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Bed Bugs - Importance, Biology, and Control Strategies

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Foreword. The common bed bug, *Cimex lectularius* L., the tropical bed bug, *C. hemipterus* (Fabricius), and a few closely related species of blood-feeding true bugs (Hemiptera: Cimicidae) have been persistent pests of humans throughout recorded history. They may have evolved as cave-dwelling nest ectoparasites of mammals (probably bats), with at least one species later switching to feed mainly on cave-dwelling humans. As humans moved from caves to tents and, ultimately, houses, bed bugs, especially the common bed bug, were probably brought along. Bed bugs appear in the literature and folklore of many cultures and countries, from the Egyptians, Greeks and Romans to early Jewish and Christian writings, and in the records of colonial Americans (Usinger 1966). After World War II, widespread use of synthetic insecticides led to sharp declines in bed bug populations in most industrialized countries. By 1997, they were so scarce in the U.S., Canada and Europe that it was difficult to find fresh specimens to use in teaching college entomology classes (Snetsinger 1997). Some contemporary Pest Management Professionals (PMPs) with years of experience have still never seen an active bed bug infestation. During the past 12 years, a resurgence of bed bugs has been reported in the U.S., Canada, European countries, Australia and parts of Africa. Infestations have occurred in homes, hotels, hostels, cruise ships, airplanes, trains, schools, and long-term care facilities (Cooper and Harlan 2004, Doggett *et al*. 2004, Hwang *et al.* 2005, Johnson 2005). This Technical Guide was developed to meet the need for current information and guidance regarding bed bugs and their control.

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Acknowledgments

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Disclaimer

Trade names are used in this TG to provide specific information or examples, and do not imply endorsement of the particular items or products named, or any criticism of similar ones not mentioned. Mention of trade names does not constitute a guarantee or warranty of the products by the author, the AFPMB, the Military Services, or the Department of Defense (DoD).

Introduction:

In recent years, bed bugs have become much more common worldwide, especially in developed countries. The purpose of this TG is to provide general information about the main pest species of bed bugs, including their importance, key aspects of their biology and behavior that can affect control efforts, and strategies and techniques that pest management professionals (PMPs) and others may wish to implement to achieve desired levels of control. Management strategies and techniques chosen will usually be dependent on important details of the local situation, such as physical conditions (especially temperatures), the condition of the affected human population, military activity, and available control resources and expertise. Unless otherwise stated, the focus of this TG is the common bed bug, *Cimex lectularius* L.

Corrections or suggestions to improve this TG should be sent to: Editor, TG # 44, Bed Bugs – Importance, Biology, and Control Strategies, Information Services Division (ISD), Armed Forces Pest Management Board (AFPMB), US Army Garrison - Forest Glen, 2460 Linden Lane, Building 172, Silver Spring, MD 20910-7500, Phone: (301) 295-7476, FAX: (301) 295-7473; or DSN: 295-7476. Email: http://www.acq.osd.mil/eie/afpmb/contactUs.html

Purpose:

To provide background information on the importance, biology and behavior of bed bugs that can impact control efforts against them, and to suggest a range of current control strategies and techniques that are known to usually be effective. Emphasis must be placed on integrated methods, timely resolution of the pest problem, and maximum education of, and involvement by, members of the affected human population. This TG is also intended to provide additional references to assist decision makers and local PMPs in resolving and preventing bed bug infestations.

Importance

Blood feeders. Bed bugs consume only blood, usually feeding on a mammal (*e.g.*, bat, human) or bird. They need at least one blood meal of adequate volume in each active life stage (instar) to develop to the next stage and to reproduce. There are five nymphal stages, and each one may feed multiple times if hosts are readily available. Fig. 1 shows the egg and nymph stages; Fig. 2 shows an adult.

Fig. 1. Bed bug eggs and nymphs. Photograph by H. J. Harlan.

Fig. 2. Adult female bed bug feeding. Photograph by G. D. Alpert.

Adult bed bugs may feed every three to five days throughout their estimated six to 12 month adult life span. The act of biting a host can cause both physical and psychological discomfort, and can result in local allergic skin reactions to injected salivary proteins (Feingold *et al.* 1968, Reinhardt and Siva-Jothy 2007, Goddard and deShazo 2009).

