AN ABSTRACT OF THE DISSERTATION OF

Alexandra B. Degher for the degree of Doctor of Philosophy in Civil (Environmental) Engineering presented on October 7, 2003.
Title: Effects of an Industrial Fire on a Community of South Phoenix, Arizona.

Abstract Approved

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Kenneth J. Williamson

On August 31, 1992, Quality Printing Circuits, a circuit board manufacturing plant in Phoenix, Arizona, burned to the ground. The fire lasted approximately eight hours, creating a thick, black smoke that blew into the surrounding community. Emergency evacuation was erratic and since no air samples were taken during the fire, community exposure levels were unknown. Immediately afterwards, residents reported health problems but government studies on the community were unable to link reported health problems and the fire.

Eight months after the fire, a local advocacy group performed a health study on the community. The 690 people surveyed reported symptoms such as asthma, blurred vision, vomiting, hair loss, rashes, and extremity numbness. The survey was never analyzed and the case was closed. Community members continued to report health problems and five years after the fire, the US Environmental Protection Agency reopened the case. They performed two sampling studies but results found that chemical levels were below allowable exposure levels.

This thesis contains three chapters that investigate the political, health, and scientific issues related to the QPC fire. The scientific chapter uses the EPA's ISCST3 dispersion model and a mixed-box model, to approximate community exposure concentrations and compare them to allowable human exposure levels. Results of the ISCST3 model show that four (hydrogen chloride, polycyclic aromatic hydrocarbons, Acrolein, and naphthalene) of the twenty chemicals modeled were above government allowable concentrations. Inhalation exposure to these chemicals causes similar symptoms as those reported by residents.

The health-focused chapter characterized health symptoms reported in the 1993 health survey. Results found that symptoms experienced by residents were similar to those documented in other studies of exposure to chemical smoke. The study also found that residents living closest to QPC reported a greater number of symptoms than residents living further away.

The political chapter analyzed the debate as to whether QPC officials and government agencies took the steps needed to protect the exposed community during and after the QPC fire. What became evident was that a significant conflict existed between the interests of residents involved in the QPC fire and the government agencies responsible for protecting them.

Effects of an Industrial Fire on a Community of South Phoenix, Arizona

by
Alexandra B. Degher

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I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

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Alexandra B. Degher, Author

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CONTRIBUTION OF AUTHORS

Dr. Anna Harding developed the study design and contributed in the writing and editing of Chapter 3. Dr. Harding and Dr. Douglas Degher assisted with the editing of Chapter 4.

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DEDICATION

This dissertation is dedicated to my exceptionally thoughtful, caring and unbelievably wonderful parents,

Doug and Jane.

Thank you all for your selfless support and love.

EFFECTS OF AN INDUSTRIAL FIRE ON A COMMUNITY OF SOUTH PHOENIX, ARIZONA

INTRODUCTION

In the late 1980s, Quality Printed Circuits (QPC), a manufacturing facility for computer circuit boards, moved into a poor, minority residential neighborhood in South Phoenix, Arizona. The facility was located on the western edge of Census Tract (CT) 1160; in 1990, approximately 65% of CT 1160's residents were identified as African American, 18% identified as Hispanic, and 16% identified as White. Approximately 37% of CT 1160's residents lived below the poverty line (USBC, 1990). The City of Phoenix Economic Development Agency approved the relocation of QPC into this community under the pretense economic development, although very few residents from CT 11609 were ever employed at the facility.

Soon after being constructed, small fires began to plague the plant. The facility continuously failed fire compliance inspections and avoided investing in needed improvements. On August 31, 1992, a large fire wholly consumed the facility. The fire began at approximately 11:00 a.m. and lasted 8 hours, creating a thick black plume of combustion products that blew through the surrounding community. The building was completely destroyed, leaving nothing but a few walls and a four-foot pile of debris. Air samples were not taken during the fire.

An hour after the fire started, the Phoenix Police Department requested that residents leave the area, with instructions to return at their own discretion. Because an evacuation was not ordered, however, many residents were confused about what to do and remained in their homes. The lack of proper evacuation and premature reentry of residents into the neighborhood resulted in greater exposure to the fire combustion products.

The plume of combustion products from the fire drifted in a predominantly easterly direction, entering approximately 1,800 homes and exposing residents to compounds generated during the combustion of the facility and all its materials, furniture, and equipment (USEPA, 1999). Immediately after the fire, residents began complaining of various health problems including asthma, blurred vision, congestion, hearing loss, hair loss, rashes, nausea and vomiting, and numbness of the extremities (ADHS, 1993). South Phoenix residents also reported that pets, grasses, and other plants unexpectedly died a few days following the fire.

Because of such reports, the Arizona Department of Environmental Quality (ADEQ) and the Arizona Department of Health Services (ADHS) began investigating the incident. Arizona government agencies carried out several studies on the community in an attempt to determine if there was a link between reported symptoms and contaminants released during the fire. Between

October 1992 and May 1994, these agencies conducted six limited sampling studies. Soil and air samples were analyzed for selected metals and semi-volatile organic compounds. Other potential combustion products of the fire, however, were not included in sampling efforts. Results of these investigations found that the concentrations of the sampled chemical were not significantly different between the control and study homes.

Using results from two of these studies, ADHS performed two risk assessments and concluded in both that residents were not exposed to chemical levels great enough to adversely impact their health. Using results from one of these studies, QPC officials hired their own contractor to perform a risk assessment who also concluded, "there were insufficient quantities of metals present to be a health concern to residents" (USEPA, 1999). Critics of these studies, however, insisted that the study sample was not representative of the area in which the affected residents lived, that the control group was also exposed to the plume, and that the compounds tested failed to include the full range of combustion products released during the fire.

Because residents were still reporting health concerns eight months after the fire, *Don't Waste Arizona* (*DWAZ*), a local nongovernmental organization, requested assistance from ADHS to conduct a health survey with residents of Census Tract 1160, the area most affected by the fire. *Don't Waste Arizona* developed the health survey in consultation with a federal health agency and under contract with ADHS, and distributed it to 690 residents (17 percent) of CT 1160. Approximately one third were surveyed by means of a door-to-door campaign, another third through a random telephone survey, and the final third by their voluntary attendance at local community meetings. ADHS later deemed the health survey to be invalid due to a lack of randomized sampling, refused to analyze the data, and closed the case later that year.

The community continued to report health problems even years after the fire and believed that the Arizona government had mishandled their case. Because of these concerns, the community appealed to the US Environmental Protection Agency (EPA) for assistance. Four and a half years after the fire, the EPA reopened the case and began its own inquiry into the QPC fire incident. The EPA performed two sampling studies in the South Phoenix neighborhood in May and November of 1997. Results detected differences in chemical levels between study and control homes, but once again, a risk assessment showed that exposure concentrations were not high enough to have caused adverse health effects. As a result of this information, the EPA was legally unable to force QPC to provide medical assistance to the South Phoenix residents or clean residents' homes, despite documentation of persistent health problems.

On March 11, 1999, the EPA held a meeting to inform South Phoenix residents that they could not find a link between their health problems and the QPC fire. They did report, however, that since the studies showed higher levels of chemicals in the air cooling system filters of the exposed homes, the EPA would hire a firm to professionally clean the air ducts of any "exposed" area residence. Following this announcement, the EPA closed the South Phoenix case. Residents believed that their health problems were still being ignored and continued to blame the state government for not forcing QPC to clean their houses immediately after the fire occurred.

Several additional health studies were carried out on the community. In early 1993, the Arizona Department of Environmental Quality hired a University of Arizona researcher, Russell Dodge, to set up a protocol for analyzing respiratory illnesses in the area. Using this protocol, ADEQ opened up a community health clinic to perform these health analyses on local residents. Also, Maricopa County performed a mortality study on the area to determine if deaths had increased significantly after the fire. Though results of these various health studies showed that residents became ill and that there were excess deaths after the fire, none could prove that they were a direct result of the fire.

To the residents involved in this incident, it was obvious that the fire had caused their health problems and questioned why the government failed to prove this link. Though health studies showed that the South Phoenix residents were suffering from health effects "consistent with those produced by direct exposure to high concentrations of irritant gases during fire conditions," the Arizona government stated that because a direct "scientific" connection between the fire and reported health effects could not be proven, they were powerless to ameliorate resident's health and environmental issues (ATSDR, 1993).

The three main chapters of this dissertation set out to analyze what happened in the South Phoenix case from technical risk evaluation, public health, and political points of view. A brief introduction of these papers follows.

Modeling and risk assessment

This chapter discusses the utilization of computer modeling to estimate the South Phoenix community's exposure to combustion products from the QPC fire and compares these results to government sampling studies and risk analyses done on the community. Since no air samples were taken during the fire, actual community exposure levels were unknown. In order to approximate community exposure concentrations, two air dispersion models, the EPA's ISCST3 dispersion model and a mixed-box model, were utilized. The first objective was to compare exposure results obtained from the two distinct dispersion models to determine the accuracy of a less sophisticated model such as the mixed-box model. Another goal was to compare exposure concentrations from the ISCST3 model to government-established health-based exposure concentrations to determine if any exposure concentrations exceeded these guidance levels. A third objective was to qualitatively compare ISCST3 modeled exposure concentrations to health symptom data reported in the 1993 *DWAZ* health survey of South Phoenix residents.

Health study assessment

This chapter focuses on a health study that was performed on 690 residents of Census Tract 1160, almost eight months after the occurrence of the QPC fire. It also briefly discusses a health study done by the EPA more than four years after the fire.

Though residents began reporting health problems immediately after the fire, it was not for another eight months that ADHS asked *Don't Waste Arizona*, a local advocacy group, to conduct a health survey with residents of Census Tract 1160, the area most affected by the fire. After the survey was completed, ADHS argued that it had not been distributed using randomized sampling procedures and subsequently refused to analyze the results.

The South Phoenix community was disappointed with this judgment and for years fought to change the government's decision. Finally, they appealed their case to the U.S. Environmental Protection Agency. The EPA performed a sampling study and developed and administered a brief health survey to approximately 200 residents attending a December 1996 community meeting, to document unresolved health concerns related to the 4½–year-old fire.

Seven years after the fire, we analyzed the 1993 and 1996 health surveys. The purpose of our study was to characterize health symptoms reported in the 1993 health survey, and to determine differences in reported health symptoms based on residents' proximity to the fire. We also discuss results of the 1996 health survey.

Political assessment

This chapter focuses on how political issues affected the unfortunate outcome of this case. The government agencies involved were remiss in the handling of this situation and three theories have arisen as to why this occurred. The first is due to environmental racism, the second to what we have termed organizational issues, and the third to an inability of current scientific methods to predict health problems. Environmental racism implies that the agencies involved failed to adequately protect South Phoenix residents because of racial and/or social discrimination. Organizational issues may include inadequate funding, lack of personnel, poor communication between environmental agencies, and an unfriendly political environment. Scientific failure may be due to the fact that a risk assessment is one of the few tools currently used to prove a chemical exposure.

In this chapter we present the QPC fire incident as a case study to explore how these three issues might have played a part in the unsatisfactory outcome of this event. It is hoped that this discussion will contribute to a broader understanding of the events that occurred in this incident, a better appreciation for a community's perspective in such situations, and will help highlight the importance of a coordinated effort by government agencies responsible for protecting its citizenry in an environmental emergency. The article also demonstrates that "problems" can serve as an impetus for improving emergency response systems.

PURPOSE AND SIGNIFICANCE OF THE STUDY

The purpose of this study was to give an in-depth analysis of the QPC fire from a political, engineering, and public health perspective. Analyzing this incident from three perspectives should provide readers with an understanding of such events from multiple viewpoints and the complexity involved in linking exposure to health outcomes. This paper should supply government agencies and communities involved in similar chemical release incidents with an understanding of what can go wrong in such situations and provide them with the tools to prevent these problems. It is hoped that government and community groups will learn more about each other's roles in these events so they can work together more easily. On a technical level, it should provide both groups with a catalog of steps that must be taken after a chemical release event.

SCOPE AND LIMITATIONS

The greatest limitation of this study was the fact that air samples were not taken during the fire. The amount and types of chemicals, miscellaneous materials, and equipment consumed within the facility were unknown. By not taking air samples, the chemicals and their associated concentrations within the byproduct plume needed to be estimated through computer modeling efforts. In addition, all of the studies, including the sampling studies and health surveys, were done months and even years after the fire.

COMMUNITY EXPOSURE TO COMBUSTION PRODUCTS FROM AN INDUSTIAL FIRE: COMPARING MODELED EXPOSURE CONCENTRATIONS TO GOVERNMENT DEFINED PERMISSIBLE HEALTH-BASED CONCENTRATIONS

INTRODUCTION

In the late 1980s, a manufacturing facility for computer circuit boards was sited in a residential neighborhood in Phoenix, Arizona, on the upper western edge of Census Tract (CT) 1160. The facility was destroyed by fire on August 31, 1992; the fire began at approximately 11:30 a.m. and lasted for 8 hours, creating a thick, black plume that was blown primarily east by northeast into the nearby community (Figure 1). About 45 minutes after the fire began, the Phoenix Police Department instructed residents to leave the area; since an evacuation was not ordered, however, only 69 residents out of approximately 1,800 affected residences left the area, exposing them to the combustion products for a longer period. (ATSDR, 1993).

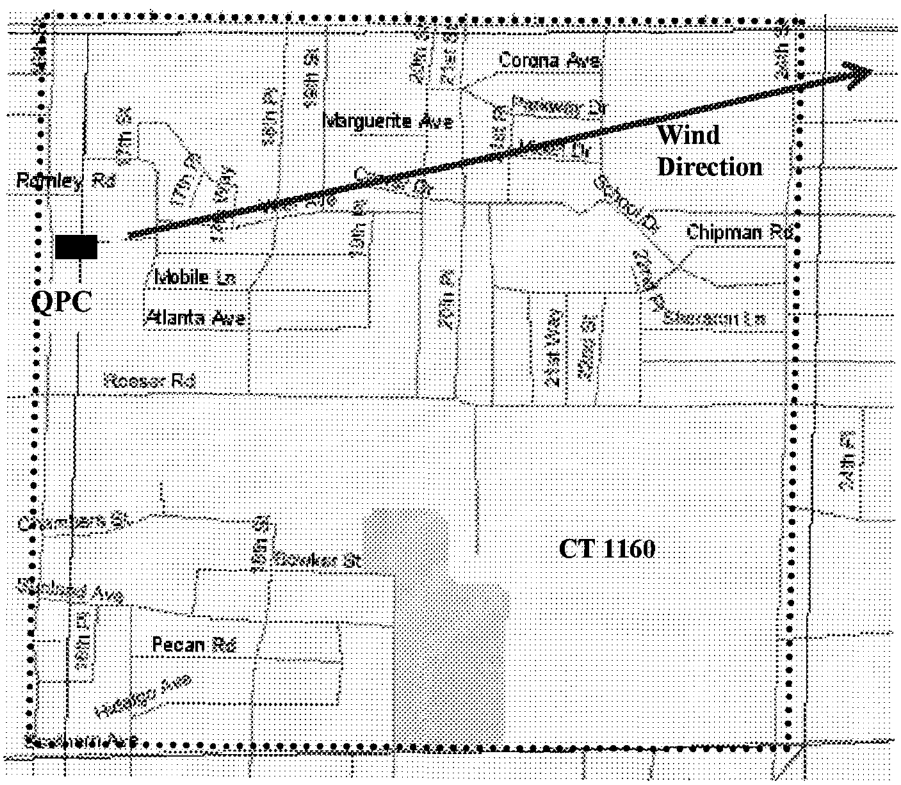


Figure 1: Map CT 1160 with the location of the former QPC facility (USBC, 2003).

Within days of the fire, residents began reporting health problems as well as lethal effects to plants and animals. As a result of these reports, the Arizona Department of Environmental Quality (ADEQ) and the Arizona Department of Health Services (ADHS) began an investigation. Between October 1992 and May 1994, ADEQ performed six chemical sampling studies on a total of 32 homes. Results of the largest study found that zinc, copper, and lead concentrations in the air, soil, and air duct dust were slightly higher in study homes than in control homes (USEPA, 1999). However, an accompanying risk assessment found that all chemical levels were below Health-Based Guidance Levels (HBGLs), and should not have generated the reported symptoms (ETI, 1993).

Eight months after the fire, residents were still reporting health problems that they attributed to the fire. In response, ADHS contracted with *Don't Waste Arizona* (*DWAZ*), a local community advocacy group, to perform a health survey of CT 1160. The 690 residents that were surveyed listed symptoms such as nausea, vomiting, dizziness, numbness and/or tingling of the limbs, blurred vision, trouble breathing, eye irritation, and rashes. These symptoms are typical of those reported after exposure to irritant gases (NLM, 2002). These symptoms correlate well with two other studies involving chemical smoke exposure (Haponik, et al., 1988; Ackermann-Liebrich and Rapp, 1992). Degher and Harding (in review) analyzed the CT 1160 health survey and found that the number of reported symptoms differed based on proximity to the fire.

For several years, the South Phoenix community reported health problems that they attributed to the 1992 fire. Due to the community's perseverance, the United States Environmental Protection Agency began additional studies in December 1996. Over the next year, the EPA sampled 39 residences. Results showed that levels of several chemicals were higher in study homes than in control homes, but all concentrations were again below HBGLs.

