity and very short environmental half-lives (Pesticide Profiles, 1997). The search for more potent and longer-lived products led to the introduction of pyrethroids that were formulated to increase toxicity, increase resistance to degradation (either hydrolysis or enzymatic), and decrease water solubility (Pesticide Profiles, 1997; Elliot, 1977; Itaya et al., 1977). By extension, these products may be more soluble in human membranes, including those important to neurological function (Marei et al., 1982; Staatz et al., 1982).

In contrast to the phased-out organochlorines and organophosphates, currently used pyrethroids have started to dominate indoor residential pesticide exposures. The occurrence of pyrethroid insecticides in indoor air and house dust is expected to supplant that of the organophosphates (Gordon et al., 1999), especially given that the major suppliers of pyrethroids to the residential market produce "fogger" formulations, which (in organophosphate studies) are associated with the highest indoor air levels of pesticide active ingredient (Fenske et al., 1990). "Foggers" or "bombs" are devices that release a pesticide mist over an area. In fact, in a recent representative sample of 500 occupied homes in the U.S., permethrin, a pyrethoid, was detected in 89% of the floors sampled. Phased-out pesticides, such as chlorpyrifos and chlordane, were found in 78% and 64% of homes, respectively (Stout et al., 2009). Pyrethroid pesticides are also being used to a greater extent in the agricultural arena, so dietary exposures to these pesticides are expected to increase. In addition to the pesticide active ingredient, adjuvants such as piperonyl butoxide, which is used to enhance the "knock-down" effect of pyrethroids, and inert ingredients, such as solvents, may cause health problems for sensitive individuals such as children, older adults, and people with chronic illnesses (Watson et al., 2003).

Of particular concern is children's exposure to pesticides because it is generally considered that they are more vulnerable to the effects of many toxicants. Children generally receive higher exposures to pesticides (i.e., per kilogram of body weight) through food and as a result of their behavior (e.g., play and mouthing behavior) (EPA, 2000a; EPA, 2000b; Olden and Guthrie, 2000). Except in cases of gross misapplications, chronic exposure to organochlorine and organophosphate insecticides residues in the home will often be overshadowed by the dietary ingestion of residue levels in foods. For example, for the organochlorines the dietary ingestion levels are driven by bioaccumulation in meat, fish, milk, and other high fat foods (EPA, 2003b). For the organophosphates, the dietary ingestion levels are driven by fruit, vegetable, and grain products where agriculture uses are still permitted (EPA, 2003b). Congress recognized the importance of protecting children when it unanimously passed the Food Quality Protection Act (FQPA) in 1996. The law represents a major breakthrough, amending the two major pesticide laws, the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and the Federal Food Drug, and Cosmetic Act (FFDCA), to establish a more consistent, protective regulatory scheme grounded in sound science. It mandates a single, health-based standard for all pesticides in all foods; calls for special protections for infants and children; expedites approval of safer pesticides; creates incentives for the development and maintenance of effective crop protection tools for American farmers; and requires periodic re-evaluation of pesticide registrations and tolerances to ensure that the scientific data supporting pesticide registrations will remain up to date in the future (EPA, 2003a).

The use, misuse, and/or misapplication of insecticides in the residential environment can lead to acute, sub-acute or chronic exposures. In addition, illegal pesticides—such as insecticidal chalk, "Tres Pasitos," and naphthalene mothballs that are not registered and approved by the EPA—can pose significant health risks (EPA, 2005a). Due to concern over the health hazards associated with pesticide use in homes, alternative pest control methods have become more widespread. For example, integrated pest management (IPM) is a less-toxic, prevention-based strategy that employs knowledge of a pest's feeding, travel, and hiding habits, rather than implementing chemical extermination methods such as perimeter sprays or pesticide "bombs" or "foggers". Pest management companies that practice IPM will first employ non-chemical controls, such as sanitation, physical exclusion, or trapping, before turning to chemical pesticides (Consumer Reports, 1997). Typical IPM treatment plans include sanitation and maintenance, structural repairs, physical controls, spot application of pesticides when needed, and long-term monitoring (Siddiqi, 2001) (see Section 3.3 for more details on IPM).

# 2.0 Hazards Associated with Pesticide Use in the Home

## 2.1 Nature and Extent of Pesticide Hazards in the Home

Past studies have shown that the presence of certain physical housing characteristics can lead to an increased risk of pesticide use, which in turn can contribute to or even increase the exposure to pesticides and lead to detrimental health outcomes. Housing characteristics that are associated with increased risk of pest infestation and the subsequent risk of pesticide exposures include a degraded foundation and building envelope, presence of nearby trees and shrubs that touch the building, broken or poorly installed fascia and soffits, unsealed utility penetrations, unscreened doors and windows, and doors without a door sweep (Health Canada, 2001). All of these items allow easier access into the structure. Pets may also introduce pests, such as fleas, into the home from the outdoor environment if they are not properly screened and treated (Ohio State University Extension, 2003). Once inside a home, common plumbing in multifamily or conjoined housing allows migration of pests from one unit to adjoining units (Health Canada, 2001). The presence of clutter and improperly stored food or garbage, along with plumbing leaks, can also serve as harborage and food sources for pests. Conditions such as these can lead to pest infestations and may result in increased pesticide use.

Poor ventilation and the presence of certain household materials can influence the level of pesticides found in homes. For example, household materials such as carpets, upholstered furniture, and draperies can serve as sorbents or reservoirs resulting in subsequent slow release of the pesticides over time (Cohen Hubal et al., 2000; Hore et al., 2005; Rudel et al., 2003). Concentration or surface loading levels for individual pesticides span up to five orders of magnitude (Gordon et al., 1999; Nishioka et al., 1999; Roinestad et al., 1993; Simcox et al., 1995; Whitmore et al., 1994).

Within an agricultural community, Harnly et al. (2009) found that other housing factors, such as use of an air conditioner and cleanliness of the home, influenced pesticide dust levels. For example, higher levels of permethin, which is often used indoors, were found in homes with air conditioners than those without, while the levels of organophosphates which were used more often for agriculture were significantly lower in homes with air conditioners. This is likely due to homes with air conditioning having less air from the outside flowing into the home with homes with open windows. Also, homes that were considered "difficult to clean" due to housing density and disrepair had higher overall concentrations of pesticides.

A correlation between pesticides typically used within a geographic region and type of pesticide found in the home has also been noted (Colt et al., 2004). For example, in one study, residents living in southern California reported using pesticides mostly for crawling insects, fleas/ticks, and termites and had high levels of insecticides in their homes. Residents in Iowa reported using pesticides mainly for lawn/garden weeds and had higher levels of herbicides in their homes (Colt et al., 2004). In addition to location, the age of the housing unit is also an important factor. Offenberg et al. (2004) found that older homes, built between 1945 and 1959 when chlordane was used frequently in construction to prevent termites were more likely to contain higher levels of chlordane than homes built during a later time period.

## 2.2 Health Impacts and Toxicity

Children are more susceptible than adults with respect to the potential adverse health outcomes that can result from pesticide exposures (EPA, 2000a; EPA, 2000b; Olden and Guthrie, 2000; Wilson et al., 2003). Most pesticides found in indoor air and household dusts are present at levels that, on a compound by compound basis, do not appear to constitute an immediate health risk. However, there are several major unknowns in the determination of potential health outcomes. First, the health impacts and outcomes from chronic pesticide exposures are unknown at this time (EPA, 2000b; Weiss, 2000). Animal data and in-vitro work suggest that chronic pesticide exposures might be tied to learning and behavioral problems, such as attention deficit hyperactivity disorder (ADHD) and other neuropsychological deficits (Chanda et al., 1996; Rice et al., 2000). These possible effects can, and will, be ascertained only from epidemiologic data where both exposure and outcome are monitored, with control for the many other potential neurotoxic covariates and confounders of the residential environment and food (e.g., lead, mercury, PCBs) (Jacobson and Jacobson, 1996). In addition, difficulty in ascertaining the precise timing of exposure makes it difficult to determine specific health outcomes. Short-term exposures, during vulnerable windows of opportunity (such as periods of rapid prenatal development), may have the greatest impact on children's health (Arbuckle et al., 2001; Selevan et al., 2000).

Another complicating factor is that within each pesticide formulation there are active and inert ingredients. Active ingredients are defined as those that prevent, destroy, repel or mitigate a pest, whereas inert ingredients have no direct effect on pests (EPA, 2002a). Inert ingredients are not defined based on toxicity or risk to human health (EPA, 2005b). Many health-based studies and risk assessments have tended to focus solely on active ingredients, which may comprise a small percentage of the total formulation (Grossman, 1995). However, inert ingredients may pose an additional health risk or possibly contribute to the health effects associated with the active ingredients (EPA, 2005b; Watson et al., 2003).

Also, there are generally multiple pesticides present in environmental media (e.g., dust, air) in and around the home. These include previously deregistered organochlorine insecticides (e.g., chlordane, DDT), organophosphate insecticides (e.g., chlorpyrifos) and newer, replacement pyrethroid insecticides. The cumulative effects of exposures to several different pesticides are not well known. However, given the toxicity of all insecticides toward some component of the nervous system (both central and peripheral nervous systems), it is believed that children are a vulnerable, at-risk population because complete development of the nervous system does not occur until late in childhood (Hall et al., 1997).

**Organophosphate Toxicity Studies.** Extensive mammalian studies of organophosphate toxicity in general, and chlorpyrifos toxicity in particular, have suggested that neurotoxic effects can be expected from low dose/chronic exposures. In addition to inhibiting nerve transmission, organophosphates also interfere in the acquisition and development of new brain cells and inhibit DNA synthesis (Whitney et al., 1995; Dam et al., 1998; Li and Casida, 1998). These functions are critical to proper neurological development, especially with respect to cognitive functions (Rice and Barone, 2000; Weiss, 2000).

**Pyrethroid Toxicity Studies.** Even though research in the area of pyrethroid insecticides is only beginning, there is existing evidence on pyrethroid toxicity and the associated modes of action and metabolism that point toward the possibility of an association between pyrethroid compounds and adverse health outcomes.

