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REPORT ON AMBIENT EXPOSURES TO VOLATILE ORGANIC COMPOUNDS IN THE KANAWHA VALLEY

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REPORT ON AMBIENT EXPOSURES TO VOLATILE ORGANIC COMPOUNDS IN THE KANAWHA VALLEY.

by

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The following appendices are not included with this report but are available from the authors or the National Institute for Chemical Studies.

Appendix 1: "Indoor/Outdoor Measurements of Volatile Organic Compounds in the Kanawha Valley of West Virginia" by Martin A. Cohen, P. Barry Ryan, Yukio Yanagisawa, and John D. Spengler. This manuscript provides results of the indoor/outdoor monitoring study conducted in the Kanawha Valley in August, 1987.

Appendix 2: Tables of the percent of samples with detectable concentrations, the chronic daily intake (CDI), the ratio of CDI to reference dose (RfD), and the estimated lifetime individual exposure for each chemical at each sampling location and for all sampling locations combined.

Appendix 3: Table of median outdoor concentrations of each VOC at each sampling location.

Appendix 4: Descriptive statistics for each chemical at each sampling location, with selected box plots.

Appendix 5: Ratios of indoor to outdoor median VOC concentrations in the Kanawha Valley and in the TEAM studies.

Appendix 6: Further analysis of seasonal and day to night variation of VOC concentrations measured with Tenax cartridges.

EXECUTIVE SUMMARY

The Kanawha Valley is one of the largest centers of chemical manufacturing in the United States. Many of the plants are close to residential areas. Further, the plants handle thousands of tons of chemicals each year and the topography and climate of the Valley make it likely that residents will be exposed to air pollutants when they are released during manufacturing processes. Although many measures have been adopted to reduce risks, residents, public officials, and industry leaders remain concerned about the impact of chemical emissions on the health of the community. The memory of Bhopal and the chemical release at Institute, West Virginia linger in the minds of many residents.

The National Institute for Chemical Studies (NICS) was formed in 1985 to identify and reduce the health and safety risks posed by chemical manufacturing in the Valley, while minimizing impact on economic activity. NICS initiated several projects, including a collaboration, initially with investigators from Harvard University and later with additional participants from Marshall University and the University of New Mexico, to study the impact of chemical manufacturing on the health of Valley residents.

The investigators developed a three-phase study. The first phase consisted of a program of air pollution monitoring, designed to determine whether residents of the Valley are exposed to high concentrations of Volatile Organic Compounds (VOCs). The second

phase is an epidemiologic study of the health status of children attending the third through fifth grades of Kanawha County schools. The third phase is still under development.

This report describes and interprets the results of the first phase. It summarizes data on concentrations of a selected set of 19 VOCs measured in outdoor and indoor environments over a twelve-month period. While the report uses risk assessment methodologies to evaluate the observed outdoor VOC concentrations, it is not a comprehensive assessment of the health risks from exposures to chemical air pollution and should not be interpreted as such. Rather, it is a first step in the effort to make such an assessment. The epidemiologic study now under way and other health data collection efforts under way or being planned will provide more direct information on health risks associated with manufacturing activities in the Valley.

Major Findings

- Of 19 Volatile Organic Compounds (VOCs) monitored at four outdoor locations, 13 were detected in at least 40% of the 261 twelve-hour samples collected.

- Concentrations of chloroform and carbon tetrachloride were elevated at the Belle monitoring site, tetrachloroethylene concentrations were elevated at South Charleston, and somewhat surprisingly, a number of

monitored VOCs possibly associated with vehicle emissions were highest at the remote site in Hurricane.

- The estimated health risks associated with the average outdoor concentrations of these VOCs are small relative to total risk of cancer and other diseases, but may still be of public health concern.

- This finding mirrors conclusions reached in the 1986 Kanawha Valley Toxics Screening Study sponsored by the Environmental Protection Agency (EPA), except that this study was not able to monitor acrylonitrile, 1-3 butadiene, and ethylene oxide, three potential carcinogens identified in emissions inventories reviewed by the EPA.

- While the sample size is small, indoor data from 35 homes indicate that, on average, indoor concentrations of most VOCs are higher than outdoor concentrations. This is an important conclusion, since most people spend 80 to 90% of their time indoors.

- Benzene, carbon tetrachloride, and chloroform should be considered for exposure reduction. Chloroform made the largest contribution to estimated cancer risk, while carbon tetrachloride had the highest mean concentration relative to EPA's reference dose, the concentration below

which health effects other than cancer are not expected to occur.

VOC Monitoring Methodology

This study had two components, an outdoor monitoring program at four sites and a comparative study of indoor and outdoor concentrations at 35 homes in or near the Valley. The outdoor monitoring study was conducted over a twelve-month period, from April, 1987 to March, 1988. During this period, a mobile van provided by the EPA rotated among three Valley sites in Belle, Institute, and South Charleston at monthly intervals. A smaller monitoring effort was conducted during most of this period at a fixed site in Hurricane, WV. In each month, fifteen twelve-hour daytime VOC samples and five twelve-hour nighttime samples were collected on Tenax cartridges at the van sites and three twelve-hour samples were collected at the fixed site in Hurricane.

Because recent work by EPA scientists has shown that many VOCs are found at high concentrations in indoor air, the Harvard investigators also conducted a small comparative study of indoor and outdoor VOC concentrations at 31 homes in the Valley and 4 homes outside the Valley during August of 1987. This substudy was partially supported by the EPA, but much of the work was donated by Clayton Environmental Consultants, Inc. At each home, a three-week VOC sample was collected in the master bedroom and a second sample was collected in the yard at a location away from the driveway and

house. Because most outdoor samples had VOC concentrations below the limits of detection of the less sensitive passive-badge collection and analysis method used in the indoor/outdoor study, only the indoor measurements from that study are discussed in this summary and report. Thus, all references to outdoor air pollution measurements refer to measurements at the four fixed outdoor sites. A manuscript describing complete results from the indoor/outdoor study is one of six appendices to this report available on request from the authors or NICS.

Results of VOC Monitoring

The 19 VOCs chosen for study are listed in Table 1. Two (1,2-dibromoethane and 1,2-dichloroethane) were detected in only 1 of the 261 samples collected at the four outdoor sites. Four others, chlorobenzene (4%), 1,2,4-trichlorobenzene (8%), p-dichlorobenzene (15%), and trichloroethylene (15%), were detected in a relatively small percentage of samples. All other VOCs were detected in at least 40% of the 261 samples.

A comparison among the four monitoring sites showed that concentrations of chloroform and carbon tetrachloride were elevated at Belle, tetrachloroethylene concentrations were elevated at South Charleston, and somewhat surprisingly, a number of VOCs had the highest concentrations at the remote site, Hurricane (Table 3). This finding will be explored further, both by investigating the representativeness of the Hurricane site and by further study of

geographic variation of VOC concentrations in the samples collected at elementary schools during Phase 2.

Comparison of Indoor and Outdoor Values

For most VOCs, average indoor concentrations were substantially higher than average outdoor concentrations (Table 4). This result may seem surprising, but it is consistent with results of the TEAM studies conducted by the Environmental Protection Agency, which showed that many commonly used household products are sources of VOCs. Only one VOC, styrene, had higher average concentration outdoors than indoors. For the other VOCs, the ratio of indoor to outdoor means varied from 1.4 to over 200, with most ratios between 2 and 10. Although these indoor to outdoor comparisons are useful and consistent with results from other studies, they should be interpreted cautiously because the indoor and outdoor samples were collected and analyzed using different methods and because the outdoor data were collected over a twelve-month period while the indoor data were collected during August of 1987.

Comparison with EPA Monitoring Data

The EPA measured many of the same VOCs at outdoor sites in Institute and Belle in March and April of 1986, as part of the Kanawha Valley Toxics Screening Study (KVTSS). The mean concentrations measured in the current study agreed well with the measurements obtained in the KVTSS (Table 5). Mean concentrations obtained

in this study were within the range of values seen in the KVTSS for every pollutant measured in both studies. The EPA also used emissions data and complex dispersion and meteorological models to estimate VOC concentrations at various sites in the Valley. The modeling estimates agreed reasonably well with our measured concentrations at Belle, agreed with the measured concentrations of chloroform but not benzene at Institute, but were far lower than measured concentrations at Hurricane (Table 6).

