Evaluating the Health Significance of Hazardous Air Pollutants Using Monitoring Data

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SYNOPSIS

Objective. Though many contaminants are released into the atmosphere, in the US only six air pollutants—ozone, particulate matter, sulfur dioxide, carbon monoxide, nitrogen dioxide, and lead—are closely monitored and carefully assessed for health significance. Other pollutants, even if highly toxic, are neither widely monitored nor routinely assessed at the national level. The goal of this study was to analyze the availability of information needed to characterize the health significance of hazardous air pollutants, focusing on urban areas in California.

Methods. The authors compared different approaches to identifying which contaminants should be considered hazardous air pollutants of potential health concern; reviewed the availability of toxicity values for these pollutants; and analyzed the usefulness of air monitoring data from California agencies for determining populations risks, by comparing method detection limits with health benchmarks.

Results. Approaches to identifying air contaminants of possible health concern differ. Toxicity values are not available for many hazardous air pollutants, including those identified in the Clean Air Act. In California, monitoring data are available for many, though not all, pollutants of concern. Monitoring methods for several pollutants do not have adequate sensitivity to detect all relevant concentrations.

Conclusion. The information necessary to fully assess the health significance of hazardous air pollutants is not currently available.

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Many hundreds of toxic compounds are released into the atmosphere as a result of human activities. Industrial facilities, for example, are required to report releases of approximately 550 chemicals and compounds under the reporting requirements for the Environmental Protection Agency's (EPA's) Toxics Release Inventory.¹

A great deal of effort has been devoted to monitoring ambient concentrations of the six air pollutants defined by the EPA as criteria pollutants-ozone, particulate matter, carbon monoxide, sulfur dioxide, nitrogen dioxide, and lead-and assessing their health effects. The EPA has adopted and periodically updated national standards for the maximum concentrations of these pollutants in the air, consistent with protection of the public health.² Both state and federal agencies are responsible for taking steps to achieve these standards by setting and enforcing limits on emissions from stationary and mobile sources and implementing other measures. States monitor these pollutants and report results to a national data system. Environmental agencies use these monitoring results to determine whether to take steps to reduce emissions.³ Public health agencies use the monitoring data to determine how much of the population is exposed to unhealthful air. Reducing this percentage is an important public health objective.⁴

For the many other pollutants released to the air, the situation is quite different. There are no national standards or guidelines to define allowable concentrations in the air of contaminants other than the six criteria pollutants. These other air contaminants usually referred to as hazardous air pollutants—are not subject to a comprehensive monitoring network.³ (A few are included in monitoring by state and federal environmental agencies for compounds that contribute to ozone formation.) Each state can decide whether to monitor ambient concentrations of hazardous air pollutants, and the level of effort varies considerably. There is no ongoing process for the assessment of whether ambient concentrations of air contaminants pose health risks.

Since passage of the Clean Air Act Amendments of 1990, the national strategy for hazardous air pollutants has focused on setting limits for emissions, and not on standards for concentrations of pollutants in the air. In Section 112, Congress directed the EPA to set technology-based limits on emissions of hazardous air pollutants. These emission limits were to reflect the "maximum achievable control technology" (MACT) for categories of sources and were to be adopted by the year 2000.^{5,6} This approach relies on engineering judgment about the amount of reduction in emissions that can be achieved, not on analysis of where action is needed to protect the public's health.

Congress also directed the EPA to assess the health risks that would remain after the implementation of the MACT standards,⁷ a process known as assessing residual risk.⁸ In addition, Congress directed the EPA to devise a strategy to reduce health risks resulting from multiple sources releasing hazardous air pollutants close to urban areas.⁸⁻¹¹ These assessments have not been completed.

Though the residual risk and urban air toxics analyses have not been completed, some analysis of the health risks posed by hazardous air pollutants has been done, based on computer modeling of pollutant concentrations. These analyses, though limited, suggest that hazardous air pollutants pose health risks.12-14 The EPA developed and ran a model that used information about emissions to predict ambient concentrations of 148 hazardous air pollutants for census tracts in the contiguous states for 1990.15,16 This modeling predicted concentrations of pollutants in many counties that would exceed health benchmarks representing a theoretical lifetime cancer risk of one case per million population.15,16 While this modeling effort has limitations, acknowledged by its authors,15 the finding that many millions of people face these exposures of possible health concern warrants follow-up investigation.

In 2000, the EPA conducted an updated modeling effort, the National Air Toxics Assessment, to generate predictions of ambient concentrations of 33 pollutants and diesel particulate matter for 1996.^{17,18} The draft results have been released, but are under review by the EPA Science Advisory Board, which is expected to release its report soon.¹⁹

A PUBLIC HEALTH APPROACH

An approach to investigating the health significance of ambient concentrations of hazardous air pollutants, grounded in principles of public health, would involve five steps. The first would be to identify pollutants of concern based on their toxicity and the magnitude of releases or potential releases. The second step would be to determine ambient concentrations of these pollutants and the number of people exposed at different concentrations. The third would be to define standards or guidelines for allowable concentrations of these pollutants, consistent with public health protection. The fourth step would be to compare ambient concentrations to these health-based standards or guidelines and to identify populations at risk. Following these investigations, regulatory agencies would be able to take action to reduce risks deemed to be unacceptably high.