Potential to transmit human pathogens. Bed bugs have been found naturally infected with at least 40 human pathogens but have never been proven to biologically or routinely mechanically transmit any of them (Usinger 1966, Cooper and Harlan 2004, Goddard and DeShazo 2009, Cooper 2011, Doggett *et al*. 2012). Nonetheless, shedding of viral DNA fragments in bed bug feces and retention of hepatitis B virus through a normal molt seem to support a possibility of mechanical transmission, as when bugs are crushed onto abraded human skin (Jupp *et al.* 1991, Blow *et al.* 2001).

Bites and health effects. Bed bug bites are often almost undetectable on some people, but their saliva contains biologically and enzymatically active proteins that may cause a progressive, visibly detectable allergenic skin reaction to repeated bites. Depending on bite intensity and frequency, on persons who do show reactions there are typically five post-bite effect stages: no reaction (no, or too few, antibodies developed), delayed reaction, delayed plus immediate reaction, immediate reaction only, and no visible reaction (due to excess circulating IgG antibodies). Typical symptoms include a raised, inflamed, reddish wheal at each bite site, which may intermittently itch intensely for several days (Fig. 3). "Immediate" immune reactions may appear from one to 24 hours after a bite and last 1-2 days (Fig. 4) (Feingold *et al.* 1968, Goddard and deShazo 2009).

Fig. 3. Reaction from bed bug bites, 30 minutes after feeding. Photo by H. J. Harlan.

Fig. 4. Reaction from bed bug bites, 48 hours after feeding. Photo by H. J. Harlan.

"Delayed" immune reactions usually first appear one to three (up to >14) days after a bite, and redness and periodic intense itching may last 2-5 days (Reinhardt and Siva-Jothy 2007). Humans who are frequently bitten by bed bugs may develop a sensitivity "syndrome" that can include nervousness, almost constant agitation ("jumpiness"), and sleeplessness. In such cases, either removing the bed bugs (physically or chemically) or relocating the person can cause the syndrome to disappear over time. Several additional cimicid species are known to bite humans, including tropical bed bugs, poultry bugs, various species of bat bugs, and swallow bugs. A social stigma may be associated with bed bug infestations (Usinger 1966), but at present, there is rarely an expectation, and no requirement, to report infestations to any public health or government agency.

Additional health effects reported in medical literature have included: facilitated secondary infections from scratching bites (Goddard and deShazo 2009), causing and worsening asthma (Abou Gamra *et al*. 1991), blister-like skin eruptions (Liebold *et al*. 2003, Doggett *et al*. 2012), true anaphylactic reactions (Parsons 1955), and anemia (Pritchard and Hwang 2009).

Importance as pests. Because they are nocturnal, use cryptic harborages, are very small and elusive, and can detect and avoid many chemicals, including cleaning agents, bed bugs are often difficult to control. Complete elimination of an established bed bug population is nearly impossible to accomplish in a single service visit by most PMPs. They are easily transported on or in luggage, furniture, boxes, and clothes. Except after a blood meal, they are very thin and can fit through, or hide in, very narrow cracks.

Unfed adults can live for several months, sometimes >1 year under certain conditions, while 2nd through 5th stage nymphs can survive for >3 months without feeding (Polanco *et al*. 2011). The numbers, geographic distribution, and severity of bed bug infestations are still increasing in Europe, North America, Australia and other parts of the world. The public's fear of bed bugs, the effects of their bites, the stigma of having an infestation, and the characteristic, "musty-sweetish" smell of large or long-standing infestations magnify their importance as pests.

Because the general public is not very knowledgeable about bed bugs, their bites nearly always lead to visits to a clinical medical facility or expert (often a primary care physician). There are usually additional costs for diagnosis, or for symptomatic treatments. In 2004 alone, 17 of 65 homeless shelters in Toronto spent a mean of $US 3,085 each to address bed bug problems (Hwang *et al.* 2005). Lawsuits have produced awards of $US 20,000 to 382,000 plus expenses (Gooch 2005, Johnson 2005).