Risk Assessment

The initial goals of the phase 1 study were to measure concentrations of VOCs at several outdoor sites in the Valley and to use the data on the levels and geographic variation of these compounds to plan subsequent epidemiologic studies. Because the data were gathered in different months at the three van sites, they have some important limitations when used to make comparisons between sites. Nevertheless, the VOC measurements are of independent interest and a risk assessment of the observed concentrations can be helpful to efforts to understand their potential health significance. Thus, this report uses methodology recommended by the EPA to estimate the health risk associated with the average concentrations observed at each of the four outdoor monitoring sites.

Risk assessment methods recommended by EPA differentiate between risk of cancer and risk of other diseases. The EPA method

assumes that no concentration of a cancer-causing chemical (carcinogen) is completely without cancer risk. For all other diseases, the EPA method assumes that a reference dose (RfD) can be identified below which exposed persons are unlikely to experience adverse health effects. EPA data bases do not include toxicity values for all VOCs. The toxicity values now available from the EPA for the 19 VOCs considered in this study are listed in Table 2.

Only carbon tetrachloride and chloroform had average outdoor concentrations larger than 10% of EPA's reference dose (RfD) (Table 9). The largest ratio, 110%, was in Belle where the mean carbon tetrachloride concentration exceeded the RfD. We modified occupational exposure limits to derive an alternative measure of noncancer risk for 4 of the 7 VOCs for which the EPA did not provide an RfD (Table 12). Among these 4 VOCs, only benzene had a ratio of observed concentration to toxicity value (0.07) that approached 0.1.

Estimated excess cancer risks, obtained by assuming that exposure remained constant over a lifetime and adding the cancer risks for all VOCs with toxicity values, ranged from 34 per one hundred thousand persons in Belle to 12 per one hundred thousand persons in Hurricane (Table 10). Most of the estimated risk could be attributed to outdoor concentrations of chloroform, with smaller contributions from carbon tetrachloride and benzene. Because the EPA data base includes unit risk values for only 8 of the 19 chemicals under study, we used work of other investigators to estimate the contribution to risk of an additional 9 chemicals

(Table 11). The inclusion of these 9 chemicals in the calculation of estimated excess cancer risk produced a 16% increase in estimated risk. Further comparison of the unit risks reported from the two different sources shows that different analysts can arrive at appreciably different unit risk values.

In interpreting these cancer risks, it is important to remember that the EPA method gives an upper bound estimate of risk, that is, a value that is likely to be higher than the actual risk. Thus, the actual cancer risk is likely to be lower than this value and may even be 0. Second, these estimates assume continuous exposure to these concentrations over a lifetime. Most people spend 80% to 90% of their time indoors and the indoor data show that indoor environments are both variable and different from outdoor environments. Finally, under some simplifying assumptions, the largest of these risk values would represent an increase in cancer incidence of about one cancer case per year among the approximately 230,000 residents of Kanawha County. Although cancer incidence data are not available for the County, cancer mortality rates averaged 393.4 deaths per year between 1970 and 1979.

The upper bound estimate for the cancer incidence caused by these chemical exposures is about 0.3% of the cancer mortality rate in the County from all causes. Nationally, the number of new cases of cancer is about twice the cancer mortality rate each year, thus the estimated risk represents an even smaller percentage of expected total cancer incidence for Kanawha Valley and therefore represents a

small contribution to total risk. Recall, however, that the review of emissions in the Kanawha Valley by the KVTSS identified other potential carcinogens, including acrylonitrile, 1,3-butadiene, and ethylene oxide, that could not be monitored using the methods employed in this study.

Two other aspects of this risk assessment deserve mention. First, the cumulative cancer risk was obtained by adding the estimated risks for individual chemicals. It is possible that exposure to two chemicals simultaneously produces greater risk than the sum of the risks of each chemical. This phenomenon is called synergism. Though it is a theoretical possibility, little is known about whether it occurs at low concentrations. The second issue concerns variability among individuals in chemical exposure. If a concentration equal to 10% of a reference dose is measured at an outdoor station, this does not imply that every individual is exposed to this concentration. It is more likely that individual exposures vary, both because of varying proximity to outdoor sources and differences in indoor environments. The data on indoor environments gathered in this study suggest, in fact, that much of the total exposure burden may be occurring indoors.

In interpreting this risk assessment, the reader should also remember that the VOC measurements were obtained at only four sites and during only one year. More importantly, the health risks attributed to these exposures were derived in most cases from analyses of studies of animals exposed to much higher

concentrations. This problem of extrapolation from mouse to man creates considerable uncertainty in the estimates of health impact. Direct assessments of health status of Valley residents provide a more direct and, in some ways, more informative evaluation of health risk due to chemical manufacturing. The epidemiologic study being carried out as Phase 2 of this study will gather such direct information on reports of respiratory complaints, eye and skin irritation, and other endpoints obtainable by questionnaire in third to fifth grade children. Some analyses planned for these epidemiologic data would require geographic variation in exposure within the Valley. The data gathered in Hurricane during phase 1 raise some important questions about geographic variation in VOC concentrations. Additional VOC monitoring at 74 Kanawha County schools is being conducted as part of phase 2, and these data will provide important additional information on geographic variation.

We have also recommended that NICS work with the West Virginia Department of Health and the Kanawha County Board of Health to establish a registry of all incident cases of cancer reported for Valley residents. Such registries have been established in other states and provide one of the most effective methods available for monitoring cancer risk in a large population.

INTRODUCTION

The Kanawha Valley region of West Virginia, which includes Charleston and surrounding communities, is one of the largest centers of chemical manufacturing in the United States. The industrial facilities are concentrated along the Valley floor and residential neighborhoods are located close to many of these facilities. Residents and public officials have been concerned for many years that chemical manufacturing might pose health risks to residents of the Valley. Unfortunately, public health statistics provide very little information about the health impact of chemical manufacturing. Cancer mortality rates for the Valley do not provide a clear answer to the question of excess risk (1), but mortality data are known to have limited value for investigating environmental risk because of the long latency period between exposure and diagnosis of cancer, the mobility of the U.S. population, and problems with determination of cause of death. Little if any other evidence exists to demonstrate that residents of the Kanawha Valley are at increased health risk. Nevertheless, a consensus has emerged among business leaders, residents, and public officials that the impact of manufacturing activities on the environment must be reduced. Federal and state government officials have been working closely with the major chemical companies towards this end (2).

Despite these efforts, public concern about exposure to the products of chemical manufacturing has remained significant. The Environmental Protection Agency (EPA) responded to these concerns in

1984 by undertaking the Kanawha Valley Toxics Screening Study (KVTSS) (2). The EPA investigators screened a set of 450 chemicals listed on an emissions inventory for the Valley and identified 20 known or suspected carcinogenic chemicals. Emissions and risk data for these chemicals were used to estimate the cancer risk, and in a more limited way, non-cancer risk to residents of the Valley. These modeling efforts were supplemented in March and April of 1986 by a limited effort to monitor the concentrations of 22 volatile organic compounds (VOCs) in the outdoor air (3), including 14 compounds from the initial list of 20 carcinogens. This study identified four chemicals, chloroform, 1,3 butadiene, ethylene oxide, and acrylonitrile, as having the greatest potential to adversely affect public health.

Public concern about health risks increased sharply after the widely publicized accident in Bhopal, India, in 1984, and the subsequent chemical release in Institute, West Virginia in 1985. Business and labor leaders, public officials, and other members of the community responded to these concerns by forming the National Institute for Chemical Studies (NICS). NICS' mandate was to identify and reduce risks posed by chemical plant operations, while minimizing impact on economic activity in the Valley. To achieve this goal, NICS began an effort to collect additional data about the nature and magnitude of health risk.

A series of discussions with scientific leaders and public officials led to a collaboration with investigators from the Harvard School of Public Health and the Energy and Environmental Policy

Center of Harvard's Kennedy School of Government to undertake an environmental health study in the Valley. NICS and the Harvard scientists developed a three-phase plan for investigating the health effects of chemical manufacturing. The first phase of the study focused on monitoring of outdoor air at Belle, Institute, South Charleston, and Hurricane to measure a) concentrations of selected VOCs, b) concentrations of particles, aerosol acidity, ozone, and nitrogen dioxide, and c) the elemental composition of fine particles. Because studies conducted by EPA scientists showed that many VOCs are found indoors (4), the Harvard investigators also carried out a small comparative study of indoor and outdoor VOC concentrations at 35 homes in the Valley. The laboratory analyses for the indoor/outdoor monitoring study were donated by Clayton Environmental Associates, Inc.