Based on their chemical structure, synthetic pyrethroids are divided into two major classes

(Type I which lack a cyano moiety and Type II which contain a cyano moiety). Laboratory studies on the oral toxicities of Type I and II pyrethroids in rats, together with data on the toxicities of diazinon and chlorpyrifos, indicate that many pyrethroids approach the toxicities of the organophosphates (Kamrin, 1997; Miyamoto, 1976; Elliott, 1977; Worthing, 1983). The active ingredient(s) of major insecticide products for in-home use may be either Type I or Type II pyrethroids, and many high volume products (e.g., Raid with 23% of the market share, Hot Shot with 16% of the market share) contain Type II pyrethroids (Market Share Reporter, 2001). Many current products for outdoor use are convenient-to-use aerosols and sprays that can easily be used indoors (against label directions), and these products contain both organophosphates and pyrethroids.

The primary site of action for these insecticides is the central nervous system, rather than peripheral (Staatz et al., 1982). In a study of a high level exposure to permethrin, certain groups of rats showed significantly lower retention capacity, decreases in coordination and balance, and higher incidence of conflict behavior (Sherman, 1979). Other important studies have also demonstrated critical issues for neonatal exposures to pyrethroids. Cantalamessa (1993) found two pyrethroids, permethrin and cypermethrin, to be more toxic to the neonate compared with the adult rat. Sheets (2000) identified no difference between neonate and adult susceptibility for exposure to Type I pyrethroids but a three-fold difference for exposures to Type II pyrethroids. Sheets attributes this increased susceptibility in neonates to a limited detoxification capacity for Type II compounds, as well possibly the ability of Type II compounds to accumulate in biological tissues. Initial pyrethroid exposures may occur early in life, when metabolic systems have limited capacity and exposures may have life-long implications. Therefore, more research needs to be done to better understand the frequency and magnitude of early childhood exposures, the routes by which these exposures occur, and the outcomes of such exposures.

**Acute and Sub-Acute Exposures.** The most obvious adverse health outcome for children is poisoning from an accidental acute exposure. Cases of acute poisoning are generally due to direct contact with a product via inadvertent ingestion, dermal contact, and/or inhalation. In 2008, the American Association of Poison Control Centers documented 684,572 cases of nonpharmaceutical pediatric (<6 years of age) poisonings in the United States (Bronstein et al., 2009). Of the total nonpharmaceutical pediatric poisoning cases, 6% (42,260) were attributable to pesticide exposures. Overall, pesticide exposure ranked ninth in the list of 25 substance categories most frequently involved in pediatric exposure. Of the 6%, approximately 11,674 cases (28%) were attributed to rodenticide exposure. These numbers are likely an underestimate of the true number of cases each year due to the fact that the symptoms of mild insecticide poisoning and the "flu" or other common ailments are often very similar. The symptoms of insecticide poisoning include headache, fatigue, dizziness, shortness of breath, and loss of appetite with nausea, vomiting, stomach cramps, and diarrhea (University of Nebraska Cooperative Extension, 1997). For very young children, the increased salivation, crankiness and loss of appetite due to mild pesticide poisoning may be dismissed as "teething." Organizations such as the American Academy of Pediatrics have developed resource materials (e.g., *Handbook of Pediatric Environmental Health*) to help raise awareness among pediatricians and clinicians about the symptoms of pesticides and other environmental toxicants (Etzel and Balk, 1999).

The majority of sub-acute poisoning cases (i.e., "mild poisoning" cases with flu-like symptoms) occur after indoor use of insecticides, such as in homes or schools, and appear to be primarily due to either misapplication or a failure to fully ventilate the rooms after application. In studies examining such scenarios, levels of the insecticide chlorpyrifos were measured indoors on the day of application and the following day, and these data were combined with assumptions about exposure to estimate a dose for comparison with the NOEL (No Observable Effect Level; 30 μg/kg/day for chlorpyrifos) and the defined chronic exposure MRL (Minimum Risk Level; 1 μg/kg/d for chlorpyrifos) reported by the Agency for Toxic Substances and Disease Registry (ATSDR) (Fenske et al., 1990; Krieger et al., 2000; ATSDR, 2000). Both studies found that the NOEL and chronic exposure MRL were in some instances exceeded in the short term.

There has also been speculation in the scientific community about a potential association between pesticide exposure and neuro-developmental effects (Mendola et al., 2002), as well as potential asthma exacerbation (Quarles, 1999) in adults. The acute health outcomes for farmers and farm workers routinely exposed to organophosphates have been studied, and symptoms such as headache, dizziness and sleepiness appear to be associated with exposure, as well as some loss of peripheral nerve function (Eskanazi et al., 1999). Contaminants such as odor-producing agents in organophosphate pesticides have been linked to asthma in adults; these agents are thought to be low-molecular weight mercaptans and sulphides (Quarles, 1999; O'Malley, 1997).

Pesticides are of particular concern in low-income, inner-city neighborhoods, where conditions favor pest infestation (Berkowitz et al., 2003). In a study conducted by Columbia University on the effects of indoor air pollutants on pregnant women and their newborns in minority communities within the New York City area, strong associations were observed between substandard housing and pesticide exposures. Results suggested widespread use of pesticides in these areas, with 85% of the women reporting the use of pest control techniques during pregnancy, and at least four pesticides detected in the personal air samples of all women who consented to monitoring during their third trimester (Whyatt et al., 2002). The project also reported a high degree of correlation between maternal pesticide levels and levels found in cord blood samples, indicating that exposures are easily transferred between mother and fetus (Whyatt et al., 2003). Another study found highly significant inverse associations between birth weight and length and blood cord levels of chlorpyrifos and diazinon (Whyatt et al, 2004). Among newborns born after the EPA regulatory actions to phase out residential use of these insecticides in 2000–2001, exposure levels were substantially lower, and significant increases in infant birth weights were observed (Whyatt et al., 2004). In another study of prenatal exposure to common urban pollutants, maternal chlorpyrifos exposure was associated with reduced birth weight and length among African Americans newborns, as assessed by personal monitoring, biomarkers, questionnaire data, and medical records (Perera et al., 2003).

There has also been suggestion that children exposed to pesticides in utero and early childhood may be at increased risk for childhood cancers, including development of Wilms Tumor. However, a recent case-control study examining this issue, found no significant association between reported insecticide use and development of Wilms tumor (Cooney et al., 2007). Self-reported use of insecticides during pregnancy has also been linked to childhood leukemia and non-Hodgkin's lymphoma (Menegaux et al., 2006; Rudant et al. 2007); however, better exposure assessment and further investigation needs to be done to determine if these observed associations are a causal relationship (Metayer et al., 2008, Turner et al., 2010).

**Chronic Exposures.** Pesticide residues remain in a home for years after exposure, even if precautions are used when applying them. These residues can result in chronic exposure (Whitmore et al., 1994; Whyatt et al., 2007). Studies on health outcomes related to chronic exposure in children are very limited. At the initiation of several major studies funded by the National Institute of Environmental Health Sciences (NIEHS) and EPA on health outcomes for very young children exposed long-term to diazinon and chlorpyrifos, the EPA reached an agreement with manufacturers to remove these products. Thus, children's exposures have been significantly reduced throughout the course of these critical studies. One study (Guillette et al., 1998), though, did document significant differences in stamina, gross and fine eye-hand coordination, 30 minute memory, and the ability to draw a person among two identical populations of children—one essentially unexposed to pesticides, and the other exposed to insecticides indoors in the home on a daily basis. The pesticides used by the families were not documented, but they are presumed to have been organophosphates.

## 2.3 Methods Used To Assess Pesticide Hazards In The Home

The following section provides the reader with an overview of the range of assessment techniques that are available, from both a research and programmatic perspective. The level of rigor for assessing hazards in a research setting surpasses that which is needed for programmatic or public health use. From a housing or public health perspective, a home assessment is generally constrained by the need for cost effective methods that are sufficient to allow for the identification of targeted substances at levels of concern. Low cost residential assessment methods typically employed from a programmatic perspective include inventory surveys of pesticides and resident questionnaires; however, there are disadvantages to both approaches. More rigorous research studies utilize human biological sampling data, as well as samples taken from environmental media to assess pesticide levels in the home. Each of these approaches is described below.

**Home Surveys and Questionnaires.** From a public health program perspective, simple, non-invasive methods to assess potential pesticide exposures in the home include inventory surveys of pesticides stored throughout a home and garage and recall questionnaires about pesticide use and frequency of application (Adgate et al., 2000). These methods are lower in cost than conventional sampling and chemical analyses and point to the general prevalence of pesticides use in and around the home, and thus the potential for an exposure event to occur. However, the inventory approach will miss a product that has been used completely and no container remains for counting. Surveys are also often flawed because personal recall of pesticide use has low validity generally and recall of specific product use is quite poor (Gordon et al., 1999). Some of this is due to the very nature of insecticide use indoors—products are readily available in convenient-to-use containers, and use is sporadic and rapid. In addition, individual activity factors, for the applicator, the child, other family members, and even pets, can have dramatic impacts on exposure. The role of personal activity factors has only recently been identified and quantified in one study, so that specific questions to capture these factors are only now beginning to appear in questionnaires and surveys (Nishioka et al., 1999). An individual's attitude and perception of risk related to pesticide use can also influence information obtained in questionnaires and potentially result in underreporting, especially when questions used to obtain information are limited in scope (Nieuwenhuijsen et al., 2005).

Very limited information is available on how well pesticide exposure information obtained from questionnaires corresponds with data collected from environmental samples taken in the home. Sexton et al. (2003) found that telephone screening and questionnaires were inadequate predictors of households exposed to higher levels of target pesticides, possibly due to incongruity between the general questions asked on the survey and the far more specific pesticide measurements taken in sample homes. However, Colt et al. (2004) found information gathered from the use of detailed questionnaires that included visual aids and focused on the types of pests treated, who applied the pesticide, how often the pesticide was applied, and longer time frames of interest, correlated well with the types of pesticides found in vacuum bag samples. In addition, authors suggest that detailed questionnaires can be useful in capturing pesticides used in the home prior to the installation of carpets. Therefore, when used in conjunction with environmental sampling, questionnaires can provide additional useful information that may not otherwise be captured.

In the event of acute or sub-acute poisonings, the causative event or product can usually be inferred by parents or caregivers via area surveillance. Because "mild poisonings" (e.g., with flu-like symptoms) often occur when a pesticide misapplication is made in the home or school, sudden onset of conditions for multiple individuals can be used as an indication of possible sub-acute exposure. At these times, ventilation of the rooms and cleaning of surfaces must be performed immediately to reduce the levels of toxic residues.

