Do Waste Incinerators Induce Adverse Respiratory Effects? An Air Quality and Epidemiological Study of Six Communities

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The purpose of the study presented here was to simultaneously measure air quality and respiratory function and symptoms in populations living in the neighborhood of waste incinerators and to estimate the contribution of incinerator emissions to the particulate air mass in these neighborhoods. We studied the residents of three communities having, respectively, a biomedical and a municipal incinerator, and a liquid hazardous waste-burning industrial furnace. We compared results with three matched-comparison communities. We did not detect differences in concentrations of particulate matter among any of the three pairs of study communities. Average fine particulate (PM$_{2.5}$) concentrations measured for 35 days varied across study communities from 16 to 32 µg/m^3. Within the same community, daily concentrations of fine particulates varied by as much as eightfold, from 10 to 80 µg/m^3, and were nearly identical within each pair of communities. Direct measurements of air quality and estimates based on a chemical mass balance receptor model showed that incinerator emissions did not have a major or even a modest impact on routinely monitored air pollutants. A one-time baseline descriptive survey ($n = 6963$) did not reveal consistent community differences in the prevalence of chronic or acute respiratory symptoms between incinerator and comparison communities, nor did we see a difference in baseline lung function tests or in the average peak expiratory flow rate measured over a period of 35 days. Based on this analysis of the first year of our study, we conclude that we have no evidence to reject the null hypothesis of no acute or chronic respiratory effects associated with residence in any of the three incinerator communities. *Key words*: air pollution, particulate matter, respiratory hypersensitivity, respiratory function tests, respiratory tract diseases, toxic waste, waste incinerators. *Environ Health Perspect* 103:714–724 (1995)

Incineration of municipal, biomedical, and hazardous wastes is a widely used waste management option for reducing and destroying substances that pose a risk to human health and safety. However, emissions of trace quantities of metals, chlorinated dioxins and furans, hydrogen chloride, and other emission products of incineration have raised concern about the health and environmental consequences of incineration (1–3). Many of these concerns are based on the potential for long-term exposure via multiple routes including air, water, soil, and locally grown vegetables. For the most part, risk assessments of incinerators have been derived from toxicological data extrapolated from relatively high-dose animal or occupational exposures to the much lower concentrations expected to occur in communities surrounding waste incinerators (1,4). To our knowledge, there are no published studies based on simultaneous direct measurements of exposures and health effects in these communities. In this study we investigated the potential association between population exposure to incinerator emissions and nonmalignant respiratory effects by the inhalation route; we did not address exposures via ingestion or other indirect routes. Although the impact of well-operated incinerators on air quality is projected to be small, incinerators may emit particles and gases that are not routinely monitored but are nevertheless irritating to the respiratory system. By comparing respiratory symptoms and lung function in incinerator and comparison communities, we can evaluate whether unmeasured emission products of incinerator combustion may produce an acute respiratory effect that is not anticipated with measured levels of pollutants. Thus, the purpose of this study was twofold: to measure longitudinally and directly air quality and respiratory function and symptoms in populations living in the neighborhoods of incinerators and to estimate the contribution of incinerator emissions to the particulate air mass in these neighborhoods. Three types of incinerators were studied: a biomedical incinerator, a municipal incinerator, and a liquid hazardous waste-burning industrial furnace. In this article we present an overview of the study and our findings from the first of 3 years of data collection.

Methods

An overview of the study design is shown in Figure 1. Each of the three incinerator communities, located in southwestern North Carolina, was matched with a comparison community that is generally upwind of the incinerator. These communities were chosen for study because they were located in the most populous area of North Carolina and because each incinerator community had one of the major types of waste incinerators in common use. A one-time baseline telephone survey was performed to characterize social, demographic, and respiratory risk factors in the communities, and a subsample of the population was selected for longitudinal daily evaluation of exposures, respiratory function, and symptoms for 1 month during each of three successive years, 1992–1994. After subjects included in the subsample performed baseline spirometry at the beginning of the month, they recorded peak expiratory flow rates and respiratory symptoms twice daily in a diary for 35 successive days during each of the three years; concurrently, air quality, wind direction, and wind speed were monitored daily in each community during the study months. A second subsample of subjects performed spirometry and provided a sample of nasal washings once each year.

Site Selection and Assessment of Community Health Effects

Incinerator communities were defined as all households within a 2 × 5-km ellipse centered on the incinerators and oriented along an axis parallel with the long-term average wind direction. We targeted 400–500 households for inclusion in the
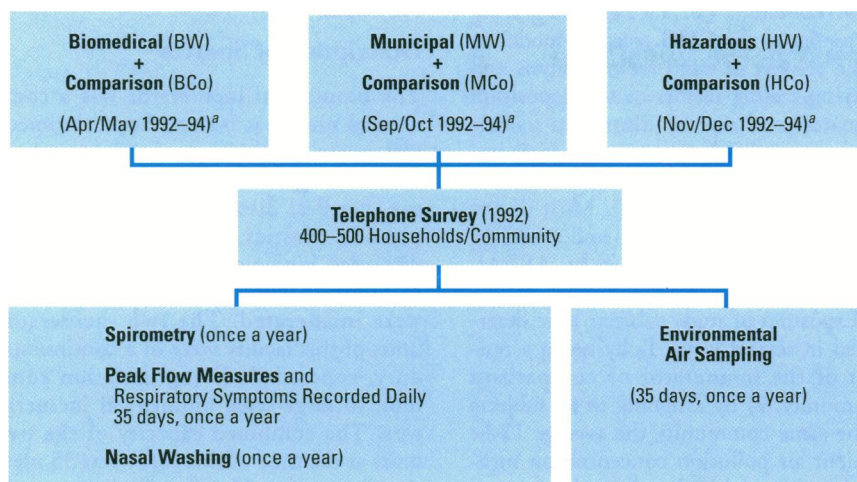
Figure 1. Design for an epidemiological study of six communities. [a]Period during which peak flow and respiratory symptoms were recorded daily.

baseline descriptive survey, in part because this was the total number of identifiable households in the biomedical incinerator and industrial furnace communities. Comparison communities were chosen on the basis of similar socioeconomic characteristics and population densities as judged by external appearances of the neighborhoods and were selected to be upwind and no closer than 5 km from the incinerator. In this article we identify the study communities by letters: BWI and BCo for the biomedical waste incinerator and comparison communities, respectively, MWI and MCo for the municipal waste incinerator and comparison communities, and HWI and HCo for the liquid hazardous waste-burning industrial furnace and comparison communities.

Each household in the study communities was initially contacted by letter to prepare them for administration of a 20–25-min telephone survey. Questions were drawn from the respiratory disease questionnaire of the American Thoracic Society (5), with additional questions on household characteristics and demographics, including family size and composition, chemical exposures at work and home, type of heating and cooking appliances, and perceived quality of the outdoor air in the immediate neighborhood. Information about air quality, demographics, and household characteristics was only asked from one adult resident who was home at the time of the telephone call. Questions on respiratory symptoms, smoking and other exposures were asked of all family members, and were answered by each adult family member present at the time of the call, and by one adult for those family members not present (surrogate respondents) and for children less than 18 years of age. Subsequently, 20% of homes that provided surrogate responses for adults were telephoned again, and symptom questions were asked of those adults not originally present.

Based on responses to the telephone survey, we attempted to recruit approximately 80 persons from each community for the longitudinal component of the study. Of the 80, 40 subjects were to be selected because they responded positively to one of the questions regarding wheezing or other asthmalike symptoms during the past 12 months. The other 40 were selected because they gave negative responses to all questions regarding chronic respiratory and acute respiratory allergic-type symptoms. The former group of 40 subjects are termed "sensitives" and the latter "normals." All subjects were nonsmokers and were not regularly exposed to cigarette smoke in their home. We included children 8 years of age and older and adults up to 80 years of age among both groups, except for the first year of the study in the BWI and BCo communities when only adults were selected for the subsample of normals. We recruited subjects for the subsample until we reached the target figure of approximately 80 in each of the six communities.

