Journal of Exposure Analysis and Environmental Epidemiology (2000) 10, 682–694
© 2000 Nature America, Inc. All rights reserved 1053-4245/00/$15.00
www.nature.com/jea

A school-based strategy to assess children's environmental exposures and related health effects in economically disadvantaged urban neighborhoods

KEN SEXTON,[a] IAN A. GREAVES,[a] TIMOTHY R. CHURCH,[a] JOHN L. ADGATE,[a] GURUMURTHY RAMACHANDRAN,[a] RICHARD L. TWEEDIE,[a] ANN FREDRICKSON,[a] MINDY GEISSER,[a] MARY SIKORSKI,[a] GEORG FISCHER,[b] DAVID JONES[b] AND PAUL ELLRINGER[c]

[a]*School of Public Health, University of Minnesota, 420 Delaware Street, SE, Minneapolis, Minnesota 55455*
[b]*Minnesota Department of Health, 121 E 7th Place, St. Paul, Minnesota 55101*
[c]*Clean Air Group, 4611 Meadow Road, Minneapolis, Minnesota 55424*

The School Health Initiative: Environment, Learning, Disease (SHIELD) study is a novel school-based investigation of children's environmental health in economically disadvantaged urban neighborhoods of Minneapolis. This article describes the study design and summarizes lessons learned about recruiting and monitoring this historically understudied population. The SHIELD study focused on measuring children's exposures to multiple environmental stressors [volatile organic chemicals (VOCs), environmental tobacco smoke, allergens, bioaerosols, metals, pesticides, polychlorinated biphenyls (PCB), phthalates] and exploring related effects on respiratory health (e.g., lung function) and learning outcomes (e.g., standardized test scores, academic achievement). It involved intensive exposure monitoring, including environmental measurements inside and outside the children's schools and inside their homes, personal measurements with passive dosimeters worn by the children, and biological marker measurements in blood and urine. The SHIELD participants comprised a stratified random sample of 153 "index" children and 51 of their siblings enrolled in grades 2–5 at two adjacent elementary schools. The Minneapolis Public Schools (MPS) assisted with identifying, contacting, recruiting, and monitoring this population, which traditionally is difficult to study because families/children are highly mobile, speak a diversity of languages, frequently do not have a telephone, endure economic hardships, often do not trust researchers, and have a spectrum of unconventional lifestyles and living arrangements. Using a school-based approach, the overall SHIELD enrollment (response) rate was 56.7%, with a wide disparity between English-speaking (41.7%) and non-English-speaking (71.0%) families/children. Most children remained involved in the study through both monitoring sessions and exhibited an acceptable degree of compliance with study protocols, including providing blood and urine samples. Results indicate that it is both practical and affordable to conduct probability-based exposure studies in this population, but that it is also important to improve our understanding of factors (e.g., cultural, economic, psychological, social) affecting the willingness of families/children to participate in such studies, with special emphasis on developing cost-effective recruitment methods. *Journal of Exposure Analysis and Environmental Epidemiology* (2000) **10,** 682–694.

Keywords: *children's environmental health, children's exposure, environmental justice, indoor air quality, metals, PCBs, pesticides, recruitment, tobacco smoke, volatile organic chemicals.*

Introduction

The decade of the 1990s spawned increased awareness about the importance of protecting children's health from environmental threats. The Food Quality Protection Act (FQPA) was passed in 1996 and has special provisions for protecting infants and children. Executive Order 13045, issued by President Clinton on April 21, 1997, directed federal agencies to make children's environmental health a high priority and established an interagency Task Force on Children's Environmental Health and Safety Risks. In 1998, the National Institute of Environmental Health Sciences, the Environmental Protection Agency, and the Centers for Disease Control and Prevention (CDC) initiated a joint research program to understand the causes and mechanisms of childhood disorders having environmental etiology, identify relevant environmental exposures, intervene to reduce environmental exposures and related health effects, and decrease the prevalence, morbidity, and mortality of environmentally related childhood diseases (Dearry et al., 1999).

Despite increasing attention paid to this issue by legislators, regulators, and researchers, scientific information to assess and manage children's environmental health

Abbreviations: CDC, Centers for Disease Control and Prevention; DHHS, Department of Health and Human Services; FQPA, Food Quality Protection Act; HVAC, heating, ventilation, and air-conditioning; IgE, immunoglobulin class E; IRB, Institutional Review Board; MDH, Minnesota Department of Health; MPS, Minneapolis Public Schools; NHEXAS, National Human Exposure Assessment Survey; NIH, National Institutes of Health; PCBs, polychlorinated biphenyls; PM, particulate matter; SHIELD, School Health Initiative: Environment, Learning, Disease; VOCs, volatile organic chemicals.

Address all correspondence to: Dr. Ken Sexton, School of Public Health, University of Minnesota, 420 Delaware Street, SE, Minneapolis, MN 55455. Tel.: +1-612-626-4244. Fax: +1-612-626-0650. E-mail: ksexton@mail.eoh.umn.edu
Received 16 December 1999; accepted 17 July 2000.

risks is scarce (National Research Council, 1993a; Dearry and Collman, 1999; Environmental Health Perspectives, 1999; Rylander and Etzel, 1999). Nowhere is our ability to make informed decisions about environmental health risks more limited by a shortage of knowledge and understanding than in economically disadvantaged urban communities (Sexton, 1997, 1999; Institute of Medicine, 1999; Schmidt, 1999). And children — the vulnerable population at potentially greatest risk — tend to be the least studied. Relatively few studies have focused directly on characterizing children's exposure to environmental chemicals, with the notable exceptions of lead (Fischbein, 1992; National Research Council, 1993b), oxidant and particulate air pollution (Linn et al., 1996), and environmental tobacco smoke (National Research Council, 1986; Samet et al., 1991). For the most part, however, not much is known about the magnitude, duration, frequency, and timing of childhood exposures to environmental chemicals, nor is it always apparent when, where, why, how, and for whom elevated exposures are likely to occur.

Exposure monitoring studies and epidemiological investigations must necessarily be part of research efforts to strengthen the scientific foundation for informed decision making. Although these kinds of studies often require intensive and repeated contacts with research subjects, relatively little has been published about recruiting, retaining, and monitoring children and their families. Researchers face special challenges and complexities when attempting to study children from low-income and minority families because of frequent address changes, lack of telephones, and mistrust of researchers, among other problems (Senturia et al., 1998). This article describes the design and implementation of a school-based study of children's environmental exposures and related health effects in economically disadvantaged urban neighborhoods. The focus is on (a) describing the scientific rationale and strategic plan for recruiting, retaining, and monitoring elementary school children from low-income and minority families; (b) discussing methods and techniques for resolving key administrative and technical issues that were an intrinsic part of study implementation; and (c) summarizing recruitment results from a pre-implementation pilot study and the full study.

Research strategy and study design

There is increasing evidence that poor inner-urban children, and particularly children of color, are likely to be more exposed to many environmental pollutants and more susceptible to related adverse effects than the general population (Guzelian et al., 1992; Brody et al., 1994; Weaver et al., 1996a,b; Sexton, 1997; Chuang et al., 1999; Eggleston et al., 1999; Institute of Medicine, 1999; Landrigan et al., 1999; Schmidt, 1999). But little is known about this population's complex exposure patterns, which commonly involve concurrent and sequential contact with multiple environmental agents. The School Health Initiative: Environment, Learning, Disease (SHIELD) study embodies two overarching goals: to characterize exposures to multiple environmental agents for elementary school children from two economically disadvantaged neighborhoods in south Minneapolis; and to explore related effects on respiratory health and learning outcomes.