Since samples were not taken during the fire, the primary method left for estimating residents' original exposure levels to combustion products from the fire was through back-modeling. Several modeling programs were analyzed as to their suitability for this application. The EPA has developed several modeling programs to estimate emissions including ISCST3, CALPUFF and CTDMPLUS (USEPA, 2001). These models use a Gaussian distribution with varying degrees of sophistication to estimate chemical dispersion. The National Institute of Standards and Technology (NIST) has a program that takes buoyancy effects into account in order to specifically model the smoke plume emitting from a pool of burning crude oil (McGratten, et al., 1997). Another model (Heikes, et al., 1987) was created for the Defense Nuclear Agency that can estimate the plume height and cloud formation in the atmosphere due to several fires burning simultaneously over hundreds of square miles. Finally, the USDA Forest Service (Burgen, et al., 1986) has developed several models to predict the behavior of forest fires.

Though several chemical fires in residential areas have been reported, none have been analyzed via back-modeling (Morse, 1997; Walter and Wright, 1995; Thayer, 1993; Roberts, 1994). In one of these cases, a chemical fire in a railway car in New Orleans, an exposure analysis was done, resulting in a successful lawsuit with a $3.4 billion judgment (Morse, 1997). In another case, detailed analyses of evacuees were avoided when the responsible parties provided them gift certificates a few days before the Christmas holiday (Walter and Wright, 1995). In the other chemical fire incidents, follow-up studies have been limited to factory workers and firefighter personnel (Thayer, 1993; Roberts, 1994).

OBJECTIVES

This paper focuses on exposure and estimated risks of airborne contaminants to the resident population. The first objective was to compare chemical concentrations obtained using a mixed-box model and the EPA's ISCST3 models to determine if sophisticated air pollution models are required for situations such as the QPC fire. The second objective was to compare estimated exposure concentrations from the ISCST3 model to government-established health-based exposure concentrations found in the EPA's Integrated Risk Information System and ADEQ's Arizona Ambient Air Quality Guidelines to determine if concentrations exceeded these HBGLs. The third objective was to qualitatively compare ISCST3 modeled exposure concentrations to health symptom data reported in the 1993 *DWAZ* health survey of South Phoenix residents.

METHODS

Data sources

Data used in the two models were obtained from several sources. The mass emission rate of combustion products from the fire was obtained from URS Consultants. URS Consultants used chemical inventory sheets from the site, structural information about the building, and information on non-inventory contents (i.e. machinery, furniture, etc.) to estimate the mass emission rate of combustion products. URS Consultants then used this emission rate along with other factors, including ambient temperature and mixing depth, to estimate plume height (URS, 1994). Meteorological data obtained from the American Meteorological Society was used as reported at the SkyHarbor Airport in Phoenix and the Tucson Airport. Other information on the fire was procured from Phoenix Fire Department's files, personal interviews, and from information gathered during a 1994 inquest into the fire.

Data on the health-based guidance levels of the chemicals involved were obtained from two sources. The US EPA's Integrated Risk Information System (IRIS) database (USEPA, 2002) provided the majority of data; a second source of data was ADEQ's Arizona Ambient Air Quality Guidelines (ADEQ, 1992). Data on reported health symptoms was obtained from the 1993 health survey that *Don't Waste Arizona* performed for ADHS on residents of Census Tract 1160.

ADEQ and EPA sampling studies and risk assessments

In 1993, ADEQ hired an environmental consulting firm to sample the indoor and outdoor air of 3 control homes and 10 study homes in the South Phoenix community for metals and semi-volatile organic compounds (SVOCs) (USEPA, 1999). Results of the studies showed that zinc, copper and lead concentrations were slightly higher in study homes when compared to control homes. However, an accompanying risk assessment found that all chemical levels were below HBGLs and should not have caused the community's adverse health symptoms (ETI, 1993).

During a two-phase study performed in 1997, the EPA sampled 39 residences, 34 east of the facility and 5 approximately two miles southwest of the affected area. During Phase 1, conducted in May and June 1997, the EPA sampled the yard soil, ventilation duct dust, and indoor settled dust of the 39 residences. Samples were tested for anions (fluoride and chloride), furans, dioxins, metals, phenols, and polynuclear aromatic hydrocarbons (PAHs). Results of Phase 1 showed significant differences between the 34 South Phoenix homes and the 5 control homes for approximately half of the compounds tested. However, all exposure concentrations were below HBGLs.

Because differences did exist in chemical concentrations between control and study homes, the EPA performed a Phase 2 analysis in November and December 1997. Samples taken of the indoor and outdoor air of 38 homes (one study home declined to participate) were tested for metals, anions, total dust, and PAHs. Results did not show statistically significant differences in chemical concentrations in either the indoor or outdoor air between the study and control homes. In addition, all concentrations were below HBGLs.

1993 Health study

Don't Waste Arizona developed a health survey in consultation with a federal health agency and distributed it to the 690 residents of CT 1160. To analyze the results, CT 1160 was divided into four areas based on proximity to the facility. Areas 1, 2, and 3 were located in the direct path of the byproduct plume, with Area 1 located closest to the facility; Area 2 second; and, Area 3 was the furthest east of the facility. Area 4 was identified as a control group, as it was located to the south of the facility, upwind of the fire. The overall pattern showed that the frequency of reported symptoms was highest for Area 1, and that the symptoms progressively decreased with distance away from the facility (Areas 2 and 3) and outside of the path of the plume (Area 4).

ANALYSIS

Basic Study Approach

Since the exact materials consumed in the fire were unknown and samples were not taken during the fire, several assumptions had to be made in order to estimate the South Phoenix community's exposure to combustion products from the QPC fire. The general approach to determining residents' exposures is outlined in Figure 2. A more in-depth explanation of this approach and assumptions follows.

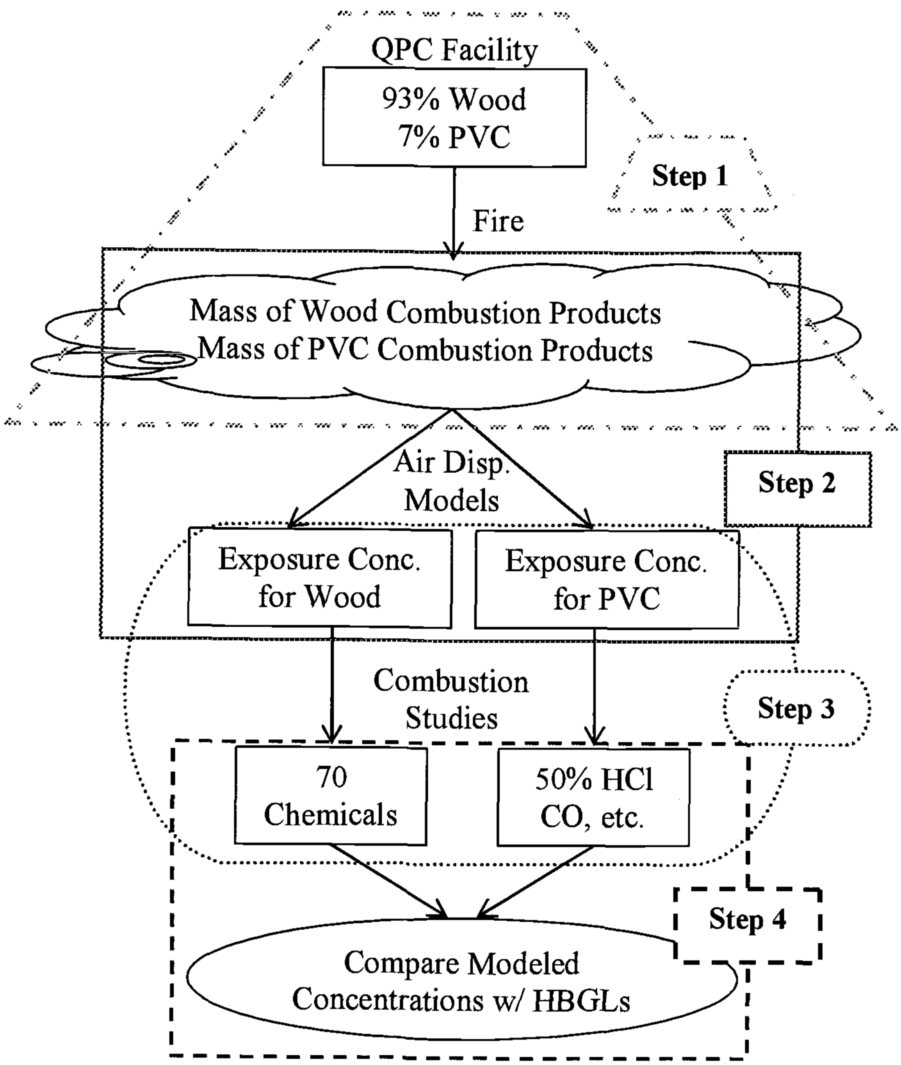


Figure 2: Approach to estimating residents' exposures to combustion products from the QPC fire and comparison to HBGLs.

Step 1: Materials consumed in QPC facility fire

Various chemicals and materials were burned in the circuit board manufacturing plant fire. Chemicals being used on the manufacturing floor (acids and metals) were consumed, as was process equipment made of polyvinyl chloride (PVC) and polypropylene (PP), miscellaneous process materials (batteries, razorblades, plastic trash liners, gloves, tape, office supplies, lab supplies), furniture, and office equipment. A fireproof vault held the most toxic chemicals.

Since air samples were not taken during the fire, it was impossible to determine the types and concentrations of combustion products of the furniture, process materials, and chemicals being used on the floor. In an analysis of the mass emission rate of combustion products from the fire, an environmental engineering firm assumed that 7% of the material consumed was PVC from the manufacturing equipment. They assumed that the majority of material burned was from the building structure (interior frame walls, ceiling, roof structure, etc.) and office furniture. There were smaller amounts of PP and chemicals in storage consumed though their contribution to total emissions was minimal, being as small as 0.004 percent for the toxic chemicals in storage (URS, 1994). For these reasons, this study assumed that 93 percent of the materials emitted came from burning wood and the remaining 7 percent from PVC. Based on these assumptions, the chemical input values used in the ISCST3 and mixed-box models were estimated as shown in Table 1.

Table 1. Chemical input values for the ISCST3 and mixed-box models

Material Type	Quantity Consumed (ton)	Emission Factor (ton/ton)	Total Emissions (ton)	Total Emissions (g)
Wood	141	0.059	8.32	$7.56E^{+}6$
PVC	6.2	0.098	0.61	$5.52E^{+}5$

Step 2: Air dispersion modeling

After the total combustion products of PVC and wood were calculated, they were used in the mixed-box model and the EPA's ISC Short Term 3 model to estimate total exposure concentration of the PVC and wood within the byproduct plume. ISCST3 was chosen because of its common use for this type of dispersion modeling. A mixed-box model, the simplest type of back-modeling tool, was used to provide a comparison for the ISCST3 model and determine if a simplistic model could be applied.

In order to compare the results from the ISCST3 and mixed-box models, the same exposure time was used. ISCST3 calculates the average concentrations over a 1-hour period and over an 8-

hour period, and calculates the highest concentration recorded within both a 1-hour and 8-hour period. All data sets were collected, but most analyses used 8-hour exposure concentrations because the mixed-box model used an 8-hour exposure scenario, the fire lasted 8 hours, and HBGLs are based on an 8-hour exposure.

Mixed-box model

A mixed-box model is a simple model used to obtain zero-order concentration estimates. A zero-order mixed box model assumes that the concentration is thoroughly mixed throughout a given sample area and that the concentration depends solely on mass of the pollutant and exposure volume (Russell, 1995). Figure 3 provides a graphical depiction of how concentration is estimated using a mixed-box model. In this model, the exposed volume is determined by multiplying the downwind velocity (v_d) by the plume height (h_p), the width of the area affected (w), and exposure time (t):

$$\text{Volume} = v_d * h_p * w * t$$

The exposure concentration (C) to residents within the "volume" is determined by dividing the total mass emission of combustion products (Q) by this volume.

$$C = Q / v_d * h_p * w * t$$

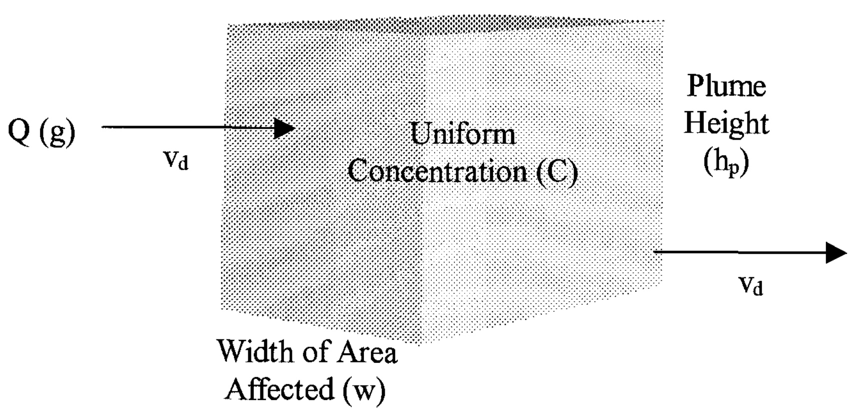


Figure 3: Diagram of how concentration is estimated in a mixed-box model.

ISCST3 model

ISCST3 was developed by the Environmental Protection Agency to model air quality impacts from combustion and fugitive emission sources. The program was developed primarily to model air dispersion impacts from hazardous waste combustion facilities and Superfund sites. The ISCST3 distribution model can be downloaded from the EPA's Support Center for Regulatory Air Models (SCRAM) website (EPA, 2002). A user-friendly Expert Interface (ExInter) program can also be downloaded from EPA's SCRAM website (EPA, 1997). ExInter was developed primarily to help untrained modelers create input files for the DOS-based ISCST3 model. Figure 4 provides a depiction of how the EPA's ISCST3 air dispersion model uses a Gaussian distribution to estimate plume dispersion. Appendix B describes in more detail the components of the ISC dispersion model and how the model works.

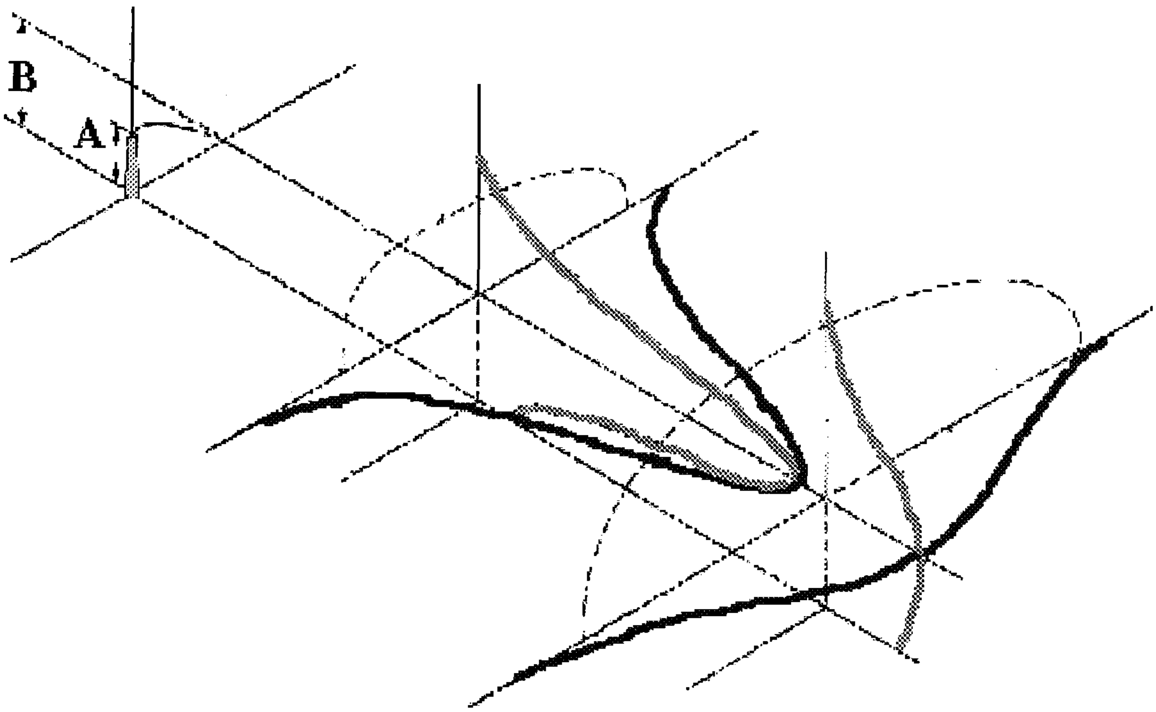


Figure 4: Diagram of how concentration is estimated in the EPA's ISCST3 air dispersion model.

Input data and assumptions used in ISCST3 and mixed-box models

All input values were based upon a best estimate of conditions at the time of the fire. Table 2 lists the values that were used in the ISCST3 and mixed-box models and the various assumptions used in the two models. Appendix C describes in more detail how each of these assumptions was obtained.

Table 2. Input values for the mixed-box and ISCST3 models

Model Parameters	Mixed-Box	ISCST3
Wind direction	30° north of East	Model calculates
Wind velocity	Constant 4.17 m/s	Model calculates
Plume release height (ht. of facility)	5.8 m	5.8 m
Plume height	244 m	Model calculates
Plume depletion	None	None
Duration of the fire	8 hours	8 hours
Width of area affected	1,609 m	Model calculates
Emission data		
Of products from wood	$7.56E^{+}6$ g	$0.113 g/m^2*sec$
Of products from PVC	$5.52E^{+}5$ g	$0.008 g/m^2*sec$
Origin of the facility (x,y,z)	NA[a]	0,0,0
Building parameters (x,y)	NA	75 m, 31 m
Building orientation angle	NA	0 degrees
Consumption of facility	100%	100%
Receptors	NA	Radial receptor grid
Number of rings		16 rings
Number of degrees		Receptor every 15°
Setting	N/A	Urban
Terrain Algorithm	N/A	Simple (no tall structures)
Receptor Height	N/A	Ground level
Human exposure pathway	Inhalation only	Inhalation only

[a] NA signifies Not Applicable

Step 3: Combustion Studies

After the total exposure concentration of PVC and wood were established, the percent of each byproduct emitted when these materials burn was determined from previous studies. Larson and Koenig (1993) measured the types and concentrations of chemicals emitted when several types of wood including pine, alder, and oak, were burned in a conventional wood-burning stove. Emissions were measured at various temperatures and a high and low concentration value for each combustion byproduct was reported. Over 70 compounds were measured in the wood smoke. Since the temperature of the fire was unknown, an average of the high and low emission concentrations measured in the Larson and Koenig study were used.

