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ORIGINAL CONTRIBUTIONS

Respiratory and Irritant Health Effects of Ambient Volatile Organic Compounds

The Kanawha County Health Study

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Kanawha County, West Virginia, is one of the largest chemical manufacturing centers in the United States. In 1988, a survey of respiratory and irritant symptoms was administered to all third grade to fifth grade children attending 74 elementary schools in Kanawha County, and concentrations of 15 volatile organic compounds were measured at each school. Exposures were characterized by school location, by the sum of the concentrations of five petroleum-related compounds, and by the sum of the concentrations of 10 compounds more specific to industrial processes. Children enrolled in schools within the valley had higher rates of doctor-diagnosed asthma (odds ratio (OR) = 1.27, 95% confidence interval (CI) 1.09–1.48) and a higher score on a composite indicator of five chronic lower respiratory symptoms (OR = 1.13, 95% CI 1.02–1.26) than children who were enrolled in schools outside of the valley. The incidence of chronic respiratory symptoms was also positively associated with the concentrations of volatile organic compounds. The estimated change in the odds ratio for chronic lower respiratory symptoms associated with a 2-$\mu g/m^3$ change in process-related compounds was 1.08 (95% CI 1.02–1.14). No consistent pattern was found between acute irritant symptoms in the 2 weeks preceding questionnaire administration and either proximity to industry or exposure to volatile organic compounds. The authors conclude that exposure to volatile organic compounds, including emissions from chemical manufacturing plants, is associated with increased rates of chronic respiratory symptoms characteristic of reactive airways. *Am J Epidemiol* 1993;137:1287–1301.

air pollution; child; environmental exposure; respiratory tract diseases

The Kanawha Valley region of West Virginia, which includes Charleston and its surrounding communities, is one of the largest centers of chemical manufacturing in the

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Abbreviations CI, confidence interval, OR, odds ratio, OVM, organic vapor monitor

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United States. The industrial facilities are concentrated along the floor of a narrow valley, in many cases close to residential neighborhoods. Public concern about health risks increased sharply after the widely publicized disaster in Bhopal, India, in 1984. Methyl isothiocyanate, the compound released in the disaster, is also produced in Institute, a small community located within the Kanawha Valley. An accidental release of aldicarb oxime from the Institute plant in 1985 stimulated additional concern.

In December 1986, Harvard University and the National Institute for Chemical Studies, a private nonprofit institution, began an Environmental Protection Agency-sponsored study of air pollution and health in the Kanawha Valley. A preliminary phase combined measurement of air pollutants with an evaluation of the feasibility of conducting an epidemiologic study in the Kanawha Valley area (1). A panel of scientific experts and community representatives was convened to discuss community concerns, health endpoints, and epidemiologic strategies for assessing the health effects of community exposure to ambient air pollutants. The panel identified cancer and respiratory/irritant effects as areas of potential health impact and community concern, and recommended that an epidemiologic study be undertaken combining ambient monitoring of chemical air pollutants with a survey of respiratory, allergic, and other symptoms and illnesses in preadolescent schoolchildren (2).

The Kanawha County Health Study was conducted to test the hypothesis that residence close to chemical manufacturing facilities and/or exposure to volatile organic compounds would be associated with increased rates of both acute and chronic respiratory symptoms. This report characterizes the incidence of respiratory and other symptoms in Kanawha County schoolchildren and investigates the associations between symptom rates and these measures of chemical air pollution exposure. An assessment of acid aerosol pollutant concentrations and their association with rates of respiratory symptoms in children living in Kanawha County and in six other US communities is reported elsewhere **(3).**

MATERIALS AND METHODS

Site characteristics

Kanawha County is transected by the Kanawha River for about 82 km from the southeast to the northwest, with a narrow valley between 0.8 and 2.5 km wide and about 120 m deep. The urban areas are arrayed as a series of small towns on alternating sides of the river. The major chemical manufacturing industries are located on the valley floor in close proximity to the residential areas, which include Charleston and the surrounding communities.

Meteorologically, the Kanawha Valley urban area is dominated by temperature inversion conditions during about two thirds of the total hours throughout the year, with at least an 18-m inversion on over 90 percent of the sunrises **(4).** Wind speeds within the valley are typically half of those above the valley walls, with an average valley wind speed of 9 km per hour in the winter and 6 km per hour in the summer.

The public school system is county-wide, and nearly 95 percent of all children between the ages of 7 and 13 years are enrolled in a public school. The 75 elementary schools are typically small, and most children attend a neighborhood elementary school.

Geographic indicators of exposure

A prior hypothesis was that exposure to chemical industry emissions would be inversely related to the distance of schools from the plants. Schools were chosen as a surrogate for residential location because the elementary schools in Kanawha County are community-based and serve very small areas

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(usually of less than a 2-km radius). The closest residential neighborhoods are within 100–200 m of the fences of many chemical industry complexes or within 300-400 m of the complex center. Proximity to industry was defined as the smallest distance between each school and the geographic centers of nine major industrial complexes.