**Human Biological Sampling Data.** The Centers for Disease Control and Prevention's National Center for Health Statistics conducts a nationwide National Health and Nutrition Examination Survey (NHANES) of randomly selected individuals and measures the levels of environmental contaminants in blood and urine samples (NHANES, 2003; CDC, 2003, 2005, and 2009). Statistics on the levels of various contaminants, including organophosphates,

**Table 3.** Average concentrations[1] of Selected Pesticides Found in Clinical Specimens[2], NHANES 1999-2000, 2001-2002, and 2003-2004

| Pesticide of concern | Analyte3 | 1999–2000 Average Concentration | 1999–2000 Limit of Detection | 2001–2002 Average Concentration | 2001–2002 Limit of Detection | 2003–2004 Average Concentration | 2003–2004 Limit of Detection |
|---|---|---|---|---|---|---|---|
| **Urinary metabolites** | | | | | | | |
| Organophosphates | Dimethylthiophosphate<br>Diethylphosphate<br>Diethylthiophosphate | 1.82 ug/l<br>1.03 ug/l<br>* | 0.18 ug/l<br>0.2 ug/l<br>0.09 ug/l | *<br>*<br>0.457 ug/l | 0.4 ug/l<br>0.2 ug/l<br>0.1 ug/l | 2.1 ug/l<br>*<br>* | 0.5 ug/<br>0.1 ug/l<br>0.2 ug/l |
| Chlorpyrifos | trichloro-2-pyridinol | 1.77 ug/l | 0.4ug/l | 1.76 ug/l | 0.4 ug/l | No information | |
| Organochlorines | 2,4,6-trichlorophenol | 2.85 ug/l | 1 ug/l | * | 1.3 ug/l | No information | |
| Para-dichlorbenzene | 2,5-dichlorophenol | 6.01 ug/l | 0.1 ug/l | * | 0.1 ug/l | No information | |
| o-phenyl phenol | o-phenylphenol | 0.494 ug/l | 0.3 ug/l | * | 0.3ug/l | No information | |
| Pyrethroids | 3-phenoxybenzoic acid | No information | | 0.321 ug/l | 0.1 ug/l | No information | |
| **Serum samples** | | | | | | | |
| DDT | p,p'-DDE | 260 ng/g lipid | 18.6 ng/g lipid | 295 ng/g lipid | 8.3 ng/g lipid | No information | |
| Lindane | beta-hexachlorocyclohexane | 9.68 ng/g lipid | 9.36 ng/g lipid | * | 6.76 ng/g lipid | * | 7.8 ng/g lipid |
| Chlordane | trans-nonachlor<br>Oxychlordane | 18.3 ng/g lipid<br>* | 14.5 ng/g lipid<br>14.5 ng/g lipid | 17.0 ng/g lipid<br>11.4 ng/g lipid | 10.5 ng/g lipid<br>10.5 ng/g lipid | 14.7 ng/g lipid<br>9.37 ng/g lipid | 7.8 ng/g lipid<br>7.8 ng/g lipid |

** Proportion of samples below the limit of detection was too high to calculate average concentrations.*

*[1]Urinary metabolites represent geometric mean of urine concentrations (in µg/L) for the U.S. population aged 6 to 59 years, National Health and Nutrition Examination Survey, 1999–2000, 2001–2002, and 2003–2004. Serum sample represent geometric mean of serum concentrations (in nanograms/gram [ng/g] of lipid or parts-per-billion on a lipid weight basis) for the U.S. population aged 12 years and older, National Health and Nutrition Examination Survey, 1999–2000, 2001–2002, and 2003–2004. [Source: CDC, 2003 and 2005 and 2009]*

*[2]Chemical specimens reflect total exposure to pesticides and do not indicate what proportion comes from home exposures.*

*[3]Exposure to some analytes could result from exposure to non-pesticide substances (e.g., o-phenyl phenol is a common analyte from exposure to disinfectants like Lysol).*

*[4]Additional research is needed to determine whether the average concentrations of pesticides detected in NHANES biological samples are at levels of concern.*

organochlorines, herbicides, and various other pesticides, are reported by gender, age and race/ethnicity. It is important to note, however, that no pesticide data are collected for children under the age of six (and often for children of any age). For several pesticides, which are rapidly metabolized and excreted in urine, contaminant levels are estimated from analysis for a pesticide's metabolite. Information from this national survey could be used in contrast or comparison with the data from poison control centers. Selected results from NHANES 1999–2000, 2001–2002, and 2003–2004 are presented in Table 3. Whether the levels of the pesticides and metabolites reported in this table are a cause for health concern is not known; more research is needed (CDC, 2003, 2005, and 2009). However, the NHANES data do provide reference ranges (levels of chemicals in blood and urine that were found in the general population) to aid physicians and health researchers in determining if a person or group of people have an unusual level of exposure.

The National Children's Study is a longitudinal study of over 100,000 children designed to examine the effects of the environment on the health and development of children. One aim of the study is to investigate if pre- and post-natal exposure to non-persistent pesticides increases the risk of poor performance on neurobehavioral tests. To address this issue, levels of pesticides may be characterized using questionnaires, biological markers, and environmental sampling data (Bradman and Whyatt, 2005). Although data are not yet available, results from this study could also provide important pesticide exposure information to which other data can be compared.

**Sampling and Analysis of Environmental Media.** Another way to assess human exposure to pesticides is through micro-environmental sampling for pesticide residues in air, settled dust and on surfaces. This can be combined with child activity profiles, such as rates of hand/object-to-mouth and crawling activities, respiration rates and time spent indoors, to estimate the exposure via a specific exposure pathway (Zartarian et al., 2000). Alternatively, personal samples, such as hand wipes and videotape records of child hand-to-mouth activity, can be used to estimate exposures (Reed et al., 1999). Finally, the measurement of a biomarker of exposure, such as the excreted pesticide metabolite in urine or pesticide concentration in blood, can be used to assess the potential internal dose (Krieger et al., 2000; MacIntosh et al., 1999). Each method has strengths and limitations (Zartarian et al., 2000; Bradman and Whyatt, 2005). At this time, two of the most useful samples for assessing a child's potential residential pesticide exposure are the bulk house dust and the child's hand wipe. The former indicates "what's there" and the latter indicates "how much" the child comes in contact with when interacting with this environment.

Sampling of dust reservoirs is usually achieved using a suction/vacuum device, wipe sampling, or a dislodgeable residue sampling device. A frequently used vacuum device for collection of floor dust for pesticide analysis is the High Volume Surface Sampler HVS3 or HVS4 (Cascade Stack Sampling Systems, Inc.; Nishioka et al., 1996). The use of this device has been formalized as ASTM method D5438-93. Surface wipe sampling has utilized a variety of sorbent media wetted with different solvents (Deziel et al., 2011) A media more recently used in several studies is a bonded microfiber surgical dressing sponge moistened with isopropanol, water, or a "sweat simulant" (Nishioka et al., 1999; Stout II et al., 2009). The National Children's Study in conjunction with the U.S. EPA has conducted research (Deziel et al., 2011) evaluating cotton twill wipes as a surface sampling media. Bonded microfiber media has been shown to contain a large mass of a glue-like binder that can interfere with analytes during chemical analysis. The twill wipe has many favorable qualities such as general availability, ruggedness, established manufacturing specifications, and durability following rigorous precleaning steps that hold promise as an ideal media for a standardized approach to sample residential surfaces.
Other dislodgeable residue sampling can be accomplished with research devices such as the Polyurethane Foam (PUF) Roller, CDFA Roller, Dow Drag Sled or the EL Press Sampler (Nishioka et al., 1996; Ross et al., 1991; Edwards and Lioy, 1999).

Since all of these techniques are most appropriate for use in a research setting as opposed to routine housing assessments, they have not been subject to the same extensive intercomparison studies that were used to select and certify techniques for lead sampling. There are also drawbacks to these techniques. The HVS3 vacuum, which is based on an upright Royal vacuum cleaner, is relatively expensive (~$3000), large, and awkward to use for routine sampling in multiple locations (the HSV4 vacuum sampler is smaller and more portable than the HSV3 sampler).

Wipe sampling is often limited in measuring contaminant loads on soft surfaces. For example, studies demonstrate that wipe sampling removes only 31–39% of pesticide loadings on carpeted surfaces compared to 84-97% on hard flooring surfaces (Bernard et al., 2008). Despite this limitation, using solvent moistened wipes has been found to be more efficient than using the El Press Sampler in measuring residue at loading rates typically found in residences (Bernard et al., 2008). In addition, the dislodgeable residue samplers are research tools and, as such, are not available commercially. Several of them are somewhat cumbersome to use and are not amenable to collection of residues on surfaces other than floors.

In general, when samples are collected in homes, the collection sites often include floor areas where children typically play (e.g., family room, bedroom, kitchen), and wipes of surfaces that children frequently contact (e.g., tables, counters, toys). Vacuum dust collection of floors typically covers a 1–2 m2 area of these rooms; wipe sampling typically covers a smaller area (e.g., 30 cm x 30 cm (1 ft2)). In a recent study, researchers found significant correlations between vacuum dust samples taken from living rooms and floor wipe samples taken from the kitchen area and suggest that kitchen floor wipes may serve as a less costly and non-intrusive sampling method in difficult sampling environments (Julien et al., 2008).

Chemical analyses for pesticides in environmental media and biomarker samples involve extraction, cleanup, and GC/MS analysis. The protocols and methods can be adapted so that multiple residues, even as many as 25–50 analytes, can be analyzed in the same sample extract (Chuang et al., 1999).

## 2.4 Methods Used To Mitigate Pesticide Hazards In The Home

While pesticide application methods, such as crack and crevice application, can limit children's exposure to pesticides used in the homes (Hore et al., 2005), the best way to eliminate pesticide hazards in the home is not to use them. Therefore, outreach to the public on alternatives to traditional pesticide use is a first step in reducing pesticide exposure in the home. In some cases, the risk posed by the pest will outweigh the risk of pesticide use. Each situation is unique. Education of inspectors and homeowners is necessary to weigh options and choose an appropriate course of action. In cases where pesticide exposure hazards are discovered through a home assessment, actions to mitigate those hazards are necessary.

**Prevention.** In many cases, the most effective and cost-effective method for mitigating pesticide exposures in the home are the prevention of improper pesticide use and application, and the minimization of overall pesticide use by managing pests by non-chemical methods. These preventive methods may be achieved best through public education programs and adequate product labeling (e.g., descriptive product instructions that are available in multiple languages and written in type large enough to be easily read). Public education programs should include, for example, information on the importance of trying non-pesticide control tactics before or in conjunction with pesticide use, following use and application labeling, sufficient room ventilation after product use, proper protective clothing and cleanup following product application, and license checks for commercial applicators.