We attempted to recruit an additional 25 subjects from each community for participation in a once yearly collection of nasal lavage samples. These subjects also performed spirometric lung function tests at the same visit. Spirometric tests of lung function and nasal lavage samples were obtained in each pair of communities during the month preceding the 35-day period of diary recording and air quality sampling. Nasal lavage samples were obtained by instilling 5 mL of physiological saline into each nostril, retaining the fluid for 10 sec, and discharging the fluid into a collection cup. Washings were centrifuged and divided into cells and supernatant. The super-

natant was stored at -80°C, and cells were treated with a mucolytic reagent and resuspended in 50% ethanol for transport at 4°C. Cell counts were performed with a hemocytometer, and viability was assessed by trypan blue exclusion. Cells were cytocentrifuged onto glass slides and stained with a modified Wright's stain (DiffQuik, Fisher Scientific, Pittsburgh, Pennsylvania). The percentage of epithelial cells, polymorphonuclear cells, and eosinophils was determined by counting 300 cells on each slide (6). Lavage supernatants were assayed for interleukin-8 using a kit purchased from R&D Systems (Minneapolis, Minnesota), and for histamine using a kit purchased from Pharmacia, AMAC (Westbrook, Massachusetts). Albumin content in the nasal lavage fluid was quantified by ELISA, using antibody and antigen purchased from CalBiochem (San Diego, California).

Subjects who participated in the 35-day diary study attended a neighborhood clinic in the month before the diary study, where they viewed a videotape demonstrating the test procedures they were being asked to perform and signed a consent form. They were again asked questions regarding the occurrence of wheezing or allergic symptoms and about their usual time and activity pattern between indoor and outdoor environments. After measuring height and weight, lung function was measured with a 10-L rolling dry-seal spirometer (S&M Instrument Company, Doylestown, Pennsylvania). Subjects performed a mininum of three forced expiratory maneuvers until three satisfactory spirograms were obtained. Subjects were then instructed on the method to perform the peak expiratory flow maneuver on a mini-Wright Peak Flow Meter (Clement Clark, Inc., Columbus, Ohio) and to keep a daily diary of these results. Subsequently, these subjects performed three peak expiratory flow maneuvers twice daily, in the morning on awakening and in the evening before retiring. In addition, they recorded daily symptoms of cough, cold, and wheezing and noted whether any allergy or asthma medications or inhalers were used. They also recorded for each day the number of hours spent outdoors in their neighborhood, whether they spent 4 hr outside the neighborhood, whether they were in the same room with a person smoking a cigarette, whether a vacuum cleaner was used in the home, and whether there was any exposure to airborne irritants at work that day. Data for the longitudinal diary study were obtained in May in BWI and BCo, in October in MCI and MCo, and from mid-November to mid-December in HWI and HCo in each of the three study years.

Exposure Assessment

During the months of the diary study, an air monitoring station was placed in each pair of study communities. The monitoring station was equipped with a versatile air pollution sampler (VAPS) system to collect ambient samples (7). Two side-by-side VAPS systems were operated serially to collect air samples in 12-hour periods, one beginning at 0630 hr (daytime sample) and the other at 1830 hr (nighttime sample). The VAPS assembly (University Research Glassware, Carrboro, North Carolina), a modification of a dichotomous air sampler, collects fine particulate matter <2.5 μm in diameter on a Teflon filter, and coarse particulate matter of 2.5–10 μm on a Nucleopore filter. A virtual impactor system permits size separation of the particulate matter. We calculated PM_{10} concentrations by summing values from the coarse and fine filters. An annular denuder coated with sodium carbonate was installed immediately before the Teflon filter in the fine-fraction sampling train for diffusion capture of acid gases (HCl, HONO, HNO_3, and SO_2). Teflon and Nucleopore filters were analyzed for elemental composition by X-ray fluorescence (8) and denuder samples were analyzed for acid gases by ion chromatography (9). Concurrent wind speed and direction measurements were obtained at each monitoring site by an R.M. Young Company (Traverse City, Michigan) wind monitor, 10 m in height. From the hourly meteorological measurements, 12-hr wind speed and direction were calculated by wind vector averaging (10) to correspond with the 12-hr ambient air measurements. The VAPS system was serviced daily by the Mecklenburg County Department of Environmental Protection. Samples from the VAPS were analyzed by the U.S. Environmental Protection Agency's Atmospheric Research and Exposure Assessment Laboratory (AREAL) in Research Triangle Park, North Carolina. Calculations of 12-hr wind speed and direction and atmospheric characterization and modeling were also performed by AREAL personnel.

Ambient air and wind speed and direction data were combined with quantitative information on emissions from incinerators and used as inputs to an atmospheric receptor model. This procedure, known as chemical mass balance (CMB) receptor modeling, is used to estimate the impact of the incinerator at each monitoring site (11,12). Statistical approaches were used, incorporating wind sector analyses, to qualitatively assess the incinerators' contribution to the monitoring site, using certain marker pollutants measured by the VAPS which are commonly associated with incin-erator emissions (11,13,14). Integrating the results of the CMB receptor modeling in the context of wind sector analysis and applying scaling factors to the deposition estimates produced by dispersion modeling, it was possible to assess the incinerator's impact at the residential location of each study participant (15). Most of the atmospheric characterization and modeling assessments were performed by AREAL personnel.

Exposures of study subjects were determined in several ways: 1) by being a resident of the incinerator or comparison community, 2) by assigning to all subjects in the same community the average 12-hr ambient air pollution concentration measured at the neighborhood monitoring station, and 3) by estimating individual exposures based on information about emissions from the incinerator; ambient air, wind speed and wind direction data obtained at the neighborhood monitoring site; and location of subjects' households relative to the incinerator. For this report, we estimated exposures of subjects only based on the first and second methods. Individual exposure estimates have been difficult and time-consuming to derive, are still in an early stage of development for this study, and thus are not incorporated in our analyses.

Statistical Methods

We used logistic regression analysis to assess differences in symptom prevalence between community pairs. For all three community pairs, the logistic model included as potential confounding factors sex, age, race, education, current smoking status, exposure to environmental tobacco smoke in the home, occupational exposure to chemicals, use of an unvented gas or kerosene heater, cooking with gas or kerosene, use of central air conditioning, and mold problems in the home. The exposure variable was the presence or absence of an incinerator in the neighborhood. A separate logistic model was constructed for each pair of communities. The exposure variable was forced into the model, and confounders were included if the covariate's Wald statistic was significant or if the parameter estimate for the exposure variable changed more than 10% when the covariate was removed. Results of lung function tests were expressed as percent of predicted for age, sex, and height. Differences in adjusted means for lung function and for nasal washings were evaluated by standard statistical tests for differences in mean values. Simple graphical plots of 12-hr air pollution concentrations were used to compare air quality differences in the paired communities.

Results

Description of Sources

The biomedical incinerator was a commercial unit that burned boxed biomedical waste-containing materials such as microbiological wastes, pathological tissue, needles, discarded instruments and utensils, plastics, paper, pigments, and discarded biologicals and chemicals used in laboratories. No radioactive wastes were incinerated. The two incinerator units of this facility were of a continuous-duty, controlled air configuration common to large-scale biomedical incinerators. The combined capacity of the two units at the time of this study was 35 metric tons per day. No air pollution controls were in use at this facility during the first year of the study.

