FORUM

Measuring Integrated Pest Management Programs for Public Buildings

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ABSTRACT Integrated pest management (IPM) tends to be perceived by different stakeholder groups either as a methodology for effective pest control or as an ideology of responsible environmental stewardship. The IPM process has never been subjected to a rigorous empirical test as a control methodology in buildings; published studies have either tested isolated program components or have presented uncontrolled, sequential descriptions of IPM replacing traditional pest control service procedures. Because ideological measurement is simpler, cheaper, and more relevant than methodological testing to evaluate structural IPM performance in the public sector, data on pesticide use/risk and customer satisfaction, rather than control efficacy, are used by the General Services Administration (GSA) IPM program to demonstrate success compatible with Government Performance and Results Act (GPRA) guidelines. Implementation of IPM in 1989 resulted in significant decreases both in quantities of insecticide applied indoors and requests for pest control service by building occupants throughout the first decade of the program. Although these results do not provide an empirical test of structural IPM methodological superiority as a means of reducing pest populations, they indicate that replacing sprayed insecticide formulations with baits and using client reporting as the primary pest surveillance method can successfully achieve the policy goals of a large-scale IPM program for public buildings.

KEY WORDS integrated pest management, public buildings, measurement, insecticide baits, monitoring, cockroach control

IN AN UNUSUAL example of a technical doctrine becoming entrenched as a legal one, IPM is increasingly being mandated by statute for public sector buildings. The movement to establish the concept as governmental policy originated in a 1972 report by the Council on Environmental Quality that, in addition to announcing a review ordered by President Nixon to determine which federal pest control programs might use IPM, served to widely popularize the newly coined term (Council on Environmental Quality 1972). This was followed by a 1979 Presidential Memorandum, in which the heads of 10 major federal agencies were directed to "support and adopt IPM strategies wherever practicable within the limits of existing resources" (Carter 1979). During the next decade, several agencies adopted formal IPM policies for properties under their stewardship (Feldman and Lewis 1995, Benbrook et al. 1996), although it was not until 1996 that Congress passed a law defining IPM in general terms and unequivocally requiring federal agencies to use and promote the process (Food Quality Protection Act 1996). Currently, one of the most rapidly expanding vanguards of public sector IPM implementation are buildings managed by states and municipalities, particularly schools. At least 13 states currently define, recommend, or require IPM by statute or regulation, with more slated to introduce or expand school pesticide legislation in the near future (Owens and Feldman 1998, Harrington 1999, Hom 1999, Rambo 1999, U.S. General Accounting Office 1999).

Critical evaluation of program effectiveness is theoretically essential for a healthy public policy process, but until recently has been a rarity in American government due to political risk-avoidance by program stewards anxious to protect hard-won funds (Buchholz 1993). In 1993, the practice of federal policy review was given strict new guidelines by the passage of the Government Performance and Results Act (GPRA) (Government Performance and Results Act 1993). The purpose of this statute was to improve the effectiveness and accountability of publicly funded programs by requiring agencies to measure well-defined aspects of their annual performance (beginning with fiscal year 1997) against planned targets. GPRA's goal was to shift the analytical focus of federal managers from procedural issues or dollars spent on programs ("inputs") to specific, measurable results ("outcomes"), with an emphasis on service quality and customer satisfaction (Kostoff 1997; Laurent 1997, 1998).

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In this article, we have three main objectives. First, we attempt to clarify a fundamental distinction between methodological and ideological interpretations of the IPM concept, and the resulting implications for relevant measurement of publicly funded structural IPM programs. Second, we describe the GPRA-compatible measurement system of a major IPM program for public buildings, and present data from this system that demonstrate program success from a policymaking viewpoint. Third, we discuss factors contributing to this success as models for optimizing performance and cost-effectiveness of other IPM programs for public buildings.

Structural IPM Methodology Versus Ideology. The rapid proliferation of public sector IPM mandates, sometimes with only vague guidance on specific operational components, has been accompanied by several difficulties that often arise at the intersection of technology and politics (Bosso 1987, Buchholz 1993). The most obvious concerns disagreement (or at least, misunderstanding) on definitions and objectives between different stakeholder groups who approach the intersection from its two principal paths. One common perception, primarily technical in orientation, considers IPM mostly as a system of principles, practices, and procedures applied to the task of pest control (i.e., a methodology). In contrast, a larger, more diverse group with a primarily political frame of reference tends to invoke IPM more as a body of ideas reflecting broader social needs and goals (i.e., an ideology).

Structural IPM methodologists are frequently academically trained in either urban entomology or a related discipline, and identify with a scientific culture that originated, and maintains intellectual ownership of, the IPM concept (National Academy of Sciences 1969, p. 449; Rabb and Guthrie 1970; Glass 1975; Royer et al. 1999). Whether from a research, extension, or commercial point of view, they generally perceive the process of pest control from a pest-centered, rather than a pesticide-centered bias (Rust 1994, Robinson 1996). To them, IPM is a paradigm for the most efficient, sustainable, and biologically rational process of suppressing undesirable organisms in and around buildings. The process is commonly presented as an array of interdependent programmatic components: for example, consistent and repeated population monitoring ("a hallmark of true IPM programs," Owens 1995, p. 94); integration of multiple control strategies ("probably is the most powerful component of the IPM philosophy," Kogan 1998, p. 260), including coordination with other programs that manage a building's infrastructure ("the secret to an IPM program's success," Breisch and Greene 1998, p. 257); an emphasis on client education at all levels ("a key ingredient of urban IPM," Bottrell 1979, p. 75); and use of pesticides only when other practices are not practicable ("implicit in the IPM concept," Entomological Society of America 1992).

Although precise, conservative use of pesticides is usually a conspicuous part of the methodologists' message, this principle tends to be embedded in their overall procedural matrix rather than standing out as a unifying raison d'etre. Indeed, some authors have gone out of their way to decentralize the chemical issue. Robinson (1995) bluntly termed the goal of using less pesticides and reducing exposure as "misdirected," and Kogan (1998) summed up a discussion on IPM implementation with the comment: "Although reduction in pesticide usage is a desirable consequence of IPM, it cannot be the only measure of success . . . even under IPM guidelines, it may be necessary to use more, not less, pesticides." In a national survey of 45 Cooperative Extension Service (CES) IPM coordinators, a majority of 23 (an additional two were undecided) responded "no" to the question: "Do you believe that the chief goal of an IPM CES Program should be to reduce pesticide use?" (Gray 1995).