The second phase of the study is an epidemiologic investigation of health status and geographic variation in measures of health among approximately 9,500 third through fifth grade children attending schools in Kanawha County. Investigators from Marshall University and the University of New Mexico collaborated with the Harvard investigators to plan the epidemiologic study. Health data collection began in October, 1988. The third phase of the study will be designed to follow up on health issues that emerge during phase 2 and is still under development.

This report summarizes and interprets the outdoor and indoor VOC measurements collected during phase 1. These data are reported first because the VOC data are most directly relevant to the issue

of unique health risks that may occur in the Kanawha Valley through environmental exposure to chemicals. Subsequent reports will summarize the monitoring data for other pollutants and the results of the epidemiologic study.

METHODS

Overview

The protocol for outdoor air pollution monitoring was designed to gather information about outdoor concentrations of VOCs and other air pollutants in the Kanawha Valley area and to investigate whether VOC concentrations varied substantially within the Valley. The VOC concentrations were to provide exposure information relevant to the epidemiologic study planned for phase 2, and the information about geographic and temporal variation of VOC concentrations would determine whether 'high' and 'low' exposure groups could be identified within Kanawha County.

VOCs were chosen as the primary focus of outdoor monitoring because a) they are widely used in chemical manufacturing, b) previous studies in the Kanawha Valley have shown that VOCs are emitted and can be detected in the outdoor air, c) an accumulating literature has suggested that some of these compounds can induce toxic effects at low concentrations, and d) the Total Exposure Assessment Methodology (TEAM) studies conducted by the EPA (4) provide comparable data on VOC concentrations in other communities in the United States. Nineteen VOCs were monitored, representing a

composite list of chemicals emitted or previously detected in the Valley and those frequently detected in the TEAM studies.

Outdoor monitoring was conducted in Belle, Institute, South Charleston, and Hurricane. The first three locations were selected because of the potential for high concentrations and for comparison with EPA's KVTSS study. The fourth site was selected as a background site outside the Valley where concentrations were expected to be low. A monitoring van equipped to collect VOC samples and other monitoring data described below was used to collect data at the first three sites over a twelve-month period. At the beginning of each month, the van was moved to a new site in the Valley and operated for a fifteen-day sampling period. At the remote site in Hurricane, two daytime samples and one nighttime sample were collected at a fixed facility at the beginning, middle, and end of each fifeen-day period. All of the these samples were collected for twelve hours on Tenax cartridges.

A separate study of indoor concentrations of VOCs was conducted at 31 homes located in the Valley and 4 homes at distant sites outside the Valley in August, 1987. At each home, a three-week indoor VOC sample and a concurrent outdoor sample were collected using a passive sampling device described below. Only the indoor measurements from this substudy are discussed in this report. A more complete discussion of this work is provided in the manuscript included in the appendices to this report.

The methods for chemical and statistical analysis of the VOC samples are described below. Essentially, we estimated the mean and

median concentration of each monitored VOC at each outdoor site and for the sample of homes. We then compared the concentrations measured in this study to values obtained in previous monitoring and modeling studies in the Kanawha Valley and to concentrations measured elsewhere in the United States in the TEAM studies. We also estimated the cancer and noncancer health risk associated with the outdoor concentrations using methods recommended by EPA. Each aspect of study methodology is discussed in greater detail in subsequent sections.

Selection of Chemicals to be Monitored

A recent analysis by the National Enforcement Investigations Center (5) showed that industrial air emissions are a major source of chemical air pollution in the Kanawha Valley. The Kanawha Valley Toxic Screening Study (KVTSS) identified 20 known or suspected carcinogens from 450 chemicals appearing on an emissions inventory for Kanawha Valley prepared by the West Virginia Air Pollution Control Commission (6). These data and the findings from the TEAM studies suggested that measurement of VOC concentrations would provide the most comprehensive data on chemical air pollution in the Kanawha Valley that could be obtained with currently available technology. Moreover, a growing literature indicates that some VOCs can be toxic at low concentrations and the TEAM studies provided an opportunity to compare VOC concentrations in the Kanawha Valley with those in other U.S. communities. These considerations led to the decision to focus on the measurement of VOC concentrations.

Two technologies are presently available for monitoring the suite of VOCs of current interest. The Tenax method (4) was used in the TEAM studies and was widely accepted at the time this study was begun. The newer canister methodology had the potential for characterizing a larger group of VOCs, but was still somewhat experimental when this study began and not readily available. Thus, we chose the Tenax method. This again provided the opportunity to make comparisons with the TEAM studies. Having chosen Tenax sampling, we reviewed the data from the KVTSS and the TEAM study to identify VOCs that were likely to be present in the Valley and that were of potential health concern. This review led to the selection of the nineteen chemicals listed in Table 1. The limitations of the Tenax methodology required the exclusion of 1,3-butadiene, acrylonitrile, and ethylene oxide from our final list of target compounds. This exclusion implies that summary measures of health risk based on concentrations of the chemicals monitored in this study will be an underestimate of risk from all chemical air pollutants.

Selection of Monitoring Sites

The KVTSS (2) identified the Belle, Institute, and South Charleston areas as potential 'high exposure' areas. Although other areas were considered, these three were ultimately chosen for study. A fourth site in Hurricane, WV, was selected to provide data on VOC concentrations in areas distant from chemical facilities.

Selection of the monitoring site in each of these areas was determined by the availability of power and site security. Because the sites were intended to represent residential exposures, they were not chosen to capture maximum or plume impacts of nearby chemical facilities. We recognize that the abundance of local sources, the hilly terrain, and the variable meteorological conditions make it unlikely that a single site can adequately represent outdoor air pollution concentrations for a community.

The locations of the four sites are shown in Figure 1. The Belle site was located at 17th Street, near DuPont Avenue, next to the West Virginia State meteorological station. The Institute site was in a residential area adjacent to the West Virginia State College. The South Charleston site was on the grounds of the State Industrial Hygiene Building. The Hurricane site was in the back yard of a home on Route 34 in the Teays Valley area, about ten miles northwest of Nitro.

Outdoor Monitoring Methods

Monitoring at the three 'high exposure' sites was conducted from a mobile van provided by the EPA. The van was equipped with a Tenax VOC sampling unit and particle impactors to measure fine particles (particles with aerodynamic diameter < 2.5 μm), PM_{10} (particles with aerodynamic diameter < 10 μm), carbon, and acidity. Additional instruments and a meteorological tower gathered continuous measurements of nitrogen dioxide, ozone, light scattering by nephelometry, wind speed, wind direction, temperature, and dew

point. Monitoring at the Hurricane site was conducted from a fixed platform and was limited to three VOC measurements per month with coincident twelve-hour measurement of carbon and aerosol acidity, and measurement of six to eight day integrated mean concentrations of fine particles and PM_{10}. Monitoring at the Hurricane site began in May, 1987.

Outdoor monitoring was conducted over a one-year period beginning in April, 1987. The van was moved among the Valley locations at monthly intervals. Monitoring was conducted in Belle in April, July, and October of 1987 and in January, 1988; in South Charleston in May, September, and November, 1987, and February, 1988; and in Institute during the months of June, August, and December of 1987 and in March, 1988.

In each month, sampling was conducted over a fifteen-day consecutive period, beginning about the fifth of the month. Twenty twelve-hour VOC samples were collected in each period, including a daytime measurement (6:00 A.M. to 6:00 P.M. EST) each day and a nighttime sample on every third day. Two blanks and two control Tenax cartridges were sent to the field site each month as part of a quality assurance program. At the Hurricane site, two daytime samples and one nighttime sample were collected in each fifteen-day period, at the beginning, middle, and end of the sampling period.

Additional outdoor measurements were collected at the 35 homes participating in the indoor study described in the next section. Because the passive sampling and analysis methodology used in the indoor study is less sensitive than active Tenax sampling, many of

these outdoor samples had VOC concentrations below the limit of detection of the method. The outdoor data from the indoor/outdoor comparative study are not discussed in this report but are presented in the manuscript included in the appendices to the report. The appendices are available from the authors or NICS.