Data on the combustion products of PVC were obtained from two studies that estimated primary combustion products from burning PVC (Tewarson, 1995; Alexeeff, 1986). Only the five major chemicals emitted from burning PVC were used in this study and included hydrogen chloride (approximately 47% of total emissions), particulate matter (20%), carbon monoxide (3%), carbon dioxide (13%), and methane (2%).

Step 4: Health-based concentration data

Concentrations obtained using the ISCST3 model were compared to government defined health-based guidance levels to determine if the modeled concentrations were above these acceptable exposure levels. HBGLs were obtained from the EPA's IRIS database and ADEQ'S Arizona Ambient Air Quality Guidelines. IRIS is a web accessible database that contains data on human health effects that may result from exposure to hundreds of chemicals in the environment.

One form of health data contained in the IRIS database are inhalation reference concentrations (RfCs), which are defined by the EPA as "an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime" (USEPA, 1993). The inhalation RfC takes into account both toxic effects on the respiratory system and on parts peripheral to the respiratory system.

The Arizona Department of Environmental Quality uses the term health-based guidance levels, which has the same definition as Reference Dose. Only 20 of the approximately 70 combustion products of the fire had government-defined levels associated with them. A list of the 20 combustion products of the fire that had associated government defined health-based concentrations can be found in Table 4.

RESULTS

Comparison of results from the ISCST3 and mixed-box models

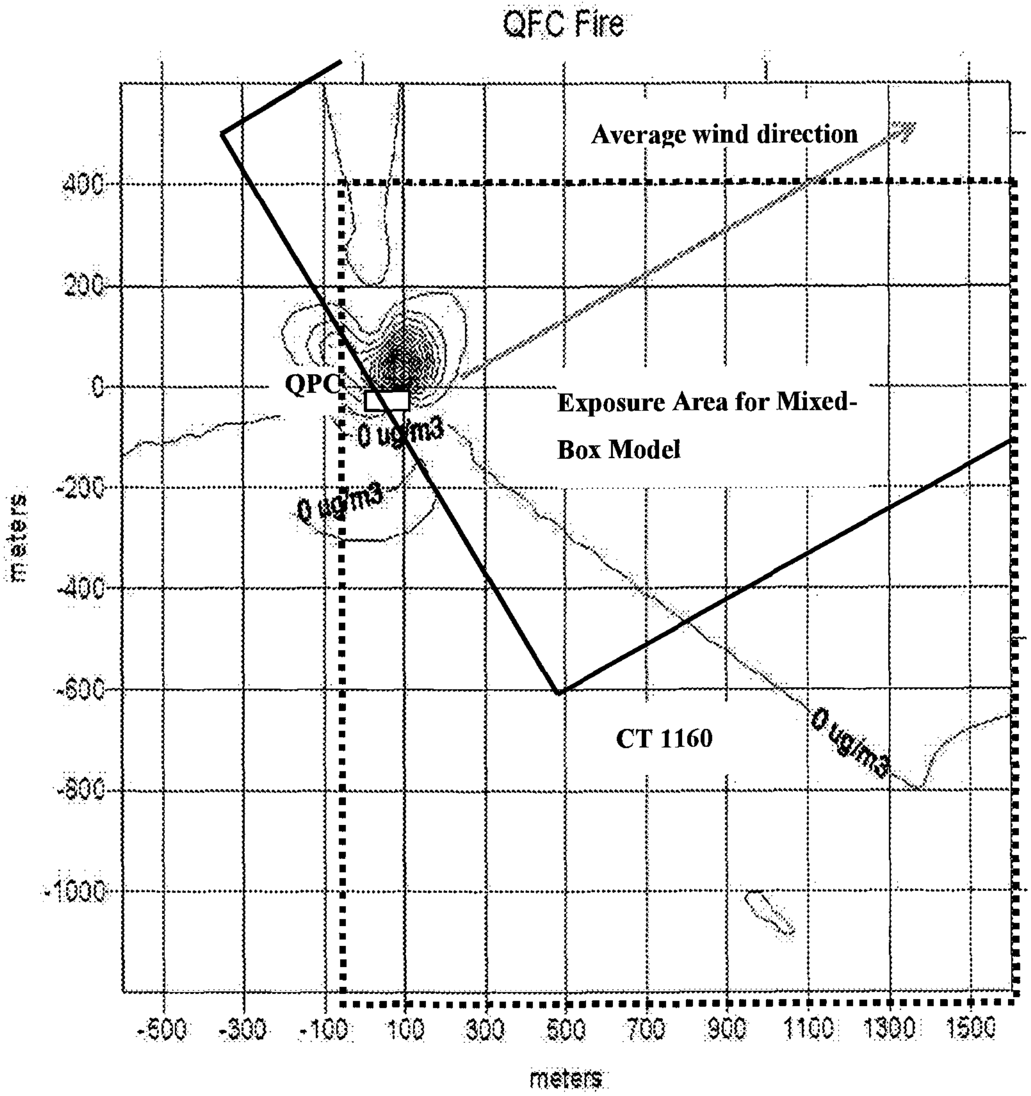
Data obtained from the ISCST3 and mixed-box models were significantly different. The total 8-hour exposure concentration of combustion products obtained using the mixed-box model was 172 ug/m^3, 42 times less than those obtained from the ISCST3 model. A sample output of the first highest 8-hour average concentration values obtained using the ISCST3 dispersion model is shown below in Table 3. This output shows these concentrations at several points on the user-defined radial receptor grid. ISCST3 calculates a concentration every 15 degrees along each 100-meter ring from the facility. Table 3 shows that the highest exposure concentration of combustion products from the QPC fire, averaged over the 8-hour duration of the fire, was 35,400 ug/m^3. This was measured 100 meters from the facility, at 75 degrees east of direct north. The exposure concentration dropped to approximately 1,000 ug/m^3 within 350 meters of the facility and to below 100 ug/m^3 within 1,000 meters.

Table 3. Sample ISCST3 output of eight-hour exposure concentrations for South Phoenix residents to combustion products from the QPC fire.

Direction from due North (Degrees)	**Distance from the QPC facility (m)**				
	100	**200**	**300**	**400**	**500**
15	1,200.31	137.45	71.90	43.93	28.92
30	4,547.94	1,409.32	694.03	396.90	251.26
45	15,090.20	4,290.13	1,777.90	942.44	576.32
60	35,336.58	5,453.99	1,963.98	986.96	586.31
75	35,442.74	4,359.99	1,569.29	790.00	468.73
90	9,228.34	2,684.52	1,149.83	632.16	399.55
105	387.27	319.45	202.45	130.49	88.79
120	3.27	2.90	2.33	1.81	1.35
135	0.00	0.00	0.00	1.81	1.35
150	0.00	0.00	0.00	0.00	0.00
165	0.00	0.00	0.00	0.00	0.00
180	0.00	0.00	0.00	0.00	0.00
195	0.00	0.00	0.00	0.00	0.00
210	0.00	0.00	0.00	0.00	0.00
225	0.00	0.00	0.00	0.00	0.00
240	0.04	0.00	0.00	0.00	0.00
255	23.50	6.01	2.51	1.40	0.90
270	509.09	236.65	130.74	80.15	52.53
285	3,054.34	1,421.76	780.97	487.37	331.22
300	7,427.20	2,736.03	1,346.26	789.15	515.46
315	9,353.13	2,415.91	1,002.03	528.49	319.99
330	7,424.03	1,316.45	466.51	223.96	126.65
345	4,402.52	472.60	120.46	45.23	21.05
360	2,065.87	65.37	6.38	1.30	0.46

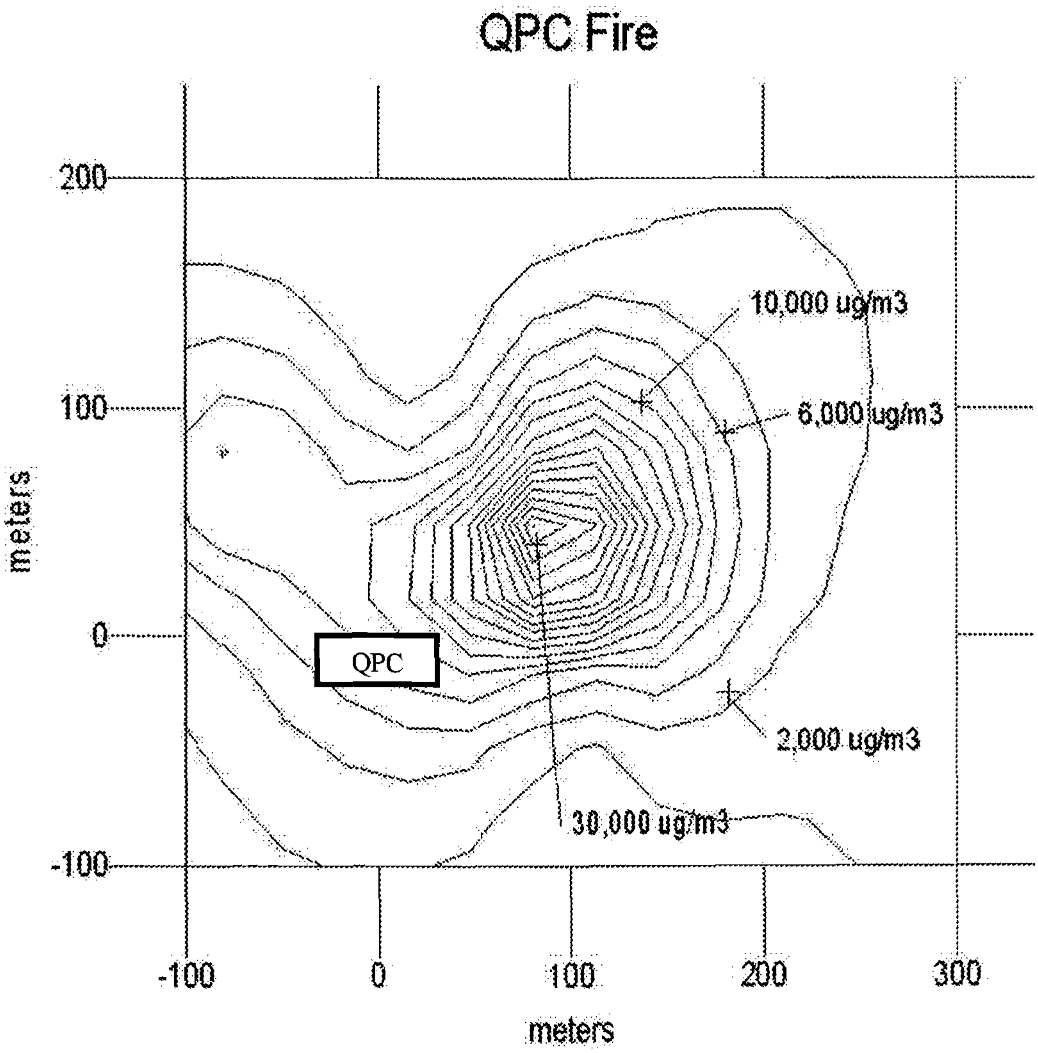
Notes. The flow vector is in the direction towards which the wind is blowing. Concentrations are in ug/m^3

The data in Table 3 was then used to create a footprint of the byproduct plume such as those shown in Figures 5 and 6, which were created using Surfer (2001), a contour plotting program. Figures 5 and 6 show that a majority of the plume was estimated to have blown to the northeast, but a significant portion also blew to the northwest. Figure 5 also shows the exposure area used in the mixed-box model and the exposure area created in the ISCST3 model. Since the concentration for the mixed-box model is assumed to be constant within the entire exposure area, the concentration of the combustion products does not decrease with distance from the facility. In addition, the mixed-box model did not predict significant exposure to residents living northwest of the facility because of the use of a single wind direction. Appendix 4 shows a sensitivity analysis of the exposure concentrations for both models.



Notes. In the ISCST3 model, the facility was located at (0,0) (Surfer, 2001).
The dotted line represents CT 1160.
The solid line represents the exposure area used in the mixed-box model.

Figure 5. Contour plot of the combustion product plume as modeled using ISCST3 and its relation to the exposure area for the mixed-box model (solid black line) and CT 1160.



Note. In the ISCST3 model the facility was located at (0,0) (Surfer, 2001).

Figure 6. Close-up of the contour plot of the combustion product plume as modeled using ISCST3.

Modeled exposure concentrations and HBGLs

A comparison of eight-hour exposure concentrations for 20 chemicals obtained from the mixed-box and ISCST3 models and their HBGLs is shown in Table 4. Using the mixed-box model, there were no chemicals with 8-hour exposure concentrations greater than their HBGL. HCl and PAHs had exposure concentrations less than, but of the same order of magnitude as their HBGLs.

Data from the ISCST3 model showed that 4 chemicals had 8-hour exposure concentrations higher than their HBGLs (HCl, PAHs, Acrolein, and naphthalene). Acetaldehyde, benzene and formaldehyde were less than their HBGL, but of the same order of magnitude. The ISTST3 model also resulted in the 8-hour exposure concentration for HCl being the most significantly greater than its HBGL, in this case 55 times higher. The 8-hour exposure concentration for HCl did not drop below its HBGL until about 1200 meters from the facility.

Table 4. Eight-hour exposure concentrations for South Phoenix residents and HBGLs

Combustion products	HBGL [a] mg/m^3	ISCST3 Exposure Conc. (mg/m^3)	ISCST3/ HBGL	Mixed Box Exposure Conc. (mg/m^3)	Mixed-Box/ HBGL
Acetaldehyde	9.0E-03	1.3E-03	0.14	6.3E-06	
Acetic Acid	*1.9E-01*	8.7E-03		4.2E-05	
Acrolein	2.0E-05	**2.5E-04**	**12**	1.2E-06	
Benzene	*5.1E-02*	9.5E-03	0.19	4.6E-05	
Carbon Monoxide	4.0E+01	1.0E+00		4.9E-03	
Chlorine	*2.3E-02*	4.4E-04		2.1E-06	
Chromium	1.0E-04	6.2E-06		3.0E-08	
Copper	2.4E-03	2.3E-06		1.1E-08	
Formaldehyde	*1.2E-02*	1.7E-03	0.14	8.0E-06	
Formic Acid	*7.1E-02*	2.9E-04		1.4E-06	
Hydrogen Chloride	2.0E-02	**1.1E+00**	**55**	5.5E-03	0.37
Lead	1.5E-03	6.4E-06		3.1E-08	
Methyl chloride	9.0E-02	1.0E-04		5.0E-07	
Naphthalene	3.0E-03	**3.8E-03**	**1.3**	1.8E-05	
Nickel	8.0E-03	2.1E-06		1.0E-08	
Nitrogen Oxides	*2.3E-01*	2.3E-03		1.1E-05	
PAHs	2.2E-05	**5.3E-04**	**24**	2.3E-06	0.14
Phenol	*1.5E-01*	2.1E-03		1.0E-05	
Toluene	4.0E-01	2.4E-03		1.2E-05	
Zinc	2.4E-03	1.8E-05		8.7E-08	

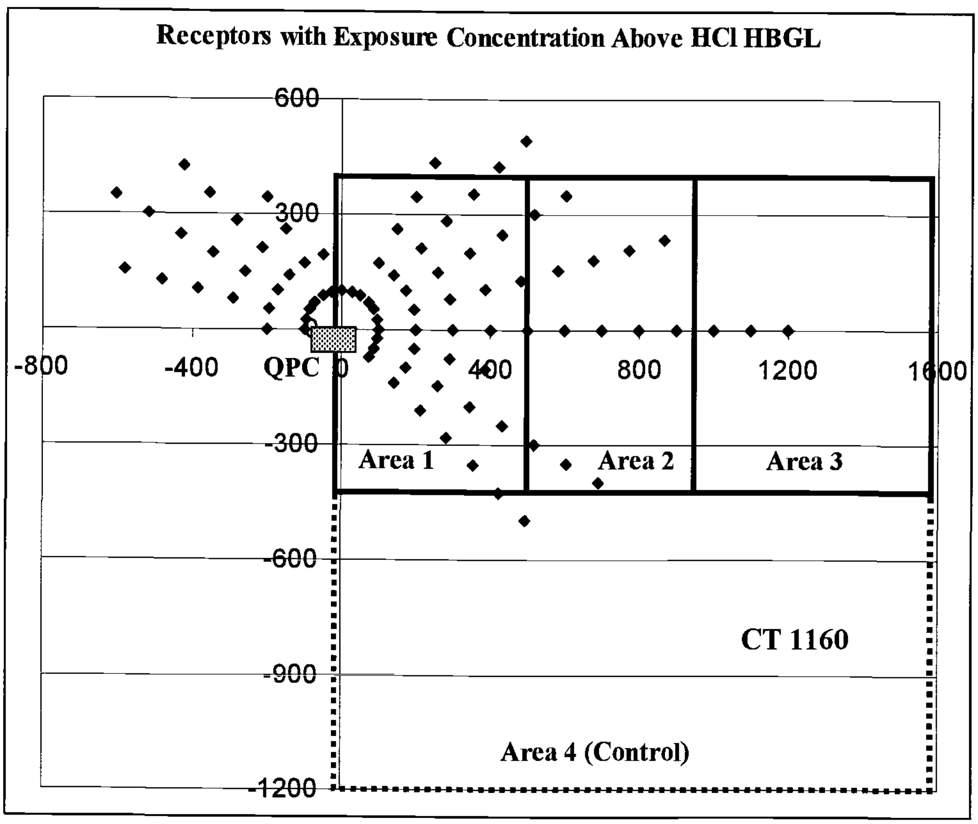
[a] HBGL data obtained from ADEQ's Ambient Air Quality Guidelines are italicized. The remaining HBGLs were obtained from EPA's Integrated Risk Information System (IRIS)

[b] Exposure Concentrations in bold are greater than their HBGL

Chemical exposure and symptom distribution

Data obtained from the 1993 health study performed by *Don't Waste Arizona* showed that many residents of CT 1160 began reporting adverse health symptoms almost immediately after the fire. Reported symptoms included irritated eyes and blurry vision, nausea and/or vomiting, allergies, troubled breathing, rashes, headaches, fatigue, frequent colds, dizziness, numbness and/or tingling of the limbs, and loss of smell. Results obtained from analyzing the health survey (Chapter 3) show that for all measured symptoms, the residents' proximity to the facility had the greatest influence on symptom prevalence than any other factor; the overall pattern showed that symptoms decreased as the homes of the residents were located farther from the facility.