- **Proper use.** Consumer education can focus on using the least toxic approach, using pesticides only when necessary, and following the application rates provided on the label. Many homeowners over-apply, for example assuming that "the more, the better," or desiring to empty the container to eliminate concerns over long-term storage, stability, and potential child contact.
- **Modification of the living environment.** Consumer education should focus on modifying the living environment to make it less attractive to pests.
  - **Eliminate food sources and manage garbage.** By preventing access to food, keeping food properly stored, frequently cleaning counters, floors, and dishes, and securing trash, residents can reduce pest infestation.

- **Eliminate home access points.** The use of caulking, sealants, weather stripping, screens, door sweeps, escutcheon plates, and the installation of floor drains can help prevent pests from entering the home.
- **Eliminate water sources.** By controlling leaking pipes, toilets, faucets, standing water, and excessive humidity, homeowners can reduce the attraction of pests who seek out and thrive in damp environments.

- **Targeted use of pesticides.** The need to use insecticides on a whole-room or whole-house basis is rare. Use of pest-specific insecticides such as insect growth regulator bait instead of spray or dust in concealed areas are increasing in popularity. For example, flea infestations may be reduced by using products directly on pets, such as insecticide impregnated pet collars.
- **Proper ventilation.** For products used indoors, the instructions for proper ventilation after application are important. This includes direct ventilation with a fan of those treated closets and enclosed areas that are not reached by general air streams from open windows and doors.
- **Treatment of applicator clothing and shoes.** For pesticides used outdoors, or with a heavy indoor application, the applicator should either place/leave shoes outdoors or wash them off (as in rubber boots) before wearing them indoors. Use of coveralls and/or removal of contaminated clothing outdoors, with immediate laundering, can prevent some of the contamination and dispersion within the home that comes from this source.
- **Assessment of contract applicators.** Homeowners and renters can check with commercial applicators, or building supervisors for rental property, to verify that the applicator is licensed (ask to see the license), and that the applicator is applying an approved and registered pesticide for that situation/location. (For pesticide related questions, homeowners and renters can contact the National Pesticide Information Center at 1–800–858–7378.)

Questions to be asked before committing to a pest control contract may include:

- Are employees trained applicators who receive continuing education?
- Does the pest control company have the capacity to respond to urgent requests?
- Do you have the capacity to act on their recommendations?
- Who will be responsible for physical control measures?
- Do technicians remove pests and pest evidence with a HEPA vacuum cleaner?
- Will the pest control company develop a site plan that doesn't involve routine pesticide application?

**Post-Contamination Clean-Up.** While preventive measures are preferable, post facto decontamination procedures must be included in any public health program responding to the misuse of pesticides indoors. In the case of overuse of an approved pesticide, continued and aggressive use of ventilation, combined with repeated detergent-based cleaning of toys, countertop, table, and dish surfaces, can reduce residue levels that children may contact. This work needs to be instigated at the earliest possible time before pesticide residues have time to migrate into carpet backing and pads, where they are no longer amenable to removal by cleaning (Fortune et al., 2000).

If early interventions do not occur, removal of carpets may be necessary. Steam cleaning has been shown to help reduce pesticide residues in carpets initially to levels below the limit of detection (McCauley et al., 2006). However, in homes tested twelve months later, the levels of pesticides increased to one-third of the original baseline level (McCauley et al., 2006). Steam cleaning may have only minimal utility since the majority of pesticide residues in floors reside in the carpet backing and pad compartments and not in the dust per se, and therefore may not be reached by cleaning the top of the carpet (Fortune et al., 2000). As the pesticides slowly volatilize from this reservoir, they equilibrate with the settling dust. Frequent vacuuming or steam cleaning may be sufficient to remove superficial residues but probably will not remove the larger source. Carpets should be removed from closets and enclosed areas that cannot be readily ventilated. Some consideration may be given to periodically replacing carpets and pads of high traffic areas or removing them from high use areas.

Removing pesticide residues from linoleum flooring can also be difficult. Frequently wringing a mop, using floor cleaner and changing the water after cleaning and before rinsing does not guarantee removal of pesticide residues and in fact, may result in moving the residues around the floor (McCauley et al., 2006). Using a different mop between washing and rinsing and hanging used mops outside to dry in an effort to breakdown the residues may help in reducing pesticide contamination; however, these strategies need to be investigated further to determine their effectiveness (McCauley et al., 2006).

# 3.0 Integrated Pest Management (IPM)

## 3.1 Overview of Integrated Pest Management in the Home

Growing concern over the health hazards associated with exposure to pests and pesticides in the indoor environment has also led many municipalities, homeowners, school districts, and public policy officials to seek ways to achieve effective, sustainable pest management while reducing reliance on chemical controls. IPM has received recognition internationally as a beneficial approach to pest control, due to the fact that this approach encourages reducing overall pesticide use (i.e., applying only as needed), using the least toxic product if a pesticide is needed, and confining the area of pesticide application (e.g., with targeted gels, baits, and powders). In addition to reducing the probability of human pesticide exposures, IPM has been credited with greater sustainability in keeping pest populations down (in contrast to extermination-only methods, which typically need to be repeated), and with reducing pesticide release into the environment (New York State Integrated Pest Management Program, 2001). IPM also helps to combat the problem of insecticide resistance, which has been documented in cockroaches across many classes of commonly used insecticides (Wu et al., 1998) and diminishes the sustainability of any pesticide's use.

Effective IPM involves all stakeholders in the community doing their part. Increasing awareness of all individuals using a property aides in early detection and rapid response and helps ensure non-pesticide methods are employed to a standard that will mitigate pests. As an example, in public housing units the housing authority, pest control operators, and tenants all have responsibilities in IPM. The housing authorities and property managers have to provide and maintain units to avoid issues that contribute to pest infestations and pest control operators have to carefully inspect units, identify potential issues, treat units safely and effectively and provide ongoing monitoring (http://www.nchh.org/Portals/0/Contents/Case_Study_Cuyahoga_10-20-07.pdf). Tenants must cooperate with the efforts and help provide and maintain an environment that supports success of IPM. In order to do this effectively, residents must be educated about pests and IPM practices.

A recent study in an urban community found IPM to be a cost-effective and successful method of controlling cockroach infestation when community residents are involved at every stage of the project and provided with hands on training and education (Brenner et al., 2003). Similarly, another study conducted in older, urban dwellings found that IPM (incorporated as part of a multi-hazard, multi-strategy approach to home remediation of hazards) was more effective in reducing allergen levels in homes if residents were trained compared to using IPM in homes where residents received no training (Klitzman et al., 2005).

In a pilot study, public housing residents were recruited and trained as peer educators to work with families on the role of sanitation in infestations, pest habits, and preparing for IPM treatments. In addition to three visits from pest control operators, families received a total of three visits from the peer educators to reinforce the importance of resident involvement in IPM. Results showed that preparation for pest control treatment significantly improved after the peer education intervention. In addition, sanitation improved and the cockroach population was significantly reduced by the third visit in units that received the peer education (Condon et al., 2007). Units that did not receive the peer education showed no improvement. Subsequent projects have also found similar results (http://www.nchh.org/Portals/0/Contents/Case_Study_Boston_HA_11-13-07.pdf).

## 3.2 General Guidelines for IPM in Homes

Because IPM is a process, the specific management strategies used are defined by a particular situation. For example, an IPM plan may include use of mechanical and physical controls, such as structural repairs, preventive maintenance, or pest trapping, as well as targeted application of pesticides. The following general framework can be applied with modifications to most specific situations. In addition, the U.S. Department of Housing and Urban Development has identified ten elements of an effective IPM program which are outlined in Table 4. In general, IPM programs consider the following key elements:

**Identification, Monitoring & Recordkeeping.** To attain the benefits of an IPM program, information must be gathered about the target pest population, site, and people who use the space. Information on these factors are used to determine the appropriate IPM course of action whether it be prevention or bringing a population under control and then preventing future outbreaks. The pest and/or the problem (including the type of pests and how many), or potential pest problem, must be correctly identified and observed at regular intervals. Inspection is routine, pesticide application is not. Records are kept on what is seen, decisions made, actions taken, and results. Analysis of these records helps identify trends and allows decision makers to make the program more efficient.

**Tolerance Levels.** When a pest problem is identified, a decision is made on whether the pests should be controlled. Considerations when determining if action is necessary may include: whether the benefits derived from control justify the costs and risks incurred, when (if not currently) the pest problem is likely to become serious enough to require some action, and tolerance levels (e.g., a certain number of pests may be tolerable).

**Table 4.** Ten Elements of an Effective IPM Program

**1. Communication**
Communicate IPM policies and procedures to all building occupants, administrative staff, contractors, and maintenance personnel.

**2. Identification of problems**
Identify the presence of pests and conditions that lead to their presence.

**3. Monitoring and tracking**
Establish ongoing monitoring and a record keeping system for regular sampling and assessment of pests, surveillance techniques, and remedial actions taken, including criteria for program effectiveness.

**4. Identification of thresholds**
Work with residents to set thresholds at which pest populations warrant action.

**5. Improvement of methods**
Improve waste and pest management methods.

**6. Prevention of pest entry and movement**
Monitor and maintain structures and grounds. Add physical barriers to prevent pest entry and movement.

**7. Education of residents and updating of leases**
Develop outreach/educational program to ensure leases reflect residents' responsibilities in pest management.

**8. Enforcement of lease provisions**

**9. Using pesticides only when necessary**
Use pesticides only when necessary and use effective products that pose the least harm to humans and the environment.

**10. Posting of signs**
Provide and post 'Pesticide Use Notification' signs or other warnings.

**Least Toxic Treatments.** In an IPM program, the object of treatment is to suppress pest populations to an acceptable level. For some species, the intent may not be to eradicate them. Control strategies that are proven effective, easy to carry out effectively, long lasting, and least disruptive to the environment (including people) are selected.