Indoor Monitoring Methods

Indoor and outdoor monitoring was conducted at 31 homes in the Belle, Institute, and South Charleston areas and in 4 additional homes located in remote areas outside of the valley during August of 1987. At each home, a passive air sampler (3M Organic Vapor Monitor (OVM)) was placed in the master bedroom and a second sampler was placed outside the home on the property but as far from the house and driveway as possible. The outdoor samplers were placed in a special shelter that contained no VOCs and kept the sampler dry. Ten percent of the samplers were used as field blanks. Additional information about study methods is provided in the appendices.

Chemical Analysis

The Tenax cartridges were analyzed by Gas Chromatography/Mass Spectroscopy (GC/MS) at the Research Triangle Institute using laboratory protocols established for the TEAM studies (4). The passive badges were analyzed by solvent extraction, followed by gas chromatography using a flame-ionization detector (FID), at Clayton Environmental Consultants, Inc. The GC/MS method provides much lower limits of detection than the FID method. Consequently, the

percentage of outdoor samples with a detectable VOC concentration was much larger with the active Tenax system than with the passive badges.

Statistical Analysis

Both mean and median concentrations are used in this report to characterize concentrations of VOCs at each outdoor site and the 35 indoor samples collected at homes participating in the indoor study. Mean values from the outdoor sites were used to describe average concentrations and in the risk analyses described below. Median concentrations were used only in comparisons with other studies that had used median values in published summaries. For most VOCs, some samples had concentrations below the limit of detection (LOD) of the method. We investigated the effect of these values on the analysis of the outdoor data by creating three copies of the data set, the first having a 0 for each value reported as below the LOD, the second with LOD/2, and the third with the LOD in place of those values. We then calculated the mean and standard error of each VOC at each location for each data set. The differences in the three analyses were negligible and only the results using LOD/2 are reported. The analyses of the indoor measurements used a statistical method to impute values below the LOD (see appendices). This method gave results close to those obtained by using LOD/2.

Two VOCs were detected in only 1 of the 261 Tenax samples. No mean values are reported for these VOCs and the contribution to risk is assumed to be 0.

Because some data from the TEAM studies were reported as median concentrations of VOCS, median values from this study were used in comparisons with those data. The medians were estimated by standard methods for all chemicals except when the VOC was detected in no more than one sample at a sampling location. In that case, the median was assumed to be 0. Otherwise, when more than 50% of the samples had nondetectable concentrations, the median is reported as LOD/2.

Comparisons among sites were based on one-way Analysis of Variance. Scheffe's method of multiple comparisons was used to identify pairs of sites that had significantly different mean concentrations.

The comparisons among sites and between indoor and outdoor measurements are subject to some very significant limitations. First, monitoring was not conducted concurrently at the four outdoor sites. Thus, differences between sites may be due to temporal differences in air pollution concentrations. Second, the indoor measurements and outdoor measurements were collected using different sampling methods, and comparative data on the two methods are quite limited. Third, the homes identified for the indoor monitoring study represent a sample of convenience rather than a random sample of Valley homes. Thus, tests of significance should be interpreted cautiously. Nevertheless, it seems appropriate to use these data as they are used in this report to draw broad conclusions about VOC concentrations in the Valley.

Evaluation of Health Risks

The determination of risk from a chemical requires information regarding human exposure, and evidence which describes a chemical's toxicity. If either of these components is lacking, a risk estimate cannot be generated. We measured the concentrations of 19 VOCs in outdoor air and combined these measurements with toxicity information to characterize health risks. Risk estimates were made only for those chemicals for which the EPA has developed adequate toxicity values. (Additional information not available through the EPA data base is described in the discussion.) Consequently, the risk evaluation that follows is a partial description of potential adverse health effects resulting from chemical exposures in the Kanawha Valley. It does not consider health risks when risk data are not available, nor for chemicals that were not monitored. Nevertheless, risk analysis can be of value in identifying chemicals of concern among those monitored.

Our approach to evaluating health risks followed the methodology set forth by the EPA in "The Risk Assessment Guidelines of 1986" (7). We evaluated only the risk resulting from exposures to outdoor air. Note that we assumed as others have that concentrations measured at the outdoor monitoring sites represent average outdoor air pollution exposures of residents of the communities. We evaluated two types of health risks - risks of systemic toxicity (non-cancer) resulting from chronic exposures and carcinogenic risks resulting from lifetime exposures to the target chemicals. For non-cancer effects, EPA assumes that there is a daily exposure level for

each chemical below which adverse health effects are not expected to occur. This threshold level is called the Reference Dose (RfD). This dose is usually derived from experimental data in animals, and extrapolations required for the prediction of the human threshold increase the uncertainty of the estimate.

When considering potential carcinogens, EPA's position is that there is no concentration that is without adverse effect, and that it is possible to estimate a plausible upper bound for the magnitude of risk for a given concentration. For these chemicals, EPA's Cancer Assessment Group (CAG) has generated Unit Risk estimates which are based upon mathematical models that have been applied to experimental data in animals. The Unit Risk is defined as "the upper-bound excess lifetime cancer risk estimated to result from continuous exposure to an agent at a concentration of 1 μg/L in water or 1 $\mu g/m^3$ in air". Because the multi-stage model of carcinogenesis used in risk estimation implies that risk is a linear function of exposure at low doses, the risk for a group of exposed individuals is a multiple of the mean of the concentrations to which they are exposed. Thus, we have used the mean concentrations measured at each site rather than the median values in risk calculations.

The RfD values applied in this analysis are given in Table 2. RfD's are available for approximately two-thirds of the chemicals we studied. We used inhalation RfD's when they were available and oral RfD's otherwise. Although the use of route-specific toxicity values is preferable, the use of oral RfD's when assessing inhalation risk

is permitted under EPA guidelines with the understanding that the extrapolation between routes of exposure increases the uncertainty inherent in risk assessment.

Non-Carcinogenic Risk Estimates for Individual VOCs

One method of measuring the health risk of a chemical is to compare actual exposures to Reference Doses. Guidelines in the Superfund Public Health Evaluation Manual (8) suggest that a Chronic Daily Intake (CDI) be calculated and that the ratio of the CDI to the RfD be used to measure risk.

The CDI is defined as

$$\text{CDI (mg/kg/day)} = \text{concentration (mg/m}^3\text{)} \times \frac{20\ \text{m}^3/\text{day}}{70\ \text{kg}}$$

where concentration is the mean concentration measured in outdoor samples, 70 kg is the weight of an average male adult, and 20 cubic meters is the volume of air breathed per day. The CDI/RfD ratio is then defined as

$$\text{CDI/RfD ratio} = \text{CDI (mg/kg/day)/RfD (mg/kg/day)}$$

If the ratio exceeds unity, then the outdoor exposure estimated by assuming that an individual is exposed to the mean concentration continuously exceeds the recommended exposure.

Ratios were calculated by site for each chemical. For the two VOCs detected in only one sample, 0 was used in risk calculations. For all other VOCs, values below the limit of detection (LOD) were replaced by LOD/2 and the mean was calculated in the usual way.

Carcinogenic Risk of Individual VOCs

The Unit Risks (Table 2) are the upper limits of 95% confidence intervals for the probability of cancer if an individual is exposed to 1 $\mu g/m^3$ of a carcinogen for a lifetime (70 years). Because these are upper bound estimates, the actual risks will rarely exceed these values and will frequently be somewhat lower (possibly zero, although the utility of the confidence intervals is limited somewhat by larger uncertainties such as extrapolation from animal to man). A Unit Risk of 1.0×10^{-4} (one times ten to the minus fourth power) means that there is one chance in ten thousand that a person who is exposed to 1 $\mu g/m^3$ of the chemical over a lifetime will develop cancer. Or, if a population of 10,000 is exposed to 1 $\mu g/m^3$ for their lifetimes, one person will develop cancer. Individual lifetime cancer risks from a chemical at a given exposure can be calculated by multiplying the exposure by the Unit Risk for that chemical. For example, if a hypothetical compound has a concentration in air of 2.5 $\mu g/m^3$ and a Unit Risk Factor of 1.0×10^{-4} per $\mu g/m^3$, the Lifetime Individual Risk equals $(2.5\ \mu g/m^3) \times (1.0 \times 10^{-4}) = 2.5 \times 10^{-4}$. We performed these calculations for the subset of chemicals having EPA unit risk values; benzene, carbon tetrachloride, chloroform, 1,2-dibromoethane, 1,2-dichloroethane, styrene, tetrachloroethylene, and trichloroethylene.