In contrast, structural IPM ideologues invariably regard the protection of environmental and human health from toxic chemicals as their primary imperative, and therefore view the process of pest control from a pesticide-centered bias (Feldman and Lewis 1995, Benbrook et al. 1996).

Rather than minimization of pest damage, the focus is on minimization of pesticide use, risk, and waste (U.S. Environmental Protection Agency 1993, Hom 1999), all of which are often implicitly included in the word "use" (sensu lato). Although there is general agreement with the methodologists on key programmatic components, increased attention is often given to administrative elements such as the creation of a written IPM policy, a formalized decision-making process, and a prohibited/acceptable materials list (Feldman and Lewis 1995, Owens and Feldman 1998). From an ideological point of view, IPM is regarded as an "indicator program" or litmus test of an organization's environmental or infrastructural stewardship. The relationship between these two policy issues (Sanford et al. 1995) is particularly well illustrated by the dependence of effective pest management on a building's physical and administrative support system (Breisch and Greene 1998).

Obviously, the multitude of viewpoints among IPM proponents do not all fall conveniently into a strict dichotomy. What is crucial for an analysis of program measurement is the recognition that, as a political mandate, IPM is *always* an ideological concept, reflecting public concern with environmental degradation in general, and specifically with the impact of pesticides on human health and nontarget organisms (Flint et al. 1991, Brenner et al. 1998, Rambo 1999). As such, added to the diverse pool of IPM stakeholders who approach the process as a public policy first and a good pest control practice second, are the managers of administrative agencies charged with statute implementation (Buchholz 1993). Accountable to both clients and supervisors for program efficacy, these officials (some of whom, like the senior author, ironically began their professional careers as methodologists) must pragmatically focus on policy or regulatory "drivers" when selecting measures for evaluating results.

Methodological Versus Ideological Measurement of Structural IPM Programs. The ideal measurement of IPM purely as a pest suppression or prevention methodology would take the form of replicated field tests in which various combinations of IPM program components and non-IPM program components were applied by the same personnel to identical pest challenges in concert with an untreated control series. Pest population levels or damage would constitute the test's central standard of program effectiveness. The best experimental design would isolate and quantify which components (at specific levels of input) were most critical to program performance, thus refining and optimizing the IPM concept. Finally, the rigor and validity of these tests would have to pass scrutiny by technical experts who specialize in applied biology.

Such a definitive test would present formidable logistic difficulties, and has never been accomplished in a structural environment. In fact, all that is currently available are tests on specific "least-toxic" control technologies– both nonchemical and those with reduced pesticide use and risk–which in recent years have been developed for virtually every insect pest. It is beyond the scope of this article to review all such references, but it is instructive to examine those for cockroaches, which form the bulk of "IPM" program citations in the structural pest control literature (e.g., Rust 1994, Robinson and Zungoli 1995). The most elaborate demonstration to date was performed by Smith et al. (1995), who compared two treatment protocols for effectiveness in reducing abundance of smokybrown cockroaches, *Periplaneta fuliginosa* (Serville), around houses. The IPM treatment consisted of several landscape alteration procedures and targeted insecticide use (either spot spraying by itself or in combination with three other formulations), whereas the non-IPM treatment was simply a conventional perimeter spray application. However, because the landscape alteration component was not tested as a separate variable, the effect of its inclusion in the overall IPM treatment remains unknown, and the results remain functionally equivalent to similar work by the same authors (Smith et al. 1997, 1998) comparing targeted to conventional insecticide application techniques. The only study of pesticide application alone and in combination with one or two nonpesticidal treatment components (sanitation and client education) has been that of Kramer et al. (2000) for German cockroaches, *Blattella germanica* (L.), in low income housing units. Much of the literature on modern cockroach control technologies is reviewed in Rust et al. (1995). Two more recent studies on nonpesticidal methods are that of Kaakeh and Bennett (1997) on trapping and vacuuming, and Brenner et al. (1998) on monitoring combined with spatial statistics.

In contrast to a methodological approach, the ideal measurement of IPM as an environmentally or socially beneficial ideology, particularly one expressed through a publicly funded program, would have to clearly demonstrate to a broad spectrum of nonscientist stakeholders (e.g., pest control clients, fiscal overseers, lawmakers, and competing advocacy groups) that the process was a sufficient improvement over the baseline set by any predecessors to justify the total cost of its implementation. Because an overall, net improvement in environmental or human well-being would be extremely difficult to unequivocally evaluate (Guillebeau 1994), the measurement would have to isolate specific items (or "outcomes" in GPRA terminology) to serve as an index of policy success (Swinton and Williams 1998).

Ideological measurement reported in technical journals takes a much different form than methodological testing. Rather than a series of controlled treatments that are usually performed more or less simultaneously and attempt to identify which variables are most critical to success, ideological tests are typically uncontrolled and sequential, evaluating a program as a whole and describing changes in outcomes over time as a result of the paradigm shift. Often they are "social experiments" that examine the transformation of real-world programs existing before the new policy implementation. Several of the most frequently cited studies of cockroach IPM program implementation are structured in this manner (Slater et al. 1979, Robinson and Zungoli 1985, Zungoli and Robinson 1986, Snell and Robinson 1991).

In fact, some of the most widely publicized measurements of IPM efforts by both program advocates and managers are not only frankly ideological in nature, but deal mainly with process rather than outcome. In this type of evaluation, establishment of an IPM policy or business strategy is essentially treated as an end in itself and the input-type variables measured are presence and degree of key programmatic components, such as a formal decision-making process and monitoring program (Feldman and Lewis 1995), use of nonpesticidal preventive measures (Benbrook et al. 1996), and education of stakeholders (Pruitt et al. 1992). Although program format is obviously crucial to its success or failure, ideological measurement is inherently more convincing when it focuses on quantitative end-results of organizational change (Government Performance and Results Act 1993). This principle was strongly emphasized by Swinton and Williams (1998), who prefaced their review of efforts to assess the economic impacts of agricultural IPM by clarifying the distinction between input and outcome-oriented definitions. Noting that an "important drawback of input-oriented definitions is that they ignore the fact that IPM is a means to one or more ends" (identified as increased farmer profitability, human health, and environmental quality), the authors concluded that measurements of IPM outcomes are far better suited to the assessment of public IPM programs (Swinton and Williams 1998).