**Pest Control Options/Treatment Strategies.** If action is called for, actions with minimum adverse effects are preferred. Examples of different control methods commonly used in IPM programs include:

- **Behavioral methods.** Many behavioral practices (also known as "cultural control") can reduce pests by changing people's routines so that environment less conducive to infestation. For example, proper disposal of garbage at the end of the day (assuming the target pest is most active at night), using storage systems that reduce open food and clutter in offices and basements, discouraging residents from bringing home used furniture, and planting trees and shrubs away from buildings so that they do not grow to touch the siding.
- **Mechanical or physical methods.** Mechanical controls are direct measures that either kill the pest or block their entry, dispersal, or survival. For example, traps can be used to catch a variety of pests, including cockroaches, ants, and mice. Several practices physically keep insect pests from places where they're not wanted by eliminating home access points. Barriers, such as window screens and caulking/sealing cracks, will help exclude many health and nuisance pests from buildings.
- **Biological methods.** Virtually all species, including all types of pests, have natural enemies. The use of natural enemies to combat pests is generally restricted to lawn and garden areas. For example, predators, such as ladybugs and lacewings, feed on aphids, caterpillars, and beetle larvae. Parasitoids such as mini wasps and flies are important in the fight against aphids, scale insects, and whiteflies. Some research has demonstrated the use of parasitoids for indoor pest control, but pesticides targeted at their host and low tolerance for any insect indoors has limited their practical use in indoor IPM programs.
- **Chemical methods.** Least toxic chemical herbicides, insecticides, fungicides, or rodenticides are preferred for controlling pests. Chemical pesticides that are selective (i.e., target specific pests) are preferred. During treatment, instructions the applicator must follow the label directions carefully and use appropriate protective equipment and clothing. Chemical pesticides are used only when other methods and techniques have failed to manage the pest, and they are used for spot treatments rather than for broadcast applications. If a chemical control is justified, care is taken to implement it properly in a targeted location and at the right time. For instance, targeting pregnant females is crucial for cockroach control, but these cockroaches are usually hiding and not very active. The pest management professional must seek out these hiding spots with careful inspection and monitoring.

**Evaluation/Re evaluation.** After the treatment action has been taken, pest control operators, as well as residents, must conduct inspections and assess the short term and long-term effectiveness of the treatment strategy. Monitoring is an ongoing event. Checking monitors and inspecting for new pest-conducive situations should replace routine pesticide applications in the transition from traditional pest control to IPM.

**Resident Involvement.** In general, IPM requires more active participation by residents and homeowners than more traditional treatments (Consumer Reports, 1997). The New York State IPM Program recommends five specific preventive management strategies for residents who want to implement IPM in their homes.

- Keep the home clean by wiping up spills, not leaving food exposed for long periods of time, and removing clutter.
- Prevent access to pests by storing all dry food, pet food, and birdseed in tightly covered containers.
- Remove open, uncovered enticements such as sweet and greasy foods from the home.
- Control the amount of moisture that may be in the home by fixing leaks and encouraging ventilation, because insects often seek wet spots.
- Erect blockades, such as caulking, door sweeps, netting, and screens to exclude pests (The New York State IPM Program—fact sheet).

These strategies, as well as others, are incorporated into EPA publications including:

- "Citizen's Guide to Pest Control and Pesticide Safety" http://www.epa.gov/oppfead1/Publications/Cit_Guide/citguide.pdf,
- "Preventing Pests at Home" http://www.epa.gov/oppfead1/Publications/preventpest.pdf,

- “Help! It’s a Roach!” http://www.epa.gov/oppfead1/Publications/helpitsroach.pdf,
- and other documents available through EPA’s Office of Pesticide Programs http://www.epa.gov/oppfead1/Publications/catalog/subpage3.htm.

Additionally, consumer outreach materials are available from:

- the National Center for Healthy Housing http://www.healthyhomestraining.org/ipm/education.htm,
- the Northeastern IPM Center www.stoppests.org,
- and Boston’s Healthy Pest-Free Housing Initiative http://www.bphc.org/hpfhi/Pages/home.aspx.

**Involvement of Property Managers.** Property managers also have key role in the effectiveness of IPM. There are several tools created to help this group development and implement IPM practices. These include:

- trainings courses offered by:
    - the National Center for Healthy Housing http://www.healthyhomestraining.org/ipm/training.htm
    - the Northeastern IPM Center http://www.stoppests.org/.
- and resources such as “Integrated Pest Management: a Guide for Managers and Owners of Affordable Housing” developed by the Asthma Regional Council and Boston Public Housing Commission http://asthmaregionalcouncil.org/uploads/IPM/asthma_ipm_guide.pdf.

**Involvement of Pest Control Operators.** Contractors can receive training and obtain voluntary certification in IPM through organizations such as:

- the IPM Institute of North America, Inc., a nonprofit institute that operates a training and certification called GreenShield certified (http://www.greenshieldcertified.org/).
- the GREENGUARD Environmental Institute, an organization focused on improving health and reducing exposure, evaluates and certifies pest control practices of pest management providers and facilities.
- GreenPro (http://www.npmagreenpro.org/), managed by the National Pest Management Association, is an IPM service protocol that companies that are Quality Pro certified can offer. The Quality Pro program promotes professionalism and environmentally friendly approaches for structural pest management.

The National Center for Healthy Housing has compiled information about these and other certifying organizations at http://www.healthyhomestraining.org/ipm/PMP_Comparisons.htm.

## 3.3 IPM Control Methods for Specific Pests

### 3.3.1 Cockroaches

In addition to being a common household nuisance pest, cockroaches have also been identified as an important indoor allergen source related to the exacerbation of asthma, particularly in any area where substandard housing permits cockroach infestation (Katial, 2003; DeVera et al., 2003; Arruda et al., 2001). Although there are 70 cockroach species that occur in the U.S., only five species are commonly found in residential settings: the German cockroach (*Blatella germanica*), the American cockroach (*Periplaneta americana*), the Oriental cockroach (*Blatta orientalis*), the smoky brown cockroach (*Periplaneta fuliginosa*), and the brown-banded cockroach (*Supella longipalpus*) (Eggleston and Arruda, 2001). The widespread use of chemicals to control cockroach populations has led to insecticide resistance in some species, particularly the German cockroach. Resistance in the German cockroach has been documented extensively for organophosphates, carbamates, and more recently, pyrethroids. Repeated exposure to these compounds has allowed the German cockroach to develop behavioral, physiological, and metabolic defenses that allow populations to thrive even after extensive insecticide application (Wu et al., 1998). In addition, more recent evidence indicates that certain strains of the German cockroach have developed an aversion to the food ingredients (sucrose, fructose, glucose, and maltose) used in gel baits (Wang et al., 2004). The resistance behavior is very stable and can be maintained in many generations (Wang et al., 2006). The development of behavioral and physiological resistance to gel baits in cockroaches further emphasizes the need for adoption of IPM strategies.

An IPM program for cockroaches may consist of both physical and chemical control measures. These include reduction or elimination of food, water, and shelter resources (such as use of good sanitation practices and plugging major holes around plumbing, sealing cracks and crevices to prevent entry and limit hiding places), in combination with careful placement of the least toxic baits and insecticides necessary (Katial, 2003; CMHC, 1998; Ogg et al., 1994). Following initial intervention, IPM approaches emphasize continued monitoring of cockroaches in the same areas to assess the success of the control program and whether additional intervention is necessary (Ogg et al., 1994). The humidity in a home may be another important factor in cockroach infestations for some species, such as the German and American cockroaches which tend to aggregate in warm, humid crevices such as those around water heaters, laundries, bathrooms, appliances, and plumbing fixtures, and the Oriental cockroach which prefers damp areas such as basements, plumbing, and sewers (Eggleston and Arruda, 2001).

Insecticides, including inorganic compounds (e.g., boric acid), pyrethrins, avermectins/ abamectin (e.g., Raid®, Combat®), and newer compounds (e.g., fipronil, hydramethylnon, imidacloprid, and sulfluramid) are often used in the home to kill cockroaches (Katial, 2003; Vaughan and Platts-Mills, 2000; Eggleston and Arruda, 2001). Boric acid and a less processed form (disodium octoborate tetrahydrate) may be appropriate for persons who are chemically sensitive (Katial, 2003; Vaughan and Platts-Mills, 2000). Studies reviewed by Eggleston (2000) indicated that pesticides such as these can be effective in reducing cockroach populations by as much as 90% for as long as three months. Although these pesticides may be applied in almost any form, cockroach gel baits are available and can be applied to cracks and other critical areas in a manner that will reduce potential exposures to pets and children (Eggleston and Arruda, 2001). Gel baits may also be preferred because they have a longer duration of effectiveness and because the insecticides can be carried back to areas of heavy infestation (Kopanic and Schal, 1999; Durier and Rivault, 2000; Buczkowski et al., 2001; Buczkowski and Kopanic, 2001). Bait traps have also been developed that limit access to the pesticide (Eggleston and Arruda, 2001) but may require frequent replacement to provide long-term benefit (Katial, 2003; Ogg and Gold, 1993).

There is evidence that the use of cockroach allergen abatement strategies that combine extermination and cleaning can temporarily reduce exposure. Arbes et al. (2003) observed substantial reductions in cockroach allergen levels in low-income, urban housing through a combination of occupant education, use of insecticide bait, and professional cleaning. Although levels in some areas (e.g., the kitchen) remained above estimated asthma exacerbation thresholds (8 U/g), cockroach allergen levels (Bla g1) in areas highly relevant for exposure

Demonstrating the importance of home repair and maintenance in mitigating cockroach populations, Rauh et al. (2002) investigated levels of cockroach allergens (Bla g 2) in a sample of low-income households with young children in northern Manhattan in New York City (40% were receiving public assistance) to determine whether the distribution of allergens is a function of housing deterioration. Results showed significant positive associations between housing deterioration and cockroach allergen levels (measured in dust) in kitchens. These findings demonstrate that indoor household cockroach allergen levels are related to the degree of household disrepair, suggesting that social-structural aspects of housing may be appropriate targets for public health interventions designed to reduce allergen exposure (Rauh et al., 2002). Also in support of these findings, Peters and colleagues (2007) found that public housing units that had holes in the walls or ceiling had significantly higher levels of cockroach allergens (Bla g2) in the kitchen compared to other units (a 6–11 fold increase over units with no holes). Poor housekeeping, general cleanliness and presence of clutter, was also associated with airborne concentrations of cockroach allergens, especially Bla g 1.