RESULTS

Outdoor VOC concentrations

Mean VOC concentrations at the four outdoor monitoring sites are displayed in Panel A and inter-site comparisons based on One-Way Analyses of Variance are given in Panel B of Table 3. Two VOCs (1,2-dibromoethane and 1,2-dichloroethane) were detected in only one of the 261 Tenax samples. No means are given for these compounds. All other compounds were detected in 10 or more of the 261 samples, and values below the limit of detection (LOD) were replaced by LOD/2 for calculation of the mean. Two chemicals, carbon tetrachloride and chloroform, were elevated at the Belle site and a third, tetrachloroethylene, was elevated at the South Charleston site. Surprisingly, many VOCs had significantly higher concentrations at the Hurricane site. These included benzene, p-dichlorobenzene, ethylbenzene, 4-ethyltoluene, toluene, 1,2,4-trimethylbenzene, and the xylenes.

Although mean concentrations are more appropriate than medians for cancer risk assessment, they also tend to be larger than medians, especially when the sample contains several high values. Site-specific median concentrations are given in the appendices to this report. Descriptive statistics for each chemical at each monitoring location and for all locations combined are also provided in the appendices.

Mean values of daytime and nighttime samples differed significantly in only one case. In Institute, the mean nighttime

benzene concentration (4.9 $\mu g/m^3$) was significantly higher than the daytime mean (3.6 $\mu g/m^3$). Average concentrations during four quarter-years of sampling were compared using the Analysis of Variance. Only 11 comparisons identified statistically significant seasonal variation, and these did not suggest clear patterns of temporal variation. Additional information about seasonal variation and daytime to nighttime differences is provided in the appendices.

Comparison of Indoor and Outdoor Concentrations

Table 4 compares mean outdoor VOC concentrations from the combined data from all four outdoor sites to mean indoor concentrations for the 35 homes participating in the indoor study. Two VOCs (chloroform and toluene) could not be measured in the indoor samples because of interference arising from the extraction method. Mean indoor concentrations were higher than mean outdoor concentrations for every other chemical except styrene. For some VOCs (chlorobenzene, decane, p-dichlorobenzene, 1,2,4-trichlorobenzene, and trichloroethylene), the ratios of indoor to outdoor mean concentrations exceeded 20. Most ratios fell between 1 and 10. A parallel analysis based on median indoor and outdoor concentrations, along with comparisons of these ratio of medians to values obtained in the TEAM studies, is provided in the appendices to this report.

This finding may seem somewhat surprising, but it is consistent with the pathbreaking TEAM studies (4) carried out in other parts of the country. These studies found that VOCs are present in many

products present routinely in the home, including wall board, new fabrics, dry cleaning fluids, and cleaning solvents.

Comparison with Results from the KVTSS

Table 5 compares mean VOC concentrations obtained in the current study to the range of values detected by Fitz-Simons et al (3) in January, 1987. Fitz-Simons et al collected 24-hour integrated samples in Belle and Institute and measured concentrations of fourteen target chemicals identified by the KVTSS and eight additional compounds. The mean concentrations from the current study fall within the range of concentrations measured by Fitz-Simons et al for all compounds measured in both studies. The agreement between the two sets of measurements is remarkable considering that the data were collected in different time periods. Although 1,2-dibromoethane was one of the target compounds in the earlier study, it was detected in only four samples in that study and in one of the samples collected in the current study.

The KVTSS used emissions data and meteorological modeling to estimate concentrations of VOCs in the Kanawha Valley. The modeling estimates compare well with the measured concentrations when the model predicted appreciable concentrations, but differ substantially from measured values when the model predicted low concentrations (Table 6). The differences in Hurricane are especially noteworthy. The grid point nearest to Hurricane in the EPA model was at Nitro. Hurricane is slightly west of Nitro and more distant from local industrial sources. We expected, therefore, that EPA predictions

for Nitro, which has many local sources, would be higher than measured concentrations at Hurricane. In fact, predicted concentrations at Nitro were several orders of magnitude lower than the observations in Hurricane.

There are many possible explanations for these results. The EPA model requires accurate emissions data for hundreds of local sources. The emissions data will inevitably be incomplete and are typically averaged over long time periods. Moreover, the EPA analysis may have substantially underestimated the VOC emissions in the vicinity of Nitro (9). The complex terrain and meteorological conditions in the Valley could not be fully represented in the EPA model. Another possibility is that the measurements at Hurricane were affected by a local source such as a roadway that does not affect the area as a whole. Finally, it is important to remember that the two studies covered different time periods.

Comparisons to TEAM Studies

The TEAM studies collected outdoor measurements in two industrial areas, Bayonne, NJ and Contra Costa, CA, in two rural areas in North Dakota and North Carolina, and in Los Angeles on two occasions. Twelve-hour samples were collected for 20 target compounds between 1981 and 1984 using a Tenax sampling and laboratory analysis protocol similar to that used in this study.

Table 7 gives median concentrations for chemicals that were reported in both studies. For many of the chemicals, concentrations in the Kanawha Valley are comparable to those measured in other

industrialized areas and lower than those observed in Los Angeles. Carbon tetrachloride and chloroform are notable exceptions, with medians two to five times higher than TEAM values in NJ and CA. The opposite is true for tetra- and trichloroethylene, which are lower in the Valley than in the nonindustrial locations investigated in the TEAM studies. Most other VOC levels, were higher in Kanawha Valley than in those rural areas.

Comparisons of indoor concentrations measured in the two studies are given in Table 8. For most chemicals, the median indoor concentrations in the Kanawha Valley are comparable to those found in homes elsewhere in the United States. Indoor medians for benzene, tetrachloroethylene, and 1,1,1-trichloroethylene were lower in this study than in TEAM studies in rural areas. Decane concentrations were relatively high in the current study. Because the TEAM study used Tenax sampling in its indoor studies while the current study used passive badges, these comparisons must be interpreted cautiously.

Evaluation of Health Risk

The CDI/RfD ratios for carbon tetrachloride and chloroform (only in Belle), the only VOCs with ratios greater than .10 among those monitored, are given in Table 9. A complete set of CDI/RfD ratios is provided in the appendices. RfD values were available for only 12 of the monitored VOCs.

The cancer risk calculations for each chemical and each site are provided in the appendices. The estimated lifetime cancer risk

exceeded one in ten thousand for only three chemicals, benzene, carbon tetrachloride, and chloroform. These risks are given in Table 10. We also calculated a cumulative risk by assuming that the carcinogenic risks of individual compounds in a mixture are additive and summing the risks of individual chemicals for each site.. Table 10 also gives the estimated excess lifetime individual risk for each site.

DISCUSSION

This study demonstrates that many Volatile Organic Compounds can be detected in outdoor air in the Kanawha Valley. Geographic comparisons among sites are qualified by the fact that measurements at three of the sites were obtained in different months using a single monitoring van. Nevertheless, these comparisons identify chloroform and carbon tetrachloride as significantly elevated in Belle. Surprisingly, several VOCs were significantly elevated at the Hurricane site. Some of these VOCs, including benzene and the xylenes, are found in automobile exhaust fumes. Thus, further investigation of the Hurricane area should focus on the comparability of the monitoring site to other locations in Hurricane.

Given the limited duration of the monitoring study, the excellent agreement between our results and the monitoring component of the Kanawha Valley Toxics Screening Study provides reassuring evidence that the concentrations measured at Belle, Institute, and

South Charleston during this study are representative of longer term average concentrations in the Valley. Our indoor measurements suggest, however, that most VOCs are present in higher concentrations indoors than outdoors. This is consistent with the TEAM studies and is not surprising, because many of these VOCs can be found in common household products.

For several reasons, our risk assessment focused on the health risks of exposure to outdoor air pollution. First, the impetus for mounting the study was the need to investigate the health effects of chemical manufacturing. Second, the sample of 35 homes selected for the indoor/outdoor study was a sample of convenience and rather small. Third, additional methodologic issues arise in estimating the risk due to indoor exposure, including the need to consider the number of hours spent at home.

Estimates of the risk of cancer and other health events based on methodology recommended by EPA showed that concentrations of VOCs are sufficiently high to raise the possibility of both cancer and other health effects. Concentrations of carbon tetrachloride and chloroform approached, and in one case, exceeded the EPA reference dose for noncancer health effects.