We divided the schools into four proximity-to-industry regions: in valley, near (region 1); in valley, far (region 2); out of valley, near (region 3); and out of valley, far (region 4). The "in valley, near" region included schools within 2 km up-valley or across the valley from a major industrial facility or within 3 km down-valley of a major facility. The second region included all other schools located on the valley floor. The third group included schools located outside of the valley but within 4 km of the valley floor. The final region included schools more than 4 km from the valley floor. Figure 1 shows the locations of the schools by their proximity-to-industry group.

Selection of volatile organic compounds

Volatile organic compounds were chosen as the primary focus of monitoring because 1) previous studies in the Kanawha Valley

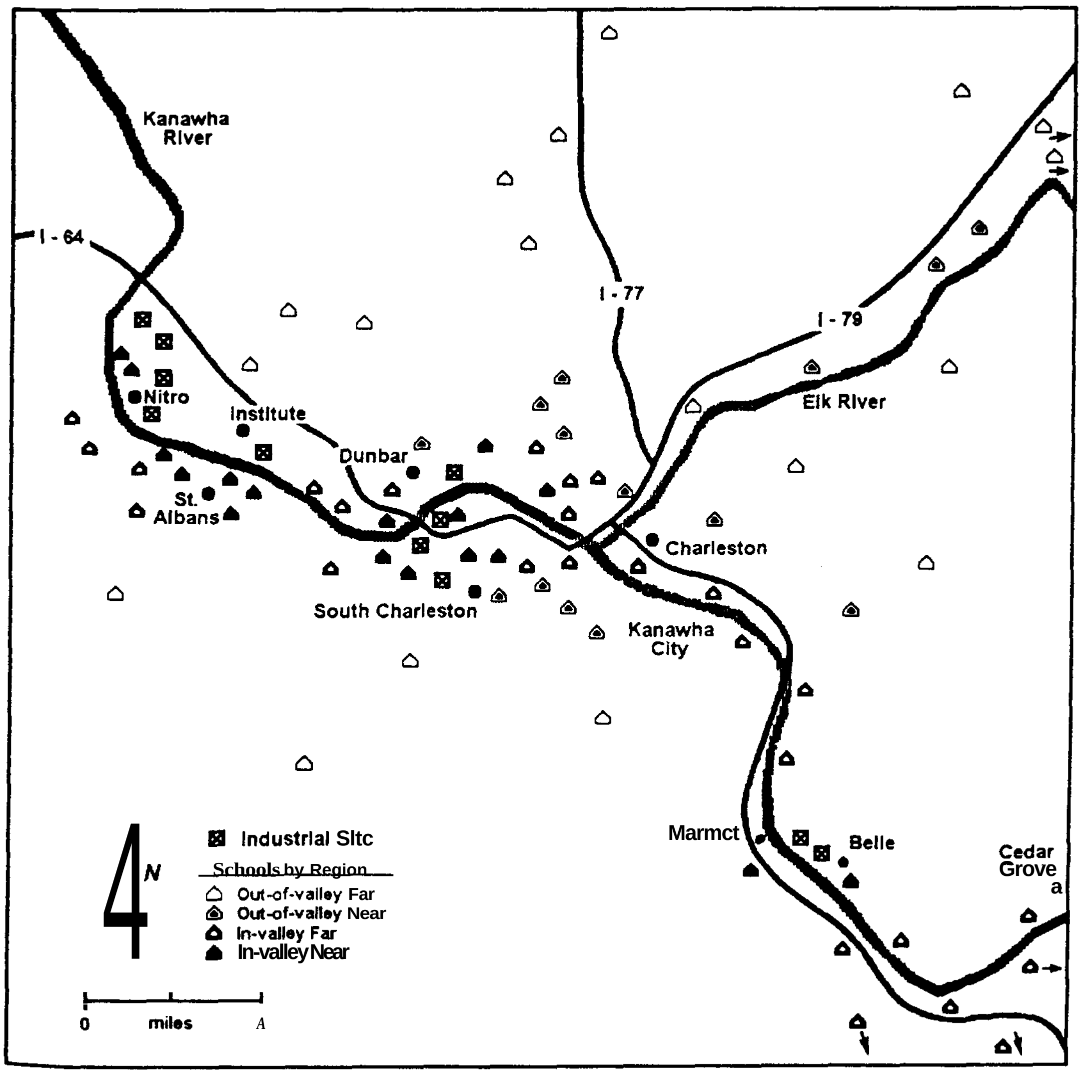

FIGURE 1. Locations of 75 public elementary Schools and 11 chemical manufacturing plants, identified by proximity of the schools to the industrial sites, Kanawha County, West Virginia, 1988.

showed that these compounds were present in the outdoor air (1, 5, 6); **2)** these compounds are widely used in chemical manufacturing and are found in other **US** communities **(7)**; and **3)** some of the compounds can induce toxic effects at low concentrations **(8,** 9).

Fifteen compounds were selected through a multistage process. First, the investigators identified 51 pollutants emitted in quantities in excess of 50,000 pounds **(22,700** kg) per year (10). Several compounds that had been monitored previously but did not meet the 50,000 pound selection criterion were added to this list. The list was then restricted to chemicals for which toxicity ratings were available (11–13). The last step was to use vapor pressure data to select compounds that could be measured accurately using available technology. Table 1 shows the final list of compounds selected for monitoring. These compounds can serve as markers for other chemical air pollutants released at the same location.