Monitoring of ambient concentrations of chemicals and chemical compounds would likely be an important component of such an approach. Monitoring can show how multiple sources of pollution are interacting to produce ambient levels of pollution. Groups such as the Presidential/Congressional Commission on Risk Assessment and Risk Management, charged with reviewing assessment issues relevant to air pollutants, have recognized the importance of considering multiple sources of pollutants in conducting risk assessments and assessing policy options.^{20,21} Perhaps the most direct way to arrive at an overall assessment of the concentrations of pollutants present in an environment, regardless of source, is to measure them. Monitoring can also contribute to ascertaining progress made through implementation of the MACT standards.

For the present study, we assessed the availability of the information necessary to carry out such an investigation of the health significance of hazardous air pollutants. The study focused on the urban areas of California, because these areas already have a relatively extensive monitoring network. We looked at the availability of complete and current listings of pollutants of concern, the availability of monitoring data about ambient concentrations of the pollutants identified as being of concern, whether detection limits were sufficiently sensitive to allow measurement of pollutants at all relevant concentrations, and the availability of standards or guidelines to serve as a point of comparison to assess risks to the population.

METHODS

Several types of information were used in this study. First, we looked at existing approaches to identifying air contaminants of potential health concern, used available data to identify pollutants of concern for California, and then determined which pollutants were included in the monitoring conducted by three California agencies.

Second, we considered whether information was available about the toxicity of pollutants of concern to allow us to define a health benchmark as a point of comparison for the California monitoring data. Because no national standards or guidelines have been adopted for ambient concentrations of hazardous air pollutants, we defined appropriate health benchmarks to evaluate the measured concentrations, using the toxicity values that we were able to identify.

Third, we determined whether the three California monitoring programs measured concentrations of the hazardous air pollutants that were low enough to allow for a full assessment of any potential risks. Both

monitoring equipment and laboratory analytic methods can have limitations; they may be able to detect or measure pollutants only to certain levels. Below these concentrations, often called detection limits-which vary across methods and substances-pollutants cannot be accurately measured. When the concentration of a pollutant is below the detection limit of the monitoring and analytic methods used, it is reported as "not detected," even though it may be present in the environment. Ideally, a monitoring program would be able to measure concentrations of pollutants in the air at levels below those defined as posing a health risk. Thus, for example, if the concentration of a pollutant that represents a potential cancer risk of one per million is 10 parts per billion (ppb), it would be desirable to be able to measure the pollutant down to 10 ppb or even 5 ppb. The fourth part of our analysis was to determine whether the detection limits for the California monitoring data were sufficiently sensitive to capture all such relevant values.

Approaches to identifying hazardous air pollutants of potential health concern

To see if information was available to identify the hazardous air pollutants that might be important in terms of adverse health effects, we examined two kinds of information.

Available lists. We looked at several existing approaches to defining hazardous air pollutants of potential health concern. We started with the list of 189 hazardous air pollutants identified by the US Congress in the Clean Air Act Amendments of 1990.22 We next considered the revision published by the EPA in 2000, which included 188 of the 189 pollutants in the earlier list.²³ We then reviewed designations of chemicals and chemical categories as being of concern under the California Toxic Air Contaminant Identification and Control Act by the California Environmental Protection Agency (Cal-EPA) in 1999.24 This agency incorporated the 189 pollutants identified by Congress in 1990 and considered toxicity, exposure, persistence, and emissions of the substances, as well as an opinion issued by a scientific review board, in identifying additional toxic air contaminants.²⁵ We also reviewed a priority list of 40 pollutants identified under the California process as being of greatest concern for management attention or further review with regard to health concerns. Finally, we looked at the hazardous air pollutants identified by the EPA in 1999 as priority pollutants under an initiative to develop a National Urban Air Toxics Strategy.¹¹

Predictions by computer model. The second type of information we considered was a set of predictions for outdoor, annual average ambient concentrations of hazardous air pollutants, produced by a model called the Assessment System for Population Exposure Nationwide (ASPEN), developed by the EPA.¹⁶ The EPA used the model to predict concentrations of hazardous air pollutants for 1990 for all counties in the 48 contiguous states. Of the 189 hazardous air pollutants defined in the Clean Air Act, 148 were included in this modeling effort.

Data used to make these predictions included emission rates, frequencies of various meteorological conditions, and the effects of atmospheric processes such as decay, secondary formation, and deposition.^{15,26} The emissions included were those from large stationary sources such as factories; small stationary sources, including facilities such as dry cleaners (also known as area sources); and mobile sources such as cars and trucks.²⁷⁻²⁹ For 28 hazardous air pollutants, the model also included estimates of background concentrations in areas far from emission sources. These background concentrations could be due to long-range transport, re-suspension of historical emissions, or natural sources.

The ASPEN model has several limitations. In general, the model tends to underestimate actual concentrations of pollutants.^{15,26} Uncertainties in model outputs appear to be smaller for gaseous pollutants and greater for particulate pollutants. In addition, the model does not capture any peak concentrations that could be significant in terms of the acute health effects of pollutants, as it was designed to generate estimates of annual average concentrations.

We obtained ASPEN model predictions for California census tracts for 1990³⁰ and used them to compute statewide mean annual concentrations for the 148 hazardous air pollutants included in EPA's modeling. We compared the statewide means (unweighted means of county values) to health benchmarks developed by the EPA in conjunction with the modeling project. These EPA health benchmarks represented estimates of theoretical lifetime cancer risks of one per million or concentrations considered to be without appreciable risk for non-cancer effects with long-term exposure.¹⁴

Toxicity values and health benchmarks

To determine whether an outdoor, ambient concentration of a hazardous air pollutant is of potential health significance, a point of comparison is needed. For the six criteria pollutants, the EPA has adopted ambient air quality standards that are supposed to incorporate health concerns. However, because there are no national standards or guidelines for the hazardous air pollutants, we needed to calculate health benchmarks that reflected the toxicity of the pollutants. (It is important to note that the benchmarks we calculated are not identical to the benchmarks developed as part of the EPA's modeling project.)