Figure 7 shows the locations of receptors that have 8-hour exposure concentrations for HCl greater than its HBGL and their relation to the areas used in the health survey to reported symptoms within CT 1160. As can be seen, the areas with the greatest exposure were Area 1 and Area 2. Area 3 had a few receptors that experienced high concentration values. Area 4 had a single receptor that experienced a concentration greater than an acceptable level though this receptor is not located near a residence. These results match well with the health symptom data, which showed that residents living in Area 1 and Area 2 reported having significantly more symptoms than residents living in either Area 3 or Area 4. According to the ISCST3 model, residents within Areas 3 and 4 were exposed to very low concentrations.



Note. CT 1160 is the entire boxed in area; Area 4 is the outlined in a dotted line.

Figure 7. ISCST3 receptors with 8-hour exposure concentrations greater than the HBGL for HCl and their relation to the facility and exposed communities within CT 1160.

DISCUSSION

Comparison of ISCST3 and mixed-box data

A mixed-box model appeared to not be complex enough to show how the byproduct plume was dispersing even though the fire represented a simple modeling scenario with flat terrain, nearly constant temperatures, and close proximity of the community. The mixed-box model appeared to predict exceptionally low estimates of chemical exposure. It was also unable to show that residents to the northwest were being exposed to high chemical concentrations. Lastly, it could not predict how quickly the combustion products from the fire would be dispersed. Models that use a Gaussian distribution and take meteorological data into account such as the ISCST3 model, appear to be far better at modeling dynamic events such as the QPC fire.

Modeled exposure concentrations and HBGLs

The plume models predicted that most of the chemical concentrations were below their HBGL and therefore would not have caused reported symptoms. However, the ISCST3 model showed that four of the 20 chemicals (HCl, PAHs, Acrolein, and naphthalene) did have exposure concentrations greater than the government-defined health-based concentration levels. Benzene acetaldehyde and formaldehyde were the same order of magnitude as their HBGLs.

The above-listed chemicals could have caused the symptoms reposted in the 1993 *DWAZ* health survey by residents of CT 1160 immediately following the fire since they cause symptoms similar to those reported. According to ToxNet (NLM, 2002a), inhalation of Acrolein causes irritation of the eyes, nose, and throat, shortness of breath, nausea and vomiting. Hydrogen chloride can cause coughing, pain, inflammation, edema of the upper respiratory tract, and even necrosis of the bronchial epithelium at high concentrations. HCl exposure can also produce burns on the skin and mucous membranes, and contact with the eyes may produce reduced vision or blindness (NLM, 2002a). Naphthalenes cause headache, dizziness, nausea and sometimes vomiting (NLM, 2002a).

Though benzene, acetaldehyde and formaldehyde were not above their HBGLs, they were of the same order of magnitude. Formaldehyde inhalation leads to irritation of mucous membranes, especially of eyes, nose and upper respiratory tract and higher concentrations can cause cough, bronchitis, pneumonia, and edema. Breathing benzene has the greatest effect on the central nervous system causing symptoms including dizziness, weakness, euphoria, headache, nausea, vomiting, and chest tightness (NLM, 2002a). Acetaldehyde causes eye irritation, and irritation of respiratory tract, nose and throat (NLM, 2002a).

In addition to causing acute risks, several of these chemicals are also potential carcinogens and their effect may not yet be known on the community. According to ToxNet, Acrolein is a suspected carcinogen and formaldehyde is a probable human carcinogen (NLM, 2002a). According to ChemID*plus*, PAHS are "reasonably anticipated to be a carcinogen" (NLM, 2002b). In addition, the Carcinogen Assessment Group at EPA has designated a sum total of 15 PAHs as potential carcinogens (NIH, 2002). Since the health survey was done 6 months after the fire, potential increases in cancer cases would not be expected.

Chemical exposure and symptom distribution

The ISCST3 model was able to show that residents living closer to the former facility were exposed to higher chemical concentrations than either residents living farther away or residents living upwind from the facility. Data from the *DWAZ* health study of CT 1160 shows that residents living closer to the facility reported more symptoms than those living farther away. The health survey did not, however, capture symptom data for the residents living to the northwest who were also exposed to the combustion products since this area was not included in the survey. The plume contour plot obtained using ISCST3 (Figure 7), shows that residents in the two areas closest to the facility were subjected to levels greater than permissible levels for several chemicals for an 8-hour period.

CONCLUSIONS

Results from the ISCST3 model associated well with symptoms reported in the *DWAZ* heath study. Both studies showed that residents living closer to the fire were exposed to greater chemical concentrations and probably had greater health impacts than those living farther away or upwind. The ISCST3 model also showed that exposure concentrations for many of the residents were much higher than allowable exposure levels (HBGLs) for HCl, PAHs, Acrolein, and naphthalene.

Though exposure information obtained from both the ISCST3 model and the *DWAZ* health survey suggest that South Phoenix residents' symptoms resulted from the QPC fire, a risk assessment done using air samples taken in May 1993, predicted that chemical levels were not high enough to cause adverse health effects. However, if results from the ISCST3 model were used in a risk assessment, it would have shown that residents were exposed to chemical concentrations high enough to cause adverse health effects and the outcome of this incident may have been different.

The most probable explanation for the inability of the risk assessment to predict adverse health effects in this case, is the long time delay between the exposure event and the risk assessment, allowing the chemicals time to disperse. This illustrates how important sampling at the time of the event is in order to ascertain the health effects from a short-term air-bound exposure such as that from the QPC fire. As it stands, by using current air pollution modeling techniques, we will never know the magnitude of the chemical exposure that resulted from the fire nor can we determine the impacts of the fire on the continuing health problems within the community.

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A COMMUNITY-BASED SURVEY OF HEALTH SYMPTOMS FOLLOWING AN INDUSTRIAL FIRE IN AN URBAN MINORITY NEIGHBORHOOD

On August 31, 1992, Quality Printing Circuits, a manufacturing plant for computer circuit boards located in a residential area of South Phoenix, Arizona, caught fire and was completely consumed. Shortly before noon, thick black plume from the facility blew into the surrounding neighborhood, and lingered for over eight hours in and above the area. The materials burned created a plume of combustion products formed from the hazardous compounds, hydrogen fluoride, sulfuric acid, fluoboric acid, nitric acid, ammonia, dioxins, polycyclic aromatic hydrocarbons, and furans (USEPA, 1999).

An hour after the fire started, the Phoenix Police Department requested that residents leave the area, with instructions to return at their own discretion. Because an evacuation, however, was not ordered, many residents were confused about what to do and remained in their homes. Eight hundred children attending schools in the path of the plume were evacuated to other institutions where they remained until the end of the school day. They were then transported by bus back to their still smoky neighborhood (Sowers, 1992).

Almost immediately after the fire, residents reported health and environmental problems. Reported health symptoms included asthma, blurred vision, congestion, hearing loss, hair loss, rashes, nausea and vomiting, and numbness of the extremities (ADHS, 1993). South Phoenix residents also reported that pets, grasses, and plants unexpectedly died a few days following the fire.

Although chemical fires occurring in residential areas similar to South Phoenix have been documented, limited efforts have been made to analyze resident health concerns afterwards. More commonly, follow-up studies have been conducted on factory workers and firefighters, even when resident exposure was of concern (Roberts, 1994; Thayer, 1993). A notable exception to this includes a study in which residents reported gastrointestinal discomfort (nausea and vomiting), respiratory problems, skin and eye irritation, headaches, fatigue, and vertigo after exposure to smoke from a neighborhood chemical fire (Ackermann-Liebrich and Rapp, 1992).

Other cases in which residents reported health concerns after chemical fires resulted only in financial settlements. For example, a 1987 butadiene fire in a railway car in New Orleans caused the forced evacuation of approximately 1000 residents. Residents won an unprecedented $3.4 billion after suing the transport companies on the basis of physical and mental anguish (Morse, 1997). In another case, residents reported health effects after exposure to chemical smoke from a nearby pesticide manufacturing facility. Residents stopped complaining, however, after being given gift certificates by the responsible parties a few days before Christmas (Walter and Wright, 1995).

Unlike these communities, South Phoenix residents were not placated with settlements. With limited success, residents pressured the Arizona Department of Environmental Quality

(ADEQ) and Arizona Department of Health Services (ADHS) to respond to complaints related to the Quality Printed Circuits (QPC) fire, and to perform sampling studies in their neighborhood. Between October 1992 and May 1994, these state agencies sampled for selected metals and semi-volatile organic compounds in soil and air. Other potential combustion products of the fire were not included in sampling efforts. Results of these investigations found that chemical concentrations were not significantly different between the control and study homes, and that, "there were insufficient quantities of metals present to be a health concern to residents" (USEPA, 1999). Critics of the studies, however, insisted that the study sample was not representative of the affected residents, that the control group was also exposed to the byproduct plume, and that the compounds tested failed to include the full range combustion products released.

Because residents were still reporting health concerns eight months after the fire, ADHS asked *Don't Waste Arizona*, a local advocacy group, to conduct a health survey with residents of Census Tract (CT) 1160, the area affected by the fire. *Don't Waste Arizona* developed the health survey in consultation with a federal health agency and distributed it to 690 residents (17 percent) of CT 1160. The ADHS did not oversee the administration of the survey and subsequently refused to analyze the data, arguing that the survey had not been distributed using randomized sampling procedures. The ADHS and ADEQ closed the case later that year, citing inconclusive results in both the sampling and survey studies.

The South Phoenix community was disappointed with this decision, and appealed their case to the U.S. Environmental Protection Agency (EPA). In December 1996, the EPA reopened the case, basing its decision on the community's continuing health problems coupled with the ADEQ's limited sampling efforts. They also sought to provide the community with an independent assessment of current environmental conditions.

In May and November 1997, the EPA sampled indoor air, outdoor air, yard soil, indoor dust, and ventilation ducts in the South Phoenix neighborhood for metals, polynuclear aromatic hydrocarbons, phenols, fluorides/anions, dioxins/furans, and pH (USEPA, 1999). Significant differences were found in concentrations of chemicals between study and control homes for approximately half of the compounds, but all concentrations were below the EPA's Health Based Guidance Levels (USEPA, 1999). Health Based Guidance Levels represent the concentration of a chemical to which a person may be exposed that will not cause adverse health effects.

The EPA also developed and administered a brief health survey to residents attending a December 1996 community meeting, to document unresolved health concerns related to the 4½–year-old fire. Approximately 200 residents filled out the survey, answering questions about how far they lived from QPC and how long they had lived in the neighborhood. The survey also asked for residents to list personal and family health concerns related to the fire, and current symptoms. To our knowledge, this survey was not analyzed, nor results summarized for the community.

Because none of the chemical levels in the EPA studies were above the Health Based Guidance Levels, the EPA was legally unable to provide medical assistance to the South Phoenix residents or to remediate the neighborhood, despite documentation of persistent health problems. The studies, however, did report higher levels of chemicals in the cooler pads of the exposed homes. With this information, the EPA hired a firm to professionally clean the air ducts of any "exposed" area residence. Following this announcement, the EPA closed the South Phoenix case. To date, neither the results of the 1993 community-driven health study or the 1996 EPA study have been reported.

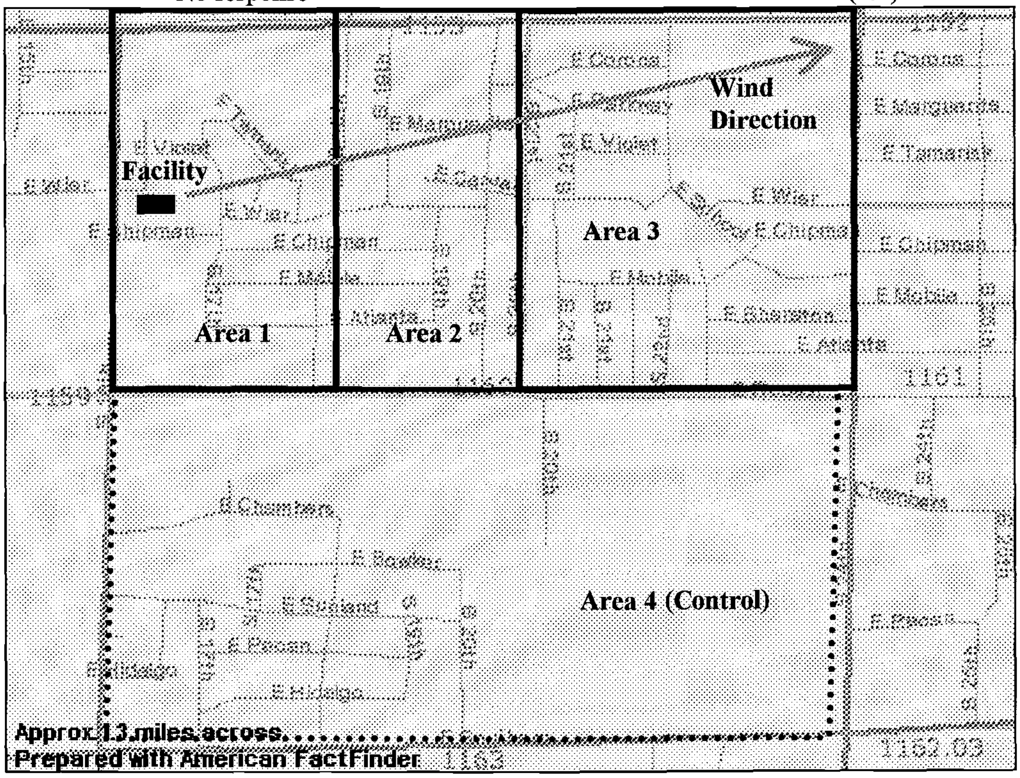
The purpose of our study, therefore, was to characterize health symptoms reported in the 1993 health survey, and to determine differences in reported health symptoms based on residents' proximity to the fire. We also briefly comment on results of the 1996 survey.

METHODS

Study sample

The study community is located in southwest Phoenix, Arizona, on the western edge of CT 1160, and directly adjacent to the QPC facility (Figure 8). QPC moved into the primarily low income, minority neighborhood of South Phoenix in the late 1980s.

Area	Location	Proportion of Residents in Each Area (% of Total Residents)	
1	West of S. 18th Place	154	(22.0)
2	Between S. 18th Pl. and S. 20th Pl.	134	(19.7)
3	East of S. 20th Pl.	194	(28.5)
4 (Control)	South of Roeser Rd.	202	(29.0)
	No response	10	(1.4)



Notes. Area 1 was closest to the fire and Area 4 was farthest away.
This map was created using American FactFinder database created by the US Census Bureau

Figure 8: Area divisions of census tract 1160 used for identifying participants' proximity to the QPC facility: South Phoenix, AZ

We divided CT 1160 into four areas based on proximity to QPC, and of approximately equal population sizes. Areas 1, 2, and 3 were located north of Roeser Road, in the direct path of the plume that blew in an east by northeasterly direction. Area 1 was located closest to the facility; Area 2 was next in proximity; and, Area 3 was the furthest east of the facility. Area 4 was identified as a control group, as it was located to the south of QPC, in an area upwind of the fire.

Data

We used health survey data collected in 1993 by the members of *Don't Waste Arizona.* The group developed the survey with the assistance of a federal health agency. According to the community group leader, ADHS approved the final version of the survey, and requested that the community group administer the survey to the neighborhood residents in Census Tract 1160. The data collection process, however, was not supervised by either of the health agencies.

The community group used three separate techniques for their data collection. Approximately one-third of the surveys were administered in a door-to-door canvas of the area; surveyors approached every third house of each block. If residents were away, the surveyor continued to the next home, subsequently returning to the "every third home" pattern. Another third of the surveys used a random telephoning method; surveyors called every third number on a randomized phone list of the census tract, proceeding to the next one if there was no response. A final third of the surveys were filled out by participants attending a local community meeting organized by *Don't Waste Arizona.* One member from each household filled out a survey. The community group collected a total of 690 completed surveys.

The semi-structured survey asked questions about a participant's gender, age, occupation, household cooling system, whether medical care was sought after the fire, location during the fire, and how long he/she had lived in the area. A second part of the survey listed twenty-five symptoms and asked participants to check all symptoms they had experienced during the year. Participants also reported when the symptom first occurred, and whether symptoms had improved, remained the same, or worsened following the fire.