Dispersal of bed bugs from one structure or infestation site to another is usually passive – the bugs or their eggs are unknowingly carried in or on pieces of furniture, bedding, luggage, clothing, electronic devices or cardboard boxes. Furniture rentals and purchases of used furniture are rather common, especially in poor communities, and this may help rapidly (and repeatedly) spread bed bugs to new sites, and can redistribute them back into places from which they may have been eliminated earlier.

Large multi-unit buildings can be difficult to rid of bed bugs. Once bed bugs become established, any control effort that does not include nearly concurrent inspection of all units, and a coordinated program of treatment and occupant education, will usually fail (Pfiester *et al*. 2009). The bugs often move from any partially-treated, potentially repellent active site to adjacent rooms or floors. They readily move through wall voids, utility lines, heating ducts, hallways, and laundry or mail chutes (Wang *et al*. 2010).

Because of their ability to adapt and survive in any environment suitable for their human hosts, bed bugs can become established and develop significant populations even in long-term deployment sites involving only tents as troop shelters. In more permanent military housing, they can quickly become pests wherever they are introduced.

Biology and Behavior

Adult bed bugs are about 5-7 mm (3/16-1/4 inch) long, broadly oval, flat, brown to reddish-brown true bugs, with a 3-segmented beak, 4-segmented antennae, and vestigial wings. They have very thin, vertically flattened bodies covered with short, golden-colored hairs. They give off a distinctive "musty-sweetish" odor, due to certain "alarm" chemicals that are produced by glands in their ventral thorax. Abdomen tips of males' are usually pointed and those of females are more broadly rounded.

They feed only on blood, usually of mammals or birds, and mate by "traumatic insemination." It may take 3-12 minutes for one bug to fully engorge. About 20% of the time, adult bed bugs and large nymphs will void remains of earlier blood meals while still feeding. This produces the typical rusty or tarry spots seen on bed sheets or in bug hiding places (Fig. 5). They may feed repeatedly, but every nymphal stage must have at least one blood meal before it can develop to the next stage. Both males and females must feed at least every 14 days in order to keep mating and producing eggs (Usinger 1966).

Fig. 5. Bed bug adult on sheet, showing typical fecal spots. Photo by H. J. Harlan.

Bed bugs will readily travel 5-20 ft. from an established harborage to feed on a host. Although they seem to prefer humans, they readily feed on birds, rodents, or other mammals. Their life cycle from egg-to-egg may take four to five weeks under favorable conditions [*e.g.*, 75-80% RH; 28-32^{o}C (83-90^{o}F)]. They can survive and remain active at temperatures as low as 7^{o}C (46^{o}F), if they are held at an intermediate temperature for a few hours, but their upper thermal death point is 45^{o}C (113^{o}F). Bed bugs are nocturnal but will seek hosts and feed in full daylight if hungry. Females attach their 1 mm-long, cylindrical (about four times as long as their diameter), pearly-white eggs to any nearby surfaces, usually in crevices (harborages), where the active bugs hide in groups or clusters. Each female may lay 1-3 eggs/day and 200-500 eggs during her adult lifetime (often 6-12 months or longer). Cast bed bug “skins” usually accumulate in harborages.

Common bed bugs may be found in all temperate areas of the Northern and Southern Hemispheres, almost anywhere that humans have established homes. They thrive at temperatures and humidities that are considered comfortable by most people, who usually afford them ample blood meals and plenty of good harborage nearby. The tropical bed bug, *Cimex hemipterus* (Fab.), requires a higher average temperature than does the common bed bug. It is widespread at tropical and subtropical latitudes worldwide.

In continental Europe, established infestations of this species are rare. In the Western Hemisphere, they are seldom found north of Mexico or Puerto Rico, or south of Peru or Brazil. Only occasional limited populations of this species have been found in Florida and Chile. Several species of bat bugs, swallow bugs, and other bird-feeding bugs occur in various north and south temperate regions and they may also bite humans (Usinger 1966, Gold and Jones 2000, Krinsky 2009, Harlan *et al*. 2008, Doggett *et al*. 2012).