Developing a health benchmark requires information about the toxicity of the compound, particularly the adverse health outcomes the compound is thought to cause, and exposure levels associated with these effects. (Outdoor ambient concentrations are a lowerbound estimate of exposure levels for hazardous air pollutants.)

In this part of the analysis, we determined whether toxicity values were available for given pollutants. We reviewed toxicity values for cancer and non-cancer adverse health outcomes (such as developmental disorders or birth defects) developed by the EPA and Cal-EPA. Since the health effects of acute or shortterm exposures are not addressed in this study, we did not select benchmarks for these effects.

We started with toxicity values related to the carcinogenicity of hazardous air pollutants. Both US and international agencies use categories (called weight-of-evidence classifications) to reflect the likelihood that chemicals cause cancer in humans. We obtained weight-of-evidence classifications developed by the EPA^{31,32} and the International Agency for Research on Cancer (IARC)³³ for hazardous air pollutants. Currently, the EPA classifies chemicals considered "known" human carcinogens into Group A, those considered "probable" human carcinogens into Group B, and those considered "possible" carcinogens into Group C. Group D chemicals are not classifiable due to lack of information. IARC classifications are generally similar to EPA's.

To reflect the strength of a chemical in producing any carcinogenic effects, the EPA, as well as other agencies, adopts a toxicity value called a potency estimate. We identified potency estimates for hazardous air pollutants published by the EPA in its Integrated Risk Information System (IRIS).³² If there was no potency estimate in IRIS, we searched for potency estimates produced by Cal-EPA.³⁴ (Although the EPA has announced that it intends to revise its guidelines for carcinogen risk assessment,³⁵ assessments conducted under the current guidelines remain appropriate for use, as the revisions have not been adopted.)

Agencies also adopt toxicity values for chronic adverse health effects other than cancer. The EPA adopts reference concentrations (RfCs) representing the concentrations of pollutants in air likely to be without appreciable risk of adverse health effects over a life-time of exposure.³⁶ The EPA notes that these values may have uncertainties as high as one order of magnitude. Reference exposure levels (RELs) adopted by

Cal-EPA are analogous. When no RfC was available in IRIS,³² we looked for the REL adopted by the state of California.³⁷ If no REL had been adopted, we searched for proposed values developed by the state of California.³⁸ When toxicity values were not available from any of these sources, we consulted other references as noted below.

Health benchmarks. We used the toxicity values that we identified to generate health benchmarks as points of comparison for the monitoring data. We selected the lower of two health benchmark concentrations (cancer or non-cancer) for this analysis. In most cases, the cancer risk benchmark concentration was the lower one.

For non-cancer effects, we used the reference concentrations identified in the previous step as our health benchmarks. To develop cancer benchmarks, we used potency estimates to generate concentrations of hazardous air pollutants that would represent a theoretical one-per-million cancer risk, based on lifetime exposure. A one-per-million cancer risk level has been used by the EPA as a screening level for hazardous air pollutants.¹⁴ A benchmark reflecting a higher risk level, such as one per 10,000, would represent a potential for a significant disease burden because many millions of people are exposed to multiple hazardous air pollutants.^{12,13} Consequently, we concluded that such a benchmark, reflecting a higher risk, is not appropriate for this type of analysis.

Monitoring results: sensitivity and completeness

We obtained measurements of ambient concentrations of hazardous air pollutants from the California Air Resources Board (CARB), the Bay Area Air Quality Management District (BAAQMD) in Northern California, and the South Coast Air Quality Management District (SCAQMD) in Southern California. CARB is a statewide agency, while BAAQMD and SCAQMD are regional. The data consisted of 24-hour samples collected at approximately 12-day intervals.

We obtained data collected from 1990 through 1997 at monitors located in 17 metropolitan areas with a total 1996 population of approximately 29 million.³⁹ These data were collected at 22 monitors operated by CARB (for both organic compounds and metals), 23 monitors operated by the BAAQMD (for organic compounds), and 3 monitors operated by SCAQMD (for organic compounds).

For volatile organic compounds (VOCs), approximately 153,000 observations were available. Of these observations, 56% were from CARB, 38% from the BAAQMD, and 6% from the SCAQMD. The VOCs monitored included acetaldehyde, benzene, 1,3butadiene, carbon tetrachloride, chlorobenzene, chloroform, *p*-dichlorobenzene, ethyl benzene, ethylene dibromide, ethylene dichloride, formaldehyde, MEK (methyl ethyl ketone), methyl chloroform, methylene dichloride, MTBE (methyl *tert* butyl ether), styrene, tetrachloroethylene, toluene, trichloroethylene, vinyl chloride, and xylene. For metals, approximately 50,000 observations were available from CARB. The metals monitored include antimony, arsenic, beryllium, cadmium, chlorine, chromium, cobalt, lead, manganese, mercury, nickel, and selenium. (While California agencies also collected some data on polycyclic aromatic compounds, they were not available for this analysis.)