Analysis

We analyzed the data using SPSS Version 8.0 (SPSS, Inc, 1998). Descriptive analyses provided frequency values for participant characteristics and for the most commonly reported health symptoms. Participant characteristics included age, gender, occupation, smoking status, homeowner status, type of household air-cooling system, time spent at home, and location during the fire. Commonly reported symptoms included congestion and/or coughing, trouble breathing, dizziness, nausea and/or vomiting, blurred vision, rashes, numbness and/or tingling of the extremities, and loss of smell.

We performed Chi-Square analyses to determine if there were differences in reported health symptoms based on residents' proximity to the fire, and to determine differences in reported health symptoms based on resident characteristics. To maximize statistical power, an overall significance value of $\sigma = .05$ was adjusted for multiple testing using the Holm's Sequential Bonferroni procedure (Aicken and Genster, 1996). We also performed a descriptive analysis of the symptoms reported by 27 matched residents who participated in both the 1993 and the 1996 surveys.

RESULTS

Participant characteristics

Participant characteristics are presented in Table 5. Participants were evenly distributed among the age ranges, with a quarter of the sample in each range. When compared to census data, the study sample represents a greater proportion of residents in the age ranges 40-59 years and over 60 years, and a lower proportion of younger residents. Although there were more females (54%) than males in the study, this difference was not significant. The majority of participants used evaporative "swamp" coolers (77%) rather than air conditioners to cool indoor air, and most were non-smokers (76%), homeowners (71%), and at home during the fire (57%). Approximately 27% of the participants identified their occupation as being either a student or laborer; 17% identified as being at home (retired or homemaker); and the remainder (14%) marked professionally-related occupations (teachers, engineers, counselors, etc.).

Table 5: Characteristics of the study sample (N = 690) living in census tract 1160 compared to 1990 census population (N = 4438): South Phoenix, AZ.

Characteristic	Study Sample No. (%)	1990 Census Population No. (%)
Age, y		
≤ 19	168 (24.4)	1,747 (39.4)
20 – 39	167 (24.2)	1,118 (25.2)
40 – 59	186 (26.9)	840 (18.9)
≥ 60	169 (24.5)	733 (16.5)
Gender		
Male	304 (44.1)	2,107 (47.4)
Female	374 (54.2)	2,331 (52.5)
No Response	12 (1.7)	
Smoking Status		
Non-smoker	528 (76.5)	n/a
Smoker	110 (16.0)	n/a
No Response	52 (7.5)	n/a
Occupation		
Full-time Student	190 (27.5)	1,094 (24.7)
Laborer	186 (26.9)	1,855 (41.8)
Retired, homemaker, unemployed	116 (16.8)	1,309 (29.5)
Professional (teachers, engineers, etc.)	97 (14.1)	180 (4.1)
Other	101 (14.6)	n/a
Home Owner Status		
Owner	488 (70.7)	3,349 (75.5)
Renter	86 (12.5)	1,089 (24.5)
No Response	116 (16.8)	n/a
Type of Household Cooling System		
Swamp Cooler	532 (77.1)	n/a
Air Conditioner	121 (17.5)	n/a
Other	37 (5.4)	
Location During the Fire		
Away	254 (36.8)	n/a
At Home	392 (56.8)	n/a
No Response	44 (6.4)	
Time Spent at Home, hr/day		
≤ 8	49 (7.1)	n/a
9 – 19	356 (51.6)	n/a
≥ 20	137 (19.9)	n/a
No response	148 (21.4)	

Note. Percentages may not add up to 100% due to rounding off of value

The survey did not inquire about participant ethnicity or household income. In 1990, however, approximately 65% of Census Tract 1160's residents identified as African American, 18% identified as Hispanic, and 16% identified as White. Thirty-six percent of the 1,412 households in

CT 1160 reported a total income of less than $14,000, with an average household income of $13,080. Approximately 37% of these residents lived below the poverty line (USBC, 1990).

General symptom information

We compared each of the most frequently reported health symptoms (Table 6) to participant characteristics to determine if differences existed between reported health symptoms and any of these variables.

Table 6: Most frequently reported health symptoms by 1993 South Phoenix study participants: differences with respect to geographical areas and participant characteristics

Health Symptom	Overall Reported No. (%)	Significant Differences Noted
Congestion / Cough	247 (35.8)	a,b,c,f,g,h
Trouble Breathing	208 (30.1)	a,b,c,e,f,g,h
Dizziness	158 (22.9)	a,b,c,e,f,h
Nausea/ Vomiting	142 (20.6)	a,b,e,h
Blurry Vision	138 (20.0)	a,b,e,f,g
Rashes	136 (19.7)	a,b,e,f,g
Numbness of Limbs	123 (17.8)	a,b,c,e,f,g,h
Asthma	89 (12.9)	a,b
Loss of Smell	56 (8.1)	a,b,c,e,g

Notes.
a - Significant difference between Area 1 and Area 4 (control), $p < .001$
b - Significant difference between Area 2 and Area 4 (control), $p < .001$
c - Significant difference between Area 3 and Area 4 (control), $p < .05$
d - Significant difference between Area 1 and Area 2, $p < .01$
e - Significant difference between Area 1 and Area 3, $p < .01$
f - Significant difference between Area 2 and Area 3, $p < .01$
g - Significant difference between males and females, $p < .05$
h - Significant difference between those away and those at home during the fire episode, $p < .01$

There were no differences in health symptoms based on smoking status or type of household air cooler used. Females more often than males reported symptoms of congestion and/or coughing (P=.037), trouble breathing (P=.004), dizziness (P=.001), nausea and/or vomiting (P=.033), and numbness and/or tingling of the limbs (P=.044). Residents at home during the fire experienced more congestion and/or coughing (P=.012), trouble breathing (P=.002), blurry vision (P=.003), asthma (P=.029), rashes (P=.048), and numbness and/or tingling of the limbs (P=.006) than did people who were away from home during the fire. Additionally, residents at home for twenty or more hours each day reported more congestion and/or coughing (P<.001) and nausea and/or vomiting (P=.012) than did those at home for fewer hours per day.

Reported health symptoms differed with respect to age and time spent at home. Residents younger than 20 years of age reported having more rashes than did those 20-59 years old (P=.008), and those over 60 years (P<.000). Younger residents also reported having asthma more often than those over 60 years (P=.01), and reported having nausea and/or vomiting more frequently than residents 20-59 years old and those 60 years and older (P=.001). Participants 60 years or older reported more symptoms of limb numbness than did participants 20-59 years old (P<.000) and those younger than 20 years (P<.000).

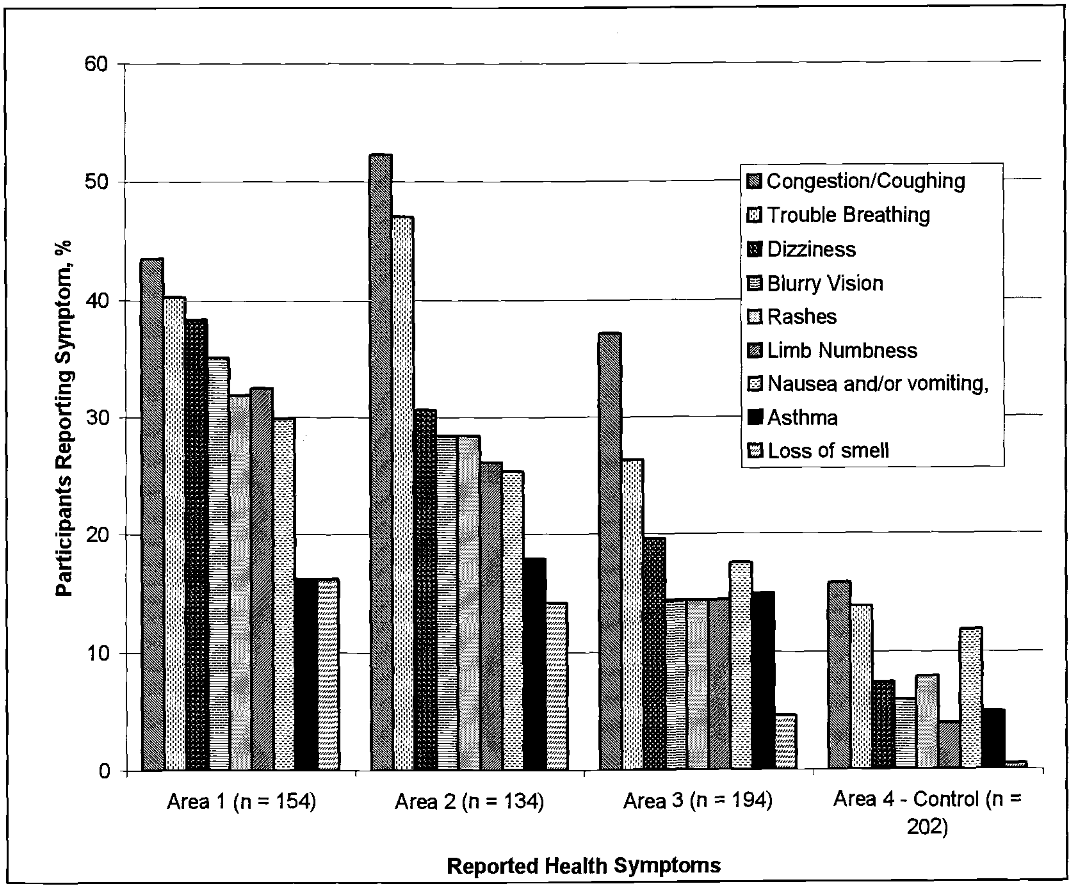
Twenty-eight percent of the overall sample sought medical care for treatment of their health symptoms. A greater proportion of participants in Area 1, however, sought medical care than did participants in Area 3 (P=.006) or Area 4 (P=.001), both of which were located further away from QPC.

Proximity to fire

Results found that significant differences existed in the frequency of symptoms reported, based on residents' proximity to the QPC facility. As discussed earlier (Figure 8), CT 1160 was divided into four approximately equal sections based on proximity to QPC, with Area 4 serving as the control. Table 6 shows the distribution of reported health symptoms and statistical differences, based on proximity to QPC.

There were significant differences in all reported health symptoms between Areas 1 and 4 (P<.001), and between Areas 2 and 4 (P<.001). Residents living in Area 4 reported fewer symptoms than did residents living in the other two areas. Significant differences also existed for all health symptoms except asthma, and congestion and/or coughing, between Areas 1 and 3 (P<.01), with residents living in Area 1 more frequently reporting symptoms. There were significant differences in reported symptoms between residents in Areas 3 and 4 for all symptoms except nausea/vomiting, rashes, blurry vision, and asthma (P<.05). In addition, there were significant differences in symptom occurrence between residents in Areas 2 and 3 for all symptoms except asthma, congestion and/or coughing, and dizziness (P<.01). There were no differences in any of the symptoms between the adjacent Areas 1 and 2.

The overall pattern shows that the frequency of reported symptoms was highest for Area 1, and that the symptoms progressively decreased with distance away from the QPC facility (Areas 2 and 3) and outside of the path of the byproduct plume (Area 4) (Figure 9).



Note. Area 1 was closest to the fire; Area 3 was farthest away; Area 4 was upwind of the fire.

Figure 9: Most reported health symptoms by study participants living in the four areas of census tract 1160 after the 1993 fire: South Phoenix, AZ.

Figure 9 also shows the high proportion of residents afflicted with these symptoms. For example, in both Areas 1 and 2, approximately half of the participants reported congestion and/or coughing, and trouble breathing. Approximately one-third of participants in Area 1 and one-quarter in Area 2 reported dizziness, blurry vision, limb numbness, rashes, and nausea and/or vomiting.

Additional participant characteristics were analyzed based on proximity to QPC to determine if they had any effect on the frequency of reported health symptoms. Smoking status, age, or location during the fire did not differ based on participant's proximity to QPC. There were, however, significant differences in gender, number of hours spent at home, and type of household cooler, based on proximity to the facility. For example, more women resided in Area 1 than in Area

4 (P=.004). Participants living in Areas 4 and 1 reported spending greater than 20 hours per day in their homes than did participants in Area 3 (P<.000). Overall, residents of CT 1160 used swamp coolers far more often than air conditioners, even though participants in Area 3 used air conditioners more frequently than did participants in the other areas (P<.01).

1996 survey

Twenty-seven matched participants completed both the 1993 community-based survey and the 1996 EPA survey. Although we realize that the later survey was more likely to be completed by those with continuing concerns, we compared the surveys' results to determine if participants' health symptoms had persisted or subsided in subsequent years. The majority of the residents (59%) of the 1996 survey participants lived in Area 1, 11% lived in Area 2, and 30% lived in Area 3, and none lived in Area 4. The majority of participants (75%) were 40 years or older, and most had homes equipped with swamp coolers.

When asked to list current health symptoms, residents reported symptoms very similar to, and of equal or greater frequency to, those reported in the 1993 survey. In 1996, residents continued to report congestion and/or coughing (45%), irritated eyes (37%), headaches (33%), dizziness (26%), trouble breathing (26%), rashes (22%), frequent colds (22%), and asthma (13%). Although these symptom categories are not identical to those described in the 1993 survey (Table 6), the symptoms are similar and reported at nearly the same frequency.

DISCUSSION

Our study indicates that residents living in the South Phoenix Areas 1, 2, and 3 of CT 1160 reported typical symptoms of smoke inhalation immediately following the QPC fire that occurred in August 1992. Symptoms reported by the South Phoenix residents (nausea and/or vomiting, dizziness, numbness and/or tingling of the limbs, blurred vision, lung and eye irritation, and rashes) are consistent with symptoms that result from exposure to metals, solvents, acids, hydrogen fluoride, nickel sulfate, copper sulfate, and stannous chloride (Hazardous Substance Data Bank). All of these chemicals were present at the QPC facility when the fire occurred (URS, 1994) The symptoms experienced by these residents are similar to those documented in a study in which residents were exposed to smoke from an agrochemical fire, in which there were reports of respiratory symptoms, gastrointestinal symptoms (nausea, vomiting, or diarrhea), eye irritation, headaches, vertigo and skin problems (Ackermann-Liebrich and Rapp, 1992). The pattern of symptoms (respiratory, followed by gastrointestinal symptoms, irritated eyes, and skin rashes) were very similar in the different population groups, even though respiratory symptoms were more pronounced in preschool children and in people suffering from a chronic disease (Ackermann-Liebrich and Rapp, 1992. Other experts have noted that symptoms related to eye irritation (conjunctivitis) and respiratory distress (nasophyaryngitis) are also associated with exposure to irritant soluble gases, affect the upper respiratory airway, and generally appear quickly after exposure. Insoluble irritant gases primarily affect the lower airway and may cause delayed symptoms (Haponik, 1988).

We anticipated that residents using evaporative coolers rather than air conditioners would note more health problems because of the different cooling processes utilized. Evaporative ("swamp") coolers pull in and cool outdoor air, whereas air conditioners remove heat from recirculated indoor air (IM, 2000). Neither air conditioners nor swamp coolers are designed to remove particles from the air. However, because residents were not instructed to turn off the evaporative coolers during the fire, both the residents and the state agencies were concerned that contaminants from the plume might have been pulled into the homes through the evaporative cooling systems. The EPA specifically sampled evaporative cooler pads for metals, fluorides, and polycyclic aromatic compounds in their 1997 Phase II sampling study, after earlier test results showed these contaminants to be at higher levels in study homes when compared to levels in control homes (USEPA, 1999).

Although we did not find differences in health symptoms based on type of air cooler, participants who were at home during the fire were more affected by congestion and/or coughing, blurry vision, rashes, and limb numbness than those who were away from home. Also, participants at home a greater number of hours each day reported more congestion and/or coughing, and nausea and/or vomiting than did those who spent less time in the home, suggesting that fire contaminants may have entered participants' homes, lingered in their homes, and perhaps contributed to their illnesses.

Elderly participants may have experienced more numbness and/or tingling limbs than their younger counterparts because they were more likely to be retired and at home when the fire occurred. Younger residents, however, reported a greater number of rashes and nausea/vomiting than did middle-aged or elderly residents. Both of these findings are consistent with literature that describes greater sensitivity among the elderly and the young to particular types of chemical exposures. The literature suggests that the young are 1.5 to 10 times more susceptible to the majority of chemicals than are adults due to such factors as deficiencies of certain detoxification enzymes, and greater adsorption in younger people (Lu, 1996). On the other hand, evidence suggests that the elderly also are susceptible to chemicals because of a decrease in detoxification and impaired renal excretion (Lu, 1996). Despite growing knowledge about the effects of chemicals in humans, the pathogenesis of smoke inhalation is not completely understood, but, nevertheless, remains a major problem encountered by pulmonary clinicians in both community hospitals and tertiary care settings due to the unpredictability of exposures (Haponik, 1988).

The number of reported symptoms differed based on proximity to the QPC facility. Residents living closest to QPC reported a greater number of symptoms than did residents living further away, for every symptom category. These findings are bolstered by television footage that shows the plume from the QPC facility billowing down towards the ground, rather than rising into the air as predicted by standard air dispersion models (EPCRA, 1997). Also, information from the Phoenix Sky Harbor Airport dated August 31, 1992 reported the wind to be blowing primarily in a northeasterly direction. This information helps to explain why there are very few differences in frequency of symptoms between Areas 1 and 2, as they are both directly east and within close proximity of the QPC facility. This information supports the finding that residents living in Area 4, the area directly south of QPC, reported the least number of symptoms. Residents living the furthest east of QPC (Area 3) reported fewer symptoms than did Area 1 and 2 residents, which implies that the byproduct plume was somewhat dispersed when it reached this area. The finding that participants in Area 1 sought medical care more often than those in Areas 3 and 4 also suggests that residents closer to QPC were more seriously impacted by the fire. Although there were few differences in the number of reported symptoms between residents of Areas 1 and 2, results showed that a higher percentage of people in Area 1 sought medical care, possibly due to higher exposure concentrations of chemicals in the byproduct plume.