Control Strategies and Techniques

Detection. A bed bug infestation is usually revealed through finding live bugs, or signs (*e.g.*, dark fecal deposits or lighter rusty spots) on bed linens or in harborages, or eggs or cast skins in harborages or near feeding sites, recording where and when alleged victims have been bitten, or smelling the bugs' characteristic odor (Fig. 6). Any combination of two or more of these signs can help verify an infestation and help determine the bugs' distribution and prevalence. Monitoring may be augmented by using pitfall or sticky traps (possibly augmented by chemical or CO2 attractants), and certain insecticidal aerosols that produce a flushing or excitatory effect. For cimicid species that mainly feed on bats or birds, detecting and locating their usual hosts' roosts or nests is important. The presence of such hosts may signal a possibility that their removal or exclusion could trigger or facilitate an infestation of nearby human living areas.

Inspection. Detailed inspection by a qualified person is the essential first component of any effective bed bug control program. If present, the bugs must be detected, accurately identified (IDed), and their harborage sites and a rough estimate of the population size must be determined as quickly as possible. Even with the use of detection dogs, or the new multi-attractant traps, a visual inspection must still be done to determine exact locations and extent of the main infested sites before any control action can be done. Certain pyrethrin-based flushing agents may help stimulate the bugs to move around, making them easier to detect where populations are limited. Cimicids that feed chiefly on bats or birds can often be located by finding and examining their hosts' nests nearby.

Fig. 6. Bed bug-infested mattress showing typical signs of infestation. Photo by B. Pannkuk.

New bed bug detection and monitoring techniques. Several new techniques have recently been developed and are being marketed for detecting and monitoring bed bug infestations. Dogs are being specially trained to detect even small numbers of live bed bugs, and possibly their viable eggs as well, with a reported accuracy of about 95% (Pfiester *et al*. 2008). Pheromones and alarm scents produced by the bugs themselves have been characterized and are being developed for possible use to attract the bugs or facilitate other control techniques or products (Siljander *et al*. 2008, Benoit *et al*. 2009, Feldlaufer *et al*. 2010). Special high-technology devices (*e.g*., see Anderson *et al*. 2009) combine various elements like CO_2, proprietary chemical lures, and heat to attract and catch bed bugs seeking their next meal. Simpler pitfall, barrier, or harborage-mimicking devices can also intercept and trap bed bugs with or without augmentation by any of the attractants just mentioned (*e.g*., see Wang *et al*. 2010).

Each of these techniques or devices offers promise as an additional tool, but none of them appears, so far, to be a "stand alone" method for detecting and characterizing bed bug infestations, regardless of the physical setting. Further, none of them can exert much of a direct effect upon control of any given bed bug infestation. Even after one of these detects (or narrows down the general locations of) an infesting bed bug population, someone must still confirm those infested sites, correctly ID the bugs, and go on to effect some form of control. Not even the trained and "currently certified" dogs are accurate all the time (they may have their "bad days," as might their respective handlers), and the devices can be avoided by a few bugs in any given population due to certain quirks in the bugs' own biology and appetitive behaviors. Further, various economic factors can influence control decisions, and the human occupants' (victims') understanding and cooperation are still essential for optimum success in any situation.

Education. Educating the occupants of any living space infested by bed bugs is essential to ensure that they actively cooperate in the control program. Occupants must understand that they will be expected to improve and maintain sanitation, minimize clutter, and perhaps also seal harborages to exclude or restrict the movements of the bed bug population. It will help if occupants know some basics of bed bug biology and behavior, as well as the proposed control strategies and techniques. Education may include verbal explanations, answering questions, posting notices, broadcasting notices, postings on web sites, or distributing handouts. Educational tools must be made available in the local language (multiple languages, in some cases). Throughout a control program, continuous communication should be maintained between occupants, building managers, PMPs, any government agencies, and any local non-government organizations (NGOs) involved.

Physical removal. Bed bugs can be vacuumed from exposed harborages or resting sites, such as box spring edges or mattress seams, but their eggs are stuck tightly to harborage surfaces and are usually hard to remove. Using a high efficiency particulate air (HEPA) filtered vacuum, which filters out >99% of all particles taken up that are >0.3 micron in diameter, will ensure that many allergens associated with bed bugs and their debris are also removed. Vacuuming, especially during inspections, will immediately remove a sizable portion of the pest population and will usually kill some of the bugs in the process. Bed bugs may also be removed from exposed resting sites by pressing down on them with the sticky side of any commercially available tape, hand-picking them, or brushing them directly into a container of over-the-counter (OTC) rubbing alcohol or soapy water (Potter 2004, Gooch 2005, Harlan *et al*. 2008, Cooper 2011, Doggett 2011).