We next assessed the data to determine if all concentrations of concern were measured. Sampling and analytical methods can measure chemicals within specified ranges; concentrations below these limits may not be measured accurately or at all. To ensure that all concentrations relevant to health risk assessment are measured, the detection limits for a compound need to be lower than its health benchmark concentration. We determined whether this was the case for the California monitoring data.

We identified the observations within these data for which concentrations were reported by the monitoring agencies as being below detection. For these observations in the California monitoring dataset that were reported as being below the detection limit, we reviewed the applicable method detection limits (MDLs), also reported in the dataset. We compared these MDLs to the benchmarks for the chemicals, identifying pollutants for which the MDLs exceeded health benchmarks. We also identified the percent of values below detection.

RESULTS

Approaches to identifying hazardous air pollutants of potential health concern

We first reviewed several approaches to identifying contaminants that might appropriately be considered of potential health concern. The lists that we reviewed were inconsistent. For example, the California toxic air contaminants identification process produced a list of 244 chemicals and groups of chemicals,²⁴ which was larger than the EPA's list of 188. Some compounds of potential concern not included in the EPA's list of 188 contaminants are chloropicrin, ethylene, Michler's ketone, crystalline silica, and hydrogen sulfide. Forty high priority hazardous air pollutants were identified by Cal-EPA. Finally, the National Urban Air Toxics Strategy developed by the EPA identified 31 pollutants of potential concern for urban areas.

Most of the 40 high priority hazardous air pollutants identified by Cal-EPA were included in the Urban Air Toxics Strategy list; 14 were not. It is important to note that the purposes of Cal-EPA's priority list and the Urban Air Toxics Strategy are different, and there may be good reasons for the lists to differ. The priorities for the nation may be different from those for California, for example. Some of the pollutants included in the Cal-EPA list of 40 but not in the Urban Air Toxics Strategy list were asbestos, chlorobenzene, 1,4-dichlorobenzene, particulate emissions from diesel engines, perchloroethylene, propylene oxide, selenium compounds, and styrene.

Pollutants of concern for California. We found that mean statewide concentrations for California based on the EPA modeling results for 1990 exceeded health benchmarks for 13 compounds—acetaldehyde, acrolein, arsenic compounds, benzene, 1,3-butadiene, carbon tetrachloride, chloroform, chromium compounds, 1,3dichloropropene, ethylene dibromide (EDB), ethylene dichloride (EDC), formaldehyde, and methyl chloride. (See Table 1 for data on 58 pollutants of greatest interest.) Modeled annual concentrations, again considered as a statewide average of values for individual

Table 1. Hazardous air pollutants: identification and prioritization, modeling results, status of monitoring by three California agencies, and completeness of toxicity review

		Listed in:				CEP model				Included in EPA IRIS database:		
		1990		Cal-		indicated	Мс	onitored	by:			
Pollutant	CAS Registry Number	Clean Air Act	1990 EPA model	EPA priority 40	EPA UATS	possible health concern	CARB	BAA- QMD	SCA- QMD	WOE for cancer	IRIS cancer risk	IRIS RfC
Acetaldehyde	75-07-0	х	х	17	х	High	х		х	Probable	х	х
Acrolein	107-02-8	х	х		х	High				Possible		х
Acrylonitrile	107-13-1	х	х	16	х	Low				Probable	х	
Antimony		х	х			Low	х			None		
Arsenic		х	х	6	х	High	х			Known	х	
Asbestos	1332-21-4	х		19		5				Known	х	
Benzene	71-43-2	х	х	1	х	High	х	х	х	Known	х	
Bervllium		х	х	8	х	Low	х			Probable	х	
Bis(2-ethylhexyl)-												
phthalate	117-81-7	х	х	25		Low				Probable	х	
1.3-butadiene	106-99-0	х	х	20	х	Hiah	х	х	х	Probable	х	
Cadmium		x	x	6	x	Medium	x			Probable	x	
Carbon												
tetrachloride	56-23-5	х	x	8	х	Hiah	х	x	х	Probable	x	
Chlorobenzene	108-90-7	x	x	19		Low	x		x	Not classifiat	ole	
Chloroform	67-66-3	x	x	8	х	High	x	x	x	Probable	x	
Chromium		x	x	-	x	High	x			None		
Chromium VI				1			x			Known	х	x
Coke oven emissions	5	х			х					Known	х	
p-dichlorobenzene	106-46-7	x	x	12		Medium	x		x	None		x
1.3-dichloropropene	542-75-6	x	x		х	High			~	Probable	x	x
1 4-dioxane	123-91-1	x	x	14		Medium				Probable	x	
Epichlorohydrin	106-89-8	x	x	23		Medium				Probable	x	
Ethyl benzene	100-41-4	x	x	20		Low	х		х	Not classifiat	ole	х
Ethylene dibromide	106-93-4	x	x	13	x	High	x	x	~	Probable	x	~
Ethylene dichloride	107-06-2	x	x	13	x	High	x	x		Probable	x	
Ethylene oxide	75-21-8	x	x	14	x	low*	X	X			X	
Formaldehyde	50-00-0	x	x	3	x	High	×		x	Probable	x	
Hexachlorobenzene	118-74-1	x	×	0	x	Low	X		X	Probable	×	
Hexane	110-54-3	x	×		X	Low				None	~	×
Hydrazine	302-01-2	x	×	25	x	Low				Probable	×	X
Lead compounds	002 01 2	x	×	10	x	Low*	×			Probable	~	
Lindane (all isomers)		×	~	10	~	Medium	~			None		
Manganese		×	~		v	Medium	×			Not classifial	مام	v
MEK	78-93-3	×	~		^		~			Not classifial		^
	10-75-5	~	~		Y		X			Not classifial		×
Mothyl chlorido	7/ 87 2	×	~		^	High	^			i vot classilidi	516	^
	/ 4-0/-5	~	~			IIIGII						