Study Population

The SHIELD study is designed to measure important environmental health variables for more than 550 children in grades 2 through 5 enrolled at two elementary schools, Lyndale and Whittier, in south Minneapolis (see Table 1).

Table 1. Selected characteristics of children eligible to participate in the SHIELD study (based on enrollment at the start of the 1999/2000 school year).

Eligible children	Lyndale	Whittier	Total
Number of children enrolled in grades 2–5	269 (100%)	289 (100%)	558
Primary language spoken at home			
English[a]	146 (54.3%)	149 (51.6%)	295
Somali	70 (26.0%)	44 (15.2%)	114
Cambodian	18 (6.7%)	0	18
Spanish	12 (4.5%)	96 (33.2%)	108
Other[b]	23 (8.6%)	0	18
Qualify for free/reduced school meals[c]	211 (78%)	241 (83%)	452
Living in the same zip code as their school	95 (35%)	119 (41%)	214
Living in a zip code adjacent to their school	136 (51%)	134 (46%)	270
Living in a zip code non-adjacent to their school	38 (14%)	36 (12%)	74

[a]Mostly African–American, but also includes Asian, Caucasian, Native American, and Hispanic children.
[b]Including Laotian (12 families), Cree, and three African languages — Oromo, Amharic, Yoruba.
[c]Based on Guidelines for the National School Lunch/Breakfast Program.

The Lyndale elementary school is located eight blocks south of the Whittier school and similar numbers of children (269 at Lyndale, 289 at Whittier) were enrolled in grades 2–5 at the start of the 1999/2000 school year. Each is a neighborhood school and, although most of the children live in relatively close proximity (within a few blocks), virtually all ride buses to school. The residential neighborhoods of Lyndale and Whittier are adjacent to each other and both are home to many low-income families and people of color, including recent immigrants from Africa and Southeast Asia (see Table 2).

The 558 children eligible for SHIELD comprise a diverse mix of ethnic and racial backgrounds: 356 (63.8%) blacks (including 114 Somali); 114 (20.4%) Hispanics; 37 (6.6%) whites; 35 (6.3%) Asians; and 16 (2.9%) Native Americans. As shown in Table 1, most of these children (more than 75% at each school) receive either free or reduced-cost meals through the National School Lunch/Breakfast Program. Participation in this program is an indicator of poverty; e.g., a four-person household must demonstrate total earnings of less than US$596 per week to qualify. Just over half the children, 146 at Lyndale (54.3%) and 149 at Whittier (51.6%), live in households where English is the primary language. The rest of the children's families speak a variety of other languages, primarily Somali or Spanish (see Table 1).

Strategic Objectives

The SHIELD study takes advantage of two fortuitous circumstances to conduct a school-based evaluation of children's environmental health. First, the study incorporates evaluation of a "natural" indoor air quality experiment. Participating children were recruited from two elementary schools located eight blocks apart. One school is a new building constructed to minimize indoor air quality problems, while the other is an older building of more traditional construction. Otherwise, they are generally similar in size and structure, and draw students primarily from two adjacent, low-income communities that are comparable in terms of socioeconomic status and ethnic/racial composition. Second, personnel from the Minneapolis Public Schools (MPS) Special School District Number 1, including district administrators, school principals, nurses, teachers, and custodians, enthusiastically participated in planning, designing, and implementing the study. Their direct involvement made it possible to incorporate school-based recruitment and monitoring protocols into the SHIELD design.

Table 2. Comparison of selected sociodemographic characteristics for residents from the Lyndale and Whittier neighborhoods in Minneapolis (data from the 1990 census).[a]

Neighborhood characteristics	Lyndale	Whittier
Total population	7,012	12,951
Percent of all persons below poverty	35.2	31.9
Percent of all families below poverty	38.3	37.9
Percent of all families with children under 18 years below poverty	56.7	57.0
Percent of female householder families below poverty	58.9	68.7
Percent of female householder families with children under 18 years below poverty	71.7	77.7
Median household income	US$15,392	US$17,325

[a]The term "neighborhood" is used to describe the basic subdivision of a community, and it typically covers an area that can logically be served by one elementary school. It applies to predominantly residential areas but includes commercial, industrial, and institutional operations within the neighborhood's geographic boundaries (from Definitions of Minneapolis Communities and Neighborhoods, http://freenet.msp.mn.us).

Personal, Environmental, and Biological Exposure Measures The main objective of the exposure assessment component of SHIELD is to characterize children's exposure to multiple environmental stressors, including volatile organic chemicals (VOCs), allergens, airborne particulate matter ($PM_{2.5}$), environmental tobacco smoke, metals, pesticides, and polychlorinated biphenyls (PCBs) (see Table 3). Primary emphasis was placed on obtaining comprehensive information about children's inhalation exposure to selected VOCs because these compounds are ubiquitous in both indoor residential and outdoor community air, and because they may affect children's neurobehavioral development and/or respiratory health. The data were collected (1) to allow for determination of the relative contributions of residential, school, and ambient environments to measured VOC exposures; (2) to estimate the additional VOC exposure resulting from contact with environmental tobacco smoke; and (3) to compare environmental and personal VOC concentrations with matched VOC levels in blood.

Respiratory Health Respiratory tract illnesses, including infections, allergic rhinitis, asthma, and non-specific respiratory irritation, are common causes of morbidity in elementary school children. The prevalence and severity of asthma have increased over the past two decades in the United States, with the greatest increase occurring for poor minority children living in the inner city (Eggleston et al., 1999). Although the etiologies of asthma and other respiratory tract illnesses tend to be complex and not well understood, among the contributing factors are environmental exposures to allergens (e.g., cockroaches, dust mites) and hazardous chemicals (e.g., environmental tobacco smoke), along with genetic predisposition and other factors that play a role in this growing public health problem.

Results from questionnaires on allergies, asthma, infections, and non-specific respiratory illness, as well as results

Table 3. Summary of environmental agents measured as part of the SHIELD study.