For bed bug species other than *C. lectularius*, that feed mainly on bat or bird hosts, removing those hosts and all their nesting materials is an essential first step. Next, all access routes between those hosts' nesting or roosting sites and nearby human living areas must be sealed shut. Finally, treating their hosts' roosting or nesting areas with a properly EPA-labeled insecticide to kill all, or most, of the remaining bug populations may be necessary, and should facilitate their elimination.

Exclusion. Bed bugs have weak, flexible, piercing-sucking mouthparts, and weak, simple feet (tarsi) and claws. They cannot chew or claw through even a very thin coating of sealant or an unbroken layer of paper or cloth. Sealing a layer of almost any material in place, to completely cover a harborage opening, can halt bed bugs' passage. If they are sealed inside a void or harborage, living bugs are effectively removed from the pest population and will eventually die in place. Sealing most of the openings between a harborage and bed bugs' usual host access site(s) will at least restrict the bugs' movements and help temporarily reduce the intensity of their feeding. Storing clothes and other items in plastic bags or tightly-sealed containers can greatly reduce potential harborage sites.

Mattress covers. Commercially available plastic covers (>0.08 mm thick, usually with a zippered edge), can completely enclose a mattress or box spring and prevent any bed bugs harboring in them from accessing hosts. Originally developed to reduce human exposure to allergens in mattresses infested with house dust mites, such covers can both seal in and exclude bed bugs. They may also be homemade, using plastic sheeting (>3 mil thickness) that is sealed shut with durable, flexible tape (*e.g.*, nylon fiber tape, duct tape) (Cooper and Harlan 2004). An EPA-labeled pyrethroid insecticide has been incorporated into at least one new mattress cover that is commercially available.

Physical killing techniques **(*e.g.*, heat, cold, controlled atmospheres, steam)**

Heat. Since at least the early 1900s, bed bugs have been controlled by heating infested rooms or whole buildings to temperatures >45^{o}C (113^{o}F), the thermal death point for the common bed bug. For heat treatment to be effective, it is critical that high temperature and low relative humidity be maintained for a minimum length of time. Periera *et* al. (2009) recently published a study that addressed several aspects of this technique for eliminating bed bugs from furniture and similar items in the same room while other actions and control techniques were pursued concurrently.

Heat treatment provides no residual effect, and bed bugs can re-occupy any site so treated immediately after temperatures return to suitable levels. Potential physical distortion of structures or their contents, as well as flammability risks associated with some kinds of heat sources, may be a concern in particular situations (Usinger 1966). Laundering infested linens or cloth items in hot water with detergent, followed by at least 20 minutes in a clothes dryer on low heat, should kill all life stages of bed bugs but would not prevent reinfestation (Potter 2004, Harlan *et al*. 2008, Pereira *et al*. 2009, Cooper

2011, Kells and Goblirsch 2011, Doggett 2011). Commercial dry cleaning of suitable items would also immediately kill all stages of bed bugs on, or in, them.

Commercially available portable heat chambers now offer an alternative to hot laundering of both cloth and non-wettable items (*e.g*., picture frames, books, shoes). These chambers are constructed of insulated material, shaped generally like a box or a hanging clothes wardrobe (bag), and most are electrically heated. Electronic temperature sensors and control devices are used to regulate and monitor the heating process.

Cold. Exposure to low temperatures can kill bed bugs if they are kept cold enough long enough. Bed bugs can tolerate -15^{o}C (5^{o}F) for short periods and, if acclimated, they can survive at or below 0^{o}C (32^{o}F) continuously for several days (Usinger 1966, Harlan 1997- personal observations). Cold treatments of rooms or whole buildings to control bed bugs have not been well studied, nor often employed, but freezing furniture or other items within containers or chambers [*e.g*., below 0^{o}F (-19^{o}C)] for at least four days may be a practical alternative for limited infestations or to augment other control measures.