Environmental measurements of volatile organic compounds

The study plan called for one period of sampling at each elementary school. An initial round of sampling during the summer of 1987 was affected by the theft of samplers and by sample contamination by a laboratory reagent. The monitoring was repeated between October 20 and December 28, 1988, at the same time that the questionnaires were administered. Monitors were placed outside of each of the **75** public elementary schools for an 8-week **period of** continuous sampling. In this second round, no samplers were lost and no problems were encountered in the laboratory. Only the measurements from the second round of sampling were used in the health effects analysis.

A second monitor was placed at seven of the sites to collect data on sampler reliability. The data from these seven pairs and from five paired samples collected during the third

TABLE 1. Descriptive statistics for 15 volatile organic compounds measured at 74 elementary schools, Kanawha Valley, West Virginia, November and December 1988

Volatile organic compound	Maximum (μg/m³)	Median (μg/m³)	Mean (μg/m³)	Standard deviation
Petroleum-related compounds				
Toluene	117.4	4.8	9.7	17.2
m, p-Xylene	25.10	3.06	4.13	3.78
Benzene	6.89	3.02	3.18	1.22
o-Xylene	7.45	1.13	1.45	1.09
Decane	1.85	0.66	0.77	0.41
Total	154.40	13.12	19.19	22.27
Process-related compounds				
1,1,1-Trichlorethane	2.03	0.96	0.98	0.22
Carbon tetrachloride	1.45	0.62	0.64	0.19
1-Butanol	2.55	0.58	0.62	0.38
Chloroform	7.92	0.56	0.88	1.11
Perchloroethylene	2.24	0.46	0.57	0.37
Methyl isobutyl ketone	0.90	0.42	0.42	0.18
1,2-Dichloroethane	0.60	0.26	0.26	0.13
Styrene	0.23	0.12	0.12	0.02
Mesityl oxide	0.46	0.02	0.08	0.11
2-Ethoxyethyl acetate	0.55	0.02	0.04	0.07
Total	13.02	4.20	4.61	1.72

phase of the Kanawha Valley Study are discussed below. An additional seven pairs of samples were analyzed at two different laboratories for assessment of interlaboratory variation. These data are also discussed in this report. Ambient concentrations of aerosol acidity, particles, nitrogen dioxide, ozone, and particulate sulfate were measured between May and August of 1986 at several sampling locations in the Kanawha Valley (6, 14).

Although it is not the standard method for monitoring volatile organic compounds, integrated sampling with passive organic vapor monitor badges provided the only cost-effective method for measuring ambient concentrations at 75 sites over an extended period (15). While this type of dosimeter was developed for measurement of occupational exposures, the samplers can be used to measure ambient concentrations by exposing them for longer periods (16–18). The samplers work by diffusion of volatile compounds through air and their sorption onto carbon. A private laboratory (Clayton Environmental Consultants, Novi, Michigan) analyzed the data from the badges using selected-ion-monitoring gas chromatography with mass spectrometry and quantified the ambient concentrations of the 15 individual volatile organic compounds.

The analyses reported here were based on a division of these 15 compounds into twc composite measures of the community's general exposure to volatile organic compounds (table 1). The first exposure indicator was the sum of five petroleum-related compounds which are released from service stations and motor vehicles as well as the petroleum feedstocks of the petrochemical industry (19–21), while the second indicator group included 10 compounds that are related to chemical production processes but are minimally related to motor vehicle operation.

Health outcome measures

The questionnaire was based on instruments used in the Six Cities Study of Air Pollution and Health (22) and included the standard respiratory health questions from the American Thoracic Society questionnaire (23). For this study, questions were added about acute symptoms that had potentially been caused by imtant air pollutants. Questionnaires were distributed in three rounds, and 97 percent of the returned questionnaires were completed between October 15 and December 30, 1988. The schools represented in each round of distribution were geographically representative of the Kanawha Valley. A field surveyor visited each classroom to engage the children's interest and explain the survey. The actual distribution and collection of the questionnaires was done by teachers.

The chronic respiratory symptom questions obtained information on chronic cough, chronic phlegm, bronchitis, persistent wheezing, and attacks of shortness of breath with wheezing that had taken place during the previous year. Two composite indicators of chronic respiratory conditions were created from these individual symptoms. Lower respiratory symptoms were considered present if the child was reported to have any of the five chronic symptoms. Chronic lower respiratory response was considered present if the child was reported to have either chronic cough, persistent wheezing, or a physician's diagnosis of asthma.

A second set of questions focused on acute eye, nose, throat, and chest symptoms potentially effected by exposure to imtants. These questions asked about the occurrence of these symptoms during the 2-week period prior to the date on which the questionnaire was completed.

Analytic and statistical methods

The relative reliability of the measurements of volatile organic compounds was estimated by the relative standard deviation, expressed as a percentage, defined as

$$100 \times \sqrt{2} \times |x_1 - x_2|/(x_1 + x_2),$$

where x_1 and x_2 are the first and second values of a paired sample. We report the mean and standard deviation of the relative standard deviation for sets of paired samples.

The sample included all children enrolled in the third, fourth, and fifth grades of all general purpose public elementary schools in Kanawha County. Children placed in special instructional units were excluded unless they resided in the community in which their school was located.