	CAS Registry Number	Listed in:				CEP				Included in EPA IRIS			
		1990		Cal-	indicated possible V EPA health UATS concern	indicated	Monitored by:						
Pollutant		Clean Air Act	1990 EPA model	EPA priority 40		CARB	BAA- QMD	SCA- QMD	WOE for cancer	IRIS cancer risk	IRIS RfC		
Methyl chloroform	71-55-6	х	х			Low	х	х	х				
Methylene chloride 4,4-methylene-	75-09-2	х	х	5	х	Medium	х	х	х	Probable	х		
dianiline	101-77-9	х	х			High							
MTBE	1634-04-4	х	х			Low	х	х	х	None		х	
Nickel		х	х	4	х	Medium	х			Known ^b	х		
2-nitropropane	79-46-9	х	х	22		None				None		х	
Particulate emissions from diesel engines				10						None		х	
Pentachlorophenol	87-86-5	х	х			High				Probable	х		
Polychlorinated						-							
biphenyls	1336-36-3	х	х	21	х	Medium				Probable	х		
Polycyclic organic				10						Nama			
matter Drawalana diablariala	70 07 F	X	X	10	X	1				None			
Propylene dichionde	70-07-0	X	X	10	х	LOW				None Drahahla		X	
	/ 3-30-9	х	х	ΙZ		LOW				Probable	х	х	
Culnoline	91-22-5	X	X	17	х	Inone				Niet ele estitie	le le		
Selenium compound	S 100.42 E	X	X	17		LOW	X			Not classifia	elde		
2,3,7,8-tetrachloro-	100-42-5	х	Х	20		LOW	х		х	None		х	
dibenzo-p-dioxin	1746-01-6	х	х	13	х	Low				Probable			
1,1,2,2-tetrachloro-													
ethane	79-34-5	х	х		х	Medium				Possible		х	
Tetrachloroethylene	127-18-4	х	х	2		Medium	х	х	х	None			
Toluene	108-88-3	х	х			Low	х	х	х	Not classifia	able	х	
1,1,2-trichloroethane	79-00-5	х	х	25		Low	х			Possible	х		
Trichloroethylene	79-01-6	х	х	9	х	Medium	х	х	х	None			
Vinyl chloride	75-01-4	х	х	11	х	Medium	х	х	х	Known	х	х	
Xylenes (isomers													
and mixtures)	1330-20-7	х	Х			Low	Х		х	Not classifia	able		

NOTES: The first column shows the CAS Registry Number. The second column ("1990 Clean Air Act") indicates which pollutants are listed as hazardous air pollutants in the 1990 Clean Air Act. The "1990 Model" column indicates chemicals and chemical compounds included in the modeling conducted by EPA in 1990 to identify ambient concentrations of hazardous air pollutants.¹⁶ The "Cal-EPA priority 40" column shows the pollutants that the California Environmental Protection Agency (Cal-EPA) identified in 1999 as priority hazardous air pollutants for management action or further assessment activities; the numbers represent rankings in the Cal-EPA prioritization process, with 1 indicating the highest priority.²² The "EPA UATS" column indicates pollutants included in EPA's 1999 Urban Air Toxics Strategy.¹¹

The sixth column shows the pollutants identified as being of potential health concern because statewide annual average concentrations exceeded health benchmarks in the Cumulative Exposure Project (CEP) modeling of ambient concentrations of hazardous air pollutants in California. Pollutants of *high* concern are those for which the statewide average of all counties exceeded the health benchmark concentration developed in conjunction with the model. The pollutants denoted as being of *medium* concern were those for which the statewide average of all counties was within an order of magnitude of the health benchmark concentration developed in conjunction with the model. The statewide annual averages for the other pollutants were more than an order of magnitude below the health benchmarks. Those marked with an asterisk, though not of concern on a statewide basis, exceeded health benchmarks in some counties.

The next section of the table shows which pollutants were monitored at any point during the years 1990–1997 by three California air quality agencies: the California Air Resources Board (CARB), the Bay Area Air Quality Management District (BAAQMD), and the South Coast Air Quality Management District (SCAQMD).

The final section shows the pollutants for which toxicity values are included in the EPA database, the Integrated Risk Information System (IRIS).³¹ The "WOE" (weight-of-evidence) cancer risk column gives the cancer classification adopted by EPA, if there is one; this represents the likelihood that the compound causes cancer in humans. The "IRIS cancer risk" column indicates whether a cancer unit risk (or potency) value has been adopted that refers to inhalation exposures. The "IRIS RfC" column indicates whether a reference concentration value has been adopted.

^aElemental mercury

^bNickel refinery dust

^cSpecific compounds included under the general category of polycyclic organic matter may have toxicity values in IRIS

counties, were within one order of magnitude of the benchmark for another 12 compounds—cadmium compounds, 1,4-dichlorobenzene, 1,4-dioxane, epichlorohydrin, lindane, manganese compounds, methylene chloride, nickel compounds, perchloroethylene, polychlorinated biphenyls (PCBs), trichloroethylene, and vinyl chloride (Table 1). We considered these 25 compounds to be of concern for California.