The municipal incinerator was a publicly owned, continuously operating facility which primarily burned paper, plastics, and other household wastes; these were used as refuse-derived fuel for generating steam. This facility contained two incinerator units with a total capacity of 224 metric tons per day. Waste gases were passed through a 73-m stack equipped with an electrostatic precipitator.

The third facility was an industrial furnace which was permitted to burn liquid hazardous wastes in one of its four rotary kilns at a maximum rate of 1220 L/hr. The kilns were fed with raw slate to produce a lightweight aggregate used in construction materials. During the first year of this study, the operators of this facility were not burning liquid wastes but instead were using fuel oil or coal while they were in the process of obtaining upgraded air pollution control devices to comply with the 1990 Clean Air Act; the maximum permitted heat input to each kiln was 35 million BTU/hr. Liquid wastes were burned during the second and third year of the study.

The BWI/BCo pair is separated from each other by 5.2 km, 19 km north of a city of 396,000 population and has a mixed suburban and rural population density. The comparison community is located northwest of the incinerator. The MWI/MCo pair is 5.7 km apart, lies within or on the border of the city limits of the above-mentioned city, and is entirely urban in population density. The comparison community is located south of the incinerator. The MWI community contains a campus of the state university system. The HWI/HCo pair is 10 km apart, consists of small settlements or towns, is a rural setting, and is located approximately 40 km east of the same city. The comparison community lies west of the hazardous waste industrial furnace.

Air Quality and Meteorological Assessments

Daily concentrations of fine particulate air pollution <2.5 μm in diameter (PM$_{2.5}$) are shown for the three community pairs during the first year of the study, 1992, in Figure 2. There was little difference between the incinerator and comparison communities in daily PM$_{2.5}$ concentrations; the paired communities closely resembled one another in the day-to-day variation of this pollutant. Twelve-hour PM$_{2.5}$ concentrations did not exceed 80 μg/m^3. Table 1 presents 12-hr daytime and nighttime concentrations of PM$_{10}$, PM$_{2.5}$, particulate species, and gases averaged over 35 days in each of the six study communities. No consistent pattern of differences within community pairs was observed. In the BWI/BCo pair, PM$_{10}$, PM$_{2.5}$, and coarse (particles between 2.5 and 10 μm in diameter) and fine (particles <2.5 μm in diameter) sulfur particles were higher in the comparison community, whereas fine silicon and zinc particles were higher in the incinerator community. In the MCI/MCo pair, coarse and fine iron, coarse and fine silicon, and fine zinc were higher in the incinerator community, while coarse sulfur particles were higher in the comparison community. In the HWI/HCo pair, coarse and fine silicon were higher in the incinerator community, while PM$_{10}$, PM$_{2.5}$, and coarse sulfur particles were higher in the comparison community. Across the six communities, the average 35-day concentrations varied from 18 μg/m^3 to 37μg/m^3 for calculated PM$_{10}$ and from 16 μg/m^3 to 32 μg/m^3 for PM$_{2.5}$.

Wind sector analysis, incorporating meteorological data and ambient air concentrations, was used to identify the likely contribution of air emissions from the

incinerators to the total particle mass (12–14). Fine particulate zinc, lead, and HCl gas were assumed as markers of incinerator emissions (16–19). In general, these markers were found to be elevated when winds were coming from the direction of the incinerators, as shown in Figure 3.

With the exception of the MCo site, the highest concentration of zinc was observed on days when the monitoring station was downwind of the incinerator. Ambient concentrations of fine particulate zinc were consistently higher in the BWI and MWI communities than in their respective com-
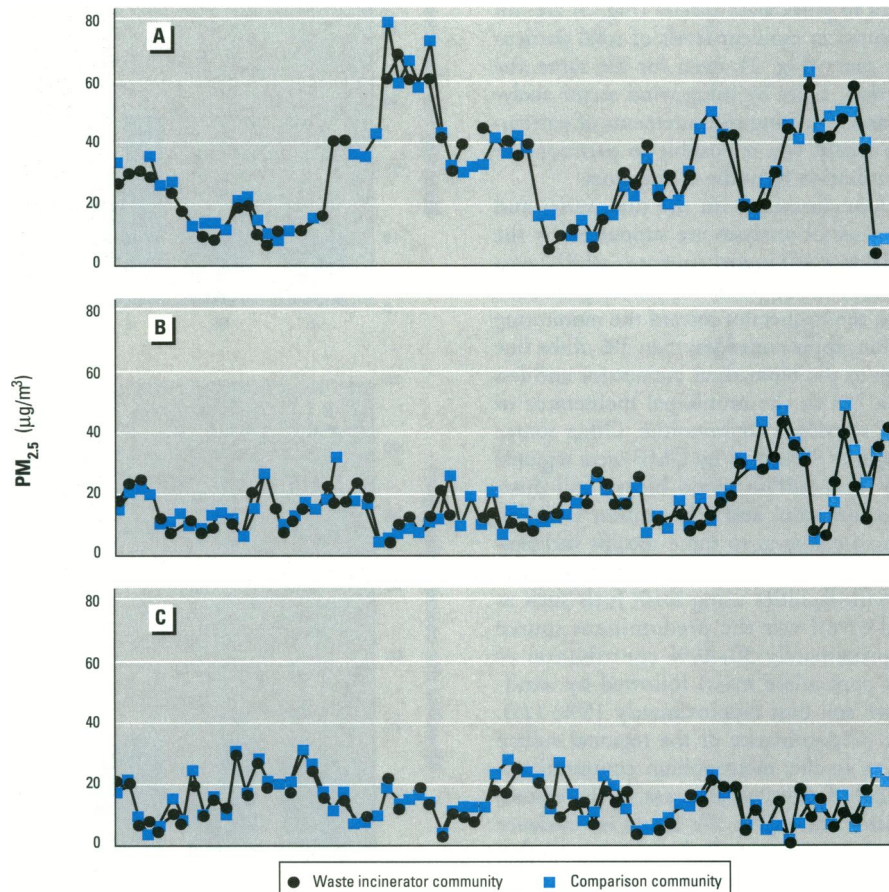

Figure 2. Paired-community fine particulate concentrations (PM$_{2.5}$), 12-hr samples. (A) Biomedical waste communities, 30 April–4 June 1992; (B) municipal waste communities, 21 September–29 October 1992; (C) hazardous waste communities, 9 November–17 December 1992.

Table 1. Twelve-hour concentrations of particulates and gases averaged over 35 days in each study community

Air quality component[a]	Nighttime concentrations (μg/m^3)						Daytime concentrations (μg/m^3)					
	BWI	BCo	MWI	MCo	HWI	HCo	BWI	BCo	MWI	MCo	HWI	HCo
Particulates												
PM$_{10}$	33	38	23	25	21	24	33	35	21	22	15	18
PM$_{2.5}$	29	33	19	22	19	20	29	30	18	18	13	15
Aluminum, C	0.30	0.32	0.34	0.21	0.18	0.16	0.30	0.27	0.20	0.20	0.14	0.16
Aluminum, F	15	0.23	0.12	0.12	0.11	0.14	0.16	0.18	0.11	0.12	0.16	0.10
Iron, C	0.11	0.10	0.16	0.11	0.08	0.08	0.08	0.09	0.13	0.12	0.05	0.07
Iron, F	0.09	0.08	0.16	0.08	0.07	0.11	0.07	0.06	0.09	0.07	0.06	0.10
Sulfur, C	0.09	0.24	0.08	0.18	0.05	0.07	0.09	0.23	0.04	0.13	0.03	0.07
Sulfur, F	2.4	2.8	1.6	1.6	1.3	1.3	2.6	2.8	1.6	1.6	1.2	1.2
Silicon, C	0.48	0.39	0.40	0.35	0.27	0.24	0.42	0.43	0.37	0.28	0.20	0.19
Silicon, F	0.17	0.16	0.14	0.10	0.10	0.08	0.17	0.14	0.13	0.11	0.11	0.08
Zinc, F	0.02	0.02	0.03	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.01	0.01
Gases												
SO$_2$	4.1	4.2	5.4	4.8	6.0	4.5	6.8	7.5	7.4	7.8	9.2	8.9
HCl	0.31	0.31	0.16	0.13	0.19	0.19	0.59	0.47	0.30	0.32	0.28	0.22
HNO$_2$	0.74	0.77	1.2	1.5	0.88	1.1	0.30	0.29	0.47	0.51	0.46	0.51
HNO$_3$	1.2	1.2	0.66	0.65	0.79	0.63	3.0	3.0	1.6	2.0	1.1	1.1