The analysis examined the association between the health outcomes and either the geographic variables or the environmental exposure measurements, while controlling for parental smoking, familial socioeconomic status, and other potentially confounding variables such as the child's age and characteristics of the child's home that were predictive of indoor air quality. The socioeconomic status indicator was a composite variable based on parental education, occupation, and head-of-household status (details available from the authors upon request). The data were analyzed by standard multiple logistic regression methods (24–26). Results of individual logistic regression analyses were summarized by the estimated adjusted odds ratios and their 95 percent confidence intervals.

RESULTS

Concentrations of volatile organic compounds

Because data from one school were lost during laboratory analysis, analyses were based on a total of 74 observations. Values below the limit of detection for each volatile organic compound were assigned a value equal to the limit of detection. Table 1 gives the maximum, median, and mean values and standard deviations for each of the 15 volatile organic compounds and for the summary measures of petroleum-related and process-related volatile organic compounds. Correlation between the petroleum-related compounds and the process-related compounds was 0.73. Note that for toluene there was a large standard deviation and a substantial difference between the mean and median values for the 74 sites. The mean values for both petroleum-related and process-related compounds tended to be higher within the valley, particularly at the in-valley-near schools, than outside of the valley (table 2). The trend did not achieve statistical significance for the petroleum-related compounds because of the large var-

TABLE 2. Composite levels of volatile organic compounds by the proximity to industry of 74 elementary schools, Kanawha Valley, West Virginia, November and December 1988

Proximity-to-industry region*	No. of schools	Median ($\mu g/m^3$)	Mean ($\mu g/m^3$)	Standard error	P†
Petroleum-related compounds‡					>0.375
In valley, near	16	19.71	27.53	8.53	
In valley, far	26	12.05	18.98	3.76	
Out of valley, near	14	10.55	15.50	3.85	
Out of valley, far	18	11.01	14.94	4.13	
Above category excluding toluene					0.02
In valley, near	16	11.62	13.11	1.71	
In valley, far	26	7.34	9.28	0.90	
Out of valley, near	14	6.51	7.87	1.25	
Out of valley, far	18	6.86	8.00	1.28	
Process-related compounds					<0.005
In valley, near	16	5.00	5.68	0.57	
In valley, far	26	4.76	4.85	0.33	
Out of valley, near	14	3.89	3.83	0.26	
Out of valley, far	18	3.77	3.91	0.24	

* See text for detailed description of regions.
† Probability associated with the F statistic in one-way analysis of variance.
‡ See table 1.

iability induced by a few very large toluene measurements. When the toluene data were excluded from the petroleum-related group, the trend in concentrations remained and became statistically significant.

An analysis of 12 paired samples gave intralaboratory mean values for the relative standard deviation of 18.8 ± 5.3 percent (standard error) and 15.1 ± **3.6** percent for the process-related and petroleum-related compounds, respectively. An interlaboratory comparison of seven paired samples gave mean values of 23.1 ± **4.5** percent and **16.1** ± 2.3 percent for the process-related and petroleum-related compounds, respectively.

Health characteristics

Completed health questionnaires were obtained for **8,549** children, a return rate of **97** percent. Because of the restrictions noted above, **753** children (**9** percent) were excluded from the analysis data set. The **7,796** children included in the analysis data set were approximately equally distributed across the third, fourth, and fifth grades. The percentages of children belonging to the four proximity-to-industry regions ranged from **15** percent to **37** percent. Information on race, familial socioeconomic status, parental smoking status, and other characteristics of the children's home environment is shown in table 3.

Symptom rates for the entire sample and for the four proximity groups are displayed in table **4.** The latter rates were adjusted for familial socioeconomic status and parental smoking. The cumulative incidence of chronic respiratory symptoms ranged from 8 percent for bronchitis or chronic phlegm to 14 percent for persistent wheezing. The cumulative incidence of chronic cough was **9** percent, and that of attacks of shortness of breath with wheezing was 11 percent. For the 2-week period preceding administration of the questionnaire, a small proportion of children were reported to have had eye symptoms (7 percent) or lower respiratory symptoms (10 percent), while a much larger proportion were reported to have had nasal symptoms (25 percent) or throat symptoms (21 percent).

Potential confounders

Preliminary analyses explored associations with potentially confounding factors. Because of the narrow age range of the children, child's age was not associated with any of the health outcomes. The dampness variable showed a strong relation to health out-

TABLE 3. Characteristics of children by the proximity to industry of 74 elementary schools, Kanawha County, West Virginia, 1988*

Sample characteristic	In valley		Out of valley	
	Near	Far	Near	Far
No. of schools	16	26	14	18
No. of children	1,566	2.768	1.122	2,136
% of children	20.6	36.5	14.8	28.1
Male sex	49.4	51.1	52.3	50.3
Race				
White	90.2	84.6	91.9	97.5
Black	8.0	13.2	4.9	1.1
Other	1.8	2.3	3.2	1.4
Passive smoke exposure	50.7	52.6	47.2	48.4
Socioeconomic status				
High	12.1	14.0	23.3	13.9
Medium high	21.7	19.4	19.8	17.5
Medium low	30.5	30.0	24.9	25.7
Low	35.8	36.6	32.1	42.9
Gas cooking stove in the home	40.0	38.3	35.0	30.8
Exposure to mold, mildew. or water damage	24.7	22.4	25.5	21.3

* All data shown are percentages unless otherwise indicated.