A new commercial technology uses CO_2 from pressurized cylinders deposited as a "snow" to kill bed bugs and a variety of pests by rapid freezing. Further controlled tests and field trials of this technology are needed to verify its efficacy. The safety of releasing moderate to large amounts of CO_2 into certain types of human living spaces should also be further evaluated (*e.g*. basement apartments, and similarly enclosed or partially sunken spaces may allow a build-up of harmful concentrations at their floor level).

Controlled atmospheres. In preliminary laboratory tests by the German Federal Environmental Agency, all life stages of common bed bugs were reportedly killed by constant exposure to very high concentrations of carbon dioxide (CO_2), at ambient atmospheric pressure, within 24 hours. However, high concentrations of nitrogen gas (N_2) were not very effective under the same conditions (Herrmann *et al.* 2001).

Steam. Steam treatments have been used effectively by some PMPs to quickly eliminate live bugs and their eggs from the seams of mattresses and other cloth items. However, this technique requires practice and care. Manufacturer's instructions must be followed concerning the steam generating devices' operation, maintenance and safety precautions. The steam emission tip must usually be about 2.5-3.8 cm from the surface being steamed. If the tip is too far away, the steam may not be hot enough to kill all the bed bugs and eggs that it contacts. If the tip is too close, excess moisture may be injected into the treated material, which may lead to other problems (*e.g.*, facilitating dust mite population survival and increase; growth of surface molds).

Sticky Monitors. Sticky traps are a simple way to monitor many crawling pests, and have been used to augment other techniques for control of spiders and cockroaches. Although bed bugs will often get caught on such monitors, many recent reports from PMPs in North America have indicated that they are not very effective at detecting small to moderate populations of bed bugs, even when infestation signs are obvious, bugs are easily observed, and people are being bitten routinely nearby.

Pesticides

Insecticide Resistance. This TG is intended mainly as a background information source and will not detail the nature, prevalence, distribution, or history of insecticide resistance in bed bugs. That resistance has been well documented by many other investigators, in many geographically widespread populations of common bed bugs, and it can make controlling them very difficult. Resistance may have been a major contributing factor to their past and continuing spread (Potter 2004, Moore and Miller 2006, Romero *et al*. 2007, Harlan *et al*. 2008, Cooper 2011, and Doggett *et al*. 2012). For a lot more details about the nature and distribution of past and recent insecticide resistance in bed bugs, see: Adelman *et al*. 2011, Mamidala *et al*. 2011, Romero *et al*. 2007, WHO 1982, WHO 2006, Yoon *et al*. 2008, and Zhu *et al*. 2010.

Residual applications. Currently, non-chemical products and techniques have been incapable of efficiently or quickly controlling or eliminating established bed bug populations. Precise placement of a suitably-labeled, EPA-registered and formulated residual chemical insecticide is still one of the most practically effective bed bug control techniques. Effective control can consist of, or be augmented by, applying interior sprays or dusts to surfaces that the bed bugs contact and to cracks and crevices where they rest and hide. Many currently-labeled chemical insecticides still can provide some residual control of even slightly-resistant bed bugs, if they are properly and precisely applied.

When using residual insecticides, you should choose the least toxic active ingredients and formulations. Microencapsulated and dust formulations will have a longer residual effect than others. Synergized pyrethrins are often lethal to bed bugs, and some may cause a flushing effect, allowing faster analysis of the infested area. If the label permits, addition of pyrethrins at 0.1-0.2% to organophosphate, or carbamate (where these active ingredients are legal and labeled for this use), or other microencapsulated insecticide formulations may increase efficacy by irritating the bugs, initiating an excitatory effect, and causing them to leave their hiding places, thus increasing their exposure to the fresh insecticide layer. Retreatment, when needed, should be carried out after the shortest interval permitted by the label until the pest bug population has been eliminated.

Some newer active ingredients (*e.g*., chlorfenapyr; in the product Phantom™) and products with multiple classes of active ingredients (*e.g*., imidacloprid plus a pyrethroid; in the product Temprid ™) have recently had bed bugs added to their labels. Some of these products have been reported by some PMPs to have been fairly effective against field populations of bed bugs, so far, but some act much more slowly than pyrethroids.