Other pollutants may also be of concern in localized areas. The annual average concentrations for benzyl chloride, dichlorvos, ethyl carbamate, and pentachlorophenol, for example, exceeded health benchmarks in model predictions for some counties.

We compared the 25 pollutants identified as being of potential health concern with those that were monitored. Table 1 shows the pollutants included in monitoring programs conducted from 1990 through 1997 by CARB, BAAQMD, or SCAQMD. Most, though not all, of the Cal-EPA priority pollutants were monitored in California. Some omissions include acrylonitrile, bis(2-ethylhexyl)phthalate, 1,4-dioxane, ethylene oxide, and propylene oxide. In addition, acrolein, which was identified as a concern in the EPA modeling, was not monitored by any of the three California agencies.

Toxicity values and health benchmarks

Cancer potency values or non-cancer reference concentrations are available from the IRIS database for only a fraction of the 58 contaminants shown in Table 1. Half have not been evaluated for carcinogenicity, or inadequate information is available to conduct an evaluation. The IRIS database lists cancer potency values for only 28 of the 58 pollutants. For non-cancer effects, only 18 of the 58 compounds have RfCs in IRIS.

Health benchmarks. The health benchmarks that we calculated from available toxicity values are shown in Table 2. As noted, these benchmarks are concentrations that represent, for cancer effects, a theoretical lifetime cancer risk of one per million. In some cases, the benchmark is based on the upper bound of the estimate for this cancer risk. For chronic health effects that are not cancer, they represent a concentration not likely to be associated with a risk of the health effect given lifetime exposure.

Sensitivity of detection limits

Because ambient concentrations of hazardous pollutants are relatively low, the detection limits of monitoring technologies and analytic methods are an important concern. The key question is whether the detection limits are low enough to measure concentrations of potential health concern. We found that several of the detection limits reported in the monitoring data for hazardous air pollutants were higher than the applicable health benchmarks.

Table 3 shows a comparison of reported detection limits to the health benchmarks that we calculated. The results are expressed as ratios; a ratio of 1 would mean that the detection limit most commonly reported is equal to the benchmark, and a ratio of 10 would mean that the detection limit most commonly reported is 10 times as high as the benchmark. Note that the benchmarks here represent, for the most part, concentrations representing a theoretical lifetime cancer risk of one per million.

The MDLs were higher than benchmark concentrations for many hazardous air pollutants monitored in California, including 1,3-butadiene (188 times as high), chloroform (2.3 times as high), 1,4-dichlorobenzene (13 times), ethylene dibromide (34 times), ethylene dichloride (11 times), formaldehyde (1.6 times), methylene chloride (1.7 times), and vinyl chloride (60 times).

Pollutants for which measured concentrations are consistently below detection may be present at concentrations that pose a public health concern. For a number of pollutants, a high percentage of observations were reported at concentrations below reported detection limits (Table 3). These include antimony (89.7%), chlorobenzene (96.3%), cobalt (99.7%), p-dichlorobenzene (85.7%), ethylene dibromide (98.4%), ethylene dichloride (100%), methylene chloride (74.8%), trichloroethylene (68.6%), and vinyl chloride (100%). A high percentage of values below the detection limit would be a concern in cases in which the detection limit is close to, or higher than, the health benchmark, as is the case for ethylene dibromide, ethylene dichloride, methylene chloride, and vinyl chloride. A high percentage of observations below the detection limit would not be of concern in cases in which the detection limit is markedly lower than the health benchmark and the health benchmark is based on a complete toxicity database.

DISCUSSION

Many hazardous pollutants are released into the air in the US. These pollutants are ubiquitous in urban areas, and many millions of people are exposed to them. However, assessment of the public health significance of air contaminants other than the six criteria pollutants is at a rudimentary stage. The only national assessment that has been completed was based on a modeling project conducted by the EPA using 1990 data, which predicted concentrations of pollutants for census tracts in the contiguous states and compared

	Weight-of classifi	-evidence cation	Benchmark						
Pollutant	IRIS	IARC	ng/m³	ppb	Туре	Source of toxicity value			
Acetaldehyde	В	2B	450	0.25	Cancer	IRIS			
Antimony (total)	None	None	None	None		None			
Arsenic (total)	A	1	0.23		Cancer	IRIS			
Benzene	A	1	290	0.09	Cancer	IRIS			
Beryllium (total)	В	1	0.42		Cancer	IRIS			
1,3-butadiene	В	2A	3.6	0.0016	Cancer	IRIS			
Cadmium (total)	В	1	0.56		Cancer	IRIS			
Carbon tetrachloride	В	2B	67	0.011	Cancer	IRIS			
Chlorobenzene	D		70,000	15	Non-cancer	CAPCOA			
Chloroform	В	2B	42	0.0088	Cancer	IRIS			
Chromium (total)	А	1	0.083		Cancer	IRIS			
Cobalt (total)	None	None	5	None	Non-cancer	EPA-CAA			
<i>p</i> -dichlorobenzene	None	2B	91	0.015	Cancer	OEHHA-Cancer			
Ethyl benzene	D	None	1,000,000	230	Non-cancer	IRIS			
Ethylene dibromide	В	2A	4.5	0.00059	Cancer	IRIS			
Ethylene dichloride	В	2B	38	0.0094	Cancer	IRIS			
Formaldehyde	В	2A	77	0.063	Cancer	IRIS			
Lead (total)	В	2B	8		Cancer	OEHHA-Cancer			
Manganese	D		50		Non-cancer	IRIS			
MEK	None	None	1,000,000		Non-cancer	IRIS			
Mercury	None	None	300		Non-cancer	CAPCOA			
Methyl chloroform	None	None	320,000	59	Non-cancer	CAPCOA			
Methylene chloride	В	2B	2,100	0.6	Cancer	IRIS			
MTBE	None	None	6,000	1.67	Cancer	OSTP			
Nickel (total)	None	1	4.2		Cancer	IRIS			
Selenium (total)	D		500		Non-cancer	CAPCOA			
Styrene	None	2B	1,000,000		Non-cancer	IRIS			
Tetrachloroethylene	None	2A	170	0.025	Cancer	OEHHA-Cancer			
Toluene	None	None	400,000	None	Non-cancer	IRIS			
Trichloroethylene	None	2A	500	0.09	Cancer	OEHHA-Cancer			
Vinyl chloride	None	1	13	0.005	Cancer	OEHHA-Cancer			
Xylene	D		300,000	None	Non-cancer	CAPCOA			