Upper-bound estimates of the excess cancer risks associated with the VOC measurements obtained in this study varied from 12 per one hundred thousand persons to 34 per one hundred thousand persons exposed for a lifetime. The true risks are expected to be smaller than these estimates and may be 0. The higher of these values would

imply an excess incidence of about one case per year in the population of Kanawha County, or about 0.3% of the annual cancer mortality rate. Nationally, annual cancer incidence rates are about twice as large as cancer mortality rates, implying that the estimated risks represent an even smaller percentage of cancer incidence rates in the Kanawha Valley. Thus, the estimated excess risk, while not negligible, is small.

These estimates of health risks based on toxicity values have some important limitations. First, some of the toxicity values needed to estimate the risks of exposure to these 19 VOCs are not available in EPA data bases. We return to this point in the next paragraph. Second, some potential cancer-causing chemicals, especially acrylonitrile, 1,3-butadiene, and ethylene oxide, could not be studied using the Tenax sampling technique employed in this study. Third, the EPA toxicity values are based primarily on animal studies and the toxicity of chemicals may be different for animals and human beings. Finally, variation in emissions and the topography and meteorology of the Valley may cause substantial temporal and spatial variation in concentrations, so that the average concentrations at fixed sites do not represent the risk to maximally exposed individuals.

Because the EPA data base does not include toxicity values for all of the VOCs monitored in this study, we used risk values reported by other scientists to quantify the risk contributed by these chemicals. Tancrede et al (11) reported cancer potency estimates for over 50 compounds. Their estimates were generated

from National Cancer Institute animal bioassay data when available, and otherwise from bioassay data for chemicals judged to to be chemically similar. Table 11 compares EPA unit risk estimates with unit risks reported by Tancrede et al. Note that, for chemicals included in both data bases, the EPA values are consistently larger. This pattern is due to methodologic differences. The EPA estimates are derived by using upper bound estimates from the bioassay analysis and then adjusting the values upward to reflect the assumption that humans are more sensitive than rodents. Tancrede et al use median potency estimates and then assume equal sensitivity for humans and rodents. The EPA potency value for trichloroethylene is lower because of differences in interpretation of available data. This comparison underscores the uncertainty associated with toxicity values obtained by any method.

We utilized the unit risk estimates of Tancrede et al to evaluate the contribution to risk of the chemicals not included in the original risk assessment. When the Tancrede values were used to calculate total risk for the chemicals having EPA unit risk values, the estimated total cancer risk for the mean concentrations in the total of 261 samples was 2.8×10^{-5}. Inclusion of the additional chemicals having risk values in the Tancrede data set increased the total risk to 3.3×10^{-5}, an increase of 16%. Although the total risk obtained from the Tancrede values is an order of magnitude lower than the value obtained using EPA unit risk values (1.9×10^{-4}), we believe that it is reasonable to conclude that the

observed excess risk contributed by the additional chemicals (16%) is a reasonable estimate of their contribution to total risk. Thus, we conclude that most of the total risk can be attributed to the chemicals for which EPA unit risk values are available.

To further explore non-cancer health hazards associated with chemicals without RfD values, we utilized occupational exposure limits, adjusting them downward to reflect 168 hours of exposure per week rather than 40 hours and to incorporate a safety factor of 100. These adjusted values are displayed in Table 12.

When we compared mean concentrations to these adjusted values, we found that chloroform and carbon tetrachloride again had the highest ratios of mean concentration to toxicity value. Among the other chemicals, the ratio of exposure to adjusted limit approached 0.1 only for benzene (0.07). Occupational limits have not been established for decane and 4-ethyltoluene.

Further scientific activities sponsored by NICS will focus on direct assessment of the health of the community. Investigators from Harvard University, Marshall University, and the University of New Mexico have already begun an assessment of health of preadolescent schoolchildren based on questionnaire data gathered through the Kanawha County Schools. NICS is also working to develop a cancer registry that could, over time, provide information about cancer incidence in Kanawha County. Federal and State EPA offices are also pursuing studies to develop improved estimates of short-term and chronic chemical exposures of persons living in different parts of the Valley, along with the potential health risk.

Although no single study is likely to completely determine whether residents of the Kanawha Valley are at increased health risk because of emissions from local industry, each of these studies will provide additional information that can guide these industries and health officials in their efforts to reduce health risks when they can be identified.

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Table 1

Measured VOCs with Synonyms

Name	Synonyms
Benzene	
Carbon tetrachloride	Tetrachloromethane Perchloromethane
Chlorobenzene	Monochlorobenzene Phenyl chloride
Chloroform	Trichloromethane
Decane	
1,2-Dibromoethane	Ethylene dibromide
p-Dichlorobenzene	1,4-Dichlorobenzene
1,2-Dichloroethane	Ethylene dichloride Ethylene chloride
Ethylbenzene	Phenylethane
4-Ethyltoluene	
1,1,1-Trichloroethane	Methylchloroform Chloroethane
Styrene	
Tetrachloroethylene	Tetrachloroethene Perchloroethylene
Toluene	
1,2,4-Trichlorobenzene	
Trichloroethylene	Trichloroethene Ethylene trichloride
1,2,4-Trimethylbenzene	
m,p-Xylene	
o-Xylene	1,2-Dimethylbenzene

Table 2

EPA Toxicity Values for Monitored Compounds

	RfD (route) (mg/kg/day)		Upper Bound Unit Risk (µg/kg/day)	
Benzene	NA[1]		7.4×10^{-6}	E
Carbon tetrachloride	0.0007 (oral)	I	1.5×10^{-5}	E/I
Chlorobenzene	0.029 (inhal)	I	NA	
Chloroform	0.01 (oral)	I	2.3×10^{-5}	E
Decane	NA		NA	
1,2-Dibromoethane	NA		2.2×10^{-4}	E
p-Dichlorobenzene	0.014 (inhal)	E	NA	
1,2-Dichloroethane	NA		2.6×10^{-5}	I
Ethylbenzene	0.10 (inhal)	E	NA	
4-Ethyltoluene	NA		NA	
Styrene	0.2 (oral)	I	5.7×10^{-7}	E
Tetrachloroethylene	0.02 (inhal)	E	4.8×10^{-7}	S
Toluene	4.6 (inhal)	E	NA	
1,2,4-Trichlorobenzene	0.0026 (inhal)	E	NA	
1,1,1-Trichloroethane	0.091 (inhal)	E	NA	
Trichloroethylene	NA		1.3×10^{-6}	E/I
1,2,4-Trimethylbenzene	NA		NA	
m,p-Xylene	1.8 (inhal)	E	NA	
o-Xylene	1.8 (inhal)	E	NA	

[1]NA indicates that the toxicity value is not available.

Sources:
- E: Personal Communication from EPA's Environmental Criteria and Assessment Office, Cincinnati, Ohio, June, 1988.
- I: EPA's Integrated Risk Information Systems (IRIS) chemical files.
- S: USEPA Superfund Public Health Evaluation Manual (8)

Table 3

Mean Outdoor VOC Levels in the Kanawha Valley
by Sampling Location (in $\mu g/m^3$) and
Analysis of Variance Comparing Sites

Panel A

Compound	Concentration in Air ($\mu g/m^3$)			
	Belle	Hurricane	Institute	S. Charleston
Benzene	4.18	8.13	3.92	5.00
Carbon tetrachloride	2.80	1.25	1.49	1.62
Chlorobenzene	0.07	0.12	0.10	ND
Chloroform	11.48	1.90	3.00	3.27
Decane	0.71	0.84	0.67	0.78
1,2-Dibromoethane	ND	ND	ND	ND
p-Dichlorobenzene	0.14	0.52	0.10	0.23
1,2-Dichloroethane	ND	ND	ND	ND
Ethylbenzene	1.62	2.73	1.18	1.24
4-Ethyltoluene	1.11	2.88	0.96	0.97
Styrene	2.62	1.86	1.63	2.38
Tetrachloroethylene	0.28	0.22	0.42	0.77
Toluene	7.62	10.71	6.70	5.72
1,2,4-Trichlorobenzene	0.29	0.82	ND	0.43
1,1,1-Trichloroethane	2.70	2.03	2.42	2.73
Trichloroethylene	0.21	0.31	0.19	0.15
1,2,4-Trimethylbenzene	1.62	4.68	1.48	1.96
m,p-Xylene	4.37	10.13	3.29	3.40
o-Xylene	1.78	4.30	1.27	1.41

ND indicates that the VOC was detected in at most one sample.