(e.g., the most heavily contaminated areas in the bedding and bedroom) were significantly reduced to below the estimated asthma sensitization threshold (2 U/g). In a follow-up study of homes that participated in the six-month intervention conducted by Arbes et al. (2004), it was discovered that reductions in cockroach allergen concentrations could be maintained through 12 months with the continued application of insecticide bait alone. Taking this a step further, declines in the levels of cockroach allergen and dust mite allergens in bedrooms of asthmatic children has been significantly associated with a decrease in asthma complications (Morgan et al., 2004).

In a community-based project focused on low-income housing, project staff found that engaging public housing residents in a collaborative process and using a package of interventions including IPM and intense cleaning helped to decrease cockroach allergen levels and also reduce reported respiratory symptoms (Spengler, 2005).

Suggested reasons for the lack of effectiveness in cockroach allergen level reduction by cockroach abatement strategies that have been observed in some studies include: the presence of residual cockroach allergens (due to carcasses remaining in areas that are not easily accessible or lack of thorough cleaning following extermination) and re-infestation problems (especially in multi-family dwellings). For example, in a study of thirteen homes in inner-city Baltimore, Maryland, Eggleston et al. (1999) found that although cockroach extermination was feasible, standard housecleaning procedures were only partially effective in removing residual cockroach allergen over eight months (Gergen et al., 1999; Eggleston, 2000).

Another innovative strategy for managing cockroach infestations is to use heat combined with boric acid to control cockroaches. At the U.S. Army Fort Knox food service facilities, heat was used against resistant roaches. Heaters were used in the facilities to draw cockroaches from their harborage, forcing them to congregate in cooler areas. When congregations were observed, they were vacuumed up immediately. Once cockroaches were no longer observed in large numbers, a residual adulticide was applied. Although the thermal control treatments used at Fort Knox required considerable planning and high initial capital investment, the project led to a long-term reduction of difficult-to-control, insecticide-resistant cockroach populations (Zeichner et al., 1998). The use of a portable heat gun to flush roaches in combination with a vacuum to capture them has been successfully used to achieve significant reductions in cockroach populations as part of a residential IPM strategy (Greenberg, 2004).

### 3.3.2 Mice

Mice can damage food, clothing, and other items around the home. They have also been associated with the transmission of a number of important human diseases. In addition, like cockroaches, rodents (mice) have also been associated with asthma exacerbation Research supports a significant association between exposure to mouse urine (Mus musculus) allergen (Mus m 1) and asthma sensitization, particularly in inner city, multiple family dwellings (Phipatanakul et al., 2000b). Housing conditions, such as the presence of holes in ceilings or walls, have been associated with increased mouse allergen levels in the home, and mouse allergen has been observed to be prevalent among inner-city apartments (Chew et al., 2003). In addition, high levels of mouse allergen in homes have been found where home occupants reported never seeing mice (Chew et al., 2003).

Because high mouse allergen levels have been associated with cockroach infestation (Phipatanakul et al., 2000a), and because both types of pests have similar environmental requirements (e.g., a means of access to the home, food, water), IPM approaches discussed above for cockroaches may also be effective for controlling rodent populations (Frantz et al., 1999). In general, the literature recommends “mouse-proofing” a house as one would weather-proof it. Specific recommendations include blocking small holes where mice may enter, storing food in tight-fitting containers, and trapping mice that may have already entered the house. Trapping is preferred over bait poison because it is less hazardous to people and pets and it provides physical evidence for the effectiveness of control methods. Only when mouse-proofing and trapping have failed to solve the problem are poison baits recommended, and at that point careful choice of a specific rodenticide is recommended (Olkowski and Olkowski, 1990).

The Centers for Disease Control also offers detailed advice on how to "seal up", "trap up", and "clean up" homes to prevent mice infestations (http://cdc.gov/rodents/). Examples of CDC's recommendations include: 1) sealing holes inside and outside the home by plugging small holes with steel wool covered with caulk or fixing larger holes using screen metal, cement, or other difficult to penetrate materials; 2) Placing snap traps along walls; and 3) cleaning up the inside and outside of the home out by placing food and trash in rodent proof containers and keeping outdoor grass and shrubs well maintained.

### 3.3.3 Bed Bugs

Over the past several years, there has been a resurgence of bed bugs, *Cimex lectularius* and *Cimex hemipterus*, in the United States as well as other countries. It is believed that the increase in the population of bed bugs is due to a number of factors including increasing world travel, changes in pesticide use practices, and the cyclical natures of the species (Romero et al. 2007 and 2009; Harlan, 2006). In addition, bed bugs have developed increased resistance to frequently used pesticides, including the newer pyrethroids (Zhu et al., 2010).

In a review of the literature, Goddard and deShazo (2009) found little evidence that bed bugs have the ability to transmit human disease. Many individuals bitten by a bed bug have no reaction; however, for those who do react the most common response documented in the literature is 2–5mm red itchy lesions at the feeding site (Goddard and deShazo, 2009). These lesions usually resolve within a week. In a few studies, systemic reactions, including asthma, generalized hives (or a red raised, itchy skin areas) and anaphylaxis, have been documented (Goddard and deShazo, 2009). In addition to these potential health effects, bed bugs can have significant mental health effects, such as anxiety, and economic effects (Reinhardt and Siva-Jothy, 2007; Rossi and Jennings, 2010).

Adult bed bugs require blood from mammals to survive and reproduce and may feed as many as every three to five days (Harlan, 2006). However, evidence has shown that some bed bugs can survive up to 18 months without a blood meal (Berg, 2010). They are more active at night and often hide in dark locations that have little airflow, such as in cracks and crevices and behind baseboards. Most frequently they are found in mattresses and box springs not far from the host as they are attracted to heat and carbon dioxide that hosts generate (Berg, 2010). Bed bugs thrive in conditions with adequate hosts, abundant cracks and crevices close to the hosts, and in temperatures between 28 and 32 degrees Celsius with a relative humidity of 75–85% (Harlan, 2006). Unlike cockroaches, poor housekeeping and lack of sanitation have not been linked with the bed bug infestations (Harlan, 2006; NCHH 2010).

The presence of bed bugs can be difficult to determine. Although bed bugs infestations are often identified through resident complaints, in one recent study (Wang et al., 2010), 50% of residents living in a multi-unit building who had an infestation in their unit were unaware of the issue. Visual signs of bed bug infestations include reddish stains on mattress or sheets, dark spots on fabrics from bed bug excrement, and the presence of eggs, eggshells, or visible bed bugs (EPA, 2010).

Generally, visual inspection alone is unreliable as a detection method. The ability of traps to reduce bed bug infestations has been somewhat limited. However, traps have been helpful in identifying the presence of bed bugs. Recent research has shown, in both laboratory and field studies, traps that emit carbon dioxide are more effective for baiting and trapping bed bugs than traditional traps without (Anderson et al., 2009). Interceptors, placed in strategic locations such as at the base of bed posts, have also been shown to be effective tools in estimating bed bug populations and also serve as a way to isolate the bed after all bedbugs have been removed (Wang et al., 2010). More recently, trained dogs have also been used to identify the presence of bed bugs (NCHH, 2010; Rossi and Jennings, 2010).

Washing materials in 140 degree Fahrenheit water has been shown to be an effective method for eliminating bed bugs during all lifecycle stages (Naylor and Boase, 2010). Alternatively, placing items in a household dryer for at least 30 minutes at temperatures greater than 104 degrees Fahrenheit (Naylor and Boase, 2010) has been shown to be effective. Other heating

Currently there are over 300 pesticides registered by the EPA for use against bed bugs. Consumers can use the EPA's Registered Bed Bug Products Search Tool to help identify the most appropriate pesticide to use. (This tool is found at: http://cfpub.epa.gov/oppref/bedbug/). However, it is important to recognize that repeated application of large amounts of pyrethroid and non-pyrethroid pesticides has been shown to decrease bed bug populations in multi-unit housing during an eight-week period, but have not been effective in completely eliminating bed bugs from the housing units (Moore and Miller, 2009). Therefore, a more integrated approach is needed to effectively control bed bugs. An integrated approach often has the added benefit of decreasing exposure to pesticides. IPM strategies to control bed bugs include: 1) conducting surveillance to identify bed bug infestations, 2) making environments less attractive to bed bugs by removing clutter, encasing bedding, and conducting thorough cleaning of affected areas, and 3) using selective chemical and non-chemical treatments to kill bed bugs (Rossi and Jennings, 2010).

methods used to reduce bed bug populations include using professional steam cleaners and new room heating technologies to raise the temperature inside rooms to 135 degrees Fahrenheit for several hours (Miller, 2010). Containers with heat sources can also be used to treat furniture and other household objects.

In addition to heat, intensive cold can also be used. Freezing items in temperatures of 1.4 degrees Fahrenheit for colder for more than two hours can help eliminate bed bugs (Naylor et al., 2010). Some pest control companies have also started using new technology to freeze bed bugs to death by exposing them to pressurized CO2 snow at -108 degrees Fahrenheit (Miller, 2010). Overall, success in controlling bed bugs relies on the use of multiple strategies, since no one strategy is effective in completing eliminating bed bugs. A comparative analysis of bed bug control techniques is found in the NCHH publication 'What's Working for Bed Bug Control in Multi-Family Housing?" (http://www.nchh.org/Portals/0/Contents/bedbug_report.pdf)

### 3.3.4 Other Pests

There are other household pests that may cause residents to use excessive pesticides in an effort to get rid of them. Some pest-specific IPM tips, from the New York State IPM Program, include:

- **Bats:** Inspect the exterior of the building for openings larger than ¼" in height and seal them; light your attic; and offer a "bat house" away from areas of human activity.
- **Carpenter Ants:** Fix the problem that is causing moist wood and replace the damaged wood. Also, baits specifically for carpenter ants are available.
- **Fleas:** Vacuum regularly and place contents outdoors in the trash and treat the animal, preferably by a veterinarian.
- **Flies:** Repair broken and replace missing window and door screens. Store garbage in containers with tightly fitted lids.
- **Mosquitoes:** Prevent water from accumulating or eliminate sources of standing water; replace bird bath water every few days; and keep window and door screens tight and in place until winter.
- **Spiders:** Scoop them into a container and release them outside or use a fly swatter. Most spiders are beneficial for killing other insects.

The use of vacuum cleaners may also be useful for quick removal of incidental pests and rodent droppings, flying insects, beetles, sowbugs, pill bugs, crickets, spiders, and anything else that can be caught. An ordinary vacuum may be used, but if the machine is used almost entirely for catching pests, a HEPA-filtered vacuum is preferred. Moths and cockroaches have allergenic particles and compounds that escape through an ordinary filter. HEPA vacuuming can also be used to remove accumulated rodent droppings and dead insects. Re-inspection will determine if rodents are still present. See the San Francisco Department of the Environment Pesticide Program web site for more information (http://www.sfdph.org/dph/EH/Vector/default.asp).