Abbreviations: WI, waste incinerator community; Co, comparison community; B, biomedical waste; M, municipal waste; H, hazardous waste.
[a]C, coarse fraction: particles between 2.5 and 10 μm in diameter; F, fine fraction: particles less than 2.5 μm in diameter.

parisons, but exceptions to this pattern were observed when the wind shifted to a different direction, i.e., from the west for the biomedical pair and from the north for the municipal pair of communities. The patterns for lead and chloride were similar to those for zinc.

It is noteworthy that community differences in particulate species (Fig. 3) are not reflected in ambient levels of total particulate mass (Fig. 2), even for the same size fraction. Only by using wind sector analyses and obtaining measurements of particulate species was it possible to partition the contribution from the incinerators.

Conclusions from the time series and wind sector analyses are supported by the CMB receptor model estimates, which, even on days when wind was blowing directly from the incinerator toward the monitoring station, apportioned less than 3% of the fine mass to the biomedical incinerator and less than 2% to the municipal incinerator in their respective communities. Other source categories identified by CMB were regional and local sulfate, wind-blown soil dust, transportation, and other minor emission sources common to those specific incinerator locations. Regional/local sulfate associated with facilities using fossil fuels such as coal or oil was the predominant source (approximately 30–40% contribution of fine particulate mass) followed by wind-blown soil dust (approximately 15%) (12). The predominance of the regional sulfate source in this metropolitan community is typical of most urban areas in the eastern United States (20). We found no evidence that the incinerators had a major or modest impact on concentrations of pollutants commonly measured, i.e., fine particulates and acid gases. The CMB receptor model was not applied to the HWI/HCo community pair because this facility was not using liquid waste as a fuel during the first year of our study.

Assessment of Health Effects

In total, 2592 households with 6963 individuals participated in the baseline descriptive survey administered by telephone. In nearly all communities, we completed interviews on the target number of 400–500 households; the exception was the HWI community, which was the smallest in population and yielded only 357 participating households. Among contacted households, participation rates by the community varied from 66 to 80%. Table 2 provides a profile of sociodemographic characteristics and of respiratory risk factors in the six communities. The educational level was higher in the MWI than in the MCo community, reflecting the fact that the MWI community contains one of the campuses of the state uni-
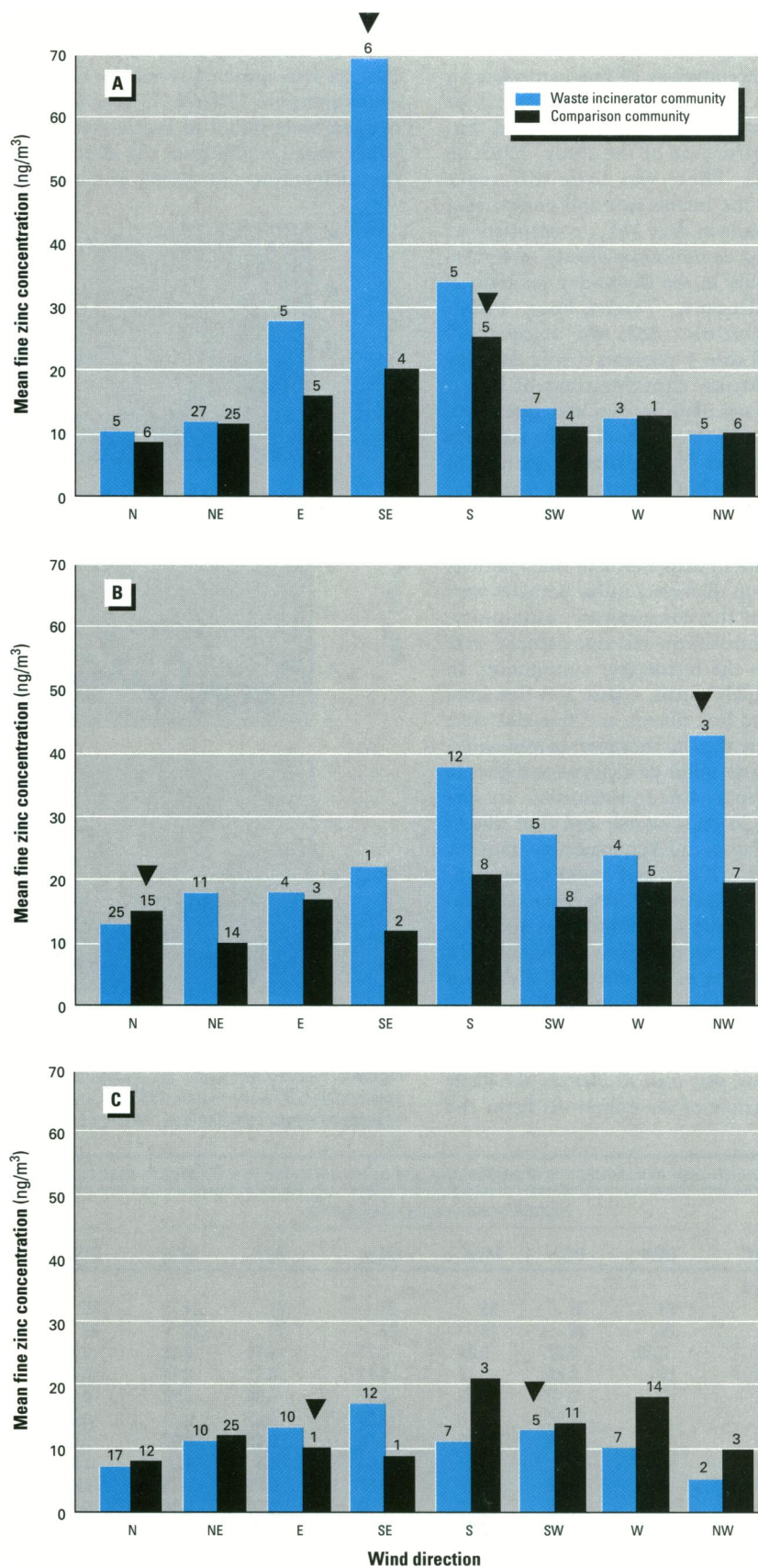

Figure 3. Fine-zinc concentrations by wind direction. Arrowheads indicate wind blowing from incinerator to monitoring site. Numbers above bars indicate number of observations. (A) Biomedical waste communities, 30 April–4 June 1992; (B) municipal waste communities, 21 September–29 October 1992; (C) hazardous waste communities, 9 November–17 December 1992.

versity system. Paired communities did not otherwise differ in sociodemographic characteristics. Table 1 also reveals a higher prevalence of respiratory disease risk factors in comparison communities, including the prevalence of current smokers, percentage of homes in which smoking occurred on most days, use of an unvented gas or kerosene heater, and frequency of mold problems in the home.