GSA Structural IPM Program. The U.S. General Services Administration (GSA) is the federal government's civilian landlord, providing space and support services for other agencies, as well as policy oversight and guidance for the management of federal real property and other infrastructure. Although the agency was one of the recipients of the 1979 Presidential Memorandum on IPM implementation (Carter 1979), it was not until 1988 that a middle management initiative succeeded in establishing an entomologist position to modernize and improve pest control for GSA-managed buildings in its National Capital Region (NCR). More than 100 buildings and their surrounding property in Washington, DC, Maryland, and Virginia, collectively containing ≈30 million gross square feet (gsf) of indoor space, were included in this program (Greene 1996). Although an IPM policy was established for GSA's nationwide real estate inventory in 1993, the term "GSA IPM program" will refer only to NCR buildings in this article.

Measurement of the GSA program is based on cost containment and two customer-based outcomes: client satisfaction and pesticide use/risk reduction. Pest population levels, the critical parameter for methodological IPM testing, are not tracked for two principal reasons. The first is that gathering and analyzing this type of data would be prohibitively expensive, the second is that it is not essential (or even relevant) as a measure of policy success in a program that provides service in a real-world environment. Structural pest control industry firms, whether delivering IPM or not, normally rely on customer satisfaction for survival and growth rather than providing numerical data on the pests they control. However, because IPM policy is considered synonymous with reduction of pesticide problems (Flint et al. 1991, Benbrook et al. 1996), some quantification of this objective is essential to demonstrate policy compliance even in the absence of other measures.

Operating expenses of the GSA program are usually evaluated solely in terms of contract prices. However, an accurate determination of public sector IPM costs must take into account numerous other variables, including resources needed for program management, contract administration, and infrastructural upgrades in other program areas. Measurement of structural IPM costs is beyond the scope of this article. Here we report our methods and results of evaluating the GSA IPM program's effectiveness in the areas of client satisfaction and pesticide reduction.

Materials and Methods

General Program Format. The GSA IPM program is managed by an in-house staff that is responsible for developing and coordinating the educational and preventive aspects of the agency's pest suppression efforts, as well as administration of pest control term contracts. Most of the monitoring, trapping, pesticide application, and pest removal components of the program are performed under these contracts by commercial firms. Although areas at particular risk for pests are inspected on a regular basis in each building, the program largely operates on a service call system. Building occupants phone in requests for pest control service to their facility manager's office, where they are logged on a work order document (GSA Form 3638) and answered by a contractor technician on the next scheduled service visit (with the exception of emergency requests). Most office-type buildings are visited weekly. Warehouses and small buildings with minimal pest problems are generally visited every 2 wk or, at the very least, monthly.

Data from 3 yr were analyzed for this study: 1988, the last complete calendar year in which a conventional pest control contract was in place, and thus used as the IPM program's performance baseline; 1994, the last complete year of the first IPM-style contract; and 1999, the last complete year of the second IPM-style contract. The GSA program distinguishes "conventional" pest control from "IPM" on the basis of ten operational and administrative procedures (Table 1).

Focus Buildings. Although ≈100 NCR federal structures are included in the GSA IPM program at any given time, the set of specific buildings under contract normally changes from year to year for various reasons. To standardize comparisons, analyses in this article are restricted to a subset of 55 focus buildings totaling 16,332,298 gsf that were under contract in all three sample years. Thirty-six of these were office buildings (12,369,989 gsf); 12 consisted mainly of storage space (2,919,695 gsf), i.e., warehouses and archival facilities; and seven had miscellaneous functions (1,042,614 gsf), including heating plants, laboratories, testing facilities, and a garage.

Measurement of Customer Satisfaction. GSA's policy on selection of performance measures is that the data should be easily captured, preferably as an automated byproduct of the normal course of business (GSA Office of Business Performance 1997). Rather than using periodic customer surveys, therefore, it was decided that the IPM program's most logical "built-in" measure of customer satisfaction was information obtained from its pest control work orders. The central assumption is that the number of service requests for specific pest problems is the most direct and reliable variable to quantify program performance from the clients' viewpoint. Although the majority of entries on the work orders are telephoned complaints from building tenants, contractor technicians also use the form to document pest problems they have discovered and treated. These latter entries, which usually involved non-occupied space, were included in our analysis of the work orders.

All service requests are logged in by location and type of pest. Additional sections allow IPM program inspectors to record adequacy of service, and for the technicians to briefly report their method(s) of treatment. Location of service requests is generally submitted as a room number, or at least a relatively discrete area such as a loading dock, daycare playground, or entrance lobby. However, a distinctive type of entry during the pre-IPM era were blanket requests for pesticide application to large blocks of space perceived to be at special risk (e.g., "do all rest rooms," "spray offices on 7700 corridor"). Our protocol for analyzing the 1988 data was to tabulate these broad, multiple-site entries for preventive treatment as single requests, unless there was evidence that all units of the cluster were indeed affected with a genuine pest problem. By 1994, clients had become familiar with the IPM program's rule that service requests not based on site-

Table 1. Procedural distinctions between IPM and conventional pest control used by the GSA structural IPM program

Procedure	IPM	Conventional
Front line (contractor service methodology)		
Service visits to building	By schedule, higher frequencies	By request, or if by schedule, lower frequencies
Inspection	Often aided by sticky traps	Rarely aided by sticky traps
Pesticide treatments	Only when inspection confirms that pests are present; applied with restraint and precision	Not contingent on inspection, often prophylactic; often applied in excessive amounts and remote from harborage
Cockroach/ant control (corrective)	Mainly baits	Mainly sprays and dusts
Flying insect control (corrective)	Mainly traps	Mainly insecticides
Interior rodent control (corrective)	Mainly traps	Rodenticide often used
Administrative (agency program management)		
Contractor selection	Rigorous evaluation of qualifications via RFP[a]	Minimal evaluation of qualifications via sealed bidding[b]
Contract administration	Guided by technical expertise	Administered by nonspecialists
Public relations and information transfer	Extensive	Minimal
Coordination with other facilities management programs	Extensive, program emphasizes prevention through sanitation and exclusion	Minimal, program mainly corrective

[a] Denotes "request for proposal," i.e. a procurement in which offerors submit proposals detailing how they would carry out the contract's technical specifications.
[b] Refers to a procurement determined solely by the lowest bidded price.

specific evidence of pest activity would only be "treated" with instructional handouts on pest biology and pest management principles.