Diatomaceous earth, silica gel, or other properly-labeled, slow-acting, dust formulations can also be used to treat certain sites, like cracks and crevices. Retreatment, if needed, should be done after the shortest interval permitted by the product label until the bug population has been eliminated. The choice of chemical products and specific application techniques can depend on many factors, like the physical location and structural details of the bugs' harborages, product labels (which can vary by political jurisdiction), the immediate environment, cost factors, and local or national laws.

Crack-and-crevice applications. Because of their habit of hiding clustered together in cracks and narrow harborages, precisely applied crack-and-crevice treatments are among the most effective control techniques against bed bugs. Active ingredients change over time, and several are currently available, as well as some products that contain multiple ingredients labeled for use against bed bugs. Various formulations and devices are also available for applying insecticides to bed bug-infested areas. For example, dust formulations should be used in electrical outlet boxes and in other places where it is desirable to employ low-risk (low volatility and toxicity), long-lasting products.

IGRs. When properly applied, insect growth regulators (IGRs) have essentially no immediate effect on vertebrate metabolism because of their mode of action and low application rates, but they can have a significant, but slow-acting, impact on bed bug fertility and egg hatching success (Takahashi and Ohtaki 1975, Moore and Miller 2006).

Fumigation. Fumigation of furniture, clothing, or other personal items can kill all bed bug stages present. However, such treatments will not prevent reinfestation immediately after the fumigant dissipates. Fumigation of an entire building would be equally effective but, again, would not prevent reinfestation, and would seldom be necessary, practical, or affordable (WHO 1982, Snetsinger 1997, Gooch 2005, Harlan *et al*. 2008, Cooper 2011).

Impregnated fabrics and bednets. Fabrics and bednets, factory- or self-impregnated with formulations of residual chemical insecticides, can help deny bed bugs access to hosts, and may kill some of the bugs that crawl on them. This can be economical because spraying, dipping, or coating formulations of products containing permethrin will often remain effective through many launderings, some for the life of the fabric (Lindsay *et al.* 1989). However, one West African population of tropical bed bugs, *Cimex hemipterus* (Fab.), has been recently reported to have become resistant to both permethrin and alpha-cypermethrin that had been used to treat bed nets, so as to protect their occupants against bites by malaria vector mosquitoes (Myamba *et al.* 2002).

Ultra Low Volume (ULV), aerosols, and foggers. Insecticides currently labeled for application by ULV, aerosols and foggers have little or no residual effects on bed bugs. When used exactly according to their own product label directions, most of these applications (and products) will seldom penetrate into typical, cryptic bed bug harborages. If directly injected into such harborages, these products may stimulate some of the bed bugs to become active and move out into the open, allowing them to be seen by inspectors. Otherwise, bed bugs are seldom killed by such products, even with prolonged or repeated exposure to them, when applied according to their own labels.

Follow-up. At least one follow-up inspection of infested sites should be conducted at a suitable interval (*e.g.*, 10-21 days) after each control effort or treatment, to detect any of the typical signs of continued infestation, such as live bugs, cast skins (after those present earlier had been removed), fecal spots on bed linens or harborages, or unhatched eggs.

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Some Example Web sites offering bed bug information.

Please note that web sites may sometimes contain incorrect information. Government and university web sites are usually more unbiased and reliable than sites created by commercial or private interests.

EPA's bed bug web page: https://www.epa.gov/bedbugs**;** EPA Spanish Website: http://www.epa.gov/espanol/

CDC Bed Bugs website: https://www.cdc.gov/parasites/bedbugs/

Connecticut Coalition Against Bed Bugs:
"http://www.ct.gov/caes/cwp/view.asp?a=2826&q=437580&caesNav=|"

Michigan bed bug information site (see their posted manual):
www.michigan.gov/emergingdiseases/0,1607,7-186--147759--,00.html"

New York State IPM Program under Cornell Univ.: www.nysipm.cornell.edu

VA Dept. of Agric. Bed Bug Fact Sheets:
http://www.vdacs.virginia.gov/pesticide-bed-bug-outreach-and-education-program.shtml

National Center for Healthy Homes: www.nchh.org (and search)

Bed Bug Foundation (an international NGO): http://www.bedbugfoundation.org/

University of Kentucky Extension Entomology:
www.uky.edu/Ag/Entomology/entfacts/struct/ef636.htm

Univ. of Minnesota: www.ipmctoc.umn.edu (then search)