To assess differences in symptom prevalence between community pairs while controlling for differences in respiratory risk factors, a logistic regression analysis was performed to compare the odds of reporting a given respiratory condition in incinerator versus comparison communities. For all three pairs, the logistic model included sex, age, race, education, and the list of respiratory disease risk factors cited in the Methods section. Figure 4 shows the results of these analyses for a representative 10 of the 28 symptom questions included in the questionnaire. Most odds ratios are close to the null value of 1.0. For the BWI/BCo and MWI/MCo pairs, there is no consistent pattern of differences in chronic respiratory symptoms. The odds of having an acute respiratory symptom (runny nose, sore throat, cough) in the month preceding the questionnaire was significantly lower in the BWI than in its comparison community. However, in the HWI community, the odds of having doctor-diagnosed sinus trouble (as reported by respondents), a chronic cough, or three or more episodes of wheezing in the past year were significantly greater than in its

matched comparison. The odds for most of the other chronic and acute respiratory symptoms (not all of which are shown in Figure 4) also were slightly greater in the HWI community, with the exception of having at least one asthma attack in the past 12 months or a sore throat in the past month. However, on comparing the unadjusted prevalence of all respiratory symptoms in the HCo community with the other two comparison communities, we observed a pattern of lower prevalence of self-reported chronic and acute respiratory symptoms in the HCo population. This finding suggested the possibility that this community was more healthy than, and not typical of, other nonexposed communities that could have been studied, or was underreporting symptoms.

To evaluate the possibility of reporting bias, we considered the prevalence of reported ear infections during the past 12 months in children. We used this variable as a marker for reporting bias, because this symptom is not expected to be affected by community differences in air pollution concentrations, and if over or underreporting were occurring, we would expect this variable to reflect the bias. The prevalence of reported ear infection in children was nearly equal in the HWI (26%) and HCo (31%) communities, thereby arguing against underreporting in the latter. Since we had no direct means to evaluate whether the HCo community was more healthy than average, we combined the results of the three comparison communities and compared these with each of the

incinerator communities, adjusting for respiratory risk factors by the same logistic models as above. The results, shown in Figure 5, fail to show any pattern of excess chronic or acute respiratory symptoms in the HWI or in any of the other incinerator communities. We repeated the logistic regression analysis with the inclusion of the respondents' perception of the quality of the outdoor air of the neighborhood as potential confounding variables. Only those adult respondents who directly answered the questions, is the air in your neighborhood visibly polluted, smoky, or smelly, were included in this analysis. Persons who answered "very often" to these questions were coded as "1", and others were coded as "0". After adjusting for the potential confounding effect of these air-quality perception responses, comparisons of symptom prevalence between community pairs did not change the results.

Lung function data as assessed by spirometry were obtained from 100–144 subjects in each of the 6 communities during the first of the 3 study years. Here, we present results only for the first year. These data were obtained from volunteers in the 35-day diary and the nasal lavage components of the study. This subsample included 32–56 persons from each community selected because of questionnaire evidence of asthmalike symptoms during the past year, with the remainder being normals who had no reported chronic respiratory symptoms and were neither actively nor passively exposed to cigarette smoke in the home. Table 3 presents the results obtained by spirometry for forced expiratory volume in 1 sec (FEV_1) and peak expiratory flow rate (PEFR) among the six communities. Results for children and adolescents are given as percent of predicted for age, sex, and height (*21*) and for adults as percent of predicted for age, sex, height, and race (*22*). Among normals, mean FEV_1 and PEFR values are consistently higher in incinerator than in comparison communities. Among the sensitives, mean PEFR values were higher in the MWI and HWI communities than in their paired comparisons, whereas these values were slightly lower in the BWI than in the BCo community. FEV_1 results did not show a consistent difference between community pairs among the sensitive subgroup. Deviations from predicted were nearly the same between normals and sensitives within each community.

Figure 6 shows the results of the nasal lavage analysis from the first year of the study. Neither cell counts nor biochemical indices of inflammation (interleukin-8, albumin, and histamine concentrations in the supernatant of nasal fluid) suggested an

Table 2. Profile of sociodemographic characteristics and respiratory risk factors by community, spring 1992

	BWI	BCo	MWI	MCo	HWI	HCo
Total respondents	1185	1148	1414	1208	880	1046
Mean age (years)	32	33	34	36	41	39
Age range (years)	±20	±21	±20	±21	±23	±22
Race (%)						
Black	3	9	15	18	<1	9
White	95	89	79	79	99	91
Other	2	2	6	3	<1	<1
Education[a] (%)						
High school	35	44	24	49	74	68
Some college	28	29	25	30	16	20
Finished college or more	37	26	50	20	9	11
Unknown	0.1	0.9	0.4	0.7	1.2	0.7
Years of residence (%)						
1–2	23	26	20	13	5.1	9.0
3–6	41	25	37	31	12	15
7+	36	49	43	57	83	76
Respiratory risk factors (%)						
Current smokers[b]	16	17	14	23	15	21
Homes with smoker	18	22	20	31	24	31
Homes with gas stove	15	38	8	17	6	6
Homes with unvented heater	7	12	6	7	13	21
Homes with mold problem	7	9	10	14	7	9

Abbreviations: WI, waste incinerator community; Co, comparison community; B, biomedical waste; M, municipal waste; H, hazardous waste.
[a]For respondents >17 years old.
[b]For respondents >15 years old.

inflammatory effect of residence in the incinerator versus comparison communities.