In addition to number of service requests, we analyzed what each request was for. A major category in 1988 was the generic order to "spray," which was eliminated in succeeding years. Because most entries were simply verbatim records of calls from clients with little or no biological background, the most efficient and reliable way to organize them was by the broad categories of "roaches," "rodents," "ants," "flies," and "other." In addition to denoting miscellaneous types of pest problems, the "other" category included complaints of biting sensations and the catch-all expression of "bugs" (where the identity of the insect could not be determined from the work order document). Termite treatments, wildlife trapping, and installation of bird deterrence systems are performed under separate ad hoc contracts with different accounting systems and were not included in this study.

Measurement of Pesticide Use. Formulated quantities of pesticides and numbers of other materials used in the three study years were taken from contractor service reports, which recorded the commercial application data required by state or D.C. law. In cases where the records omitted concentration of active ingredient in a product formulated on-site (e.g., wettable powders, emulsifiable concentrates), we assumed the lowest concentration recommended on the label. In addition to recording quantities of specific products, simply tabulating service requests by whether or not treatment included a pesticide application provided a readily captured statistic for demonstrating IPM program effectiveness to lay audiences.

Service to the focus buildings in 1988 was provided by a single contractor. In 1994, the buildings were divided between two contractors different than the 1988 company. One of the 1994 contractors provided service to all buildings in 1999.

Results

Service Requests. In general, service requests decreased sharply after the implementation of IPM (Table 2). The pre-IPM baseline total of 14,716 requests decreased by 77% to 3,331 in 1994. This number in turn decreased by 53% to 1,581 in 1999, approaching an order of magnitude fewer than the 1988 requests. The generic "spray" request accounted for 18% of pest control work orders in 1988, and its elimination in succeeding years was the second largest factor in the overall decline of service requests. However, by far the most important change during the IPM contracts was the progressive elimination of cockroach complaints, the consistently dominant category of pest problems that accounted for 72% of service requests in 1988, 69% in 1994, and 46% in 1999. Total cockroach complaints in 1999 were only 6.9% of the number of cockroach complaints 11 yr earlier.

The only category of pests that showed a numerical increase over the study period was flies, which accounted for 0.3% of the service requests in 1988, but grew to 3.1% of the total in 1994 and 7.4% in 1999

Table 2. Tenant service requests in 55 GSA focus buildings under a conventional pest control program (1988) and in two sample years after IPM implementation in 1989

Category	1988	1994	1999
Spray[a]	2,661	0	0
Roaches	10,647	2,308	733
Rodents	724	595	463
Ants	503	194	136
Flies	41	103	117
Other	140	131	132
Total requests	14,716	3,331	1,581
Pesticide-treated requests[b]	14,659	1,674	954

[a] Denotes all requests for insecticide application with no specific pests mentioned. This category of service request was eliminated in 1989.
[b] Denotes all service requests resulting in pesticide application.

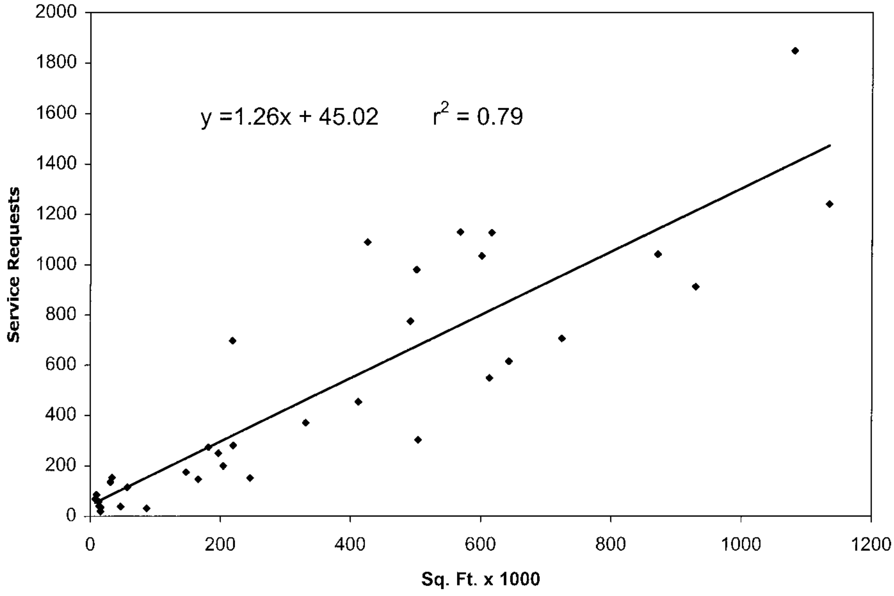

Fig. 1. Relationship between building size (gross square feet) and pest control service requests (cumulative total for 1988, 1994, and 1999) in 36 GSA office buildings.

(Table 2). Although the elimination of spray requests and the steep decline in cockroaches resulted in increasing percentages for all other pest categories, these increases were relatively minor for ants and miscellaneous pests. Rodents, however, despite their gradual numerical decrease, showed a much sharper proportional rise in importance, from 4.9% of the total in 1988, to 18% in 1994, and 29% in 1999 (Table 2).

Trends among the various structures themselves were not as clear-cut, other than the predictable observation that number of reported pest problems tended to be greater in larger office buildings, which housed far more personnel than comparatively sized warehouses or other types of structures. Mean number of service requests per building totaled over all three study years was 478 for the 36 office buildings, compared with 132 for the 12 storage buildings, and 103 for the seven structures in the "miscellaneous" category. However, buildings of approximately the same size often varied widely in service requests generated (Fig. 1), as well as degree of improvement from their 1988 performance baseline. For example, the five "worst" buildings in 1988 (i.e., those with the highest number of service calls) accounted for 37% of the total requests in 1988, but only 20% of the total requests in 1999. Mean percent reduction of requests between 1988 and 1999 for these buildings was 94% (Fig. 2). In contrast, the five buildings with the highest number of service calls in 1999 accounted for 21% of the total requests in 1988 but 40% of the total requests in 1999. Mean percent reduction of requests between the two years for these buildings was only 74% (Fig. 3), illustrating a far greater resistance to change in their pest problem status than the first group. Only one structure (designated Building B in Figs. 2 and 3) appeared in both groups. All buildings in both sets are large, with similar aggregated sizes: the 1988 top five problem structures comprised 24% of the total square footage of the focus group, and the 1999 top five comprised 22% of the total.

Use of Pesticides and Other Materials. The transition to an IPM program eventually resulted in a marked reduction in total pesticide use, as measured by several different variables. In 1988, 99.6% of all service requests resulted in some sort of pesticide application by the contractor technicians. In 1994, pesticide-treated requests had been reduced to 50.3% of all service calls, with an increase to 60.3% of the total in 1999 (Table 2).