Table 2. Benchmark concentrations calculated from toxicity values for hazardous air pollutants

ng/m³ = nanograms per cubic meter

ppb = parts per billion

NOTES: For cancer, the benchmark concentrations are set at a level that represents a theoretical lifetime cancer risk of one per million. In some cases, the benchmark is based on the upper confidence bound of a cancer toxicity value, which adds an additional degree of conservatism to the estimate. For chronic health effects other than cancer, the benchmark represents a concentration is considered to be without appreciable risk.

DATA SOURCES:

CAPCOA: Reference 37 IRIS: Reference 32 EPA-CAA: Reference 42 OEHHA-Cancer: Reference 34 OSTP: Reference 43 IARC WOE: Reference 33 EPA WOE: Reference 32

			Percent	Bench	nmarks	Most	Ratio of most common MDL to benchmark	
Pollutant	Units	Concern	below detection	Cancer	Non-cancer	common MDL		
Acetaldehyde	ppb	No	4.3	0.25	5	0.1	0.4	
Antimony	ng/m³	Yes	89.7	Not established	Not established	5		
Arsenic (total)	ng/m³	Yes	11.5	0.23	500	0.4	1.7	
Benzene	ppb	Yes	15.4	0.09	22	0.5	5.6	
Beryllium	ng/m ³	No	47.4	0.42	2	0.02	0.01	
1,3-butadiene	ppb	Yes	28.8	0.0016	Not established	0.3	188	
Cadmium	ng/m ³	No	6.2	0.56	3500	0.2	0	
Carbon tetrachloride	ppb	No	0	0.011	0.38	None		
Chlorobenzene	ppb	No	96.3	Not established	15	0.1	0.01	
Chloroform	ppb	Yes	51.2	0.0088	7.2	0.02	2.3	
Chromium (total)	ng/m³	Yes	25.5	0.083	Not established	2	24	
Cobalt	ng/m³	Yes	99.7	Not established	5	16	3	
<i>p</i> -dichlorobenzene	ppb	Yes	85.7	0.015	133	0.2	13	
Ethyl benzene	ppb	No	83.5	Not established	230	0.6	0.003	
Ethylene dibromide	ppb	Yes	98.4	0.00059	0.6	0.02	34	
Ethylene dichloride	ppb	Yes	100.0	0.0094	23	0.1	11	
Formaldehyde	ppb	Yes	1.4	0.063	2.9	0.1	1.6	
Manganese	ng/m ³	No	1.6	Not established	50	2	0.04	
MEK	ppb	No	34.1	Not established	339	0.1	0.0003	
Mercury	ng/m³	No	97.9	Not established	300	3	0.01	
Methyl chloroform	ppb	No	0	Not established	59	0.01	0.0002	
Methylene chloride	ppb	Yes	74.8	0.6	864	1	1.7	
MTBE	ng/m³	Yes	22.7	1.67	834	0.5	0.3	
Nickel (total)	ng/m³	No	25.1	4.2	240	2	0.5	
Selenium	ng/m³	No	80.2	Not established	500	2	0.004	
Styrene	ppb	No	53.5	Not established	234	0.1	0	
Tetrachloroethylene	ppb	No	0.6	0.025	5.2	0.01	0.400	
Toluene	ppb	Yes	1.8	Not established	106	0.2	0.002	
Trichloroethylene	ppb	Yes	68.6	0.09	119	0.08	0.9	
Vinyl chloride	ppb	Yes	100.0	0.005	10	0.3	60	

Table 3. Method detection limits (MDLs) compared to health benchmark concentrations for hazardous air pollutants monitored by three California agencies

NOTES: The third column shows whether each pollutant was designated as being of potential health concern as shown in this analysis. The "Percent below detection" column indicates the percentage of values reported by the three California monitoring agencies that were below the MDL. The next section of the table shows cancer and non-cancer benchmark concentrations for each pollutant. The "Most common MDL" column shows the most commonly reported detection limit. The final column expresses the relationship of the MDL to the health benchmark as a ratio. If the ratio is 1 or above, then the most common MDL is higher than the health benchmark.

the predicted concentrations to health benchmarks.¹²⁻¹⁴ A second analysis, now available in draft form, has produced predictions of ambient concentrations of 33 hazardous air pollutants for 1996.¹⁷

In the present analysis, using California data, we identified several limitations to the information available for a full assessment. First, we found that there were varying approaches to identifying the hazardous air pollutants of potential health concern. The EPA relies on a list of 189 hazardous air pollutants identified by the US Congress in 1990, with one deletion. However, we can anticipate that other compounds not on this list may also pose health threats. Certainly, no pollutant introduced since 1990 would be included in the EPA's list, and changes in any number of industrial processes or product lines could result in new compounds being emitted. Maintaining a current list of pollutants of concern would be a challenge, given rapid changes in the use and release of chemicals. However, it is necessary to maintain or develop such a list to have a credible starting point for a health assessment. Second, we looked at a part of the country for which a great deal of monitoring data for hazardous air pollutants is available. It is important to recognize that most areas of the US do not have data of this type on record.