TABLE 4. Adjusted* cumulative incidence (%) of selected health outcomes by the proximity to industry of 74 elementary schools, Kanawha County, west Virginia, 1988

Health outcome	Total	In valley		Out of valley		Trend test *p*
		Near	Far	Near	Far	
Chronic lower respiratory symptoms						
Chronic cough†,‡	8.7	9.7	8.6	7.4	8.7	0.25
Chronic phlegm†	7.7	8.2	8.5	6.4	7.1	0.06
Bronchitist	8.2	8.0	8.9	8.4	7.5	0.37
persistent wheezingt,‡	14.0	14.1	15.1	12.2	12.7	0.04
Attacks of shortness of breath with wheezingt	11.1	11.6	11.9	10.6	9.8	0.03
Physician's diagnosis of asthma$	10.1	10.4	11.2	9.5	8.5	<0.01
composite indicators						
Lower respiratory symptoms	26.1	26.6	27.3	23.8	25.1	0.09
Chronic lower respiratory response	20.9	21.6	22.1	18.6	19.7	0.04
Acute symptoms						
Eyes	7.3	7.8	8.1	7.3	5.7	<0.01
Nose	25.4	24.8	24.9	24.2	26.6	0.23
Throat	21.2	21.1	20.5	19.9	22.6	0.22
Lower respiratory symptoms	9.9	11.2	9.4	8.7	10.1	0.43

* Adjusted for parental smoking and familial socioeconomic status.
† Health outcome included in lower respiratory symptoms composite indicator.
‡ Health outcome included in chronic lower respiratory response composite indicator.

comes but no association with proximity to industry. Race and type of home heating fuel showed no association with health outcomes in these data. Thus, the final model did not adjust for these variables. Although both parental smoking and familial socioeconomic status had only weak associations with health outcomes and proximity to industry, subsequent analyses were adjusted for these variables.

Incidence of respiratory symptoms and geographic location

After adjustment for parental smoking and familial socioeconomic status, the reporting of health outcomes differed between the four proximity-to-industry regions (table 4). The trend test is a 1 df test for trend in symptom rates across the four proximity-to-industry groups, with the groups being assigned values of 1 to 4. Significant trends across the four proximity-to-industry regions were observed for acute eye symptoms and for asthma-related responses such as a physician's diagnosis of asthma, persistent wheezing, and attacks of shortness of breath with wheezing. Chronic cough and chronic phlegm did not show statistically significant trends.

For all of the health outcomes, the greatest contrasts appeared to be between the two in-valley regions and the two out-of-valley regions. A physician's diagnosis of asthma was more prevalent among children attending schools within the valley than among children attending schools outside of the valley (odds ratio (OR) = 1.27, 95 percent confidence interval (CI) 1.09–1.48). A significant in-valley effect was also noted for the composite indicators of lower respiratory symptoms (OR = 1.13, 95 percent CI 1.02–1.26) and chronic lower respiratory response (OR = 1.17, 95 percent CI 1.04–1.31), as well as for chronic phlegm, persistent wheezing, and attacks of shortness of breath with wheezing. After this in-valley effect was controlled, the near/far dichotomy was not associated with any health outcome. Among the acute symptoms, only acute eye imtation was associated with attending a school within the valley (OR = 1.30, 95 percent CI 1.09–1.56).

Symptom rates and environmental measurements

Most of the chronic respiratory symptom variables were positively and significantly associated with pollutant concentrations,

TABLE 5. Adjusted* odds ratios (ORs) and 95 percent confidence intervals (CIs) for an interquartile change in volatile organic compound exposure as measured at 74 elementary schools, by type of compound and health outcome, Kanawha County, West Virginia, 1988

Health outcome	Petroleum-related compounds (Δ 10 μg/m³) OR	Petroleum-related compounds (Δ 10 μg/m³) 95% CI	Process-related compounds (Δ 2 μg/m³) OR	Process-related compounds (Δ 2 μg/m³) 95% CI
Chronic lower respiratory symptoms				
Chronic cough†,‡	1.03	1.00-1.06	1.08	1.00-1.18
Chronic phlegm†	1.03	0.99-1.06	1.06	0.97-1.17
Bronchitis†	1.05	1.02-1.08	1.03	0.94-1.13
Persistent wheezing†,‡	1.01	0.99-1.04	1.04	0.97-1.12
Attacks of shortness of breath with wheezing†	1.04	1.01-1.07	1.05	0.97-1.13
Physician's diagnosis of asthma‡	1.05	1.02-1.08	0.99	0.91-1.08
Composite indicators				
Lower respiratory symptoms	1.05	1.02-1.07	1.08	1.02-1.14
Chronic lower respiratory response	1.03	1.01-1.05	1.07	1.01-1.14
Acute symptoms				
Eyes	0.99	0.95-1.03	1.08	0.99-1.19
Nose	1.00	0.98-1.02	0.99	0.93-1.05
Throat	1.01	0.99-1.04	1.02	0.96-1.09
Lower respiratory symptoms	1.03	1.00-1.06	1.02	0.93-1.11

* Adjusted for parental smoking and familial socioeconomic status.
† Health outcome included in lower respiratory symptoms composite indicator.
‡ Health outcome included in chronic lower respiratory response composite indicator.

and the results were consistent for the two summary measures (table 5). While both of the summary exposure measures were modeled as the linear effect of a 1-unit change in exposure (in μg/m³), the odds ratios have been rescaled separately for each measure to reflect a change in exposure approximately equal to the interquartile range for each summary exposure measure. This scaling factor was 10 μg/m³ for the petroleum-related compounds and 2 μg/m³ for the Process-related compounds.