## 3.4 IPM Programs and Effectiveness

There are many programs currently in place to evaluate and promote the human health benefits of IPM. Examples of some programs can be found in Appendix B.

IPM is increasingly being used in public sector buildings. While not extensive, some studies have been conducted to evaluate its cost-effectiveness compared to baseline pest control methods. Wang and Bennett (2006) conducted a study comparing IPM strategies to the application of insecticide bait alone in public housing buildings. Although costs associated with IPM were initially higher than costs for the bait treatment (mostly as a result of the high costs associated with the vacuuming treatment), after twenty-nine weeks costs were similar between the two interventions. However, buildings that received IPM had significantly lower levels of cockroach infestations compared to buildings, which received bait alone. Therefore, it is suggested that IPM may be a more cost-effective strategy to decrease cockroaches long-term (Wang and Bennett, 2006).

Costs associated with IPM have also been compared to "traditional" monthly crack and crevice treatment in public housing buildings (Miller and Meek, 2004). Although IPM costs were higher ($1.50 more per unit per year than the traditional treatment), IPM treated units had significant reductions in cockroach populations while the traditional treatment had little effect.

More recently, a community-wide IPM program was evaluated in two low-income apartment complexes (Wang et al., 2009). One apartment complex received IPM conducted by entomologists and members of the housing authority who were trained by the entomologists on IPM strategies. The other apartment complex received the same IPM activities, which included education, monthly monitoring, laying of sticky traps and chemical treatment based on monitoring results, conducted by pest management contractors. In both groups, the number of apartments infested with cockroaches decreased by 74%. It was estimated that the cost for implementing IPM over the course of the first year, excluding the cost of educating residents, was $7.50 per month per apartment compared to $6.30 per month for apartments that received traditional pest control management.

A study evaluated the U.S. General Services Administration's (GSA) Structural IPM Program to demonstrate whether IPM is an improvement over traditional methods. The evaluations were based on both client satisfaction and pesticide reduction. The authors found that since its implementation in 1989, the IPM program successfully decreased both the quantities of insecticide applied indoors and the number of requests for pest control services by building occupants, and they concluded that IPM can successfully reduce pest populations as part of a large-scale program for public buildings (Greene and Breisch, 2002).

Preliminary research has indicated that IPM techniques can be effective for cockroach control (Frantz, et al., 1999; Campbell et al., 1999). Results of a study which assessed the effectiveness of a pilot IPM program in controlling cockroaches in an apartment complex, without pesticide sprays, showed that education can influence building residents to accept and comply with an IPM program, and that the program can be effective in controlling cockroaches (Campbell et al., 1999). Also, tests on the effectiveness of a bait (containing 2.15% imidacloprid) to control German cockroach populations found that when applied at 15–45g per kitchen, the bait significantly reduced cockroach trappings over a 4-week period (Appel and Tanley, 2000).

Smith et al. (1993, 1995, & 1997) have published some of the most extensive IPM effectiveness studies on smoky brown cockroaches (Appel and Smith, 2002). They researched treatments for reducing smoky brown cockroaches around homes in Alabama, in both urban and rural areas. They found that by targeting management tactics where cockroaches hide and forage, use of insecticide can be decreased and control can be maintained for longer periods of time than by employing a standard perimeter spray (Smith et al., 1993, 1995). Specifically, they developed a comprehensive IPM system that includes sanitation, landscape management, and targeted application of insecticidal baits and sprays, and found that the IPM system reduced cockroach abundance faster and longer than the conventional spray while using up to 80% less of the active ingredient (Appel and Smith, 2002). The authors have concluded that IPM treatment is an effective, safe, and economical way to manage cockroaches (Smith et al., 1997).

A study in East Harlem, New York City (Brenner et al., 2003) tested the effectiveness of IPM in household cockroach infestations. Two groups were studied; an intervention group that received individually tailored IPM education and support, including advice from pest control experts and home treatment by a professional exterminator using least-toxic pesticide gels and baits, and a control group that received only an injury prevention intervention. Evaluations were performed to assess the cockroach levels, and it was found that the proportion of intervention households with cockroaches declined significantly after 6 months (from 80.5% to 39%) whereas the control group levels were essentially unchanged (from 78.1% to 81.3%). The costs of the individually tailored IPM program were equal to or lower than traditional, chemical-based pest control methods, demonstrating that an individually tailored IPM program can be successful and cost-effective in an urban community (Brenner et al., 2003).

In Los Angeles, California, a randomized trial (McConnell et al., 2005) assessed an educational intervention to control cockroach allergen levels in the homes of Hispanic children. Caretakers were randomly assigned to an in-home intervention or comparison group. In the intervention group, peer educators trained caretakers in IPM strategies including reducing harborage and food access, applying boric acid, and proper cleaning to reduce allergen levels. Caretakers were also given supplies, such as materials for blocking pest entryways and allergen impermeable mattress and pillow covers. Four months after the training session, caretakers reported an increase in the use of recommended practices and the number of cockroaches in homes receiving the intervention was 60% lower than the number found in control homes. Allergen concentrations found in kitchen dust were also lower in homes receiving the intervention.

In Baltimore, Maryland, research has also been conducted on the effectiveness of IPM intervention projects that target rodent populations. A Rodent Control Committee, created in 1992, implemented a number of programs to combat the increasing Norway rat problem. The programs focused on rodent management through IPM practices, public education, increased community clean-up, and intensified baiting, which required cooperation between local authorities, residents, and pest control operators. The direct intervention was initially successful (up to 90% of rat burrows in target communities were eliminated), but attempts to modify behavior of residents through community outreach and education were generally unsuccessful, and follow-up surveys showed that reinfestation was common (achieving pre-intervention levels within 6 months in neighborhoods where environmental factors favored rat populations) (Lambropoulos et al., 1999).

In contrast to many previous IPM studies, which involved extensive cleaning, repeat visits, and often extensive resident education, Kass and colleagues (2009) found a single IPM visit averaging 2–3 hours (8–12 person hours) without separate visits to educate residents was more effective than the regular application of pesticides in managing cockroaches. As part of the single visit, an IPM team (consisting of 2 to 3 individuals) met with residents to discuss proper storage of food items, demonstrate cleaning practices, seal cracks and crevices, and apply boric acid and baits. Although no further education was done, the levels of cockroaches found in kitchens dropped by 75% after 3 months and by 88% at 6 months. The levels of cockroach allergens also significantly decreased. During this same time period, control homes that received the usual care provided by state-licensed pest control applicators saw increases in the levels of cockroaches. Although not statistically significant, fewer mouse sightings were also reported in homes receiving IPM compared to control homes (Kass et al., 2009).

Results from another study found that IPM was effective in decreasing mouse allergen levels in inner-city mouse-infested homes in Boston (Phipataknakul et al., 2004). Over a five-month period mouse allergen levels significantly decreased in homes that received IPM interventions compared to control homes. IPM strategies included filling holes and cracks with copper mesh and sealant, using vacuums with HEPA filters, cleaning surfaces with mild detergents, trapping, applying low-toxicity pesticides in rodent "runways", such as wall cavities and pipe chases, and educating families. Mouse allergen levels in the kitchen and bedroom decreased significantly in homes receiving IPM (78.8% and 77.3%, respectively); whereas levels in control homes increased (319% in the kitchen and 358% in the bedroom). Although this study was also designed to investigate if lung function or asthma symptoms improved with a decline in mouse allergen levels, no significant clinical differences were observed, possibly due to the small sample size (Phipataknakul et al., 2004).

As evidence by the research described above, studies often examine the effectiveness of IPM focus on decreasing pest populations, decreasing allergen levels, and overall cost-effectiveness compared to other pest control measures. Although decreased pesticide use will ultimately result in decreased exposure, few studies document lower pesticide levels in biological samples related to the use of IPM. However, in a recent pilot study, that found reductions in cockroach infestations and indoor air levels of cockroach allergens in homes receiving IPM treatments, the researchers also reported lower pesticide levels in pregnant mothers whose homes received IPM treatment compared to a control group (Williams et al., 2006).

# 4.0 Research Needs and Information Gaps

The most significant data gap related to pesticide use in the home is the effect of chronic pesticide exposure on the neuro-developmental competency of children (EPA, 2000b; Goldman and Koduru, 2000). Although the National Children's Study may provide more insight into this area and animal studies suggest that there may be effects, specific outcomes are difficult to ascertain. There are not only numerous different pesticides with the same mode of action, but also other pesticides with related or unrelated modes of action, and other completely different compounds which also act on the nervous system, thus creating an enormous effort for cumulative risk assessment (EPA, 2000b; Natural Resources Defense Council, 1997).

The scientific community also lacks standardized sample collection methods for pesticides from hard surfaces and in house dust. Sampling tools that have been used for lead exposure assessment may not be useful for pesticide sampling due to the higher vapor pressure of pesticides relative to lead. The rapid airflow over dust on a filter, or continual re-suspension in less efficient sampling devices, may lead to pesticide losses during sampling. In general, sample collection tools have been used on an ad hoc basis resulting in limited understanding of the approach and a poor ability to compare between methods. Thus, comparability between findings of several large studies is difficult to determine (Cohen Hubal et al., 2000; Gordon, et al., 1999; Lioy, et al., 2000).

Despite the many micro-environmental measurements that have been collected in recent studies, no model yet exists to predict exposure from pesticide surface loadings.

Finally, studies have not been conducted to ascertain the indoor levels of pesticides in rental properties where pesticides are applied on a routine basis as a preventive maintenance measure. Lower socioeconomic populations may be at higher risk of exposure because of these use patterns.

Possible areas of consideration for future research include:

### Health and Exposure Issues

- Exposure data for all childhood life stages.
- Information on the potential combined or synergistic effects of pesticides that have and do not have a common mechanism of action.
- The effect of chronic pesticide exposure on the neuro-developmental competency of children.
- Additional data on the role of cockroach and rodent allergen exposure in asthma sensitization and exacerbation, particularly in socially disadvantaged populations.
- Information on the relationship between indoor exposure to pesticides and sensitization and exacerbation of asthma.
- Information on factors that affect pests, including research on how risk factors vary by location, or by housing or population characteristics.
- Health effects of exposure to pesticide residues that may linger for years after applications are made in residential settings

### Methodological Issues Related to Assessment

- Standardized sample collection methods for house dust to be analyzed for pesticides from floors and surfaces.
- Relation of environmental samples/pesticide surface loadings (vacuum dust, etc.) to actual exposure (e.g., information on exposure pathways and activity patterns of children).