Third, the monitoring methods used for some pollutants have had detection limits that are simply too high to allow for use of the data to assess potential health risks. In this analysis, we did not review the theoretical capacity of monitoring methods, but only examined the results reported. Identification and implementation of improved methods would be necessary in order for the monitoring of several key pollutants to be valuable in health risk assessment. Analysts who use monitoring data must be aware of the detection limits of existing technologies.

The fourth factor that inhibits a comprehensive assessment is the lack of national standards or guidelines to serve as points of comparison for ambient concentrations. The focus of the regulatory program for hazardous air pollutants under the Clean Air Act Amendments is on the development of MACT emissions standards. However, it would be appropriate to have some analysis of the potential health significance of pollutants. Guidelines could be developed for this purpose.

Until such guidelines are adopted, toxicity values (cancer potency estimates and reference concentrations) are needed to serve as the basis for the development of benchmarks. Cancer potency estimates were unavailable for several key pollutants for which evidence indicated a potential cancer concern, and reference concentrations for non-cancer effects were unavailable for the majority of the hazardous pollutants identified in the Clean Air Act. An earlier analysis that looked at the availability of toxicity values for all 188 federal hazardous air pollutants found similar gaps.¹⁴ This may be the result of a lack of adequate testing and slow progress in developing toxicity values based on the testing that has been completed. Lack of toxicity values is the fifth factor that makes it difficult to assess the health significance of ambient concentrations of the pollutants. For each exercise of this type, researchers currently need to develop their own set of benchmarks, which requires considerable expertise and resources, and results in the inability to make comparisons.

Other important considerations with regard to the use of monitoring data in health assessment include the selection of sites that are representative of population exposures and the existence of any hot spots associated with particular sources or conditions. Moreover, cumulative exposures to many pollutants, even if none exceeds health benchmarks individually, could also be a concern. We did not address these important issues in the present study.

It is important to develop an approach to providing meaningful information about ambient concentrations of hazardous air pollutants. It seems likely that some form of monitoring will be needed to achieve the goals of integrated assessment of the potential health risks of cumulative exposures from multiple sources. The most feasible and economical approach might be a combination of modeling and monitoring. This would allow for greater coverage of geographic areas and pollutants than is likely to be possible through monitoring alone, due to fiscal and logistical constraints. Monitoring results can provide real-time information for areas of interest, particularly highly polluted areas, and can be used to assess trends over time or to validate the effectiveness of the MACT standards. Because concentrations of many hazardous air pollutants tend to be higher indoors than outdoors,^{40,41} measurements of ambient concentrations can be seen as a lower bound estimate of the exposure that populations are likely to experience.

Modeling may play an important role and provide greater coverage than can be gained solely through monitoring and could be used to identify pollutants and areas of concern. Modeling, however, at present, is severely limited in value by the large time lag before data are available. The 1990 model predictions were not released until 1999. As of this writing, model results for 1996 have been released in draft form but remain under review. This delay appears to be due, at least in part, to the timing of preparation of the emissions inventory needed to model ambient concentrations. This lag means that model predictions that could be valuable for air pollution control are not available in a timely manner.

Recommendations

Because many hazardous air pollutants are emitted to the atmosphere and because these compounds may represent health threats, detailed information is needed on which to base health assessments. Generating this information will require several steps:

1. *Identify pollutants*. A regular review of chemical use, release, and toxicity data should be conducted to identify air pollutants of potential concern. This process should be ongoing, transparent to the public, and conducted through an unbiased process. It should be designed to detect changes in emissions generated through product substitutions and new areas of industrial or commercial activity.

- 2. *Emission inventories*. Data collection and reporting on emissions of hazardous air pollutants should be timely, so that information about chemicals released into the environment is available to the public and government agencies as the releases occur. Quality assurance and quality control procedures are important to ensure the consistency and quality of data.
- 3. *Model predictions*. Modeling of concentrations of hazardous air pollutants should be conducted regularly as a screening process to identify both pollutants and geographic areas of concern. These results should be made available to the public in a timely fashion.
- 4. *Monitoring methods.* Methods for monitoring hazardous air pollutants are needed that can detect concentrations down to half of the current reference concentration and half of the concentration that represents a potential or estimated cancer risk of one per ten million.
- 5. *Toxicity values*. Toxicity values should be developed for all hazardous air pollutants of concern, reflecting health endpoints and exposure levels relevant to all populations, including susceptible ones, particularly children. These values should be developed through an unbiased process.
- 6. *Monitoring*. An approach to monitoring should be developed that allows for the assessment of trends and the effectiveness of the MACT standards, will characterize the full burden of pollution for highly exposed groups, and assess the health significance of hazardous air pollutants.
- 7. Assessment of health concerns. Air pollution remains a major source of exposure to environmental contaminants in the US. Assessment of health risks associated with such exposures should be expedited and presented in a way that enhances public understanding. Additional effort will be needed to begin to address cumulative exposures to air pollutants.

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