Responses from the 27 participants who completed both surveys suggest that the health symptoms continued long after the fire. Although the surveys were previously not analyzed, the community members were persistent in their complaints to the state and federal health agencies that there were continuing and unresolved health effects from the 1992 fire. It was due to this forceful and sustained community effort that the EPA agreed to reopen the case in 1997 to evaluate current environmental conditions in selected area and control homes.

It is unfortunate that residents continue to experience serious health problems years after the fire, and view their situation as both a failure by government agencies to properly respond to a community health crisis, and as a case of environmental racism. The community's appeal to the state and federal agencies was particularly acute, as the chemical fire occurred after a long history of citizen complaints regarding Quality Printed Circuits' environmental compliance. The neighborhood "inherited" the facility in the late 1980s, when the City of Phoenix Economic Development Agency approved the relocation of Quality Printed Circuit into a low income, primarily African American and Hispanic neighborhood in South Phoenix. Although the facility failed to comply with environmental regulations soon after it was built and smaller fires occasionally erupted in the facility, the facility was never closed. Thus, the neighborhood's frustration with the governmental agency response to the QPC fire, following a series of environmental mishaps, is understandable. The neighborhood asserts that government agencies were lackadaisical in their initial response to the fire, with air sampling, in neighborhood evacuation, and, at fault for not assisting in the administration of the 1993 health study. They firmly believe they would have been treated differently if they had been a Caucasian community.

Although the case is now closed, the situation continues to evoke questions about whether environmental racism impeded the process to the extent that the community will never believe the environmental health crisis was satisfactorily resolved. It also reinforces the important role public health professionals have to being fully aware of situations in which disparities are occurring, and to respond in a manner that actively contributes toward achieving equality and better health for all (Cohen and Northridge, 2000).

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CASE STUDY OF AN INDUSTRIAL FIRE IN A MINORITY NEIGHBORHOOD: HOW POLITICS AND SCIENCE INFLUENCED HEALTH RISK ANALYSIS

INTRODUCTION

All companies that generate or use hazardous substances are required to follow federal and state regulations that outline emergency steps to be taken following an accidental discharge. In August 1992, a fire occurred at a computer circuit board manufacturing facility located in South Phoenix, Arizona, in which a byproduct plume blanketed the surrounding community for a period of over eight hours. Debate has continued, even a decade later, as to whether or not the facility executives and Arizona government agencies took the steps needed to protect the exposed community. Three main points of discussion have emerged in this debate. The first is what we term organizational issues that influenced the ability of government agencies to be responsive to the needs of the South Phoenix community. Organizational issues include:

- Inadequate personnel or funding necessary for enforcing environmental policies.
- Confusion and poor communication between environmental agencies about their roles and responsibilities.
- An adverse political environment that inhibited environmental agencies from implementing and enforcing environmental policies.

A second point of discussion is whether environmental racism toward the affected residents in this neighborhood was a factor in the unsatisfactory outcome of this event. A third issue is the inadequacy of current scientific methods (e.g., chemical sampling studies and risk assessment) to conclusively link chemical exposures to predictable adverse health symptoms.

We present this fire incident as a case study to explore how these three issues might have played a part in the unsatisfactory outcome of this event. We have also included the results of a health study conducted on 690 residents of Census Tract 1160 (N = 4438), the area predominantly exposed to the byproduct plume that emanated from the burning facility. The health study analyzed data collected from a community-based survey, and served as a tool to assist the community in determining if symptoms were more pronounced if they lived closer to the burning facility at the time of the fire.

This paper is unique in that it pulls together the organizational, political, environmental science, and health issues to present a broader understanding of the events and the community's perspective of the events that occurred in this incident. The paper highlights the importance of a coordinated effort by government agencies responsible for protecting its citizenry in an environmental emergency. In addition, the article demonstrates that not all is lost when environmental mishaps occur, as "problems" and recognition of these errors can serve as an impetus for improving emergency response systems.

METHODS

Study location

The study community is located in southwest Phoenix, Arizona on the western edge of Census Tract 1160, and directly east of the former facility (Figure 8). We divided CT 1160 into four areas based on proximity to the facility, and approximate population sizes. Areas 1, 2, and 3 were located north of Roeser Road, in the direct path of the byproduct plume that blew in a northeasterly direction. Area 1 was located closest to the facility; Area 2 was next in proximity; and Area 3 was the furthest east of the facility. Area 4 was identified as a control group, as it was located to the south of the facility, in an area upwind of the fire.

Health survey data

Information about symptoms of illness reported by residents was captured in a community-based health survey conducted in 1993 by the members of *Don't Waste Arizona* (*DWAZ*), a local not-for-profit advocacy group. The group developed the survey with the assistance and approval of the Agency for Toxic Substances and Disease Registry (ATSDR), and administered the survey under contract with the state health department. The community group was paid $5,000 under terms of the contract (ADHS, 1993).

The community group used systematic sampling techniques to collect 690 (17 percent of CT 1160) completed surveys. Surveyors called every other number using a randomized phone list of the census tract, proceeding to the next one on the list if there was no response, and returning to the "every other home" pattern. A separate survey was completed for each resident of the household. In the area immediately east of the fire and in the path of the plume, every other home was contacted. In the area outside of the path of the plume, every third home was contacted using the same pattern of random digit dialing.

The semi-structured survey asked questions about a participant's gender, age, occupation, household-cooling system, whether medical care was sought after the fire, location during the fire and how long he/she had lived in the area. The second part of the survey listed twenty-five symptoms and asked participants to check all symptoms they had experienced during the year. Participants also reported when the symptom first occurred, and whether symptoms had improved, remained the same, or worsened following the fire.

Other qualitative data

We collected information through interviews with key players and by compiling data from secondary sources including government agency files, newspaper articles, and previous studies of this case. Articles from Arizona newspapers and files from the Arizona Department of Environmental Quality (ADEQ), the Arizona Department of Health Services (ADHS), the US Environmental Protection Agency (EPA), and the community advocacy group, *Don't Waste Arizona*, were obtained from archived records. Face-to-face and phone interviews with active participants were conducted with employees from ADEQ, ADHS, Steve Brittle, president of *DWAZ*, EPA employees, and officials from the Phoenix Fire Department. We used this information to analyze events that occurred during this incident, and interpret residents' perceptions regarding both health issues and the work done by government agencies in response to the fire.

CASE STUDY: THE 1992 FACILITY FIRE

Until the 1950s, the South Phoenix area had been the only location where African Americans, including those of high economic status, were allowed to reside within Phoenix, Arizona. By the late 1980s, this area had become impoverished and the City of Phoenix Economic Development Agency approved the move of QPC, a single-story circuit manufacturing facility employing approximately 120 people, into this area under the pretense that it would give the surrounding community an economic boost. In 1990, approximately 65% of CT 1160's residents identified as African American, 18% identified as Hispanic, and 16% as White. Thirty-six percent of the 1,412 households in CT 1160 reported a total income of less than \$14,000, with an average household income of \$13,080. At the time, approximately 37% of residents lived below the poverty line (US Census Bureau 1990).

In 1989, the first large fire occurred at the facility, creating a plume of combustion products that blew east into CT 1160. The fire caused \$2.7 million in damages but the plant was quickly rebuilt (Phoenix Fire Department, 1989). One year later, ADEQ performed a hazardous waste inspection of the facility and found that it was out of compliance on several matters dealing with fire safety. A report was sent to the facility's officials instructing them to correct these problems, but no changes were made or fines levied. In 1992, the facility was sited for violating OSHA standards for having unlabeled drums and potential fire hazards (personal communication with Steve Brittle of *DWAZ* 1996). A Phoenix Fire Department spokesperson stated that the facility was never in compliance during building inspections (personal communication with L. Randall 1999).

Over the next few years, employees at the facility put out several small fires until August 31, 1992, when a fire burned out of control and consumed the entire facility. The fire began around

11 a.m. and lasted for approximately eight hours, creating a thick black plume of combustion products that blew east into the community within Census Tract 1160. Employees went through several fire extinguishers before calling the fire department at 11:25 a.m. A Fire Department spokesman that, "the fire was well underway by the time the fire department reached the facility" at 11:29 a.m., requiring twenty fire engines, HazMat trucks and personnel, medical workers, and more than 125 firefighters (personal communication with L. Randall 1999).

Organizational responses during the 1992 fire

After battling the fire for about an hour, the fire department made a decision to let the fire burn itself out. Fire department officials gave several reasons for this response including the late dispatch, the swift consumption of the facility, the rapidly changing wind direction, and the lack of knowledge of the onsite hazardous chemicals. Although the Emergency Planning and Community Right to Know Act (EPCRA) required that facility employees give the Phoenix Fire Department records of the chemicals used onsite, the files were outdated and stored in a location that was not readily accessible.

Two hours after the fire started, a firefighter requested that air monitoring be done in the area east of the facility because "smoke was banking down low to the northeast and settling throughout the neighborhood" (Phoenix Fire Department 1992). This request was ignored and no air samples were taken at any time during the fire.

Around 1:30 p.m., approximately 800 pupils from Martin Luther King Jr. Elementary and P.L. Julian Middle schools were evacuated to elementary schools upwind from the fire (Sowers 1992). However, when these schools were dismissed two hours later, the students were bussed back into the smoke-filled neighborhood. Earlier that day, the Phoenix Fire Department had instructed the Police Department to evacuate community residents. Members of the Police Department knocked on residents' doors and told them that they should leave the area but made the evacuation a voluntary activity. Two hours later, however, the Arizona Department of Environmental Quality announced that everyone east of the facility had been evacuated (Phoenix Fire Department 1992). Subsequent studies by the Agency for Toxic Substances and Disease Registry (ATSDR), however, showed that residents were not told to evacuate until three hours after the fire began. Only 69 residents left the area, even though approximately 1,800 homes were located in the path of the plume (Agency for Toxic Substances and Disease Registry [ATSDR] 1993). Residents also claimed that they were not warned to turn off their swamp coolers and air conditioners, which reportedly pulled smoke-filled air into area homes during the fire. Furthermore, even though the ADHS was responsible for informing residents on how to protect themselves from the toxic plume, this agency was not contacted until eleven days after the fire.

Eight hours after the fire began, the area was reopened, and the fire department declared the fire to be "under control," that is, no longer visibly emitting smoke (Phoenix Fire Department 1992). Approximately twelve hours after the fire had begun, the fire department declared the incident to be "closed," even though the fire smoldered for another seven days (ATSDR 1993).

Health concerns after the fire

Immediately after the fire, residents in the area surrounding the facility reported numerous health-related problems such as blurred vision, nausea and vomiting, congestion, and rashes. Residents also noted that plants and animals unexpectedly died in the days following the fire. In addition, several residents mentioned the presence of ash and soot on their properties (Brunacini 1992).

Because months passed with little government action, the community joined together to form the advocacy group Concerned Residents of Arizona, and drew attention to their predicament through press conferences and demonstrations. On March 20, 1993, Concerned Residents of South Phoenix held a memorial service at the state Capitol; seven cardboard coffins were lined up in the Capitol mall to represent seven residents who had died in the months following the fire. Of the seven, five had lived only one block east of the facility. This event persuaded state officials to perform a mortality study to determine if the seven deaths represented a higher than normal rate. The mortality study compared the number of deaths in CT 1160 to the average number of deaths in the surrounding four census tracts and reported "there were ten excess deaths in that census tract during the period Sept. 1, 1992 - Jan. 31, 1993" (Yozwiak 1993a). However, the report also declared that these deaths were not statistically higher than the number of deaths in the surrounding census tracts, and that the deaths were unrelated to the fire because the death certificates did not report fire as cause, and most of the victims were "elderly and already ill" (Associated Press 1993a).

Still believing the deaths to be unusual, CRSP sent a copy to a toxicology researcher at Arizona State University. The researcher concluded that the county had used the wrong formula in analyzing the number of deaths and stated that "overall, the entire thing was terribly done" (Yozwiak 1993b). The epidemiological and vital statistics officer who conducted the mortality study admitted that the initial report was erroneous and that "deaths were significantly higher" in CT 1160 after the fire, but did not perform follow-up studies based on these findings (Associated Press 1993b).

Residents continued to complain of illnesses they believed to be related to the fire, and solicited ADHS to perform a health survey hoping to confirm their suspicions. ADHS officials stated that it would be too expensive to do a thorough health study, but agreed to contract with *Don't Waste Arizona (DWAZ)*, a local, not-for-profit community group, to develop and administer a health survey in Census Tract 1160. *DWAZ* developed the health survey with the assistance of a federal health agency. After receiving approval in April 1993 from ADHS to proceed with the data collection, the community group administered the survey to the neighborhood, and returned the completed surveys to ADHS. Although Arizona government officials paid to have the survey done, they never analyzed the data, faulting the study's sampling and data collection procedure.

At the time that the health survey was being performed, ADEQ began a sampling study of the neighborhood. Samples of soil and cooling pad materials were taken from eleven residences in the area surrounding the former facility. Results found that some metal concentrations were high enough to suggest anthropogenic deposition, but were not statistically higher than those found in unaffected homes. ADHS finished their analysis in late 1992 and concluded that all concentrations were below Health-Based Guidance Levels, meaning that they were not high enough to cause adverse health effects. Critics complained that too few houses were sampled to get statistically accurate results, that "unaffected" homes were too close to the affected homes, and that an inadequate number of chemicals were analyzed.

Later that year, ADEQ hired Zenitech, an environmental consulting company, to perform a more extensive sampling study of the area. Soil, dust, air, and air-duct material samples were taken from ten residences near the former facility, and from three "control" homes outside the contaminated area. Results showed that levels of fluoride and a few metals were slightly higher in exposed homes versus control homes (Zenitech 1993). For a second time, results were sent to health officials at ADEQ to perform a risk assessment and once again, results showed that at the levels present, the sampled chemicals posed no threat to the community (ADEQ and ADHS 1993). To duplicate these results, the facility hired Environmental Toxicology International (ETI) to perform their own risk assessment using the Zenitech sampling study results. ETI's risk assessment concluded, "measured chemical residues in the local residential area that may be related to the [facility] fire are of insufficient quantities to cause concern for health of area residents" (ETI 1993).

Because results of the risk assessment were unable to link residents' health symptoms to the byproduct plume, ADEQ was legally unable to force the facility to decontaminate the neighborhood. Facility officials removed contaminated soil from the site, but refused to clean local houses because there was no proof that they were responsible for residents' health problems. Feeling disenchanted, residents filed a civil suit against facility executives, calling on health officials, toxicologists, and modeling experts for help. On March 22, 1995, the case was settled out of court for $1.5 million, with an average award of $1,700 per person, which was an amount not sufficient to cover medical bills (Whiting 1995).

Still feeling a lack of government assistance, *DWAZ* solicited outside help from an EPA-funded, university-based technical assistance outreach program to help them analyze the health survey results (http://tosc.oregonstate.edu/index.htm). The university group analyzed the data collected by *DWAZ* to characterize health symptoms and determine if there were differences in reported health symptoms based on residents' proximity to the former facility.

Commonly reported symptoms included congestion and/or coughing, trouble breathing, dizziness, nausea and/or vomiting, blurred vision, rashes, numbness and/or tingling of the extremities, and loss of smell. Results also found that significant differences existed in the frequency of symptoms reported, based on residents' proximity to the former facility (Figure 7).

The overall pattern shows that the frequency of reported symptoms was highest for Area 1, and that the symptoms progressively decreased with distance away from the facility (Areas 2 and 3) and outside of the path of the byproduct plume (Area 4). Also shown is the high percentage of residents afflicted with these symptoms. For example, in both Areas 1 and 2, approximately half of the participants reported congestion and/or coughing, and trouble breathing. Approximately one-third of participants in Area 1 and one-quarter in Area 2 reported dizziness, blurry vision, limb numbness, rashes, and nausea and/or vomiting.

DISCUSSION

Issues of organizational failure

Required organizational responses to chemical release events

The US EPA has written procedures, stipulated under Title III of the 1986 Superfund Amendments and Reauthorization Act (SARA), requiring facilities that have a chemical release to immediately notify the city's Local Emergency Planning Committee (LEPC) and the State Emergency Response Commission (SERC) if any hazardous substances are involved. This notification must include:

- Each chemical's name and known toxicity;
- An estimate of the quantity of each chemical released into the environment;
- The time and duration of the release;
- Information about the location of the release into air, water, and/or land;
- Any known or anticipated acute or chronic health risks associated with the release, and if necessary, advice regarding medical attention for exposed individuals; and,
- Evacuation procedures (US EPA 1993a).

The ADEQ and the ADHS are also responsible for assisting after an environmental emergency. The Remedial Projects section of the ADEQ is responsible for the identification, assessment, and remediation of sites contaminated by hazardous substances. ADHS is responsible for identifying and measuring "exposure to selected environmental contaminants and associated adverse health effects" (Kane et al 1997). During an incident these agencies are responsible for: (1) stopping the chemical release, if possible; (2) advising local residents of the release hazards, including the chemicals involved and their associated risks; (3) informing residents on how they can minimize their exposure; and (4) resident evacuation, if necessary.

After an incident, these agencies are responsible for: (1) identifying the chemicals involved and investigating their potential hazards (i.e. each chemical's toxicity, short- and long-term effects, bio-availability, and possible synergistic effects); (2) measuring the community's exposure (i.e. the number of people affected and exposure concentrations); (3) performing health studies if the public's health is affected; (4) if necessary, taking air and soil samples to measure exposure; and, (5) decontaminating the area if the release warrants such action. Because many of these steps were not carried out in the case of the fire, we suggest that the following reasons may have impacted the agencies' abilities to carry out these responsibilities.