### Methodological Issues Related to Mitigation and IPM

- Research on the relative effectiveness and cost-benefit analysis of different pest control intervention strategies (e.g., traditional insecticide use versus IPM) with regards to pest populations, undesirable pesticide exposures, and asthma/allergen control.
- Research on effective methods of clean up after use of insecticides.
- Information on the prevalence of use of IPM methods in homes.
- Information on barriers to implementation of IPM programs in multi-family housing.
- Research on the most effective methods for educating home occupants about alternative pest control/IPM techniques.
- Long-term assessment of the methods and effectiveness of IPM strategies, as employed in different housing environments, in reducing: pest infestation, pesticide residues/exposure, and the levels of pest-related allergens.

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# Appendix A. Additional Internet Resources

In addition to the references and links appearing in the reference list above, the following table provides selected links with additional information related to pesticides and integrated pest management.

| Sponsoring Organization-Topic | Internet Web Site Address |
|---|---|
| Boston Public Health Commission | Provides information about IPM practices in low-income housing units, including specific information for housing owners and building managers.<br><br>http://www.bphc.org/hpfhi/IPMandPolicy/Pages/home.aspx<br>http://www.bphc.org/hpfhi/Pages/home.aspx |
| Centers for Disease Control and Prevention | Provides information on the CDC's Healthy Homes Initiative<br><br>http://www.cdc.gov/healthyplaces/newhealthyhomes.htm |
| Environmental Health Watch | Provides information on IPM for controlling cockroaches in multi-family housing units and details for a model IPM contractor program.<br><br>http://www.ehw.org/healthy-green-housing/resources-for-a-green-healthy-home/asthma/pests-and-asthma/ |
| Michigan State University | Provides education and fact sheets on a variety of pests and provides a clearinghouse for urban IPM materials.<br><br>http://www.pested.msu.edu/CommunitySchoolIpm/ |
| National Center for Healthy Housing | Identifies 'best practices' for controlling bedbugs in multi-family housing.<br><br>http://www.nchh.org/Portals/0/Contents/bed bug_report.pdf |
| National Pest Management Association, Inc | Provides information related to bed bugs, including frequently-asked-questions, fact sheets, news stories, and best management practices.<br><br>http://www.pestworld.org/bed-bugs |
| National Pesticide Information Center | Provides resources and information related to pesticides, pest control, pesticide regulations, and IPM.<br><br>http://npic.orst.edu/ |
| New York City Department of Health and Mental Hygiene and Department of Housing Preservation and Development | Provides information on preventing and eliminating bed bugs safely for property owners, managers, and tenants.<br><br>http://www.nyc.gov/html/doh/downloads/pdf/vector/bed-bug-guide.pdf |
| New York State IPM Program | Provides general information on IPM, including using IPM in buildings and schools and using IPM to fight bed bugs.<br><br>http://www.nysipm.cornell.edu/ |

| Sponsoring Organization-Topic | Internet Web Site Address |
|---|---|
| Northeastern IPM Center | Provides information for public housing authorities, including downloadable versions of references for the IPM in Multifamily Housing training program run by the Northeastern IPM Center.<br><br>http://www.stoppests.org/ |
| U.S. EPA Pesticide Home Page | Provides information about pesticides, health and safety effects of pesticides, environmental effects of pesticides, methods to control pests, and pesticide regulation.<br><br>http://www.epa.gov/pesticides/ |
| US. EPA Search Tool for Bed Bug Products | Provides a search tool to help individuals choose an EPA-registered bed bug product that meets their needs.<br><br>http://cfpub.epa.gov/oppref/bed bug |
| University of Rhode Island | Provides fact sheets for various household insects, including descriptions of the pests and methods to control them.<br><br>http://www.uri.edu/ce/factsheets/indices/0houseinsectindex.html |
| Virginia Department of Agriculture and Community Services | Provides information related to bed bug outreach and education programs, including presentations and fact sheets.<br><br>http://www.vdacs.virginia.gov/pesticides/bedbugs.shtml<br>http://www.vdacs.virginia.gov/pesticides/bedbugs-facts.shtml |
| Washington State Department of Health | Provides information on environmental health and safety in schools, including the use of IPM in schools.<br><br>http://www.doh.wa.gov/ehp/ts/school/ |

# Appendix B. Example IPM Programs

**The San Francisco Pesticide Program.** The city of San Francisco has one of the most progressive and innovative urban pesticide-reduction programs in the country. The San Francisco Pesticide Program, established by the Integrated Pest Management (IPM) Ordinance, was enacted to regulate and reduce the use of chemical pesticides in and on city property by city departments, agencies, and contractors. The IPM ordinance bans the use of the most toxic pesticides including carcinogens and reproductive toxicants. The ordinance also requires the posting of notices to inform the public whenever a pesticide is used on city property and requires a public access telephone number for questions regarding pesticide use. Highlights of the programs include phased reductions in pesticide use (e.g., most toxic banned in 1997, etc.), departmental accountability for city agencies (e.g., monthly reporting and development of an IPM implementation plan), and extensive training of city staff in alternative methods for controlling pests. The San Francisco Department of the Environment also works with other City departments to educate businesses, residences, and other communities on reduced risk and effective means of controlling pests. Between 1996 and 2009, use of the most toxic pesticides has been eliminated and in most areas of the city, overall pesticide use has dropped by over 81%. The city's pest control contractor has also eliminated the use of chemical pesticides in more than 88% of visits to city buildings (Geiger, 2009). Additional information is available on the San Francisco Department of the Environment's web site: http://www.sfenvironment.org/our programs/topics.html?ti=1.

**The Safer Pest Control Project in Chicago.** Residents and building managers at the Henry Horner Public Housing Development in Chicago participated in a one-year pilot program (1997), sponsored by the Safer Pest Control Project, an Illinois nonprofit organization that promotes IPM. The program targeted improvements in maintenance and sanitation, promoted resident involvement and education, and included regular inspections and targeted insecticidal gel bait applications. The Henry Horner program was successful (90% of surveyed residents reported declined pest populations and declined pesticide use) and has since influenced programs sponsored by housing authorities in other cities. The Safer Pest Control Project continues to educate residents of Illinois about IPM strategies and offers numerous factsheets related to IPM and the control of bed bugs, mice, roaches, and pests on-line at: http://spcpweb.org/ipm/.

**The Chicago Community-Based Asthma Intervention Trial.** The National Cooperative Inner City Asthma Study (NCICAS) was an important national effort that addressed asthma triggers and allergen remediation in inner-city homes. The purpose of the Chicago Community-Based Asthma Intervention Trial, as part of the NCICAS, was to show the feasibility of a peer educator program for children with asthma and the effectiveness of peer education on modifying levels of indoor allergens. An inner-city Chicago population with high rates of asthma was targeted and intervention strategies included IPM for cockroach control, which emphasized housekeeping, identification of roach sources, selective use of baits, caulking leaky faucets and repair to areas that allowed roach entry. The project successfully demonstrated the feasibility of a peer educator program. The program was generally well received by educators and community residents; however, results from the study suggest that future intervention programs should focus more on reducing cockroach allergens than was previously targeted, while at the same time working to minimize the use of pesticides (Persky et al., 1999).

**The Mount Sinai and Columbia Center for Children's Environmental Health Projects in New York City.** "Growing up Healthy in East Harlem," sponsored by the Mount Sinai Center for Children's Environmental Health and Disease Prevention Research, was a community-based intervention project shaped by the Henry Horner program. This research trial, undertaken in New York City, was designed to evaluate the effectiveness of IPM in households based on measures of pesticide levels in house dust, pesticide metabolite levels in urine, and roach infestation levels (http://www.epa.gov/ncerqa/childrenscenters/sinai.html). Findings show that the intervention was a cost-effective way to significantly reduce cockroach infestations in urban housing (Brennar et al., 2003). Also in New York City, the Columbia Center for Children's Environmental Health (CCCEH) sponsored an IPM project to reduce pests and allergens in the home. Their IPM intervention included: repair of cracks, holes, and water leaks; intensive cleaning to reduce existing allergen and pesticide levels; use of low toxicity control practices (gels and baits); and education for residents on how to maintain IPM efforts. Thus far, the pilot program has shown promising results in reducing cockroach populations in kitchens, but further evaluation of the intervention's impact on allergen levels and pesticide levels is still needed.

**The Home Remediation for Respiratory Health Study in Birmingham, Alabama.** This study examined the feasibility of conducting home interventions to lower allergen levels in low-income, inner-city households in Birmingham, Alabama. The goals of the interventions were: (1) to lower levels of allergens in the homes; (2) to modify the home to prevent future problems; and (3) to educate the residents on how to maintain a healthy indoor environment. The home interventions varied according to need, but they included IPM to eliminate harborage, remove access to food, and minimize water sources. The authors concluded that the interventions were successful, but results related to respiratory health were inconclusive (Stubner et al., 2000).

**Environmental Health Watch in Cleveland, Ohio.** This organization conducted a small project to explore the effectiveness of different methods of cockroach control and allergen cleanup in public housing. The control intervention included "precision-targeted IPM" designed by the USDA Imported Fire Ants and Household Insects Research Unit (Agricultural Research Station, Gainesville, Florida). The intervention to clean up cockroach allergens included the standard lead cleaning protocol and two modifications for cleaning lead dust on hard surfaces (one used a wet vacuum instead of a mop to clean up dirty wash and rinse water and the other used a wet vacuum and substituted bleach/detergent cleaner for the detergent-only cleaner.) The IPM method used decreased the cockroach population by 95%. All three cleaning interventions significantly reduced allergen concentrations immediately following the treatment. However, standard lead cleaning was more effective in reducing allergen concentrations during the follow-up period to levels near the proposed levels of sensitization. The full report is available online at: http://www.ehw.org/Asthma/ASTH_RoachFinalRpt.pdf. In addition, this group has developed an outline for a Model Contractor Program Cockroach IPM Program which is available on-line at: http://www.ehw.org/Asthma/ASTH_ModelIPMContractor.htm.

# Notes