A conspicuous trend over the study period was the decrease in number of pesticide products used (Table 3). In 1988, the single contractor applied 25 different labeled pesticide formulations (17 insecticides and eight rodenticides) for structural pests in and around the focus buildings. In 1994, the two contractors for the program together applied 19 formulations (13 insecticides and six rodenticides), and in 1999 the single contractor applied 13 formulations (nine insecticides and four rodenticides). Only one insecticide formulation (a granular propoxur bait) and two rodenticide formulations (a pelleted chlorophacinone bait and a pelleted brodifacoum bait) were used in all three years. Other than these three, no product used in 1988 was used in 1999. Four insecticides (a containerized hydramethylnon bait, two propoxur formulations, and a pyrethrin/desiccant dust) and four rodenticide baits were used in both 1988 and 1994. Three insecticides (an orthoboric acid gel, granular propoxur bait, and a containerized sulfluramid gel) and three rodenticides (two baits and a tracking powder) were used in both 1994 and 1999 (Table 3).

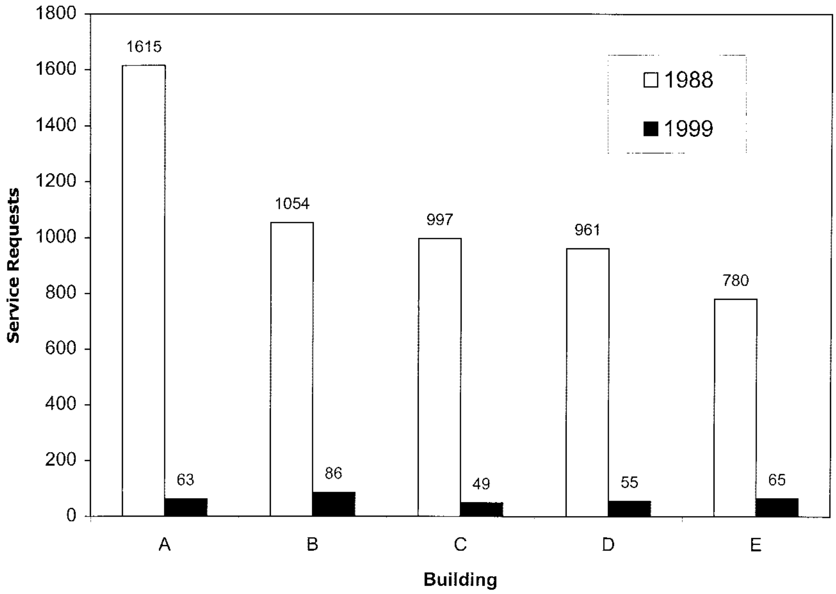

Fig. 2. Pre-IPM (1988) and post-IPM (1999) pest control service requests in the five GSA focus buildings with the highest number of requests in 1988. Buildings ordered by descending number of 1988 requests.

The dominant insecticides used in 1988 were liquid formulations applied with traditional compressed air sprayers: a combined total of 1,731.52 kg of organophosphates (chlorpyrifos, propetamphos), a carbamate (bendiocarb), a pyrethroid (fenvalerate), and hydroprene were mixed on site from either wettable powder or liquid concentrate and sprayed in the focus buildings, accounting for 97.5% of all formulated insecticide applied that year (Table 3). The first three of these chemical categories also contributed the three largest amounts by weight of active ingredient used in 1988, with the organophosphates alone accounting for 70.2% of the insecticide active ingredient total (Table 4).

The initiation of an IPM-style contract in 1989 eliminated the use of organophosphates and greatly reduced the amount of sprayed formulations in general. Although small amounts of pyrethrin/pyrethroid and propoxur aerosols were recorded, the only use of a

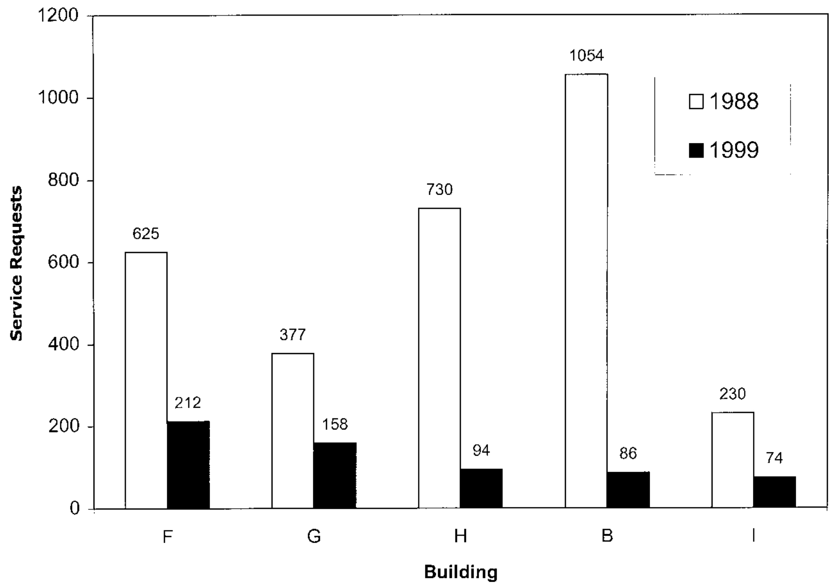

Fig. 3. Pre-IPM (1988) and post-IPM (1999) pest control service requests in the five GSA focus buildings with the highest number of requests in 1999. Building B is the same structure as Building B in Fig. 2. Buildings ordered by descending number of 1999 requests.

Table 3. Formulated amounts of pesticides (kg) and numbers of nonchemical products applied in GSA focus buildings under a conventional pest control program (1988) and in two sample years after IPM implementation in 1989