Inadequate funding needed to enforce environmental policies

Lack of funding might have influenced the outcome of this case. In 1986, the Arizona Environmental Quality Act established the Water Quality Assurance Revolving Fund to help clean up contaminated sites and prosecute polluters. Between 1987 and 1990, the Fund received $5 million a year, but this amount decreased significantly in the following years and disappeared by 1996 (Kane et al 1997). In June 1993, a spokesperson for the ADEQ stated that "the department's budget is already stretched to the limit" and that ADEQ could not fund additional contaminated sites (Yozwiak 1993c). The budget was so depleted that the Zenitech sampling study was "limited by time and financial considerations" and resulted in few samples being taken (Zenitech 1993). Finally, in a letter to the EPA, a spokesperson for ADHS stated that they had spent more than $250,000 on the fire investigation and that "these expenses are continuing to tap into the limited public health dollars of both ADEQ and ADHS" (ADHS 1996). It was argued that the community "was quite successful in an out of court settlement," and that ADHS needed to prioritize their money to get "the biggest bang for the buck" (ADHS 1996).

National funding for ADEQ also decreased, falling from 28 percent in 1978 to below 18 percent in 1990 (Ringquist 1993). States became responsible for making up the funding loss, leaving Arizona at a disadvantage with a conservative Legislature that continuously limited the amount of funding allocated for environmental organizations; the Arizona Legislature decreased state taxes over the years, the largest source of environmental funding. A lack of funding might also have contributed to the contract being given to *DWAZ* for the purpose of developing and administering the community health survey, which was considerably less expensive than if the study had been administered by the ADHS.

Role misunderstanding and poor communication by government agencies

Problems related to the sampling studies point to lack of communication in roles and responsibilities for the various agencies. ADEQ was responsible for identifying, assessing, and remediating chemicals released during the fire, and ADHS was responsible for identifying and measuring chemical effects on a community and assessing potential adverse health effects. Arizona law states that ADEQ is the lead agency during environmental incidents, but that ADHS is responsible for attending to health issues that arise. The erratic evacuation procedures point to a lack of clarity in roles and responsibilities in that both the Police and Fire Departments assumed the evacuation was taking place, but there was no oversight in actually carrying out the evacuation procedures.

An adverse political environment

An adverse political environment may also have impacted the outcome of this incident. An investigation by Hall and Kerr (1991) found that in Arizona, neither environmental nor community health issues have ranked high on the list of government priorities, and the state places low in these areas when compared to other states. Results of the Hall and Kerr investigation gave Arizona a "worst" ranking for environmental spending, and effective environmental policies. The study concluded that Arizona's conservative political climate has promoted economic development at the expense of environmental quality. In 1992, ADEQ unsuccessfully attempted to increase its power to enforce environmental remediation and in 1996, the Legislature placed a moratorium on any new enforcement actions by ADEQ (Kane et al 1997).

Issues of environmental racism

It is unfortunate that residents continue to experience serious health problems years after the fire, and view their situation as both a failure by government agencies to properly respond to a community health crisis, and as a case of environmental racism because they were mostly a minority population. The community's appeal to the state and federal agencies was particularly acute, as the industrial fire occurred after a long history of citizen complaints regarding the facility's environmental compliance. The neighborhood "inherited" the facility in the late 1980s, when the City of Phoenix Economic Development Agency approved its relocation into a low income, primarily African American and Hispanic neighborhood in South Phoenix. Although the facility failed to comply with environmental regulations soon after it was built and smaller fires occasionally erupted in the facility, the facility was never closed or forced to make improvements. The South Phoenix area has long been used for siting chemical and manufacturing facilities; a 1996 study done by the ADHS found approximately 59 toxic facilities located in the South Phoenix area (Kossan 1996). After this facility burned down, officials built a second facility located two blocks from their former plant.

Consequently, the neighborhood's frustration with the governmental agency response to the fire, following a series of environmental mishaps, is understandable. The neighborhood asserts that government agencies were lackadaisical in their initial response to the fire by not taking air samples, by failing to evacuate the neighborhood and, for not completing the analysis of the 1993 health study. They firmly believe they would have been treated differently if they had been a Caucasian community, and that their situation should be considered as care of environmental racism.

One of the most influential studies on environmental racism, performed in 1987, posited that race was the single most important factor in determining the distribution of chemical hazard exposure in the United States (Low and Gleeson 1998). Several earlier studies articulated similar positions (Bullard 1990, 1994; Eitzen and Zinn 1992; Goldman and Fitton 1994; Mohai and Bryant 1992).

Lavelle and Coyle (1992) showed that not only is race a factor in a person's proximity to hazardous sites, but it is also a factor in government clean ups of toxic waste sites and punishing of polluters. It concluded that penalties applied to hazardous waste polluters were 500 percent lower in minority communities than in white communities; that abandoned hazardous waste sites took 20 percent longer in minority communities to be placed on the National Priority List (NPL); and that cleanup procedures at Superfund sites in minority areas began 12 to 42 percent later than at other sites.

In 1994, President Clinton signed an Executive Order requiring that all federal agencies work toward ending this disproportionate environmental discrimination (Brown 1995). In May 1994, ADEQ tried to address environmental racism by initiating the Environmental Justice Project. The South Phoenix community was used as the subject for developing this project and the goals were twofold: 1) "…to identify ways to protect the public health so that no community is adversely impacted by undue exposure to hazardous contaminants/ pollution," and 2) to standardize the inclusion of environmental justice considerations into the development and implementation of its regulatory programs (ADEQ 1994). Though this project was a step in the right direction it turned out to be viewed as a technical issue of distribution of risk and ignored residents' concerns about environmental inequities.

Challenges linking chemical exposure to human health problems

The inadequacy of current scientific methods to conclusively link chemical exposures to predictable health symptoms may also have influenced the outcome of the South Phoenix case. Currently, a science-based risk assessment is one of the most powerful tools government agencies have for proving that a hazardous chemical release has affected human health. To perform a risk assessment, chemical samples within an exposed area are taken to determine community exposure concentrations, and the exposure concentration of each chemical is compared to its Health-Based Guidance Level (HBGL). HBGLs are scientifically determined estimates of an individual's daily chemical exposure, below which there should not be appreciable risk of adverse effects during his/her lifetime (USEPA 1993b). If a person's exposure concentration is less than the chemical's HBGL, the exposure is assumed to be safe, even for sensitive populations, and adverse human health effects should not occur.

In this instance, a standard risk assessment may not have been powerful enough to prove that health effects were a result of the fire. Air samples were not taken during the fire, and exposure concentrations were unknown. Thus, there was no real-time exposure data that could be compared to guidance levels, negating the practicality of performing a risk assessment. Additionally, risk assessments can only be calculated for sampled chemicals. Hence, even if an extremely toxic chemical was released in the fire, the chemical would not appear in the risk assessment if it was not measured in the sampling studies. Another consideration is that risk assessments are only valid for chemicals in which HBGLs have been calculated. Many of the chemicals released in the fire did not have HBGLs, and as a result, the adverse health effects were unknown. Finally, the science is not developed to the point at which risk assessments can predict chemical interactions, because current risk assessments separately analyze each chemical. If more than one chemical is involved, their combined effect on human health is not measured because this would entail performing animal studies for millions of chemical combinations, which is not feasible. Therefore, a chemical may be calculated to have an exposure concentration below its HBGL, but, in fact, may be toxic at a lower concentration if in the presence of synergistic chemicals. The most notable example of a synergistic reaction is that caused by the combination of smoking cigarettes and being exposed to asbestos. Asbestos workers who smoke more than a pack a day have up to 90 times the chance of dying of lung cancer compared with workers who neither smoke nor work with asbestos. Another substance that appears to act in this "combined" way with tobacco smoke is chloromethyl ether (American Lung Association 2003).

To this date, residents in the South Phoenix community maintain that the health of the community deteriorated after the fire. Though scientific methods could not prove that the surrounding neighborhood was exposed to toxic chemicals generated during the fire, the 1993

DWAZ health study did show that residents living closer to the former facility reported suffering from symptoms more frequently than those living farther away.

Several government officials acknowledged throughout the incident that residents' health problems were most likely a result of exposure to combustion products from the fire. An ATSDR employee wrote, "respiratory health effects reported by residents living in the neighborhood surrounding the [facility] are consistent with those produced by direct exposure to high concentrations of irritant gases during fire conditions" (ATSDR 1993). In a similar letter issued in April 1997, ATSDR summarized the incident by stating that both ATSDR and ADHS "have recognized that exposures did occur and that residents who were exposed to smoke from the [facility] fire may have suffered health effects as the result of the fire" (ATSDR 1997). However, because a direct "scientific" link between the fire and reported health effects could not be made, the government was powerless to rectify these problems. As an ATSDR employee states, "since no air monitoring was conducted at the time of the fire, ATSDR cannot conclude that the health effects reported by the area residents are directly related to the fire" (ATSDR 1993).

Recent research highlights the vexing issues that surface in attempts to link symptom reporting to environmental exposures, arguing for qualitative approaches, including semi-structured interviews and observational techniques to complement quantitative data (Spurgeon 2002). Unfortunately, results of the health survey could not be used to provide the impetus to force any government action and to this day, residents blame the state government for not forcing the facility executives to clean up their houses immediately after the fire. Most residents are poor and cannot afford to move out of their homes, and the stigma of the fire has considerably decreased area property values (Blair et al 1996).

CASE STUDY ELICITED A WAKEUP CALL

Though South Phoenix residents' health issues were never resolved, their problems did provide a wakeup call to the Arizona government and Phoenix Fire Department. Members of the South Phoenix community were so persistent in their outcries that ADEQ applied for and received a grant from the EPA to improve their response to environmental emergencies. As a result, ADHS now has four people on call 24 hours a day who respond to environmental emergencies. ADEQ remains the authority at emergency sites, but notifies an ADHS when health issues arise. ADHS also developed a standard health survey for analyzing residents' health effects after a chemical release incident.

ADEQ's Division of Emergency Management also received a grant to improve the response to chemical and industrial fires. As a result of this "Boulder Project," the Phoenix Fire Department has improved its system for communicating with hazardous facilities. Information on the hazardous substances used at a facility is stored on a single computer database where it is continuously updated and can be instantly accessed using a laptop and modem by firefighters. This privides firefighters advanced knowledge of the chemical hazards involved so they can decide how best to respond to the release and protect themselves and at-risk communities.

CONCLUSIONS

We found obvious discord between the articulated interests of residents involved in this environmental release incident and those of the government agencies responsible for their protection. While the South Phoenix residents believed that the unsatisfactory outcome of this case was a result of environmental racism, it is likely that government officials were impeded in their ability to be effective due to organizational issues such as inadequate funding, role confusion, or political pressures. The community was also very disappointed that current scientific methods were unable to conclusively link their exposures to reported health problems. In reality, all three issues likely played a contributing role, highlighting the complexity of the situation.

It is now obvious that the government agencies were remiss in the handling of this situation by failing to gather appropriate data in a timely fashion and failing to protect the community from the incident, both prior to and after its occurrence. The article is not meant to point blame at state and federal agencies, which often are very effective in their response to environmental emergencies despite limited resources and personnel. Furthermore, it will never be possible for health authorities to be completely prepared for environmental disasters. However, the case study demonstrates how important it is for public health professionals to respond immediately to community concerns and take proper actions in events such as these such as enforced evacuation.

Citizens depend on state and federal agencies to assist them in such emergencies and to provide leadership in the aftermath, including being attentive to and respectful of community health concerns, and collecting and analyzing appropriate health and environmental data in a timely manner. Prompt analysis of the survey might have allowed for identifying medical and/or public health interventions targeted at those living closest to the fire, with the intention of lessening long-term chronic symptoms. Although we cannot be sure that an early intervention might have lessened the number of residents that continue to be affected by chronic health problems, it is particularly important to attend to environmental health problems in communities in which health disparities are occurring (Cohen and Northridge 2000). It is unfortunate that we will never know the magnitude of the chemical contamination that resulted from the fire. We will also not be able to discern whether the continuing health problems reported by the community are the direct result of environmental exposures to the plume of combustion products from the fire, or if the contamination might have contributed in a non-specific way to more severe symptoms or increased morbidity or mortality in this population. In addition, prompt attention to health concerns by these residents, even in the absence of environmental sampling data, would have been welcomed by the residents, and might also have contributed to a better working relationship with the community, fewer concerns that environmental racism impeded the process, and a more satisfactory resolution of the environmental health crisis.

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GENERAL CONCLUSION

The goal of this study was to provide individuals with an in-depth look at an unfortunately, not uncommon emergency response failure from political, scientific, and public health perspectives. It is hoped that government agencies and communities in similar situations can utilize the information discussed in this document to help them understand what can go wrong in such situations and provide them with the tools to prevent similar problems from occurring.

In this case, there was major disagreement between the South Phoenix residents involved in this environmental release incident and the government agencies responsible for their protection. Though South Phoenix residents believed that the unsatisfactory outcome was a result of environmental racism, government officials claim it was due to organizational issues such as inadequate funding, role confusion, and lack of political enforcement authority.

Regrettably, the only current "official" method for determining whether a community has been affected by a chemical exposure such as this is through a risk assessment. If this method fails to show a link between residents' reported health symptoms and the chemical release, the government is has no additional tools and the affected community is left with no other methods for resolving their issues. In the South Phoenix case, exposure information obtained through back-modeling, and a community health study both point to the fact that South Phoenix residents' symptoms were a direct result of the fire. Both data sets showed that residents living closer to the fire were exposed to greater chemical concentrations than those living farther away. In addition, back-modeling showed that exposure concentrations for these nearby residents were much higher than allowable exposure levels and that reported health symptoms were typical of those previously documented by similar types of chemical exposures.

However, the government does not endorse these methods and only the government's responsiveness, sensitivity and attention might have allayed residents' fears. Citizens depend on government agencies to assist them in such emergencies by providing leadership and being respectful of community health concerns. Instead, emergency response to this crisis was inadequate and that the government made mistakes in their response to this emergency release event. Air samples were not taken during the fire, and both the government's refusal to administrate and analyze the 1993 health study, and lack of a proper neighborhood evacuation led to significant mistrust. In addition, modeling should have been done prior to the development of the health survey so that residents living to the northwest of the QPC facility could also have been included. The community firmly believes that they would have been treated differently if they had been a Caucasian community.

Serious health concerns have persisted in this community for years after the fire. However, we will never know the magnitude of the chemical exposure that resulted from the QPC fire, nor whether this exposure may eventually increase the morbidity, and the mortality in this population.

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APPENDICES

APPENDIX A: DEFINITION OF TERMS

Acrolein: A liquid derived from the oxidation of allyl alcohol or propylene, used as an intermediate in the production of polyester resins and polyurethanes and as an herbicide. (Definition Copyright ©1989 Technomic Publishing Company, Inc. http://composite.about.com/ library/glossary/a/bldef-a101.htm)

Anion: negatively charged ion

Air conditioner: apparatus for regulating the humidity, ventilation, and temperature in a building by recirculating indoor air

Census tract: A statistical subdivision of a metropolitan area defined by local committees to approximate a neighborhood, usually with an average of 4,000 inhabitants (Definition at MapInfo Products Knowledge Base http://testdrive.mapinfo.com/techsupp/miprod.nsf/5c41496d5951a49c852562b5004f3a44/28e42e37d41e733085256a1e0065b201?OpenDocument)

Chemical sampling study: an analysis that measures chemical concentrations in air, liquid, and/or soil

Combustion products: chemicals that are generated as a result of a material being incinerated

Community advocacy group: an organization whose purpose it is to influence outcomes that directly affect a community's existence such as public policy and resource allocation decisions within political, economic, and social systems and institutions (Definition at www.advocacy.org/definition.htm)

Control homes: a grouping of homes in a statistical study that provide a baseline for comparison with test groups. Control homes have similar attributes to the study homes but do not experience the issue being studied

Cooler pads: filters in an air-cooling system that clean the air as it is blown throughout the house

Dioxins: a family of compounds that may be carcinogenic, teratogenic, and mutagenic. The most toxic is 2,3,7,8-tetrachlorodibenzo-p-dioxin, which is present in defoliants such as Agent Orange (Definition at www.academicpress.com/inscight/10261999/dioxin1.htm)

Environmental justice: the concept that minority and lower social economic status communities are exposed more often to environmental pollution and hazardous waste sites

Evaporative "swamp" cooler: apparatus used to cool air within a building by pulling in outdoor air and running it over water pipes

Exposure concentration: the level of a chemical that an organism comes into contact with, measured in mass per volume

Gaussian (a.k.a. Normal) distribution: the frequency distribution of many natural phenomena, which can be graphed as a bell-shaped curve. (Definition at www.computeruser.com/resources/ dictionary/definition.html?lookup=2396)

Health-based guidance level (a.k.a. Reference Dose - RfD): an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime (Definition at www.epa.gov/iris/rfd.htm)

Health study: an analysis done on a group of people to determine if they have had their health adversely affected by an exposure event

Hydrogen chloride: a colorless, pungent, and corrosive gas obtained by the action of sulphuric acid on sodium chloride (Definition at www.hyperdictionary.com/search.aspx?Dict=&define =benzene)

Integrated Risk Information System (IRIS): an electronic data base run by the EPA containing information on human health effects that may result from exposure to various chemicals in the environment (Definition at http://www.epa.gov/iris/intro.htm)

ISCST3 Model: a dispersion model developed by the EPA that uses a Gaussian distribution to model air quality impacts from combustion and fugitive emission sources

Mixed-box model: a simple modeling process used to obtain first-order concentration estimates

Naphthalene: a white crystalline strong-smelling hydrocarbon made from coal tar or petroleum and used in organic synthesis and as a fumigant in mothballs (Definition at http://www.wordreference.com/english/definition.asp?en=naphthalene)

Polycyclic aromatic hydrocarbons: a group of approximately 10,000 compounds, made whenever substances are burned, that can cause adverse health effects to living organisms

Risk assessment: A qualitative and quantitative evaluation performed to define the risk posed to human health and/or the environment by the presence or potential presence and/or use of specific pollutants (Definition at http://cnie.org/NLE/CRSreports/Waste/waste-21.cfm)

Study homes: a grouping of homes in a statistical study that are studied for adverse effects compared to an unaffected control group

Superfund site: A hazardous waste site that has been determined (by a hazard ranking score) to pose a serious threat to human health and/or the environment. (Definition at http://cnie.org/NLE/CRSreports/Waste/waste-21.cfm)

Synergistic effect: When substances acting together have an effect greater than that of any chemical taken alone.