Out of the 35 successive days of diary recording of peak flows, the average number of days with both morning and evening records from the 516 participants ranged from 29.1 ± 0.8 to 33.1 ± 0.6 over the 6 communities during the first year. Table 4 provides average values for the twice-daily peak flow measurements obtained from subjects during that year; these results are expressed as the percent of predicted for age, height, and sex. As expected, subjects in all communities show a small increase in mean peak flow from morning to evening. The mean standardized change in peak flow over the day was slightly larger in incinerator than in com-
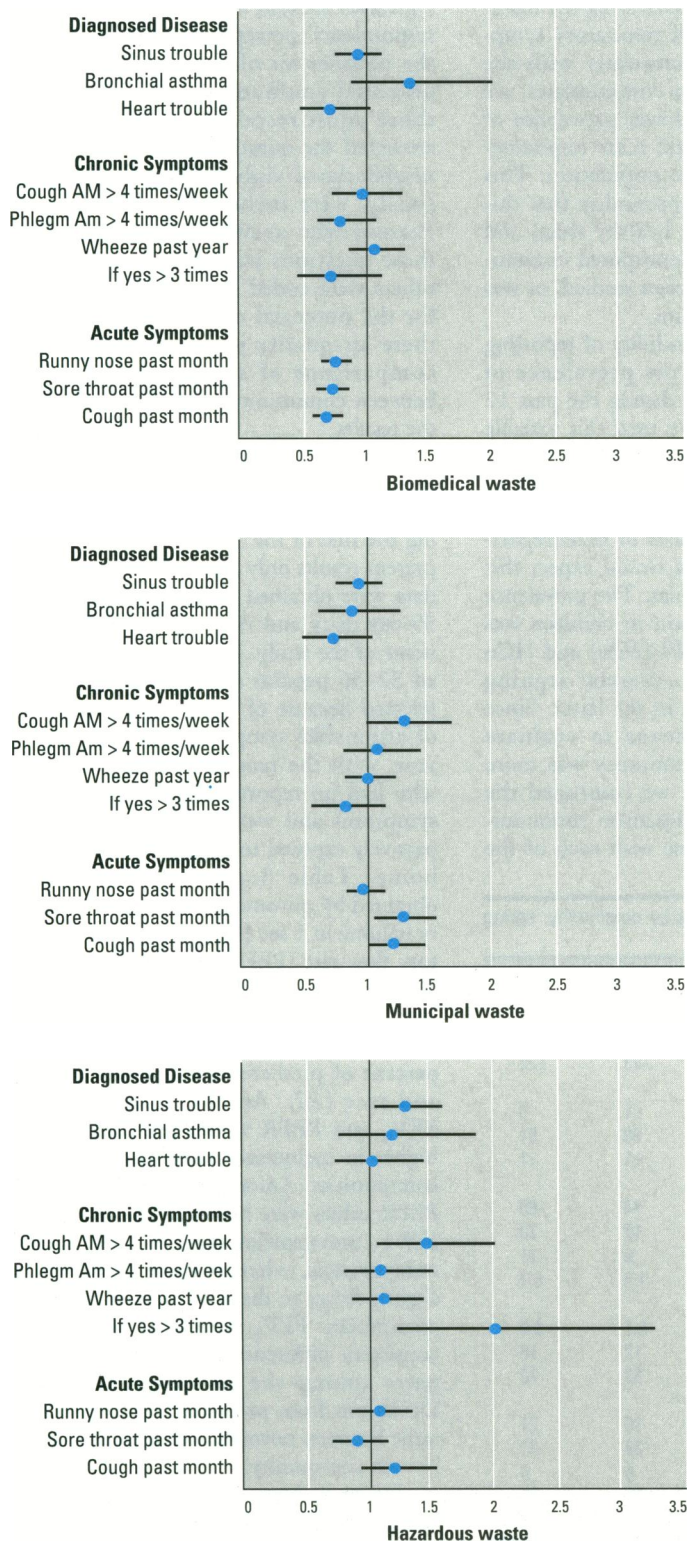
Figure 4. Adjusted odds ratios and 95% confidence intervals for respiratory diseases and symptoms in waste incinerator versus comparison communities, spring 1992.
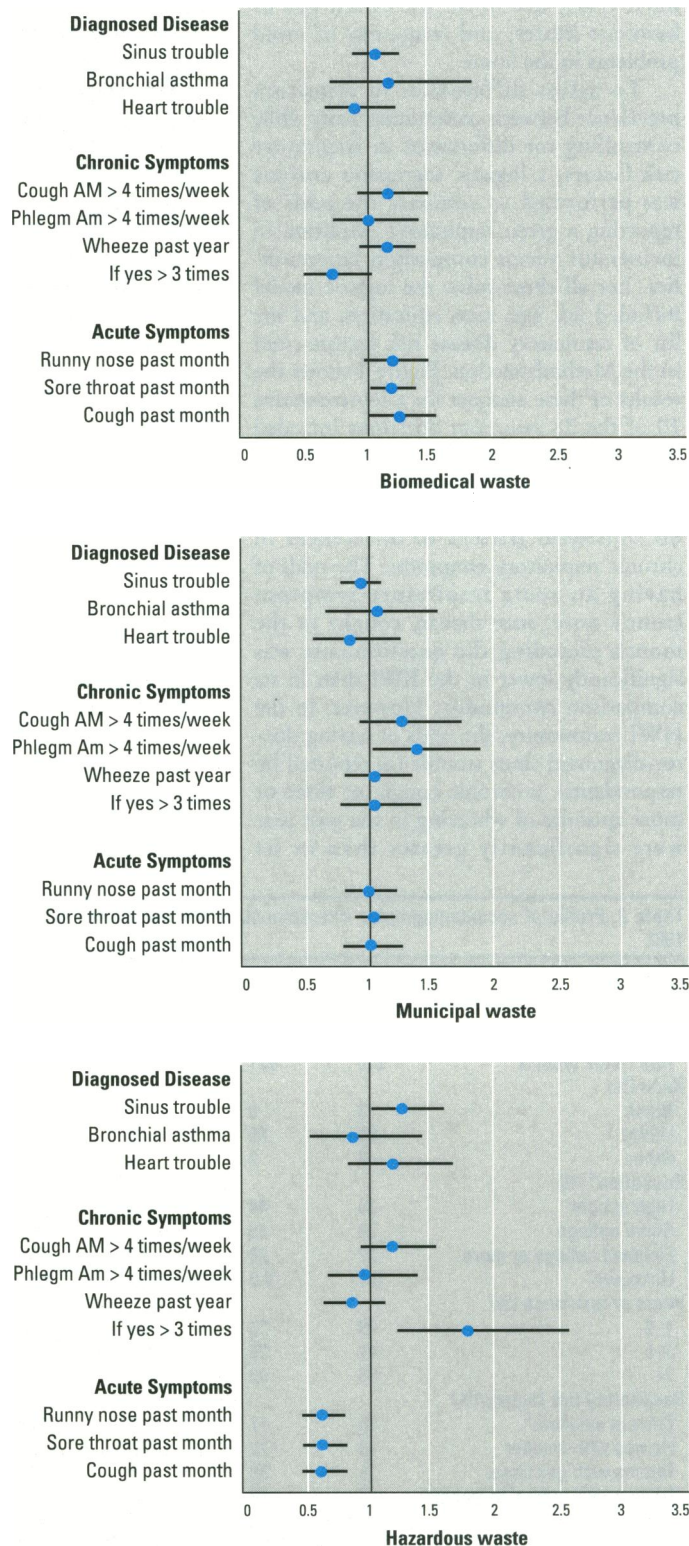
Figure 5. Adjusted odds ratios and 95% confidence intervals for respiratory diseases and symptoms for each incinerator community versus pooled comparison communities, spring 1992.

parison communities. The pattern in normals and sensitives was similar. These data suggest no important differences in average peak flows or in the diurnal change in peak flows between incinerator and comparison communities. Daily peak flow recordings were obtained from 516 subjects in the first year. A least squares regression equation was computed for each subject, relating peak flows to calculated PM_{10} concentrations, with calculations based on the sum of coarse and fine particle concentrations. Preliminary results showed that individual slopes of peak flow on PM_{10} were

randomly distributed around a zero slope, suggesting no consistent effect of PM_{10} variations, within the range of 20–80 mg/m^3, on peak flows. PM_{10} concentrations did not significantly affect the amplitude of the diurnal change in peak flow in either the sensitives or normals. Similar null results were obtained when exposures were lagged by 12 or 24 hr, and similar results were obtained for the association of peak flows with $PM_{2.5}$. Analyses of the relationship between variations in daily morning and evening peak flows and in air pollution concentrations, considering time

spent outdoors and proximity of each residence to the incinerator, are in progress.

Discussion

This is the first study to obtain simultaneously direct measurements of both air quality and respiratory function and symptoms in incinerator and comparison communities. Our preliminary results provide several noteworthy findings regarding studies of the potential health impact of any point source of air pollution on the surrounding community. First, it is important to obtain data on indoor sources of pollution and on personal risk factors for respiratory symptoms because as we found, there may be important community differences in the prevalence of these sources and risk factors, and these differences, if not accounted for, would confound any reported association between ambient air pollution and respiratory effects. We observed a higher prevalence of active and passive cigarette smoking, exposure to unvented gas and kerosene heaters, and mold problems in the homes of the comparison as compared with the incinerator communities. These differences would mask any modest-sized respiratory effects in the incinerator communities. Ideally, simultaneous measurements of indoor and outdoor air quality should have been performed at sites in all communities to determine the total exposure of study participants within and outside their homes, as studies have shown (*23*) that people spend 80–90% of their time indoors. We did, however, exclude from the diary study subjects who were regularly exposed to environmental tobacco smoke in their homes.