Product[a]	1988	1994	1999
Insecticides			
Abamectin B1, 0.05% dust (Whitmire PT 310 Avert)	0	1.63	0
Abamectin B1, 0.05% gel (Whitmire Micro-Gen Avert)	0	0	0.47
Abamectin B1, 0.05% containerized bait (Whitmire Micro-Gen Avert)	0	0	0.04
Abamectin B1, 0.01% granular (Whitmire Micro-Gen Advance)	0	0	2.57
Acephate, 1.0% aerosol (Whitmire PT 280 Orthene)	0.51	0	0
Bendiocarb, 76.0% wettable powder (Nor-Am Ficam W)	18.71	0	0
Boric Acid, 33.3% paste (Blue Diamond M.R.F. 2000)	0	6.85	0
Boric Acid, 20.0% aerosol (Whitmire PT 240 Perma-Dust)	1.02	0	0
Chlorpyrifos, 44.9% liquid concentrate DowElanco Dursban 4E	205.40	0	0
Chlorpyrifos, 41.5% liquid concentrate DowElanco Dursban L.O.	845.20	0	0
Chlorpyrifos, 0.5% aerosol (Whitmire PT 270 Dursban)	0.88	0	0
Chlorpyrifos, 0.5% granular Southern Agric. Insecticides Dursban.5G	4.99	0	0
Diazinon, 1.0% aerosol (Whitmire PT 265A Knox Out)	1.36	0	0
D-trans Allethrin, 0.13% aerosol (Whitmire PT 515 Wasp-Freeze)	0	0.11	0
Fenvalerate, 7.12% liquid concentrate (Terminix Pyrid)	448.27	0	0
Fipronil, 0.05% containerized bait (Clorox Maxforce)	0	0	0.33
Fipronil, 0.01% gel (Clorox Maxforce)	0	0	58.42
Hydramethylnon, 1.0% containerized bait (Clorox Maxforce Ant Bait Station)	0	0.22	0
Hydramethylnon, 2.0% containerized bait (Clorox Maxforce Roach Bait Station)	0.09	1.49	0
Hydramethylnon, 2.15% gel (Clorox Maxforce)	0	47.39	0
Hydramethylnon, 1.0% granular (Clorox Maxforce)	0	0	2.20
Hydroprene, 65.7% liquid concentrate (Zoecon Gencor 5E)	130.04	0	0
Lambdacyhalothrin, 10.0% wettable powder (ICI Commodore WP)	0	0.91	0
Orthoboric Acid, 5.0% gel (Waterbury Drax)	0	1.17	1.22
Propetamphos, 50.0% liquid concentrate (Zoecon Safrotin)	83.90	0	0
Propoxur, 0.2% granular (Bayer Baygon 2%)	4.14	78.84	6.85
Propoxur, 1.0% aerosol (Whitmire PT 250 Baygon)	12.56	8.85	0
Pyrethrins, 0.5% aerosol (Whitmire PT 565 Pyrethrin)	2.55	0	0
Pyrethrins, 0.3% aerosol (Whitmire PT 170A X-clude, Waterbury Purge CB-38)	0	0.31	0
Pyrethrins, 1.0%, Silica Gel, 40.0% dust (Fairfield American Drione)	8.76	0.01	0
Resmethrin, 1.0% aerosol (Whitmire PT 110 Aero-Cide)	8.19	0	0
Sulfluramid, 0.5% containerized bait (Micro-Gen Pro-Control, Whitmire Micro-Gen Advance Dual Choice)	0	0.16	0.79
Rodenticides			
Brodifacoum, 0.005% pelleted bait (Zeneca Talon-G)	20.97	23.10	0.25
Brodifacoum, 0.005% bait blocks (ICI WeatherBlok)	0	1.30	0
Bromadiolone, 0.005% pelleted bait (Bell Laboratories Contrac)	6.32	0	0
Bromadiolone, 0.005% bait blocks (Bell Laboratories Contrac)	0	0	8.87
Chlorophacinone, 0.2% powder (LiphaTech Rozol)	4.96	0	0
Chlorophacinone, 0.005% pelleted bait (Eaton's AC 90)	3.06	2.76	3.20
Cholecalciferol, 0.075% pelleted bait (Bell Laboratories Quintox)	3.23	5.58	0
Diphacinone, 0.005% meal bait (Bell Laboratories P.C.Q.)	53.13	0	0
Diphacinone, 0.005% bait blocks (Bell Laboratories Di-Blox)	39.35	1.93	0
Diphacinone, 0.2% powder (Bell Laboratories Ditrac)	0	47.29	37.45
Isovaleryl, 2.18% powder (Bell Laboratories Isotrac)	0.11	0	0
Nonchemical			
Sticky Traps (Monitors)	126	5,123	4,447
Mouse Glue Boards	262	410	1,205
Rat Glue Boards	266	57	0
Mouse Snap Traps	0	67	89
Rat Snap Traps	0	58	42
Fly Traps-Jar	0	10	21
Fly Traps-Glue	2	0	14

[a] Product name and manufacturer as stated on label in most recent year of application.

compressed air sprayer in 1994 was for three applications of a lambdacyhalothrin wettable powder (Table 3). In marked contrast to 1988, 85.3% of all formulated insecticide applied in 1994 consisted of granular propoxur bait and hydramethylnon gel (Table 3). Formulations of boric acid, propoxur (mainly granular), and hydramethylnon accounted for 99.9% of the 1994 active ingredients by weight (Table 4).

Although only 147.94 kg of formulated insecticide were applied in 1994 compared with 1,776.57 kg in 1988, total weight of insecticide active ingredient actually increased in 1994, mainly due to the proportionately greater amount of boric acid in formulated paste bait. By 1999, the absence of this product combined with a sharp decline in the use of granular propoxur bait resulted in a total application of only 72.89 kg of formulated insecticide, with a total active ingredient weight reduced 95.4% from the 1994 total (Tables 3 and 4). All insecticide applied in 1999 was in the form of containerized, gel, or granular bait, with liquid and aerosol formulations having been totally eliminated.

Table 4. Amounts of pesticide active ingredients (g) applied in GSA focus buildings under a conventional pest control program (1988) and in two sample years after IPM implementation in 1989

Pesticides	1988	1994	1999
Insecticides			
Abamectin B1	0	0.81	0.54
Boric acid	204.12	2,338.36	60.95
Carbamates	255.15	1,665.28	136.93
Fipronil	0	0	6.01
Hydramethylnon	1.75	1,050.97	21.97
Hydroprene	169.31	0	0
Organophosphates	3,094.06	0	0
Pyrethrins/Pyrethroids	680.99	1.56	0
Sulfluramid	0	0.79	3.93
Total insecticides	4,405.38	5,057.77	230.33
Rodenticides			
Brodifacoum	1.05	1.22	0.01
Bromadiolone	0.32	0	0.44
Chlorophacinone	10.07	0.14	0.16
Cholecalciferol	2.42	4.19	0
Diphacinone	4.63	94.67	74.90
Isovaleryl	2.47	0	0
Total rodenticides	20.96	100.22	75.51
Total pesticides	4,426.34	5,157.99	305.84

Far less rodenticide than insecticide was applied in all three sample years, with a gradual decrease in total formulated weight from 131.13 kg in 1988 to 81.96 kg in 1994 and 49.77 kg in 1999. Other than the progressive decline in number of products used, the most conspicuous trend was the increased reliance on diphacinone tracking powder and a corresponding decrease in the use of bait products (Tables 3 and 4).