Target environmental agents and related media or setting	Individual analytes	Collection and analysis methods
VOCs in outdoor, indoor, and personal air	1,3-Butadiene, benzene, carbon tetrachloride, chloroform, chloroprene, 1,4-dichlorobenzene, ethylbenzene, methylene chloride, methyl-*t*-butyl ether (MBTE), *m*/*p*-xylene, *o*-xylene, perchloroethylene, styrene, trichloroethylene, toluene	3M 3520 OVM monitors; analyzed by GC/MS
VOCs in blood	1,1,1-Trichloroethane, 1,4-dichlorobenzene, benzene, carbon tetrachloride, ethylbenzene, *m*/*p*-xylene, methylene chloride, *o*-xylene, styrene, tetrachloroethane, toluene, trichloroethene	Venipuncture; analyzed by GC/MS
Allergens in carpet dust samples from inside homes/schools	German cockroach, dust mite (two types), cat dander, microbials (fungi, molds)	Vacuum sampler; analyzed by ELISA for allergens, microscopy for fungi and molds
Allergens in blood	Total IgE, specific IgE for German cockroach, dust mite (two types), cat dander, short ragweed	Venipuncture; analyzed by RAST
Bioaerosols in schools	Microbials (fungi, molds)	Anderson samplers; analyzed by plating, culturing, counting, and identifying
Indoor air quality parameters in schools	CO, CO_2, temperature, relative humidity	Continuous measurements with TSI Qtrak monitor
Airborne particles ($PM_{2.5}$) in outdoor and indoor air	24-h mass concentration, continuous particle mass concentration	Gravimetric analysis of mass on filter; continuous measurements with TSI Dust Trak monitor
Markers of exposure to environmental tobacco smoke in urine	Cotinine, nicotine, NNAL, NNAL-glucuronide	Convenience urine sample; analyzed by GC/MS and GC-TEA
Metals in blood	Pb, Hg	Venipuncture; Pb analyzed by ZGFAAS, Hg by CVAAS
Metals in urine	Pb, Tl, W, Cd, Ba, Mn, Sn, Mo, Cs, U, Cr[a], Hg[b]	Convenience urine sample; analyzed by ICP-MS
Pesticides in blood	Hexachlorobenzene, *trans*-nonachlor, oxychlordane, heptachlor epoxide, DDE, dieldrin, mirex, DDT	Venipuncture; analyzed by GC/ECD
Pesticide metabolites in urine	Chlorpyrifos, malathion, diazinon, alachlor atrazine, 2,4-D, screen for common metabolites of organophosphate pesticides	Convenience urine sample; analyzed by HPLC-MS/MS
PCBs in blood	Numerous individual congener polychlorinated biphenyls	Venipuncture; analyzed by GC/ECD

CVAAS=cold vapor atomic absorption spectroscopy; DustTrak=TSI Model 8520 with $PM_{2.5}$ inlet; ECD=electron capture detector; ELISA=enzyme-linked immunosorbent assay; GC/MS=gas chromatography/mass spectroscopy; GC-TEA=gas chromatography thermal electron activation; HPLC=high-pressure liquid chromatography; ICP-MS=inductively coupled plasma mass spectroscopy; MS=mass spectroscopy; NNAL=4-(methylnitrosamine)-1-(3-pyridyl)-1-butanol; PCBs=polychlorinated biphenyls; $PM_{2.5}$=particulate matter (d_a=2.5 μm); Qtrak=TSI Model 8551; RAST=radioallergsorbent test; SHIELD=School Health Initiative: Environment, Learning, Disease; TSI=Thermo-Systems, Inc.; VOCs=volatile organic chemicals; ZGFAAS=Zeeman graphite furnace atomic absorption spectroscopy.
[a]Analyzed by ZGFAAS.
[b]Analyzed by CVAAS.

from lung function tests (spirometry and peak flow), were used to characterize respiratory health. The SHIELD study explores possible causal relationships between these variables and exposure-related measurements, including: (a) measured environmental concentrations (in-home and in-school levels of allergens in carpets); (b) measured personal exposures (breathing zone levels of VOCs); and (c) measured values for biological markers of exposure [e.g., urinary cotinine, immunoglobulin class E (IgE) levels in blood].

Learning Outcomes Neurobehavioral effects from low-level environmental exposures to lead, methylmercury, and PCBs have been documented in children. It is postulated that certain pesticides, VOCs, and polyaromatic hydrocarbons also cause such effects (Schmidt, 1999). Research to understand the nature and magnitude of related health risks in children is complicated by the difficulty of distinguishing chemically induced problems with coordination, perception, and cognitive ability from the effects of genetic, social, and cultural factors. The SHIELD study explores possible causal links between measures of learning outcomes (scores on standardized tests administered every spring, academic performance as measured by grades) and measured levels of neurotoxins in environmental samples (levels of VOCs inside/outside the child's residence and

school), personal exposure samples (levels of VOCs in the child's breathing zone air), and blood (VOCs, lead, mercury, persistent pesticides, PCBs) and urine (organophosphate pesticides, metals) samples.

Study Design

The SHIELD study has three primary objectives: (1) to compare exposures to multiple environmental agents for children attending two elementary schools; (2) to compare respiratory health and learning outcomes for children attending two elementary schools; and (3) to model associations between and among environmental measurements (e.g., outdoor, indoor, and personal VOC levels), biological markers of exposure, susceptibility, or effect (e.g., blood VOCs), and respiratory health effects (e.g., lung function) and learning outcomes (e.g., standardized test scores). Recruitment for SHIELD occurred from November 1999 through January 2000, and the data collection portion of the study was accomplished during two monitoring sessions, winter (February–March 2000) and spring (April–May 2000).

The design takes advantage of similarities in sociodemographic characteristics between residents of the two neighborhoods and between students enrolled at Lyndale and Whittier to reduce related effects on the outcomes of interest. Although observational in nature, the study utilizes students from the two schools as non-randomized, concurrent comparison groups to assess differences in both exposures and effects. Children at each school were randomly sampled in a way that accounts for over-representation of families with multiple children and assures adequate representation by gender, age, and ethnic/racial group. Determining associations such as those between exposures to different environmental agents or between exposures and respiratory health requires statistical modeling of complex relationships to account for various confounders. The epidemiological portion of the study is essentially ecologic, but ecological bias is reduced by measuring intermediate individual variables (biological markers of exposure) to verify school-based comparisons of the link between environmental exposures and health or learning outcomes. Data were also collected on other factors that may affect the comparisons, such as socioeconomic status, home environment, diet, and exposure to tobacco smoke, in order to adjust for these potential confounders.

The sampling design was developed to ensure random selection of participants given a number of constraints. First, there was a need to consider balancing the effects of different schools (two), grades (four), language categories — English- *versus* non-English-speaking (two) — and gender (two), which gives rise to 32 distinct cells or strata. The goal was to have a sample of five within each stratum (5×32), thereby defining a target of recruiting 80 children from each school (160 total). Second, to prevent within-family correlation from diluting the sample, our goal was to recruit 80 "index" children from 80 different families. A simple random sampling to fill each stratum was therefore not appropriate since the siblings of a selected index child must be omitted from further sampling. For the purposes of this study, a family was defined to be age-eligible children living at the same address with the same guardian. Third, the results from the pilot study indicated that it was necessary to design for a relatively low response rate, especially for English-speaking families. And fourth, the design had to provide an adequate sample in each stratum so it could be "weighted up" in proportion to the probability of selection to give an unbiased representation of population values for different populations included in the study. The SHIELD sampling design attempts to meet the objectives of the study within these constraints.

The target enrollment of five index children per stratum represented an average selection probability of 25%. Assuming that the overall response rate would be about 50%, we doubled the number targeted for recruitment in each stratum (from 5 to 10), which results in an average selection probability across all strata of approximately 50%. In order to obtain approximately equal numbers (up to a maximum of 10) from each stratum, all children in a stratum were randomly ordered on an eligibility list, then the strata were selected in random order 10 times. The next child on the randomly ordered list was then selected as the index subject (and deleted from the eligible list). To ensure that each index child was from a separate family and to avoid bias toward a particular age or gender, as each index child was selected, his/her siblings were also deleted from the eligible list for their respective strata. In the SHIELD study design, therefore, the sampling weights are stratum-specific and depend on the number of children in the stratum and the number and age of the siblings of each stratum member. Because of the expected 50% response rate, existing values will be used to impute the missing values due to non-response.