Panel B

Compound	ANOVA p-value	Ranking[1]
Benzene	< .001	H > B,I,S
Carbon tetrachloride	< .001	B > H,I,S
Chloroform	< .001	B > H,I,S
p-Dichlorobenzene	.008	H > B,I
Ethylbenzene	< .001	H > B,I,S
4-Ethyltoluene	< .001	H > B,I,S
Tetrachloroethylene	< .001	S > B,I,H
Toluene	.04	H > S
1,2,4-Trimethylbenzene	< .001	H > B,I,S
m,p-Xylene	< .001	H > B,I,S
o-Xylene	< .001	H > B,I,S

[1]This column identifies significant differences among site means.
B = Belle, H = Hurricane, I = Institute, S = South Charleston.

Table 4

Mean Indoor and Outdoor VOC Concentrations
Measured in the Kanawha Valley ($\mu g/m^3$)
and Ratios of Indoor to Outdoor Means (I/O)[1]

Compound	Outdoor	Indoor	I/O
Benzene	4.81	6.72	1.4
Carbon tetrachloride	1.90	10.11	5.3
Chlorobenzene	0.08	16.50	206.3
Chloroform	5.55	I	---
Decane	0.74	20.62	27.9
1,2-Dibromoethane	ND	6.06	---
p-Dichlorobenzene	0.20	45.50	227.5
1,2-Dichloroethane	ND	20.85	---
Ethylbenzene	1.52	5.35	3.5
4-Ethyltoluene	1.24	3.02	2.4
Styrene	2.17	1.19	0.5
Tetrachloroethylene	0.45	1.33	3.0
Toluene	7.18	I	---
1,2,4-Trichlorobenzene	0.32	12.76	39.9
1,1,1-Trichloroethane	2.55	19.36	7.6
Trichloroethylene	0.20	9.64	48.2
1,2,4-Trimethylbenzene	2.04	11.52	5.6
m,p-Xylene	4.47	17.73	4.0
o-Xylene	1.83	6.48	3.5

[1]Outdoor measurements were collected at four outdoor sites over a twelve-month period using Tenax cartridges. Indoor measurements were collected in August, 1987 at 35 homes using OVM badges. ND indicates that the compound was not detected in outdoor sampling. I indicates that the compound could not be measured in indoor sampling because of interference from the extraction method.

Table 5

Comparison of Mean VOC Concentrations ($\mu g/m^3$) with EPA Monitoring Data for the Kanawha Valley

	Harvard[1] (mean)	EPA[2] (range)
Benzene	4.81	1.28 - 5.25
Carbon tetrachloride	1.90	0.63 - 10.73
Chlorobenzene	0.08	0 - 1.48
Chloroform	5.55	0 - 29.82
1,2-Dichloroethane	ND	0 - 0.81
Ethylbenzene	1.52	0.73 - 15.37
4-Ethyltoluene	1.24	0.78 - 2.24
Styrene	2.17	0.68 - 19.87
Tetrachloroethylene	0.45	0 - 1.90
Toluene	7.18	1.97 - 65.0
1,1,1-Trichloroethane	2.55	1.09 - 3.92
Trichloroethylene	0.20	0 - 0.45
1,2,4-Trimethylbenzene	2.04	0.88 - 4.48
m,p-Xylene	4.47	1.98 - 23.87
o-Xylene	1.83	0 - 3.65

[1]ND indicates that the compound was detected in no more than one outdoor sample.

[2]Source: Fitz-Simons, Lumpkin and McClenny (3).

Table 6

Comparison of Mean Measured Outdoor VOC Concentrations with EPA Modeling Estimates (in $\mu g/m^3$)

		Harvard (mean)	EPA[1] (mean)
BELLE	(EPA site 4-2)		
	Carbon Tetrachloride	4.18	2.59
	Chloroform	11.48	8.12
HURRICANE	(EPA site 1-1, NITRO)		
	Benzene	8.13	0.00003
	Carbon Tetrachloride	1.25	0.00003
	Chloroform	1.90	0.00003
	Trichloroethylene	0.31	1.07
INSTITUTE	(EPA site 2-5)		
	Benzene	3.92	0.004
	Chloroform	3.00	4.67

[1]Source: The Kanawha Valley Toxics Screening Study (2).

Table 7

Comparison of Median Outdoor VOC Concentrations ($\mu g/m^3$)

with Median Overnight Outdoor VOC Values from the TEAM Studies

	Kanawha Valley (n=261)	TEAM[1] CC (n=10)	NJ (n=86)	ND (n=5)	NC (n=5)	LA[2] (n=24)	LA[3] (n=23)
Benzene	3.70	1.7	6.7	-	0.4	19	2.5
Carbon Tetrachloride	1.46	0.33	0.81	<0.92	0.1	0.65	0.65
Chloroform	2.50	0.62	0.66	<0.1	0.14	0.62	0.03
Decane	0.66	1.9	-	-	-	2.6	0.48
m,p-Dichlorobenzene	0.02 (p- only)	0.25	1.2	<0.14	0.4	1.7	0.50
Ethylbenzene	1.01	0.66	2.9	<0.06	0.3	11	1.8
Styrene	1.30	0.23	0.61	-	0.1	4.2	0.57
Tetrachloroethylene	0.11	0.25	2.6	0.69	0.7	7.4	1.3
1,1,1-Trichloroethane	2.25	2.1	4.5	<0.1	-	29	4.6
Trichlorethylene	0.04	0.12	1.3	<0.16	0.2	0.72	0.03
m,p-Xylene	2.72	1.3	9.9	<0.1	0.6	30	7.3
o-Xylene	1.12	0.39	2.9	<0.1	1.5	13	1.9

[1]Source: The Total Exposure Assessment Methodology (TEAM) Study (4).

[2]Measurements made in February 1984.

[3]Measurements made in May 1984.

Table 8

Comparison of Median Indoor VOC Concentrations ($\mu g/m^3$)

with Median Overnight Indoor Concentrations from the TEAM Studies

	Kanawha Valley[1] (n=35)	TEAM[2] CC (n=71)	NJ (n=347)	ND (n=24)	NC (n=23)	LA[3] (n=112)	LA[4] (n=50)
Benzene	2.06	4.4	15	-	11	15	4.4
Carbon Tetrachloride	3.31	0.7	1.5	0.8	1.3	0.65	0.65
Decane	11.09	0.7	-	-	-	2.0	1.1
m,p-Dichlorobenzene	1.86(p- only)	0.5	3.8	1.7	3.4	2.6	0.84
Ethylbenzene	2.68	1.9	6.3	2.8	2.2	7.9	2.5
Styrene	1.28	0.7	1.8	-	0.8	2.8	0.84
Tetrachloroethylene	1.32	1.8	6.4	4.4	2.8	8.3	1.9
1,1,1-Trichloroethane	5.15	4.3	17	37	26	26	7.2
Trichlorethylene	2.57	0.3	2.2	0.7	1.0	1.1	0.34
m,p-Xylene	7.27	6.2	14	8.4	6.4	22	8.7
o-Xylene	2.56	2.2	4.9	3.5	3.7	9.7	2.0

[1]Source: Indoor/Outdoor Measurements of Volatile Organic Compounds in the Kanawha Valley, West Virginia (Appendix A to this report).

[2]Source: The Total Exposure Assessment Methodology (TEAM) Study (4).

[3]Measurements made in February 1984.

[4]Measurements made in May 1984.

Table 9

The Ratio of Chronic Daily Intake (CDI) to EPA Reference Dose (RfD) for VOCs with Ratios of 0.10 or Greater

Site	VOC	CDI/RfD[1]
BELLE	Carbon tetrachloride	1.10
	Chloroform	0.33
HURRICANE	Carbon tetrachloride	0.51
INSTITUTE	Carbon tetrachloride	0.61
S.CHARLESTON	Carbon tetrachloride	0.66

[1]The CDI/RfD is calculated for each compound by dividing the estimated chronic daily intake (CDI) by the EPA Reference Dose (RfD) for that compound. The RfD is an estimate of a daily exposure which is not anticipated to cause deleterious effects during a lifetime. The CID/RfD ratio could not be calculated for benzene because the toxicity value has not been determined.