National Pest Management Association (NPMA): www.pestworld.org (and search)

PCT Magazine: www.pctonline.com (and search)

Pest Management Professional Magazine (formerly Pest Control Magazine):
http://www.mypmp.net (and search)

Bed Bug Central (part of Cooper Pest Solutions, Lawrenceville, NJ):
www.bedbugcentral.com or www.cooperpest.com

Appendix 1. Sample Bed Bug IPM Template

This template outlines IPM strategies for controlling bed bug infestations in many military (or other) housing situations. Additional or alternative strategies and techniques are discussed elsewhere in this TG. The following sequence of steps should facilitate control of bed bugs in troop or family housing.

1. Inspection. Prompt, careful, thorough inspection by a qualified individual of sites reported or suspected to be infested by bed bugs. Even if detection dogs or multi-element (or other) devices have detected bed bugs, do an inspection to pinpoint the main infested sites. Start at the site where biting was reported and work outward for a 5-20 ft. radius.

2. Correct identification (ID) of any pest species found. A sample of the pests present should be collected and IDed by a qualified person using suitable keys or other ID aids.

3. Education of occupants(s) and manager(s) of the infested structure(s). Occupants and managers should be provided concise, clear information about the ID, biology, and general behavior of any pest bugs found. They should be informed of the need for their cooperation and of any self-help steps they might take to reduce or limit the infestation, or that would help prevent re-infestation. Information can be provided by direct explanation, fact sheets (handouts), reference to a web site, or a combination of these.

4. Physical control measures.

a. Using a vacuum cleaner (preferably HEPA-filtered), remove the bugs and their cast skins from all observed and suspected harborage sites during the initial inspection, and periodically afterward (*e.g.*, once weekly as a self-help action). The vacuum bag should be removed immediately afterward, sealed tightly inside a larger plastic bag, and that bag incinerated or placed in the next normal trash collection.

b. Launder all infested cloth items in hot water [>120^{o}F (49^{o}C)] for >10 min., with soap or detergent, then dry in a warm or hot dryer [>140^{o}F (60^{o}C)] for >20 min., or dry clean to kill all bed bug life stages present.

c. Consider enclosing each mattress and box spring in a sealable plastic cover, such as those sold to limit exposure to house dust mites.

d. Place and seal all recently laundered cloth items (*e.g.*, bed linens, clothing) inside large plastic bags or tightly-closed bins to prevent any bed bugs from reinfesting them.

e. Seal shut all cracks, crevices, and entry points to wall voids, using a high-quality silicone-based sealant, especially within a 20-ft. radius of any spot where bed bug bites have occurred.

f. Additional physical control measures against bed bugs may include: heat, cold, steam, controlled atmospheres, physical removal/mashing, or sticky insect monitors.

5. Chemical control measures.

a. A residual insecticide should be applied (by a properly qualified and certified, when called for on any given product's label), according to label directions, to each infested site and preferably to a small area around each site. This will often involve treating cracks and crevices. When planning and conducting any such treatments, consider examining, if not treating, the opposite side of any involved wall, floor, or ceiling.

b. Electrical outlet boxes, and similar voids that cannot be readily and effectively sealed, should be treated with an appropriate insecticide dust.

c. Consider including some type of insect growth regulator (IGR) as a concurrent treatment (*e.g.*, as a tank mix).

d. Limited use of an aerosol or ULV pyrethroid may facilitate the detection of hidden bed bugs by causing them to move around more, and may also potentially increase their exposure to any previously applied residual insecticide. DO NOT use any over-the-counter (OTC) total-release "foggers." Those are simply NOT effective, may cause bed bugs to scatter, and could also pose a fire hazard.

e. Fumigation or heat (or cold) treatment of batches of furniture, clothing or other items within chambers or smaller, portable heat-treatment devices (or similar-sized freezing units) may be warranted and affordable in specific cases, but whole-structure fumigation to control bed bugs is very seldom practical or economically feasible. Any of these types of treatments provide no residual effects at all.

6. Follow-up. Re-inspection of infested structures and sites should be done about 10-21 days after any initial treatment, and (if needed) again about 10-21 days later, to detect, and to precisely target any subsequent re-treatment of, any continued infestation site(s).