To meet the SHIELD study objectives (comparing students in the two schools), analyses will be adjusted to control for potential confounding of the school effect and to minimize unexplained variability. Adjustment variables include age, gender, grade in school, exposure to contaminants outside the school, health history and status, learning outcomes and status, and sociodemographic categories that might be related to outcomes. Analysis methods depend on whether the data are continuous or discrete, quantitative or qualitative, time-dependent or stable, and the amount of missing data. Assumptions regarding homogeneity of effects across strata, proportional hazards, and time invariance will be

examined. In order to account for the unequal sampling probabilities, observations will be weighted by the inverse sampling probabilities.

Study implementation: approaches and methods

The following discussion summarizes approaches and methods used to resolve important administrative and technical issues that were a necessary part of study implementation.

Collaborations

The collaboration and cooperation of the MPS Special School District Number 1 was an essential feature of the SHIELD study. Their involvement allowed us to: (a) obtain enrollment records from the Lyndale and Whittier elementary schools to identify grade-eligible children and determine contact information for their families; (b) employ the schools' bilingual education assistants to assist with recruitment and monitoring; (c) employ school nurses to supervise in-school collection of urine samples and spirometry data, as well as to assist with collection of blood samples; (d) involve teachers as part of the in-class measurement of peak flows; (e) obtain information about students' standardized test scores and academic performance; and (f) have access to schools and classrooms for environmental monitoring purposes.

The Minnesota Department of Health (MDH), Division of Environmental Health, is also a collaborator on the SHIELD study, and staff from the Indoor Air Program are involved in designing and implementing the school and residential monitoring portions of SHIELD. The MDH assisted with translating written materials and worked to encourage children and their families to participate in the study. The MDH has lead organizational responsibility for communicating research results to MPS, the schools, the study participants and their families, and the neighborhoods.

Several additional organizations, which are listed in the Acknowledgment, are collaborating to analyze the extensive exposure-related measurements collected as part of the SHIELD study.

Neighborhood Involvement

Both the Lyndale and Whittier neighborhoods are home to a heterogeneous mixture of low-income people from diverse cultures and a variety of ethnic and racial backgrounds. The social fabric of each neighborhood is complicated by this diversity of cultures and languages, and residents are confronted with many problems common to economically disadvantaged urban areas, such as crime, substandard housing, and lack of access to medical care.

A number of activities were undertaken before and during implementation to inform and involve community members in the SHIELD study. Prior to recruitment, local newspapers and key community groups, including neighborhood, religious, and cultural organizations, were sent letters explaining the study and requesting their help to encourage participation. They were also sent a poster announcing the study and asked to display it in a prominent location. Personnel from the SHIELD study attended parent–teacher and open house meetings hosted by each school where they made presentations and distributed brochures explaining the study.

Incentives

An important issue for the SHIELD study is the subject of incentives (some individuals and organizations prefer other terms including compensation, inducements, payments, reimbursements, or rewards) for children and families participating in the research project. Because children/families volunteering for SHIELD expended substantial time and effort to comply with monitoring and testing protocols, they were offered financial incentives for successful completion of research-related tasks, according to the schedule shown in Table 4. In addition, small gifts (e.g., yoyos) were provided to children as they completed specific research-related tasks, such as providing a blood or urine sample.

Insurance

The MPS raised a concern about the financial liability (to both MPS and the study families) in the remote event that a child might suffer a SHIELD-related injury. Because the majority of families in the study were financially disadvantaged and unlikely to have health insurance, there was a strong sentiment that they should bear no liability for any study-related injury, no matter how unlikely. The MPS liability insurance would not cover this contingency, so the SHIELD study purchased medical insurance (US$10,000 medical/dental with US$25 deductible) and accidental death and dismemberment insurance (US$5000) for participating children through the University of Minnesota, Department of Risk Management and Insurance. The MPS was also added as an additional insured party on the university's general liability insurance policy.

Institutional Review Board (IRB) Approval

The University of Minnesota IRB had responsibility for approving or disapproving the study based on their evaluation of its appropriateness as well as the associated benefits and risks for the children and their families. The IRB wanted assurances that intensive exposure and health measurements were not unduly burdensome and did not intrude unnecessarily into homes and schools, potentially

Table 4. Summary of financial incentives provided to participants in the SHIELD study for successful completion of specific research-related tasks.

Task	Financial incentive (US$)
Completion of baseline questionnaire by parent/guardian and permission to conduct air measurements inside the residence	20
Child provides a urine sample and completes core monitoring group (e.g., personal VOC exposure badge, time–activity diary, residential VOC badge, lung function test)[a]	20 (×2 monitoring periods)[b]
Child provides a blood sample[a]	30 (×2 monitoring periods)[b]
Completion of follow-up questionnaire by parent/guardian	20
Total compensation possible for successful completion of all research-related tasks[c]	140[d]

[a]Children/families recruited for the intensive portion of the study were asked to volunteer for the entire range of exposure-related measurements (including blood and urine samples as well as the core monitoring group). Only if the child expressed serious reservations about the blood draw was he/she offered the option of opting out of this procedure and participating in the other components of the study. Incentives were adjusted accordingly.
[b]Participants in the SHIELD study were asked to participate during two monitoring periods — January/February and April/May 2000. Children/families who participated in the May 1999 pilot study were also asked to participate during the two subsequent monitoring periods.
[c]A family could exceed the US$140 total if a sibling(s) of the "index" child also agreed to participate in SHIELD. Siblings who volunteered to complete the core monitoring group (US$20) and provide a blood sample (US$30) received the same incentives as the index child.
[d]In addition to financial incentives, the child was given a pencil for each day he/she wore the VOC monitoring badge, a pen for completing the spirometry testing, and a small prize (e.g., yoyo) for providing a blood and/or urine sample.

disrupting lives and educational pursuits. We were able to demonstrate that the school-based design we adopted, in cooperation with the MPS, would create only minimal disruption for children and their families. Furthermore, we were able to show that data obtained from the more intrusive measurements (blood and urine samples) would provide valuable information that could be used to improve children's environmental health. For example, elevated levels of IgE in blood are indicative of allergies to specific environmental agents, and avoidance of those allergens could potentially improve an individual's respiratory health. Similarly, elevated levels of neurotoxins, such as lead (in blood) and mercury (in urine), suggest the likelihood of unrecognized environmental exposures and the need to identify sources of these pollutants and take remedial action. Based on such considerations, the IRB was convinced that knowledge of children's exposure to hazardous environmental agents, including information about whether contact occurs at school, at home, or in the outdoor ambient environment, will help public health officials make better decisions about how best to protect environmental health for all children, including those participating in SHIELD.