An increased cumulative incidence of lower respiratory symptoms was associated with both a 10-μg/m³ change in petroleum-related compounds (OR = 1.05) and a 2-μg/m³ change in process-related compounds (OR = 1.08). A similar association was observed for the chronic lower respiratory response composite and for the individual chronic respiratory symptoms, although not all of the confidence intervals for the individual symptoms indicated statistical significance at the 95 percent confidence level. The prevalence of a physician's diagnosis of asthma was associated with exposure to petroleum-related compounds (OR = 1.05, 95 percent CI 1.02–1.08) but not with exposure to process-related compounds (OR = 0.99, 95 percent CI 0.91–1.08). Acute lower respiratory symptoms were marginally associated with the ambient concentrations of both petroleum-related compounds (OR = 1.03) and process-related compounds (OR = 1.02). Rates of acute symptoms in the eyes, nose, and throat did not show an association with the measured concentrations of these compounds, except for acute eye symptoms, which were possibly associated with process-related compounds (OR = 1.08, 95 percent CI 0.99–1.19).

As figure 2 shows, one school had a very extreme measured level of petroleum-related compounds and a relatively high cumulative incidence of lower respiratory symptoms. The level at the school with the highest exposure to petroleum-related compounds (154.4 μg/m³) was an order of magnitude higher than the median and was much higher than the level at the school with the second highest exposure level (85.1 μg/m³). The exposure-response association for

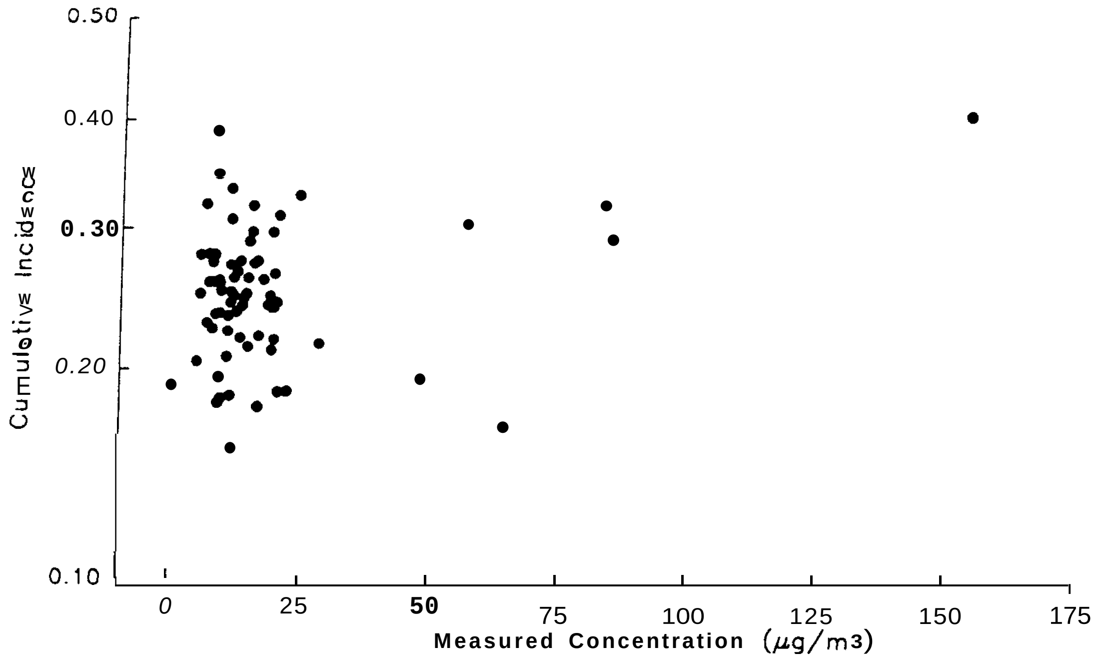

FIGURE 2. Cumulative incidence of lower respiratory symptoms according to measured concentrations of petroleum-related compounds at 74 elementary schools. Kanawha County, West Virginia, 1988. (Plotted on the bgit scale).