Second, even though an incinerator may be a point source of air pollution in a community, its contribution to the total mass of air pollution in that community may be relatively small and nearly undetectable by standard air monitoring and modeling techniques. We found no day-to-day differences in $PM_{2.5}$ concentrations between incinerator and comparison communities, whereas fine particulate concentrations of zinc, lead, and chloride, used as indicators of emissions from the incinerators, were consistently higher in the BWI and MWI incinerator communities, but this difference depended largely on wind direction. Thus, if a particular chemical component of incinerator emissions can cause respiratory effects in the exposed community, standard measures of air pollution may fail to detect the relevant differences in human exposures.

Third, prevailing wind direction may result in days when only the downwind segment of the incinerator community is exposed to incinerator-specific pollutants, whereas other subjects in the community

Table 3. Mean percent predicted FEV$_1$ and PEFR obtained by spirometry for normal subjects and sensitive subjects, 1992

	BWI	BCo	MWI	MCo	HWI	HCo
Normal subjects						
n	51	36	58	38	43	49
FEV$_1$	99.5 (±2.2)	94.8 (±2.6)	102.6 (±2.2)	100.5 (±2.5)	100.7 (±3.3)	98.1 (±2.3)
PEFR	104.8 (±3.3)	98.6 (±4.5)	119.1 (±3.9)	112.9 (±4.6)	111.1 (±4.4)	103.7 (±2.8)
Sensitive subjects						
n	32	39	56	45	46	44
FEV$_1$	96.5 (±2.5)	102.3 (±3.1)	102.7 (±1.9)*	90.6 (±3.3)	95.0 (±3.1)	95.3 (±2.9)
PEFR	100.7 (±3.5)*	112.4 (±4.7)	116.2 (±3.9)*	100.8 (±4.4)	108.9 (±4.8)	104.6 (±4.6)

Abbreviations: FEV$_1$, forced expiratory volume in 1 sec; PEFR, peak expiratory flow; WI, waste incinerator community; Co, comparison community; B, biomedical waste; M, municipal waste; H, hazardous waste.
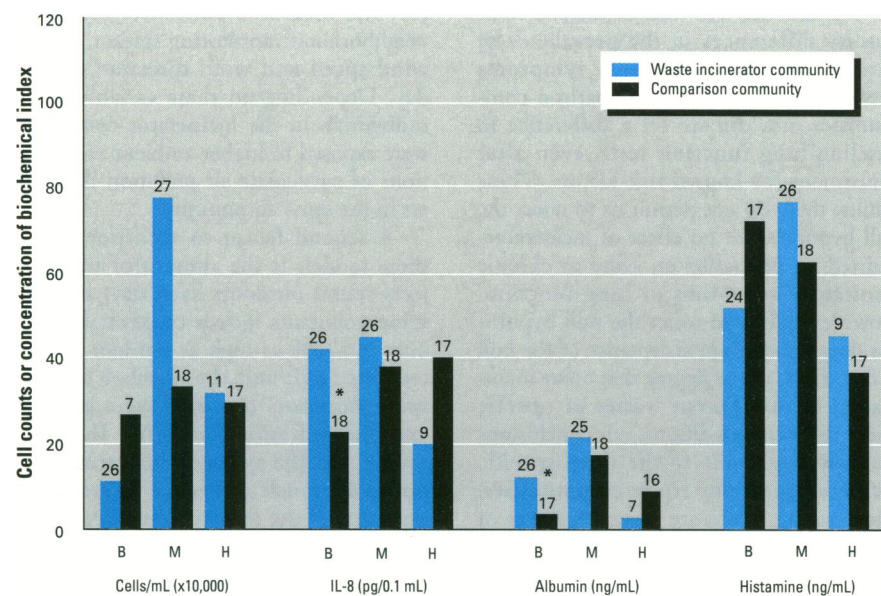*Significantly different within pairs by *t*-test (*p*<0.05).

Figure 6. Mean values for nasal lavage: cells and biochemical indices by paired communities, 1992. B, biomedical waste communities; M, municipal waste communities; H, hazardous waste communities. Numbers above bars indicate sample size. *Significantly different within pairs by *t*-test (*p*<0.05).

Table 4. Mean percent predicted PEFR, morning and evening, 1992^a

	BWI (n = 76)	BCo (n = 75)	MWI (n = 103)	MCo (n = 78)	HWI (n = 92)	HCo (n = 89)
Morning PEFR	114 (±3)	122 (±4)	134 (±4)*	120 (±4)	126 (±4)	122 (±3)
Evening PEFR	117 (±3)	125 (±4)	136 (±4)*	122 (±4)	128 (±4)	124 (±4)
Morning to evening change	2.2 (±0.4)	1.8 (±0.3)	1.3 (±0.3)	1.2 (±0.5)	1.6 (±0.3)*	0.8 (±0.2)

Abbreviations: FEV$_1$, forced expiratory volume in 1 sec; PEFR, peak expiratory flow; WI, waste incinerator community; Co, comparison community; B, biomedical waste; M, municipal waste; H, hazardous waste.
^{a}Mean percent change from morning to evening obtained by peak flow meter for 35 successive days.
*Significantly different within pairs by *t*-test (*p*<0.05).

who are not under the direct influence of the incinerator's plume may not be exposed at all from that source on those days. Therefore, if the air pollutant concentrations measured at the nearby monitoring station were attributed to all subjects in the exposed community, significant misclassification of exposures would occur. This misclassification is most likely to be nondifferential with respect to respiratory symptom reporting; i.e., exposure measurement error would be equal for persons reporting or not reporting respiratory symptoms and thus would bias results toward the null, leading to the conclusion that there is no effect of incinerator emissions on respiratory symptoms or lung function.

Last, in any comparison of an exposed and an "unexposed" community, there is always the chance that a single comparison community may be unrepresentative of its sampling universe, either by being unusually healthy or unhealthy; the position of the comparison community on the normal distribution curve cannot be easily evaluated. Thus, caution should be used in interpreting the results from a cross-sectional comparison of a single exposed community with a single comparison community, even if the distribution of individual risk factors is taken into account. This problem can be addressed if it is possible to pool data across several comparison communities, as we did, or if comparisons can be made with region-wide or national statistics for the specific health outcome being studied. Currently such data are seldom available for symptoms and conditions that do not require hospitalization.

We did not detect an effect of daily variations in air quality on peak expiratory flow rates within the relatively low range of PM_{10} and $PM_{2.5}$ particulate levels that were measured during the 35 days of our study. These results are in contrast to those of other studies on the acute respiratory effects of particulate air pollution, as reviewed by Dockery and Pope (24). On summarizing results from four longitudinal studies of panels of schoolchildren, these authors reported a decline in peak expiratory flow rates of 0.04–0.25% for each 10 $\mu g/m^3$ increase in PM_{10} concentrations (24). This discrepancy may be explained by the relatively low particulate levels in our study, since the range of month-long average PM_{10} concentrations across our six study communities was only 18–37 $\mu g/m^3$, at which levels it might not be feasible to detect effects on peak flow even if they did exist.

We did not detect overall differences in air quality between any of the three pairs of study communities, but we did find that, within the same community, daily concentrations of fine particulates varied by as much as eightfold and that these variations were nearly identical within each pair. These findings point to the conclusion that sources of particulate air pollution found in both incinerator and comparison communities, including sources within the community such as motor vehicle emissions and wind-blown soil dust and sources outside the community such as power plant emissions, were the major contributors to the particle mass in the ambient air. This conclusion is supported by the chemical mass balance receptor model that apportioned less than 3% of the particle mass to the biomedical incinerator and less than 2% to the municipal incinerator under maximum exposure conditions when the wind was blowing directly from the incinerators toward the monitoring station. We obtained no evidence that incinerator emissions had a major or even a modest impact on routinely monitored air pollutants such as fine particulate mass or acid gases. However, we have not analyzed our samples for organics such as dioxins and furans, and levels of these pollutants may differ within paired communities, but they are not known to be relevant to our concern with nonmalignant respiratory effects in this study.