An important administrative issue for SHIELD was the involvement of multiple IRBs. Because researchers at the National Center for Environmental Health, CDC, are co-investigators on the biomarkers portion of the study, we had to obtain approval for the SHIELD research protocol from the CDC's IRB. As might be expected, the IRB at the University of Minnesota did not evaluate all aspects of the study protocol exactly the same as the CDC's IRB, and there were several instances where one IRB requested changes to items already approved by the other. These differences of interpretation tended to be relatively minor and were eventually resolved, but substantial time and effort were involved on the part of both investigators and members of the respective IRBs. This underscores the need for researchers to determine at the outset whether a particular research project requires multiple IRB approval and, if so, to plan early on for coordinating multi-organizational submissions and responses.

Identifying and Contacting Participants

Children and their families eligible to participate in SHIELD were identified and contacted based on enrollment information obtained from the Student Accounting Department, MPS. The list included names, first language, addresses, telephone numbers, and other contact information. Even though children continued to enroll at both schools, only those enrolled by September 27, 1999 were eligible to participate in SHIELD.

All families received an initial contact letter from the principal of their child's school describing the study, encouraging them to volunteer and explaining that a recruiter would contact them. A bilingual education assistant from the schools contacted families that spoke Cambodian, Somali, or Spanish. English-speaking families were contacted by either a bilingual education assistant or an experienced recruiter with knowledge of the challenges involved in conducting research studies among economically disadvantaged populations.

As necessary, the bilingual education assistants translated the initial contact letters into Cambodian, Somali, or Spanish. There were two versions of the letter — one for families with a telephone and one for those without. A stamped, self-addressed postcard was enclosed to be

returned if the recipients did not want to be contacted by recruiters. Those without phones could also return the postcard to indicate that they wanted to participate and specify how they preferred to be contacted.

Recruiters began contacting families 2 weeks after the initial letter was mailed. If practicable, contact occurred by phone; otherwise, recruiters visited households that did not have a phone or that had a phone but could not be contacted because there was no answer or the line was always busy. If the phone was disconnected, recruiters looked for an additional number for the parent/guardian on the emergency card maintained by the schools. If the emergency number was disconnected or not functional, a note and brochure were sent home with the child or recruiters stopped by the residence and left a brochure on the door handle. After several unsuccessful attempts to visit the family at home, the child/family was designated a non-responder (passive refusal).

Obtaining Consent/Assent and Administering the Baseline Questionnaire

Recruiters met with children/families in their homes to explain the study and answer any questions. For those who agreed to volunteer, recruiters obtained verbal and written consent/assent and administered the baseline questionnaire (for which there was a US$20 incentive). Total time for the home visit was typically from 1 to 2 h.

Collecting Blood and Urine Samples

Blood samples were collected at school by trained pediatric phlebotomists. Children came from class to a private room where the phlebotomist, with assistance from the school nurse, obtained a 33-ml venipuncture blood sample (four tubes: 10 ml for VOC analysis; 10 ml for IgE or archive; 10 ml for persistent pesticides/PCBs; 3 ml for metals). Under supervision of the school nurse, each child provided a urine sample either before or after blood was drawn. Organic fruit juices that did not contain pesticides were provided to the children at the start of the school day to increase the volume of urine samples.

Obtaining Personal VOC Measurements

Participating children were asked to wear a small clip-on monitor (badge) for 48 consecutive hours to measure airborne VOC concentrations. Field technicians instructed the child and parents/guardians about the badge and attached it to the child's outer garment or backpack in the breathing zone area. At times when it was impractical to wear the monitor, such as at night while sleeping, children/families were instructed to place the monitor as near as possible to the child's head (e.g., on the nightstand next to the bed). Metal screens were placed over the face of each monitor to prevent children from tampering with the absorption material in the badge.

Obtaining Personal Time–Activity Data

Each child, with the help of his/her parents/guardians and teachers, was asked to maintain a 48-h diary (in the form of a simple questionnaire) of time spent in seven microenvironments (inside at home, school, other; outside at home, school, other; in transit). They also kept track of time involved in certain exposure-related activities, such as time spent in the presence of a smoker or near fresh paint. Field staff examined the diary when they picked up personal VOC badges at the end of the 48-h monitoring period and, to the extent practicable, worked with children and parents/guardians to resolve any apparent incompleteness or inconsistency.

Measuring Lung Function

Children participating in SHIELD had lung spirometry performed by the school nurse at their school using a Collins' Survey Spirometer. Each nurse attended a NIOSH-approved spirometry training course and passed competency tests for performing the procedure. As part of SHIELD, one spirometry test was performed in the spring 2000 for each participating student (minimum of three satisfactory maximum expiratory blows). Tracings were recorded electronically and stored for later analysis. In addition, all students in grades 4–5 at both schools were asked to participate in measurements of peak expiratory flow and forced expiratory volume in 1 s using small, handheld flow measuring devices made by Air Watch. The instrument electronically stored the results of each maximum expiratory blow (five per testing session). Testing sessions were supervised by teachers in the child's classroom, and occurred in the morning and afternoon on a Monday, Wednesday, and Friday of the designated testing week (testing occurred three times, in the fall 1999, winter 2000, and spring 2000).

Measuring Learning Outcomes

Scores on standardized tests, grades, and information on absenteeism are available from previous years for all children who were enrolled in the MPS system. These data will establish baseline values that can be used to adjust learning outcome comparisons between the schools. Basic measures of socioeconomic status and cultural/ethnic stratification from the baseline questionnaire will permit adjustments for valid comparison.

Results and discussion

This section discusses recruitment and data collection results from (1) a pilot study designed to test and refine methods and techniques and (2) the SHIELD study.

Pilot Study

A pilot study was conducted at the Lyndale and Whittier schools to test and refine methods for recruiting children/families (January–April 1999) and for monitoring exposures and performing lung function tests (May 1999). A random sample of 78 "index" children, stratified by school, grade, and language, was selected from the second, third, and fourth grades. Any sibling of these index children who was in grades 2–4 was also asked to volunteer for the pilot study. The total recruitment pool therefore consisted of 96 children — 78 index children and 18 siblings.

As described earlier, children/families were offered incentives to participate and complete research-related tasks (see Table 4). A summary of recruitment outcomes for the pilot study is provided in Table 5. Of the 78 randomly selected children/families, eight (10%) had transferred their children to another school and were therefore ineligible, 27 (35%) could not be contacted, nine (12%) were contacted but recruitment visits could not be scheduled/completed, and 12 (16%) refused after talking with recruiters. A total of 22 index children (plus seven siblings) were enrolled in the pilot study — an overall response rate of 31.4%% (22/70 eligible index children: the eight children transferred were not eligible). The response rates were similar at Lyndale (29%) and Whittier (26%), but there were more transfers at Lyndale (16% *vs.* 5%) and more refusals at Whittier (23% *vs.* 8%). There was a dramatic difference in response rates between English-speaking (15%) and non-English-speaking (67%) families, with English-speaking families more likely to transfer (14% *vs.* 0%) and to pose contact (41% *vs.* 17%) and follow-through problems (15% *vs.* 0%).