Table 10

Estimated Cancer Risks Larger than One in Ten Thousand (1×10^{-5}) and the Sum of the Estimated Cancer Risks for all VOCs[1]

	VOC	Excess Lifetime Individual Risk[2]
BELLE	Benzene	3.1×10^{-5}
	Carbon tetrachloride	4.2×10^{-5}
	Chloroform	2.6×10^{-4}
	TOTAL	3.4×10^{-4}
HURRICANE	Benzene	6.0×10^{-5}
	Carbon tetrachloride	1.9×10^{-5}
	Chloroform	4.4×10^{-5}
	TOTAL	1.2×10^{-4}
INSTITUTE	Benzene	2.9×10^{-5}
	Carbon tetrachloride	2.2×10^{-5}
	Chloroform	6.9×10^{-5}
	TOTAL	1.2×10^{-4}
S. CHARLESTON	Benzene	3.7×10^{-5}
	Carbon tetrachloride	2.4×10^{-5}
	Chloroform	7.5×10^{-5}
	TOTAL	1.4×10^{-4}

[1]Cancer risks were summed only over VOCs for which the EPA provides Unit Risk values.

[2]The EPA method gives upper bound estimates of the Unit Risk, the excess cancer risk estimated to result from a lifetime of continuous exposure to an agent at a concentration of 1 $\mu g/m^3$ in air. The actual cancer risks are likely to be smaller than these values and may be 0.

Table 11

Comparison of EPA and Tancrede *et al* Unit Risk Values (in $\mu g/m^3$)

Compound	EPA Unit Risk Value	Tancrede *et al* Unit Risk Value
Benzene	7.4×10^{-6}	2.9×10^{-7} (h)[1]
Carbon tetrachloride	1.5×10^{-5}	1.1×10^{-6} (b)
Chlorobenzene	NA[2]	4.0×10^{-7} (b)
Chloroform	2.3×10^{-5}	4.0×10^{-6} (b)
Decane	NA	8.9×10^{-9} (a)
1,2-Dibromoethane	2.2×10^{-4}	NA
p-Dichlorobenzene	NA	1.9×10^{-7} (b)
1,2-Dichloroethane	2.6×10^{-5}	3.7×10^{-5} (b)
Ethylbenzene	NA	9.7×10^{-8} (b)
4-Ethyltoluene	NA	NA
Styrene	5.7×10^{-7}	5.4×10^{-7} (b)
Tetrachloroethylene	4.8×10^{-7}	2.6×10^{-6} (b)
Toluene	NA	2.6×10^{-7} (b)
1,2,4-Trichlorobenzene	NA	1.0×10^{-6} (a)
1,1,1-Trichloroethane	NA	4.9×10^{-9} (b)
Trichloroethylene	1.3×10^{-6}	4.9×10^{-7} (b)
1,2,4-Trimethylbenzene	NA	1.3×10^{-7} (a)
m,p-Xylene	NA	2.8×10^{-7} (b)
o-Xylene	NA	2.8×10^{-7} (b)

[1]Method: a: Estimated from bioassay data for similar chemicals
b: Estimated from bioassay data
c: Estimated from human epidemiologic data

[2]NA indicates that the toxicity value is not available

Table 12

Comparison of EPA RfDs with Adjusted Occupational Exposure Limits

	EPA RfD (mg/kg/day)	Adjusted TLV (or PEL)[1] (mg/kg/day)
Benzene	NA[2]	0.021
Carbon tetrachloride	0.0007	0.021
Chlorobenzene	0.029	0.24
Chloroform	0.01	0.035
Decane	NA	NA
1,2-Dibromoethane	NA	0.11 (PEL)
p-Dichlorobenzene	0.014	0.31
1,2-Dichloroethane	NA	0.03
Ethylbenzene	0.10	0.3
4-Ethyltoluene	NA	NA
Styrene	0.2	0.15
Tetrachloroethylene	0.02	0.23
Toluene	4.6	0.26
1,2,4-Trichlorobenzene	0.0026	0.028
1,1,1-Trichloroethane	0.091	1.3
Trichloroethylene	NA	0.19
1,2,4-Trimethylbenzene	NA	NA
m,p-Xylene	1.8	0.3
o-Xylene	1.8	0.3

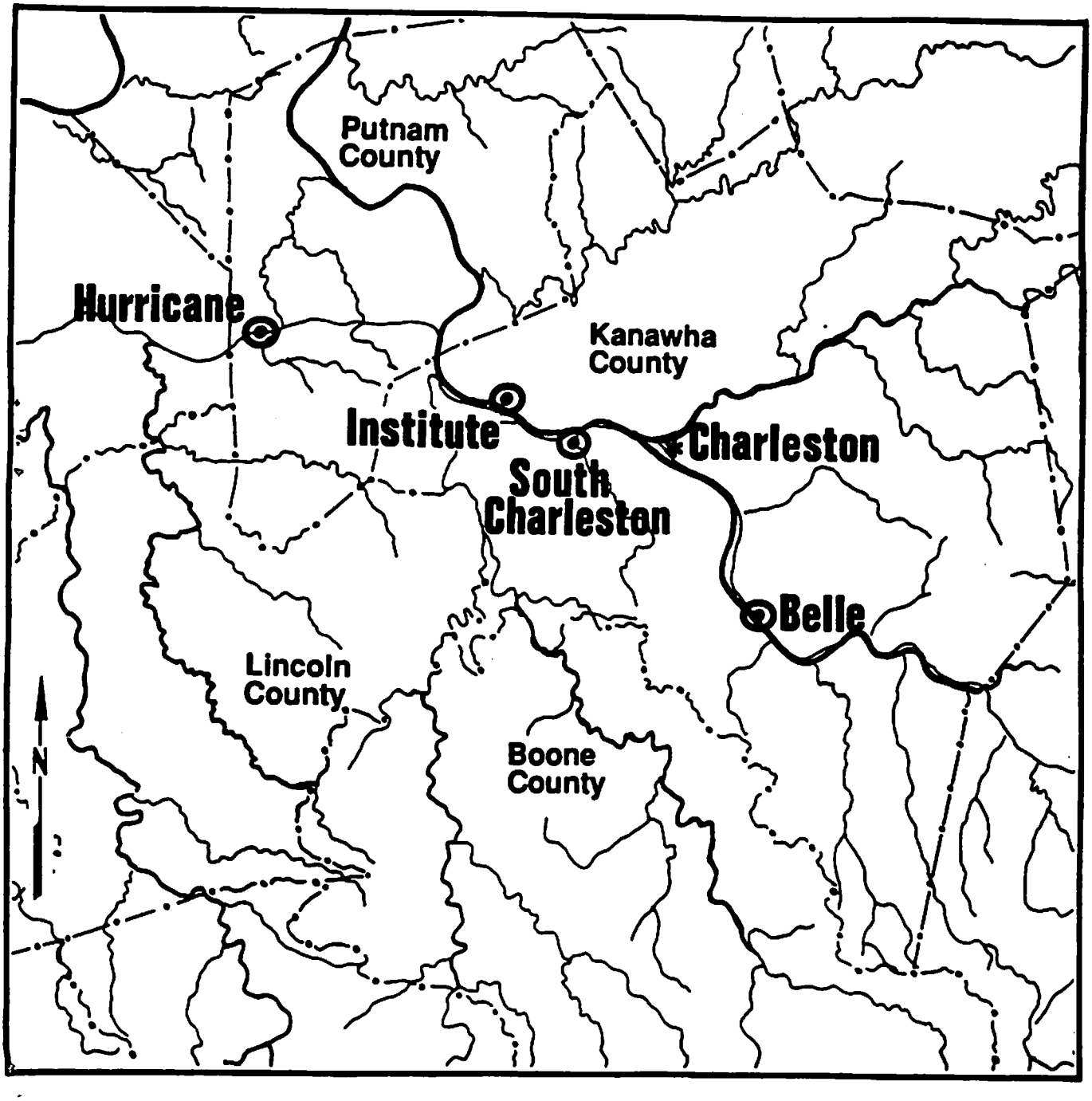
[1]All values are adjusted Threshhold Limit Values except where indicated by PEL, which is the adjusted NIOSH Permissible Exposure Limit

[2]NA indicates that the toxicity value is not available

Figure Legend. Map of the Kanawha Valley showing the locations of the four Tenax monitoring sites. (Provided by Ms. Ava Zeitz, West Virginia Department of Natural Resources.)

MONITORING SITE LOCATIONS

Monitoring Sites



10 0 10 20 30 40 Miles

10 0 10 20 30 40 50 Kilometres