We also did not find consistent community differences in the prevalence of chronic or acute respiratory symptoms between incinerator and comparison communities, nor did we see a difference in baseline lung function tests, even after adjustment for known risk factors. These results, then, do not permit us to reject the null hypothesis of no effect of incinerator-emitted air pollutants on acute or chronic respiratory symptoms or lung function. However, failure to reject the null hypothesis does not warrant acceptance of the null as fact. First, to the degree that other incinerators burn different wastes or operate under different conditions, our conclusions are only applicable to the three specific incinerators in our study communities. Furthermore, there are several features of the data, as reported here, that tend to bias

our results toward finding no effect even if there is one. The major problem is that of misclassification of exposure status on a day-to-day basis, as previously discussed. Wind direction and speed will determine which geographical sector of an exposed community is truly exposed to the point source on a given day. Unless geographical location of subjects, proximity to point source, and wind direction and speed are taken into account as a means to individualize the exposure estimates for study subjects, significant misclassification of exposure status on a given day will occur. Rarely do epidemiological studies of air pollutants take wind direction and wind speed into account, but in a study of point source air pollution, these variables can be crucial for exposure assessment. To date, our analyses have not incorporated wind speed and wind direction into the regression equations relating peak flows and symptoms to daily levels of measured air pollution, though we are in the process of doing so. Figure 7 illustrates some of the preliminary results of this effort; the figure shows the differences in exposures of individual subjects within the same incinerator community when we factor in their geographical location relative to the incinerator, the measured concentration at the neighborhood monitoring station, and the wind speed and wind direction on each day. Depending on these variables, some individuals in the incinerator community were exposed to higher ambient concentrations of particulate air pollution than others in the same community.

A second factor to incorporate into these models is the amount of time subjects spend outdoors each day, since for some pollutants indoor concentrations are only 50–70% as high as outdoor concentrations (25), and the number of hours spent outdoors can increase a subject's exposure to emissions from the point source. On the average, this variable will not make much difference in estimating exposures of the entire community because most people spend 80–90% of their time
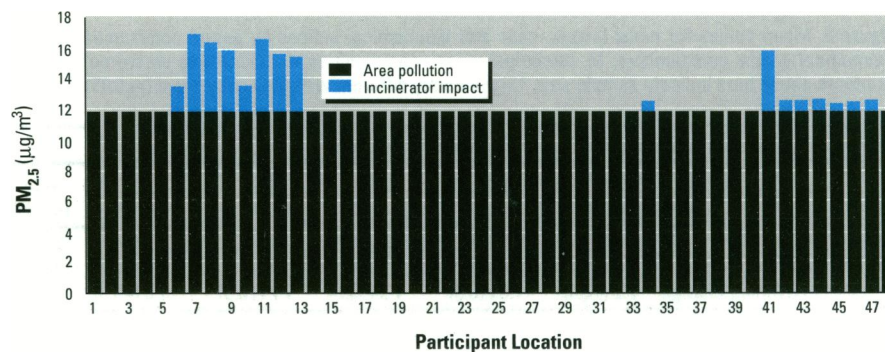

Figure 7. Comparison of area pollution and biomedical waste incinerator impact on 48 different household locations for 21 May 1992, $PM_{2.5}$, 12-hr daytime sampling period.

indoors, but there are days when some people spend considerably more time than average outdoors, and, if the wind is from the point source on any of those days, there is a potential for a significant increase in exposure. This possibility is of greater importance in studies of acute effects of point source pollution.

Although the slight but significantly higher odds of having chronic respiratory symptoms among residents of the HWI community disappeared when we pooled the HCo comparison with the other two comparison communities, the result from the pooled analysis is not necessarily the correct one. The pair of communities in the hazardous waste category of incinerators was located in a more rural area than the other communities. A rural community may be the only appropriate comparison for a rural, exposed community; the lower prevalence of chronic respiratory symptoms observed in the rural comparison community, versus the other comparison communities, may be representative of symptom prevalence in nonexposed, rural communities. If this is true, the HWI community may have a true excess of chronic respiratory symptoms, though even if that is the case, whether the association with emissions from the industrial furnace is causal or merely association by confounding cannot yet be determined. If the emissions from the industrial furnace are causing excess chronic respiratory symptoms, we would expect to see some effect on acute respiratory symptoms as well, particularly among the sensitives in our diary study. Data from the full 3 years of the diary study should allow us to draw more firm conclusions about acute respiratory effects associated with incinerator-associated emissions.

In summary, we found no differences in daily concentrations of fine particulate air pollution within incinerator–comparison community pairs. We did observe higher fine particulate zinc, lead, and chloride levels when winds were coming from the direction of the biomedical and municipal incinerators. We found similarities in the daily variation of particulate air pollution between incinerator and comparison communities. Furthermore, the results of our chemical mass balance receptor modeling indicated that incinerator emissions contributed less than 3% percent to the measured particulate concentrations. These observations lead to the conclusion that ambient concentrations of particle mass were largely determined by regional and ubiquitous sources in both incinerator and comparison communities, and that the contribution of the incinerator to ambient particle mass concentration was relatively minor during each 35-day period of measurements.

Corresponding to these findings on air quality, we observed no consistent differences in the prevalence of chronic or acute respiratory symptoms between paired incinerator and comparison communities, and no differences in baseline lung function or in the average peak expiratory flow rate measured over 35 days. We also found no association between variations in 12-hr average concentrations of particulates and peak expiratory flow results obtained from a subsample of adults without chronic respiratory symptoms and a subsample of children and adults with asthmalike symptoms.

These conclusions must be qualified by several limitations in the data from the first year of our study. First, we have not yet incorporated into the analysis individualized estimates of the air pollution exposure of our study subjects, and this is likely to bias our results toward the null. In further analyses we intend to produce individualized exposure estimates and to incorporate them into the full complement of the 3-year longitudinal diary study. Second, in each community we only have air quality measurements for 35 successive days of the year, and to the extent that this period of time is not representative of the longer-term air quality in these communities, we may not be detecting differences that actually exist. Replication of our measurements in years 2 and 3 of the study will provide more confidence in our air-quality estimates.

Third, this study excludes infants and children younger than 8 years of age; to the degree that this segment of the population is more susceptible to the respiratory effects of emissions from waste incinerators, we could be inadequately representing the respiratory health impact of incinerator emissions. To address this possibility, in the third year of the study we performed a retrospective and prospective study of acute respiratory disease in children less than 8 years of age in two of the three pairs of study communities. These results are being analyzed.

Fourth, the HWI community was not exposed to emissions from the combustion of hazardous wastes during the first year of our study; the industrial furnace facility was only burning coal during that year while it was in the process of obtaining an updated permit for burning liquid hazardous wastes. In the last 2 years of the study, liquid hazardous wastes were used as fuel in at least one of the four kilns of this facility. Thus, our first-year results are not applicable to measuring acute respiratory effects from the burning of liquid hazardous wastes, although we might have detected a persistent chronic respiratory effect because the facility used liquid wastes as fuel from 1983 until 1990.

Finally, we did not attempt to assess other health impacts of exposures to potentially toxic airborne pollutants, e.g. effects on the immune or neurological systems, carcinogenic, or reproductive effects.

Based on this analysis of the first year of our study, we conclude that we do not have evidence to reject the null hypothesis of no acute or chronic respiratory effects associated with residence in one of the three incinerator communities.

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