We obtained informed consent/assent and completed in-home baseline interviews for the 29 children (22 index+7 siblings). The mobility of these children/families is illustrated by the relatively short time they reported being at their present residence (median 8 months; average 15 months; range 2–63 months). Two children/families subsequently dropped out prior to the May 1999 monitoring period (one transferred to another school and one could not be contacted). Of the 27 children who participated in the SHIELD pilot study, all (100%) completed spirometry testing, wore a personal VOC monitor, kept a time–activity diary, and provided a urine sample. Twenty-four of 27 children (89%) agreed to provide a venipuncture blood sample (three refused at the time of the baseline interview; one was absent from school during the period of sample collection). A 33-ml blood sample (four tubes) was obtained from 18 children (67%), flow stoppage resulted in partial samples (approximately 20–30 ml) from two others (7%), and for three children (11%), no sample was obtained even though blood collection was attempted (in one case, the first attempt was unsuccessful and the child refused a second attempt; in another, there was a problem with collection tubes and the child refused a second attempt; one child's veins were too small).

SHIELD Study

Lessons learned in the pilot study were used to refine the recruitment protocol for SHIELD. The major changes implemented for the full study were designed primarily to increase response rates among English-speaking families (although we also modified the sampling protocol) and included: (1) conducting community outreach activities and attending school-sponsored meetings to encourage participation; (2) distributing a brochure, sometimes as a hanger on residential door handles, that described the study; and (3) using school employees as recruiters for English-speaking families. Recruitment for SHIELD began in November 1999 and continued through January 2000.

Table 5. Summary of recruitment results for the SHIELD pilot study from January to May 1999 (based on data for 78 randomly selected index children).

Primary language spoken by family	Reasons not enrolled				Enrolled	Total attempted to contact
	Transferred[a]	Contact problems[b]	Follow-through Problems[c]	Refused[d]		
Non-English	0	3	0	3	12[e]	18[f] (23%)
English	8	24	9	9	10[g]	60[h] (77%)
Total (English+non-English)	8 (10%)	27 (35%)	9 (12%)	12 (16%)	22 (27%)	78 (100%)

[a]Child transferred to another school and was therefore ineligible for the study.
[b]Contact problems include telephone busy or no answer after numerous attempts, disconnected or wrong number/address, and no response to letters, telephone calls, and household visits.
[c]Follow-through problems include no-shows for scheduled appointments, multiple call backs, or cancellations.
[d]Refused refers to those contacted by recruiters but who declined to participate because they were too busy, had surgery recently, did not want to provide blood sample, or for no stated reason.
[e]Three Cambodian, five Somali, four Hispanic — Spanish-speaking.
[f]Three Cambodian, nine Somali, six Hispanic — Spanish-speaking.
[g]Nine black, one white.
[h]Forty-four black, three white, three Native American, four Asian, two Hispanic — English-speaking; four unknown (no race information in school records).

A random sample of 311 index children, stratified by school, grade, and language, was selected from the second, third, fourth, and fifth grades at both schools. If the index child had siblings in grades 2–5, he/she was also asked to participate in SHIELD (51 siblings were enrolled). Eligible children and their guardians were offered incentives to participate and complete research-related tasks (see Table 4). A summary of recruitment results for SHIELD is given in Table 6. Of the 311 randomly selected children, 41 (13%) had transferred to another school by the time we tried to contact them, which made them ineligible for the study (therefore, these children are not included when calculating response rates). For the 270 index children eligible for SHIELD, 60 (19%) were not enrolled because we had problems contacting their guardians. We were able to contact the remaining 210 guardians, but 24 (8%) were not enrolled because we had problems scheduling or completing recruitment, and 33 (11%) declined to volunteer after talking with recruiters. The overall enrollment (response) rates were comparable at the Lyndale (46%) and Whittier (52%) schools, but the rate for non-English-speaking families/children was higher at Whittier (85.9% *vs.* 55.2% at Lyndale), while the rate for English-speaking families/children was higher at Lyndale (47.8% *vs.* 34.4% at Whittier).

A comparison of response (enrollment) rates between the pilot and SHIELD is presented in Table 7. Rates for non-English-speaking families went up slightly (from 66.7% to 71.0%), while rates for English-speaking families increased considerably (from 19.2% to 41.7%). The overall response (enrollment) rate increased from 31.4% in the pilot to 56.7% in SHIELD. These results indicate that the changes made to the SHIELD recruitment protocol, based on our experience in the pilot, were successful in increasing enrollment rates for English-speaking families.

Preliminary results from data collection activities are available from the first of two 5-week monitoring periods, which occurred during January–February 2000. Of the 153 index children participating in SHIELD, 139 (90.9%) volunteered at the time they were enrolled to later provide blood samples, while the other 14 (9.1%) declined but agreed to complete most other monitoring protocols. One hundred twenty-three (88.5%) of the 139 showed up at the clinic on schedule and a 33-ml sample was obtained for 106 (76.3%) while partial samples (<33 ml) were obtained for another 11 (7.9%). Blood draws were attempted on four (2.9%) but no sample was obtained due to technical difficulties, and two (1.4%) did not give their assent for the phlebotomist to draw blood. No blood draws were attempted on 16 (11.5%) of the 139 children because: they moved (seven); did not show up for scheduled monitoring appointments and could not be contacted (five); refused prior to coming to the clinic (three); or were unavailable on scheduled blood-draw days (one). Of the 51 siblings enrolled in SHIELD, 49 had previously agreed to provide blood samples. Complete 33 ml blood samples were obtained for 39 (79.6%) and partial samples for two (4.1%). No blood collection was attempted for eight children (16.3%) because three had moved since enrolling in SHIELD and five refused prior to coming to the clinic.

The 153 index children and their 51 siblings were also asked to provide urine samples. School nurses attempted to collect urine samples from 133 index children (86.9%) and were successful in obtaining at least 10 ml in all cases. No attempt was made to collect samples from 20 index children (13.1%) because seven had moved, five did not show up for scheduled appointments, three refused prior to coming to the clinic, and five were unavailable on scheduled sampling days. School nurses tried to collect urine samples from 44 siblings (86.3%) and successfully obtained at least 10 ml

Table 6. Summary of recruitment results for the SHIELD study from November 1999 to January 2000 (based on data for 311 randomly selected index children).

Primary language spoken by family	Reasons not enrolled				Enrolled	Total attempted to contact
	Transferred[a]	Contact problems[b]	Follow-through Problems[c]	Refused[d]		
Non-English	10	25	4	11	98[e]	148[f] (48%)
English	31	35	20	22	55[g]	163[h] (52%)
Total (English+non-English)	41 (13%)	60 (19%)	24 (8%)	33 (11%)	153 (49%)	311 (100%)

[a]Child transferred to another school and was therefore ineligible for the study.
[b]Contact problems include telephone busy or no answer after numerous attempts, disconnected or wrong number/address, and no response to letters, telephone calls, and visits.
[c]Follow-through problems include no-shows for scheduled appointments, multiple call backs, and cancellations.
[d]Refused includes those who refused by sending back postcards and those who declined recruiters because they were too busy, had recent surgery, did not want to provide blood sample, or for no stated reason.
[e]Eight Cambodian, 40 Somali, 46 Hispanic — Spanish-speaking; 4 Laotian.
[f]Ten Cambodian, 62 Somali, 62 Hispanic — Spanish-speaking; 12 Laotian, 1 Amharic, 1 Yoruba.
[g]Thirty-nine black, 11 white, 3 Native American, 1 Hispanic — English-speaking.
[h]One hundred thirty-two black, 17 white, 10 Native American, 3 Hispanic — English-speaking.