The implementation of IPM also resulted in major changes in the application of nonchemical products (Table 3). Between 1988 and 1994, use of sticky traps for pest monitoring increased sharply; if numbers deployed are compared relative to total pest control service requests (Table 2), these devices became even more ubiquitous in 1999. Mouse glue boards were applied in successively greater numbers during 1994 and 1999, whereas rat glue boards decreased in 1994 and were eliminated by 1999. Rodent snap traps and jar-type fly traps were not used in 1988, but were deployed in 1994 and 1999.

Discussion

Efficacy of Pesticide Reform. Reduction of pesticide use and risk, sometimes termed "pesticide reform," has become the single most important public policy goal relating to pest control in this country (Goldman 1996), and it has been part of a broader campaign initiated by the Federal Executive Branch to integrate environmentally based management and accountability into all governmental decision making and long-term planning (Clinton 2000). IPM is now considered to be the central technological paradigm for achieving pesticide reform (Flint et al. 1991, EPA 1993, Benbrook et al. 1996, Goldman 1996), and several authors have reported significantly reduced pesticide use in structural IPM projects of widely varying scale and duration, e.g., "a 99.7% reduction in area of treated surfaces" in a ship's galley (Brenner et al. 1998); "a 99% reduction in insecticide sprays and dusts applied to each kitchen, and a 97% reduction in overall pesticide use" after a year in four institutional kitchens (Snell and Robinson 1991); and elimination of all category I products and elimination or reduction of "nearly all" category II products after 18 mo in the city of San Francisco (Hom 1999). However, published data on specific pesticides used, precise amounts applied, and long-term sustainability of structural IPM control efforts have been lacking.

The data reported herein constitute the first detailed, long-term appraisal of a major structural IPM program, and demonstrate a decade-long trend of steep decreases in overall pesticide use accompanied by parallel reductions in client service requests. In fact, selecting 1994 as the first year for analysis of the new program obscures the extremely swift implementation of one of the most critical components of pesticide reform. Because the GSA IPM contract specifications introduced in 1989 prohibited scheduled insecticide treatments and limited routine applications to crack and crevice only, the relatively large quantities of sprayed formulations applied to exposed surfaces that characterized pre-IPM service (Table 3) disappeared virtually overnight. The rapid expansion of the indoor insecticide bait industry in the early 1990s was an additional enabling factor that allowed a radical transformation of chemical use by GSA pest control contractors (Greene 1996), as did the development of several new types of indoor trapping devices for flying insects (Hedges 1998). The marked shift away from the traditional organophosphate/pyrethrin/synthetic pyrethroid complex toward newer products with less potential to negatively affect nontarget organisms (Tables 3 and 4) mirrors the trend in U.S. agriculture during the past decade in which older chemicals were replaced by substitutes "with safer properties and smaller environmental impacts" (Committee on the Future Role of Pesticides in U.S. Agriculture 2000).

At the same time, our data emphasize that evaluating changes in pesticide use (sensu stricto) solely on the basis of combined active ingredient weights may provide a misleading impression of a program's progress in achieving the more critical ideological goal of decreasing pesticide risk. The most striking example is the disproportionately large effect of boric acid products in this type of accounting system, which greatly inflated the 1994 total (Table 4) and considerably exaggerated the importance of the compound's role in the program.

Although there is nothing to suggest that the GSA program's 1999 levels of pesticide use and service requests cannot be sustained or even decreased further, the magnitude of future decreases is likely to fall considerably. Most pests in a structural environment can be classified into two major groups, those that primarily live and reproduce outside the building envelope and continually penetrate to the interior, and those that primarily live and reproduce inside the envelope. Restricted to a relatively closed system, populations of the latter group are potentially far more vulnerable to both corrective and preventive control measures. The major example in the GSA focus buildings are *B. germanica*, and brownbanded cockroaches, *Supella longipalpa* (F.). Gradual elimination of local populations of these two species throughout office space by persistent use of bait products was the principal reason for the >93% reduction in cockroach complaints after the IPM program's first decade (Table 2). These results are consistent with anecdotal reports of the declining importance of *B. germanica* in the U.S. structural pest control industry due to the widespread use of baits (Gooch 1999, Hedges 1999, Robinson 1999).

In contrast, American cockroaches, *P. americana* (L.), and Norway rats, *Rattus norvegicus* (Berkenhout), are two common examples of the former group whose population reservoirs occur in sewers and other inaccessible, external habitats beyond GSA's jurisdiction. Although cockroaches are not distinguished by species on the GSA work orders, observations suggested that a relatively constant influx of *P. americana* originating from crumbling sub-basement utility chases was responsible for an increasing percentage of the cockroach service requests in many of the older focus buildings. With no feasible short-term structural solutions to this problem, the IPM program even in recent years has had to rely on repeated applications of Baygon 2%, a unique granular propoxur product, to effectively intercept migrating *P. americana* in unoccupied basement areas (Table 3). Similarly, the majority of rodent entries on the work orders were for routine treatments of active, outdoor rat burrows that cannot be reliably eliminated with any other technology. The need for repeated, external rodenticide application is an unavoidable constant for many buildings, particularly those adjacent to property with large rat populations.

Situations such as these, where externally breeding pest species are continually generated from an immutable, decaying infrastructure, create "pesticide sinks" in structural IPM programs that may persist until cost-effective alternate control technologies become available. The slight increase in percentage of service requests resulting in pesticide application from 1994 to 1999 (Table 2) probably reflects this principle. Even though raw numbers of requests continue to fall as a program matures, a progressively greater proportion of relatively intractable pest problems may remain beyond the reach of nonchemical solutions. In fact, because these situations are often only marginally improved by pesticide use, particularly on a long-term basis, they can be considered almost as resistant to IPM as to a conventional pest control program. Certain buildings appeared to demonstrate this phenomenon. By 1999, those generating the greatest number of pest-related service calls tended to be ones that had more consistently maintained their problem status after 10 yr of IPM compared with the buildings with the greatest number of service calls in 1988 (Figs. 2 and 3). However, it was unclear whether the disparity in progress between these two groups of highly similar structures was primarily due to differences in the endurance of their pest populations or of their occupants' sensitivities to pest exposure.