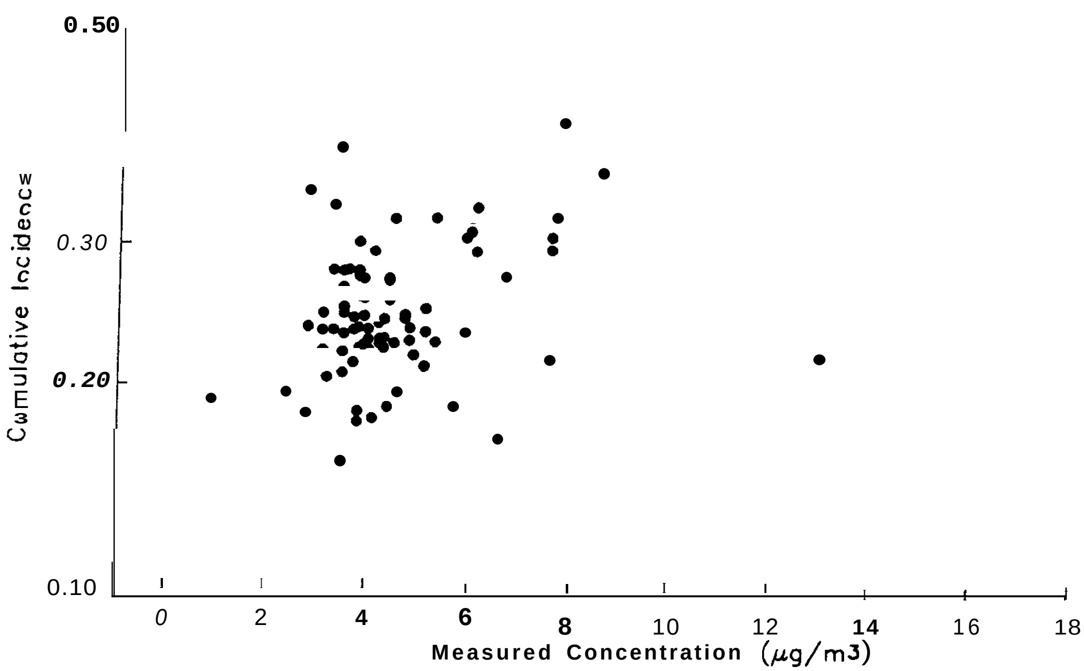

FIGURE 3. Cumulative incidence of lower respiratory symptoms according to measured concentrations of process-related compounds at 74 elementary schools, Kanawha County, West Virginia, 1988. (Plotted on the logit scale).

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petroleum-related compounds was strongly influenced by this single observation. However, the plot for process-related compounds (figure 3) did not indicate such an extreme distribution. For the latter plot. the level at the school with the highest exposure (13.0 $\mu g/m^3$) was only a factor of 3 higher than the median and was only slightly higher than the level at the school with the second highest exposure (8.6 $\mu g/m^3$).

Because of concerns about the variability of the toluene measurements across the four sites, due in large part to a few extreme values, we repeated the logistic regression analyses using the petroleum-related compound concentrations after excluding toluene. The adjusted odds ratios, when scaled to the smaller range of the modified petroleum-related summary variable, changed only slightly, and no changes were observed in the pattern of significant associations. This is not surprising, since the correlation between the sum of all petroleum-related compounds and the sum excluding toluene was 0.95.

DISCUSSION

The volatile organic compound measurements collected during this investigation showed that the air of the Kanawha Valley contains organic compounds at concentrations not typically found in outdoor air. For example, unusually high concentrations of chloroform, carbon tetrachloride. and mesityl oxide were measured at many sites. The spatial distribution of the 15 volatile organic compounds across the valley (14) was consistent with the West Virginia Air Pollution Control Commission's 1984 emissions inventory (9), which suggests that the chemical plants are an important source of these compounds.

The community was exceptionally cooperative with the survey. As a result, a large data base was established that was not compromised by either a poor response rate or a large number of carelessly completed questionnaires. Symptom rates were within the range reported from studies in other communities that have used similar questionnaires (22).

Three measures of exposure were used in this study: two composite measures based on the volatile organic compound measurements and a measure of proximity to industry. Incidence rates for respiratory symptoms were higher for schools located within the valley. Trend analysis showed that these differences were statistically significant for physician's diagnosis of asthma, wheeze-related symptoms, and the composite variables that included the symptoms characteristic of reactive airway disease (table 4). The regression analysis based on the two composite measures of volatile organic compound concentrations suggested that rates of chronic symptoms increased as the levels of the two exposure variables increased (table 5). Taken as a whole, these data show that children attending schools closer to chemical plants and children attending schools with higher concentrations of volatile organic compounds tended to report more frequent respiratory symptoms, and also were more likely to report acute eye symptoms.

Limitations

Epidemiologic studies of air pollutants inevitably have limitations arising from measurement error in both exposure data and health data and the possibility of incomplete control for other factors that affect the health outcomes. Since location is not the only determinant of the dispersal of emissions, the proximity-to-industry groups were subject to substantial misclassification as indicators of exposure. Moreover, outdoor measurements are an imperfect predictor of total personal exposure, which also depends on indoor concentrations (27). The 15 pollutants selected do not fully characterize the exposure of Kanawha Valley residents to all volatile organic compounds. Emissions of some compounds occur episodically, and their peak concentrations may be much higher than was suggested by the time-averaged values over the 8-week monitoring period. Finally, the air quality during the monitored period may not be representative of the children's prior exposure history. The consequent random misclassification of exposure, which should have affected persons with and without the health outcomes equally, would have tended to reduce the strength of the apparent relation between exposure to volatile organic compounds and chronic respiratory symptoms.