Table 7. Comparison of enrollment (response) rate for the pilot and SHIELD studies.

Primary language spoken by family	Enrollment (response) rate[a]	
	Pilot study (May 1999) $n=22$ index children enrolled[b]	SHIELD (November 1999–January 2000) $n=153$ index children enrolled[c]
Non-English	66.7% (12/18)	71.0% (98/138)
English	19.2% (10/52)	41.7% (55/132)
Total (English+non-English)	31.4% (22/70)	56.7% (153/270)

[a]Enrollment rate=number of index children actually enrolled divided by the total number eligible (i.e., not including transfers) times 100.
[b]In addition to the 22 index (randomly selected) children enrolled, seven siblings were also included in the pilot study.
[c]In addition to the 153 index (randomly selected) children enrolled, 51 siblings were also included in SHIELD (16 Hispanic, 15 Somali, 9 black, 5 white, 4 Cambodian, 1 Laotian, 1 Native American).

for 43 (84.3%). No samples were attempted for seven siblings (13.7%) because two had moved and five refused prior to coming to the clinic.

All of the 153 index children volunteered to wear small passive VOC dosimeters, and 135 (88.2%) were available to start the first 48-h monitoring period (18 were unavailable because they had moved, we could not schedule appointments, or they had changed their mind). Dosimeters were retrieved from 128 children (83.7%) (four were lost, one was left at school, one was returned to the school nurse, and one child dropped out of the study). In addition, three of the returned dosimeters were invalid because they either had not been worn by the child or had been taken off prior to the end of the 48-h monitoring period. Of the remaining 125 (81.7%), the field team raised validity questions about 16 (10.5%) because there were obvious signs of tampering or damage, foreign material was on the badge, or there was greater than 48-h exposure. Overall, acceptable personal 48-h VOC samples were obtained for a total of 109 (71.2%) out of a target of 153 children.

Discussion

The SHIELD study focused on recruiting and monitoring children from low-income minority families living in urban neighborhoods. Families in the study population were highly mobile, spoke a diversity of languages, frequently did not have a telephone, suffered economic hardships, and had a spectrum of non-traditional lifestyles and living arrangements. Even with assistance from the MPS, we still had difficulty recruiting English-speaking families, the majority of which were African–Americans. It is unlikely that traditional contact methods (random digit dialing, mailings based on commercially available address lists) would have been effective for identifying, let alone recruiting, many of the families with grade-eligible children. For example, in a 3–4-month period, 10% of the 78 randomly selected families in the pilot study transferred their children to another school, an additional 18% changed addresses but their children did not transfer, another 12% got new telephone numbers, and 6% had telephone numbers disconnected. Updated information from the schools allowed us to contact some, but not all, of these families.

Recruitment results from SHIELD provide both good news and bad. The good news is that a relatively high response rate (71.0%) was obtained for non-English-speaking families, many of whom were recent immigrants. Bilingual education assistants at Lyndale and Whittier were hired as recruiters to contact selected children/families and as translators to translate consent/assent forms and recruitment letters into Spanish, Cambodian, or Somali, as appropriate. They proved to be not only proficient but also essential. Because they knew and were known by members of their respective ethnic/racial communities, the bilingual education assistants were highly effective recruiters of non-English-speaking families.

The bad news is that despite intensive effort, the response rate for English-speaking families (primarily African–Americans) was only 41.7% (although this is a substantial increase from 19.2% in the pilot). This population presented recruitment problems across the board: they transferred their children more often; were harder to contact; posed more frequent follow-through challenges; and were more likely to refuse requests to participate. Our findings suggest that without investing substantially more time and resources, there is little likelihood of improving this response rate significantly. The simple expedient of increasing incentives is probably not a realistic option because of IRB concerns about possible fiscal coercion, and contacting parents/guardians directly through their children (e.g., accompanying the child home after school) raises confidentiality and privacy issues. One option might be to continue working with these neighborhoods and schools over a period of several years, more fully integrating SHIELD into the fabric of the community while at the same time gradually earning residents' trust. Even this approach, however, will not address the problem of the relatively high

proportion of families constantly moving into and out of these neighborhoods.

Low response rates among English-speaking families (primarily African–Americans) selected for SHIELD raise concern about potential non-response bias. Consequently, it is important to assess whether there are crucial differences between responders and non-responders (and what they are). We are fortunate in this regard because through our collaboration with the MPS, we have access to demographic information on all the children in each school, as well as standardized test scores and measures of academic performance. In addition, peak flow measurements are available for all fourth and fifth graders as part of an in-class project associated with SHIELD.

Obtaining blood and urine samples from elementary school children is always a challenge. In the pilot and SHIELD studies, successful collection of blood samples depended directly on the ability, personality, and skill of the phlebotomist. It is essential that this person be a trained pediatric phlebotomist with substantial experience in taking venipuncture samples from children, able to take the sample quickly and relatively painlessly, and good at reassuring children and putting them at ease by taking their mind off the procedure. Similarly, the key to collecting urine samples was the involvement of the school nurse who was well known to the children. Her familiarity to the students and friendly demeanor encouraged them to feel comfortable about providing a sample. She also supervised the sample collection process to ensure privacy for the children as well as validity of the samples.

The personal VOC badges were the most visible part of the study, at least from the children's perspective. They seemed to enjoy wearing the badges and, in most cases, did a good job of adhering to the monitoring protocol, thereby contributing to the overall completeness and validity of the data. At the beginning of the 48-h monitoring period, field technicians uncapped the badge and affixed it to an article of clothing worn by the child (in the breathing zone). Overnight, while the child was sleeping, the badge was placed near his/her head and then re-affixed to the clothing in the morning. The child reported to the school nurse before class each monitoring day and she recorded whether the badge was being worn properly and gave him/her a decorated pencil. Badges were retrieved and capped by field technicians at the end of the 48-h monitoring period. Results indicate that with proper care, it is practicable to obtain personal VOC measurements from elementary school children.

In the SHIELD study, as in most research projects attempting to collect environmental exposure/effects data for children, we encountered a myriad of administrative challenges, including the need to: obtain approval from multiple IRBs; get informed consent/assent; decide on financial and other incentives; acquire liability insurance; gain neighborhood involvement and support; ensure that individual privacy is protected during data analysis and interpretation; and communicate results to participants and other interested parties in a manner that is accurate, timely, and useful. Although these issues were eventually resolved satisfactorily, they necessitated a substantial investment of time and effort by the investigators. Ultimately, the effectiveness and efficiency of probability-based studies to assess children's environmental exposures/effects, especially for economically disadvantaged families and people of color, depend on researchers' early identification and resolution of these kinds of administrative issues.