Efficacy of Client-Based Monitoring. Systematic sampling of pest population levels by trained personnel has traditionally been considered as one of the most critical and defining aspects of the IPM process (National Academy of Sciences 1969, Glass 1975, Bottrell 1979). In the structural arena, routine monitoring often includes the use of sticky traps, which have been described as tools for guiding and regulating specific control actions, as well as providing data for program evaluation (Snell and Robinson 1991, Ballard and Gold 1992, Owens 1995).

IPM programs that focus on the protection of perishable specimens, artifacts, or commodities within structures are similar to agricultural systems in that control decisions are governed by action thresholds or at least quantitative trends, necessitating the establishment of monitoring regimes that continually record data from sampling devices maintained throughout the premises (Mueller 1997, Breisch and Greene 1998, Arbogast et al. 2000). In contrast, IPM programs that primarily serve the people who occupy structures, such as in schools and office buildings, operate under a different set of priorities that tend to emphasize qualitative perceptions (Hedges 1994, Tucker 1995, Robinson 1996). Routinely placing and replacing monitoring devices such as sticky traps, in addition to collecting, processing, and analyzing their yield, can be prohibitively expensive and time-consuming, particularly in larger programs. Snell and Robinson (1991) noted that "sticky traps were the most significant addition to the costs of the pest management program" compared with a non-IPM approach, and Hedges (2000) warned that "monitoring is important, but it can be practiced to such an extent that it is detrimental to the success of the overall program."

Our data illustrate that sticky traps are frequently used in the GSA IPM program (Table 3). However, their deployment, inspection, and removal are strictly at the individual technician's discretion, when they are deemed necessary for detection and evaluation of local problems. As a more logistically feasible alternative, the program uses service requests from its own clients both as its primary monitoring system and as a key performance measure of program effectiveness. Use of on-site customers as a labor source is a well-established business strategy to optimize service delivery efficiency (Jarvis 1998), and the building occupants' role in providing evaluation data is analogous to client-based performance monitoring in other service industries, such as trash collection (Donahue 1989). In the structural IPM field, the pragmatic use of treatment requests rather than pest population levels as a program performance measure was first used by Slater et al. (1979). Another early IPM project for *B. germanica* in public housing units employed surveys of residents' cockroach sightings in various rooms of their apartments to evaluate control efforts (Robinson and Zungoli 1985, Zungoli and Robinson 1986).

Despite the demonstrated efficiency of client-based monitoring systems in IPM programs for public buildings, particularly those with large quantities of indoor space, there is the potential drawback of program success ironically leading to inflated service request numbers due to increased customer expectations of effective service. Zungoli and Robinson (1986) noted "an increase in requests ranging from 13% to 200%" in the first year of their program. A similar situation was experienced by the Metropolitan Toronto Housing Authority in 1997. Replacement of conventional residual spray formulations for *B. germanica* with hydramethylnon gel and mechanical removal (vacuuming) resulted in an estimated 20% increase in requests from tenants who preferred the new, odorless treatment technology (S. Bryks, personal communication). In addition, Slater et al. (1979) suggested that use of service calls to evaluate program performance might obscure actual progress in controlling pest populations because customers continue to request service even at low levels of pest density. Although the GSA program's client request results (Table 2) were generally consistent with informal observations of declining pest populations, the sharp increase in fly complaints over the program's history (pertaining largely to drosophilids and sciarids in office space) may in part have been due to an increased willingness of building occupants to report these usually minor nuisances.

Optimization of Structural IPM Program Format. Although the data presented herein do not represent a controlled test of IPM as a superior means of reducing pest populations in buildings, they strongly demonstrate the ability of a public sector IPM program to meet the policy goals of client satisfaction with reduced pesticide use and risk. GSA's initiative therefore provides insights for optimizing the format of structural pest control programs for public buildings to achieve maximal results consistent with stakeholder expectations. For example, although pest sighting logs or pesticide-use records are seldom used in schools (Kramer 2000), these items constitute one of the most fundamental operational components of the GSA IPM system.

The basic issue of which programmatic components are essential for even earning the "IPM" designation (much less their relative contributions to efficacy–a methodological question) continues to be debated by numerous authors (Benbrook et al. 1996, Kogan 1998, Royer et al. 1999, Ehler and Bottrell 2000). This issue is not just an academic matter, because the most efficient and cost-effective way to satisfy legal mandates for structural IPM implementation is of critical interest for public sector managers in view of the large number of schools and offices in urban core areas, the aging and often deteriorating physical infrastructures of these facilities, and the chronically insufficient resources for maintenance and repairs (Committee to Assess Techniques for Developing Maintenance and Repair Budgets for Federal Facilities 1998; U.S. General Accounting Office 1995, 2000). The most pragmatic resolution of this problem is that from an ideological point of view, structural IPM must be regarded as an outcome-defined process, i.e., sustainable, effective pest control with minimized pesticide risk. Greene (1996) discussed this concept for public buildings and Smith et al. (1997) reached a similar conclusion in the case of *P. fuliginosa,* stating that, due to numerous practical constraints, minimal IPM for this species "may only consist of assessment of cockroach infestation and effective application of insecticides by understanding the biology of the pest." While maintaining that the term "IPM" should continue to denote a truly integrated system of mutually compatible tactics, Ehler and Bottrell (2000) acknowledged that, at the policy level, it is currently far more realistic to concentrate on the central, quantifiable goal of pesticide use and risk reduction.

In view of increasing societal concerns over their negative effects, it is noteworthy that chemical pesticides have been predicted to continue playing a role in agriculture for the foreseeable future, in part because of the development of more environmentally benign products, and in part because feasible alternatives are not widely available (Committee on the Future Role of Pesticides in U.S. Agriculture 2000). The situation is identical in the structural environment. Despite extensive use of nonchemical, preventive technologies (Greene 1996), the essential role of pesticides in the GSA program cannot be overemphasized, particularly the reliance on cockroach and ant bait formulations as the primary enabling agents to achieve pesticide reform (Table 3). Because the upgrading of other facilities management programs to support more effective pest control is one of the most difficult aspects of structural IPM to sustain (Greene 1996, Breisch and Greene 1998), the effectiveness of cockroach bait products even in poor sanitary conditions makes them indispensable when habitat modification is infeasible (Kramer et al. 2000). Selection of specific pesticide formulations and other service methodologies therefore stand out as some of the most important elements of GSA's IPM program format. It must also be stressed that the agency's entire IPM initiative, particularly its contract administration, has a foundation of specialized technical guidance and oversight (Table 1). Without this vital managerial component, it is doubtful the program could have achieved its policy objectives.

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