The measurements made during this investigation and during an earlier environmental monitoring study (5) show that ambient concentrations of some volatile organic compounds are unusually high in the Kanawha Valley. The organic vapor monitor (OVM) badges used in this study had not previously been used for prolonged passive sampling of outdoor air at concentrations measured in the Kanawha Valley. A 21-day chamber study was performed to compare measurements obtained by OVM badges to predicted concentrations and measurements obtained using active sampling with activated charcoal. For most of the organic compounds investigated, measurements obtained with the passive sampler were within 25 percent of predicted concentrations and were consistent with values obtained using active sampling, suggesting that these samplers can provide an inexpensive alternative to active sampling (18). Paired badges placed at 12 locations provided data on the reliability of paired measurements.

Finally, concentrations of volatile organic compounds were compared with measurements obtained by active sampling at four sites over a 12-month period (April 1986–March 1987) during an earlier phase of this research. The mean concentration of petroleum-related compounds was 18.5 $\mu g/m^3$ in the earlier study, which is quite consistent with the mean of 19.2 $\mu g/m^3$ observed in this study. Mean concentrations of chloroform and carbon tetrachloride were 5.43 $\mu g/m^3$ and 1.87 $\mu g/m^3$, respectively, raising the possibility that concentrations of these compounds might have been underestimated by the OVM badge methodology. However, these comparisons were qualified by the fact that the active sampling was done at a different time than the OVM badge sampling and at different sites. Further studies are needed to improve our understanding of the performance of the OVM badge. In particular, other investigators considering the use of OVM badges in epidemiologic studies should consider the feasibility of placing pairs of badges at each sampling site. This would provide more extensive reliability data, and the mean of the two sample values would have smaller sampling variability.

Regional air pollutants such as particulate matter and acidic air pollution were not potential confounders in this study. Cohen et al. (6, 14) found no significant differences at four Kanawha County sites in measurements of light scattering or in concentrations of nitrogen dioxide, sulfuric acid, and fine particulate matter. Despite the absence of confounding by acidity and particulate matter, the possibility remains that volatile organic compounds may be serving as markers for other pollutants emitted from industrial and mobile sources, including other emissions from the same facilities and emissions from vehicles and other activities around the plants.

Many factors might influence the reporting of respiratory symptoms in children, including exposure to environmental tobacco smoke, a history of asthma or allergies, a past history of severe lower respiratory infections, and socioeconomic status (28–30). The symptoms present in the reporting parent also influence the reporting of symptoms for the child (31–33). An attempt was made in this study to measure and control for factors that might have affected the endpoints selected for study, and parental smoking and familial socioeconomic status were included in the regression models. However, because of misclassification, control for such confounders may not have been complete.

Symptom reporting may also have been influenced by parental attitudes about the petrochemical industry and by their general knowledge of health: these factors, however. could not be readily measured or controlled in the analysis. Parents living near the chemical plants could have introduced a bias in two ways. Parents who were concerned about exposure could have overreported respiratory symptoms, while parents who were concerned about an adverse effect on employment could have underreported respi-

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The choice of residential location reflects factors related to health. Families with higher incomes may avoid living near a chemical plant, and persons adversely affected may move away. In a cross-sectional study, the bias introduced by personal choices as to place of residence cannot be fully detected or controlled.

Conclusions

The monitoring results from this study complement the results of previous studies of chemical air pollution in the Kanawha Valley. Many of the volatile organic compounds measured during this study are emitted by Kanawha Valley chemical industries in quantities of at least 50,000 pounds annually. These compounds were detected in outdoor air at schools situated in residential neighborhoods. Population exposures from outdoor activities and from contamination of indoor air are certain to take place. Some of these compounds are emitted only by industrial sources, while others are found in automobile emissions as well. Thus, the petroleum-related composite variable measured the combined exposures from industrial and vehicular sources.

The indices of exposure to volatile organic compounds were associated with increased risk of several chronic respiratory symptoms and of a physician's diagnosis of asthma. These results indicate a gradient of risk within the community which is presumed to reflect the children's general level of exposure to sources of ambient volatile organic compounds located in the Kanawha Valley. Previous studies have shown that ambient exposures to particulates and acid aerosols have been associated with chronic respiratory symptoms **(34–36),** deficits in pulmonary function **(37, 38),** and mortality (39, **40).** In this study, the geographic analyses using either the exposure measurements at each school or the proximity-to-industry regions found associations with exposure to volatile organic compounds that were distinct from the effects of regional air pollutants such as particulates and acid aerosols.

While the mechanisms are not well understood **(41),** these compounds may cause disease through direct irritation and neurotoxic effects **(42–44).** Experimental human exposures to mixtures of volatile organic compounds also produce symptoms of eye, mucosal, and airway imtation **(45).** Thus, the finding that ambient exposures were associated with respiratory symptoms is biologically plausible and is consistent with the limited available evidence on the respiratory effects of volatile organic compounds. Whether the association with asthma represents a role for exposure in the onset or exacerbation of asthma cannot be established from this study. However, in both occupational and experimental settings, volatile organic compounds have been linked to asthma and bronchial hyperreactivity **(46–48).**

This survey of respiratory symptoms in schoolchildren provides evidence that exposure to a mixture of volatile organic compounds, some emitted from chemical manufacturing plants, has adversely affected the health of some of the children living in the Kanawha Valley.

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