Conclusions

Knowledge gained from SHIELD provides insight into the effectiveness of a school-based design for recruiting and monitoring children from economically disadvantaged neighborhoods. Our experience suggests that this approach offers a practical and affordable way to address many of the inherent obstacles that often hinder environmental health research in this population. The primary advantages of a school-based design are numerous: (1) the process of identifying households with age-eligible children is direct, simple, and relatively inexpensive; (2) contact information (i.e., names, telephone numbers, addresses) and socio-demographic information (e.g., race/ethnicity of child, language spoken at home) is readily available, provided appropriate safeguards are in place to protect privacy; (3) the involvement of school personnel (e.g., recruitment letter from the principals, use of bilingual education assistants as recruiters) lends credibility to the study and increases the likelihood that children/families will volunteer to participate; (4) information available from the schools (e.g., race/ethnicity of child, language spoken at home, academic performance, standardized test scores) makes it easier to assess differences in responders and non-responders; and (5) the in-school collection of biological samples (i.e., blood, urine) and testing of lung function (i.e., spirometry, peak flow) are a convenient and effective way to monitor children's environmental health. The key to successful implementation is developing close working relationships, in effect a partnership, with school personnel and residents of the local community, ensuring that all partners are kept informed and meaningfully involved.

Notwithstanding these advantages, response rates for English-speaking, predominantly African–American, families were not as high as we had hoped. Although the school-based approach allowed us to identify all eligible children/families, obtain the best address information available, and involve school personnel in recruitment, the overall response (enrollment) rate for SHIELD was still only 56.7% (71.0% non-English-speaking families and

41.7% English-speaking families). These findings highlight the continuing need to improve our understanding of factors (e.g., cultural, economic, psychological, social) that encourage or discourage participation among this population, with special emphasis on identifying cost-effective methods for study recruitment.

Once enrolled, however, the vast majority of SHIELD children/families participated fully in this relatively burdensome study, doing their best to comply with the sometimes demanding study protocols and willingly providing blood and urine samples. These results suggest that despite certain obstacles, it is feasible to make probability-based assessments of children's environmental exposures and related health effects in economically disadvantaged neighborhoods.

Acknowledgments

This research was funded by the U.S. Environmental Protection Agency (grant no. R825813-01-0, "School-Based Study of Complex Environmental Exposures in Children" and grant no. R826789-01-0, "Health Effects of Hazardous Air Pollutants Among Inner-Urban Children") and the Legislative Commission on Minnesota Resources (grant no. subd. 12, B01, "Measuring Children's Exposures to Environmental Health Hazards"). We are especially grateful to Ken Meyer, David Heistad, Sara Mullett, and others at the MPS for their help in making this study possible. The cooperation we received from the principals (Sue Poston, Dick Shultz, and Ossie Brooks-James), teachers, nurses, custodians, and students at the Lyndale and Whittier schools was exceptional and deeply appreciated. We also thank Katy Boone, Clean Air Group, for her help with the project. We gratefully acknowledge the analytical work done by colleagues at several laboratories: Larry Needham and his colleagues at the National Center for Environmental Health, CDC; Tom Stock and Maria Morandi at the University of Texas, Houston Health Science Center, School of Public Health; Steve Hecht, Sharon Murphy, and Steve Carmella at the University of Minnesota Cancer Center; and Malcolm Blumenthal and Duaine Jackola at the University of Minnesota Medical School.

References

Brody D.B., Pirkle J.L., Kramer R.A., Flegal K.M., Matte T.D., Gunther E.W., and Paschal D.C. Blood levels in the U.S. population: phase 1 of the Third National Health and Nutrition Examination Survey (NHANES III, 1988–1991). *J Am Med Assoc* 1994: 272: 277–283.

Chuang J.C., Callahan P.J., Lyu C.W., and Wilson N.K. Polycyclic aromatic hydrocarbon exposures of children in low-income families. *J Expos Anal Environ Epidemiol* 1999: 9 (2): 85–98.

Dearry A.D. and Collman G.W. (Eds.). Children's environmental health and disease research. *Environ Health Perspect* 1999: 107 (suppl 3): 391–460.

Dearry A.D., Collman G.W., Saint C., Fields N., and Redd S. Building a network of research in children's environmental health. *Environ Health Perspect* 1999: 107 (suppl 3): 391–392.

Eggleston P.A., Buckley T.J., Breysse P.N., Wills-Karp M., Kleesberger S.R., and Jaakkola J.J.K. The environment and asthma in U.S. inner cities. *Environ Health Perspect* 1999: 107 (suppl 3): 439–449.

Environmental Health Perspectives (EHP). *Children's Health Issue* 1999: 107 (6): A277–A327, 423–510.

Fischbein A. Occupational and environmental lead exposure. In: Rom W.N. (Ed.), Environmental and Occupational Medicine, 2nd edn. Little, Brown, and Company, Boston, MA, 1992, pp. 735–758.

Guzelian P.S., Henry C.J., and Olin S.S. (Eds.). Similarities and Differences Between Children and Adults. ILSI Press, Washington, DC, 1992.

Institute of Medicine (IOM). Toward Environmental Justice: Research, Education, and Health Policy Needs. National Academy Press, Washington, DC, 1999.

Landrigan P.J., Claudio L., Markowitz S.B., Berkowitz G.S., Brenner B.L., Romero H., Wetmur J.G., Matte T.D., Gore A.C., Godbold J.H., and Wolff M.S. Pesticides and inner-city children: exposures, risks, and prevention. *Environ Health Perspect* 1999: 107 (suppl 3): 431–437.

Linn W.S., Shamoo D.A., Anderson K.R., Peng R., Avol E.L., Hachney J.D., and Gong H. Short-term air pollution exposures and responses in Los Angeles area school children. *J Expos Anal Environ Epidemiol* 1996: 6 (4): 449–472.

National Research Council (NRC). Environmental Tobacco Smoke: Measuring Exposures and Assessing Health Effects. National Academy Press, Washington, DC, 1986.

National Research Council (NRC). Pesticides in the Diets of Infants and Children. National Academy Press, Washington, DC, 1993a.

National Research Council (NRC). Measuring Lead Exposure in Infants, Children, and Other Sensitive Populations. National Academy Press, Washington, DC, 1993b.

Rylander R. and Etzel R. (Eds.). Indoor Mold and Children's Health. *Environ Health Perspect* 1999: 107 (suppl 3): 463–517.

Samet J.M., Cain W.S., and Leaderer B.P. Environmental tobacco smoke. In: Samet J.M. and Spengler J.D. (Eds.), Indoor Air Pollution: A Health Perspective. The Johns Hopkins University Press, Baltimore, MD, 1991, pp. 131–169.

Schmidt C.W. Poisoning your mind. *Environ Health Perspect* 1999: 107 (6): A303–A307.

Senturia Y.D., Mortimer K.M., Baker D., Gergen P., Mitchell H., Joseph C., and Wedner H.J. Successful techniques for retention of study participants in an inner-city population. *Controlled Clin Trials* 1998: 19: 544–554.

Sexton K. Sociodemographic aspects of human susceptibility to toxic chemicals: do class and race matter for realistic risk assessment? *Environ Toxicol Pharmacol* 1997: 4: 261–269.

Sexton K. (Ed.). Environmental justice. *J Expos Anal Environ Epidemiol* 1999: 9 (1): 3–78.

Weaver V.M., et al. Environmental tobacco smoke exposure in inner city children. *Cancer Epidemiol Biomarkers Prev* 1996a: 5: 135–137.

Weaver V.M., et al. Benzene exposure assessment by urinary *trans,trans*-muconic acid in urban children with elevated blood lead levels. *Environ Health Perspect* 1996b: 104: 318–323.