APPENDIX B: ISCST3 MODEL COMPONENTS AND MODELING STEPS

Components of the ISC model

ISCST3 has six distinct sections into which the user enters data. These include:

- Control options (file name, file creation date, last modified date, model run title, short term and overall averaging times, pollutant, use of flat versus elevated terrain).
- Source information (type and location of source, contaminants, emission rates, release height, x-side length, y-side length, angle)
- Receptor information (location of population receptors, grid origin, radial distances to grid rings, number of radial directions, starting angle and increment)
- Meteorological information (uses external meteorological data file created using PCRAMMET, anemometer height, surface air meteorological data station, upper air meteorological data station)
- Terrain grid (uses a terrain algorithm based on land characteristics)
- Output options (receptor tables for highest values at all Receptors for 1-hour and 8-hour averaging times, maximum values table for 50 highest values for 1-hour and 8-hour averaging times, plot file for doing contour mapping)

ISCST3 then uses this data and the Gaussian distribution algorithm to calculate exposure concentrations and dispersion footprint. Additional algorithms are used to correct the Gaussian distribution equation for such options as terrain characteristics (hills can cause varying wind patterns), land use classification (deposition and uptake are greater in vegetated areas) and buoyancy effects.

ISCST3 modeling steps

Before the ISCST3 program could be used to model combustion products, additional programs and data were used to create input files. PCRAMMET, a program that creates meteorological files specifically for the EPA's dispersion modeling programs, was used first. Surface and upper air data files prepared specially to be used in PCRAMMET were downloaded from the EPA's SCRAM (Support Center for Regulatory Air Modeling) website for Phoenix and Tucson, respectively (EPA, 2002). Since upper air data were not available for 1992, Tucson mixing depth data was obtained from the National Weather Service and substituted into the 1991 SCRAM file. The Phoenix surface and Tucson upper air data files were then run through PCRAMMET to create a file to be used in ExInter. ExInter then created a DOS-based input file for use in ISCST3. To obtain a graphical picture of the byproduct plume after it was modeled, concentration data was imported into Surfer (2001) a contour line modeling program.

APPENDIX C: ASSUMPTIONS USED IN AIR DISPERSION MODELING

Assumptions used in the mixed-box model analysis

Duration of the fire

It was assumed that the fire began when the fire department was called to the scene at 11:30 am, and ended when the Phoenix Fire Department declared that the fire was out at 7:30 pm (URS, 1994). This gave a total duration of the fire of 8 hours.

Wind data

Figure 1A shows the average hourly wind speed and wind direction for August 31, 1992. These data sets were then averaged over the entire 8-hour duration of the fire to obtain the input values used in the mixed-box model: wind velocity = 4.17 m/s; wind direction was 30° north of East.

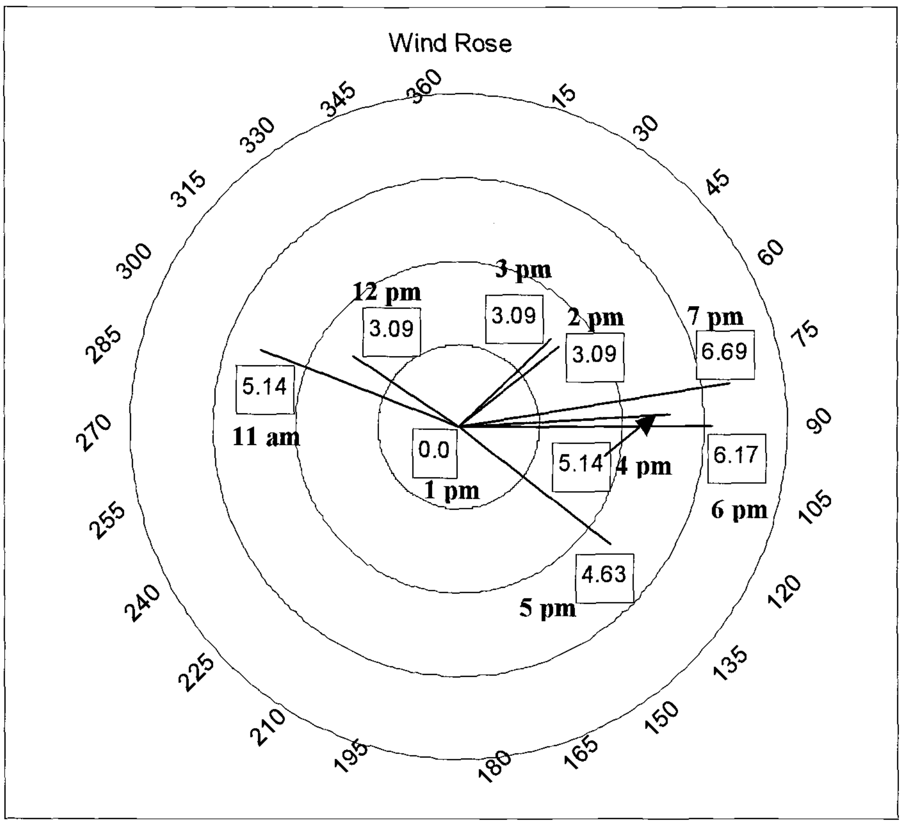


Figure 10. Wind rose for Phoenix, Arizona on August 31, 1992.

Plume information

The plume release height was assumed to be the height of the facility, which was 5.8 meters. This assumption was based on data observed in a video of the fire that showed the plume being emitted from the facility through its roof (EPCRA, 1997).

The plume rise (height) was assumed to be 244 meters, based on a calculation done by an engineering consulting firm during an inquest into this incident, three years after the fire (URS, 1994). The engineering firm used information such as ambient temperature, plume temperature, wind speed, and volumetric flow rate to calculate the final plume rise.

The plume width (width of area affected) was assumed to be 1,609 meters. The EPA made this assumption during an investigation into this incident approximately 4 years after it occurred (USEPA, 1999).

Plume depletion was assumed to be insignificant since there was no precipitation at the time of the fire, the humidity was very low, and the community was within 50 meters of the facility.

Facility information

Consumption of the facility was assumed to be 100%, based on an observation by a fire fighter present at the site after the fire was over (Siegel, Bellovin & Karnas, 1994).

The facility was assumed to be composed of 7% PVC from the machinery, and 93% wood from the facility structure. This assumption was based on a study done by an engineering consulting firm during an inquest into this incident, three years after the fire (URS, 1994). This gave us a total emission mass of combustion products from wood of 7,562,727 grams and a total emission mass of combustion products from PVC of 552,363 grams.

Assumptions used in the ISCST3 model analysis

Duration of the fire

It was assumed that the fire began when the fire department was called to the scene at 11:30 am, and ended when the Phoenix Fire Department declared that the fire was out at 7:30 pm (URS, 1994). This gave a total duration of the fire of 8 hours.

Meteorological data

Surface meteorological data were obtained from the American Meteorological Society as reported at the Phoenix SkyHarbor Airport, only a few miles from the former facility site. Upper air meteorological data was obtained from the Tucson Airport, which is located approximately 90 miles from Phoenix, and is the only location where upper air data are collected in Arizona. This data was deemed acceptable since the weather, terrain and elevation are very similar to Phoenix.

Plume information

The plume release height was assumed to be the height of the facility, which was 5.8 meters. This assumption was based on data observed in a video of the fire that showed the plume being emitted from the facility through its roof (EPCRA, 1997).

The plume rise (height) was calculated in the model based on meteorological data and volumetric flow rate.

Plume depletion was assumed to be insignificant since there was no precipitation at the time of the fire, the humidity was very low, and the community was within 50 meters of the facility.

Facility information

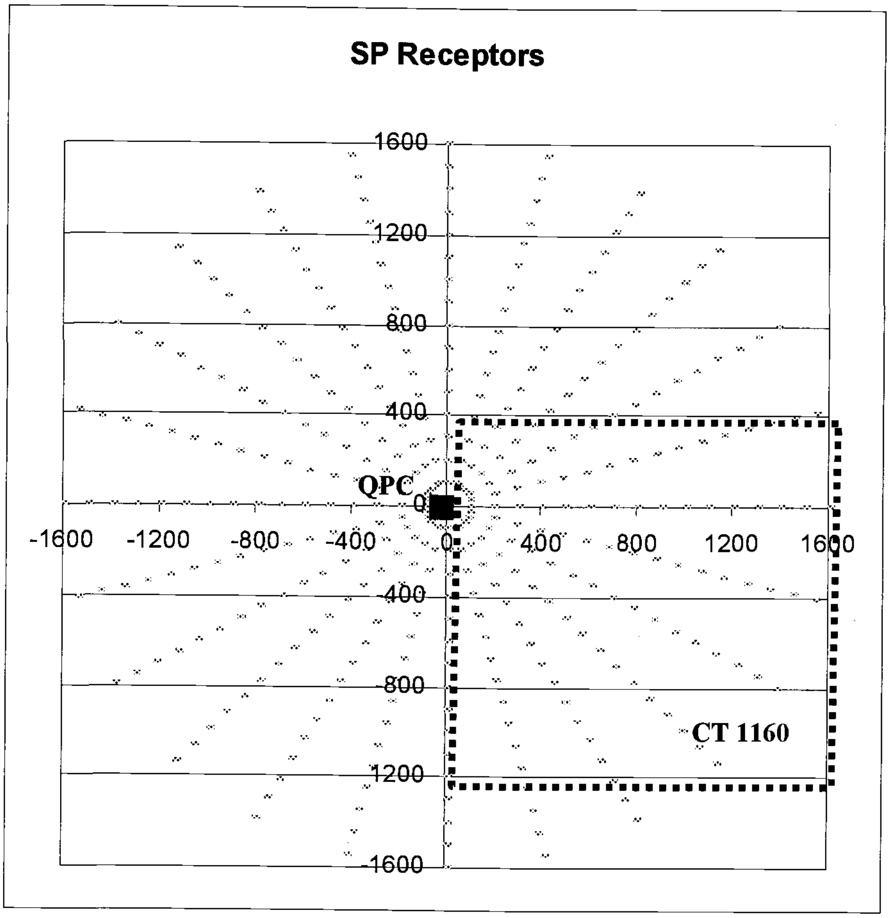
Consumption of the facility was assumed to be 100%, based on an observation by a fire fighter present at the site after the fire was over (Siegel, Bellovin & Karnas, 1994).

The facility was assumed to be composed of 7% PVC from the machinery, and 93% wood from the facility structure. This assumption was based on a study done by an engineering consulting firm during an inquest into this incident, three years after the fire (URS, 1994). This gave us a total emission mass of combustion products from wood of 7,562,727 grams and a total emission mass of combustion products from PVC of 552,363 grams.

The origin of the facility (x,y,z) was assumed to be (0,0,0). The length of the facility was 75 meters, the width was 31 meters, and the height was 5.8 meters. The building orientation angle was 0 degrees.

Receptor grid

A radial receptor grid was used with the facility at the center (0,0,0) in order to estimate how the plume of combustion products dispersed around the area. The first ring on the grid was set at 100 meters since the facility itself was 75 meters long. A total of 16 rings were used in order to make the last ring reach the end of CT 1160, approximately 1,600 meters (~1mile) due east of the former facility. Figure 2A shows the locations where exposure concentrations were calculated in the ISCST3 model and their location with respect to the facility and CT 1160. the receptor height was assumed to be at ground level.



Note. A total of 384 receptors were used in the ISCST3 model analysis.

Figure 11. Exposure concentration receptors used in the ISCST3 model and their relation to the QPC facility and CT 1160.

APPENDIX D: SENSITIVITY ANALYSES OF MODELS

Sensitivity analysis for mixed-box model

A sensitivity analysis was used to determine the effects of varying plume height and width of the area affected, on the residents' exposure concentrations. Three sensitivity analyses were done:

- Analysis 1 - Plume Height was changed from 244 meters to the height of the facility (5.8m)
- Analysis 2 - Width of Area Affected was changed from 1,609 meters to 1,200 meters (when the HCl concentration from the ISCST3 model dropped below its HBGL)
- Analysis 3 - Changed both Plume Height and Width of Area Affected to 5.8 meters and 1,200 meters, respectively

Results of these analyses were as follows:

- Analysis 1 - Exposure concentrations for all chemicals remained below their HBGL except for PAHs, Acrolein, and HCl. Exposure concentrations were 3, 4, and 12 times higher than their HBGLs for Acrolein, PAHs, and HCl, respectively.
- Analysis 2 - Exposure concentrations for all chemicals remained below their HBGL.
- Analysis 3 - Exposure concentrations for all chemicals remained below their HBGL except for PAHs, Acrolein, and HCl. Exposure concentrations were 3, 6, and 15 times higher than their HBGLs for Acrolein, PAHs, and HCl, respectively.

The plume height had a greater influence on the exposure concentrations than did the width of the area exposed. This shows that if any downwash was occurring due to the facility and the plume was not allowed to rise as high as the meteorological data would indicate, residents may have been exposed to higher concentrations.

Sensitivity analysis for ISCST3 model

The ISCST3 model automatically calculates most of the parameters it uses. However, sensitivity analyses were done on the wind direction, wind speed, and release height to determine their effects on the residents' exposure concentrations. Three sensitivity analyses were done:

- Analysis 1 - Plume release height was changed from 5.8 meters (height of the facility) to 0 (ground level).
- Analysis 2 - Wind Velocity was changed to be a constant 4.17m/s over the entire 8-hour period.
- Analysis 3 - Wind direction was changed to be a constant 60 degrees east of direct north and a constant wind speed of 4.1m/s.

Figures 3A through 5A show the contour plots resulting from these analyses. Results show that even when these parameters are changed, they do not have a great influence on the plume dispersion. This is probably due to the fact that the mixing height was between 2,500 and 3,500 meters for the duration of the fire, allowing the plume to reach 244 meters before falling back to the ground.

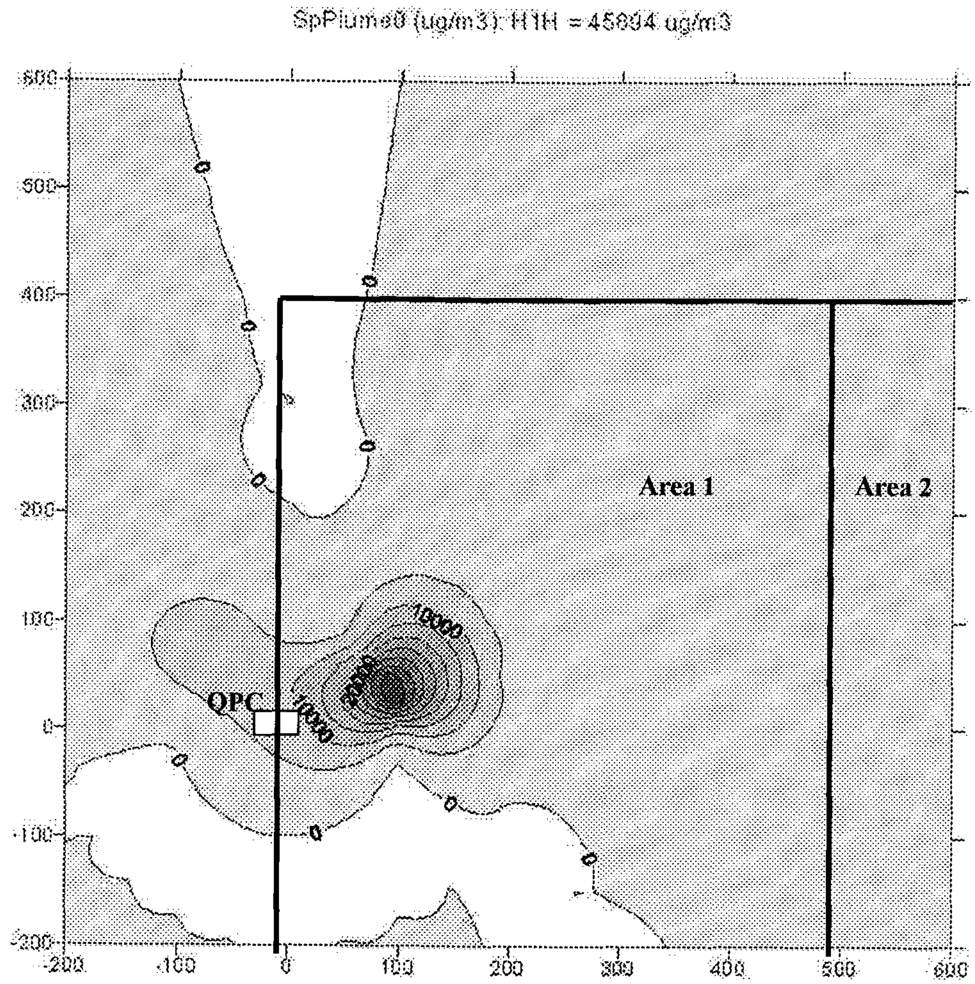


Figure 12: QPC fire plume assuming a plume release height of 0 (ground level)

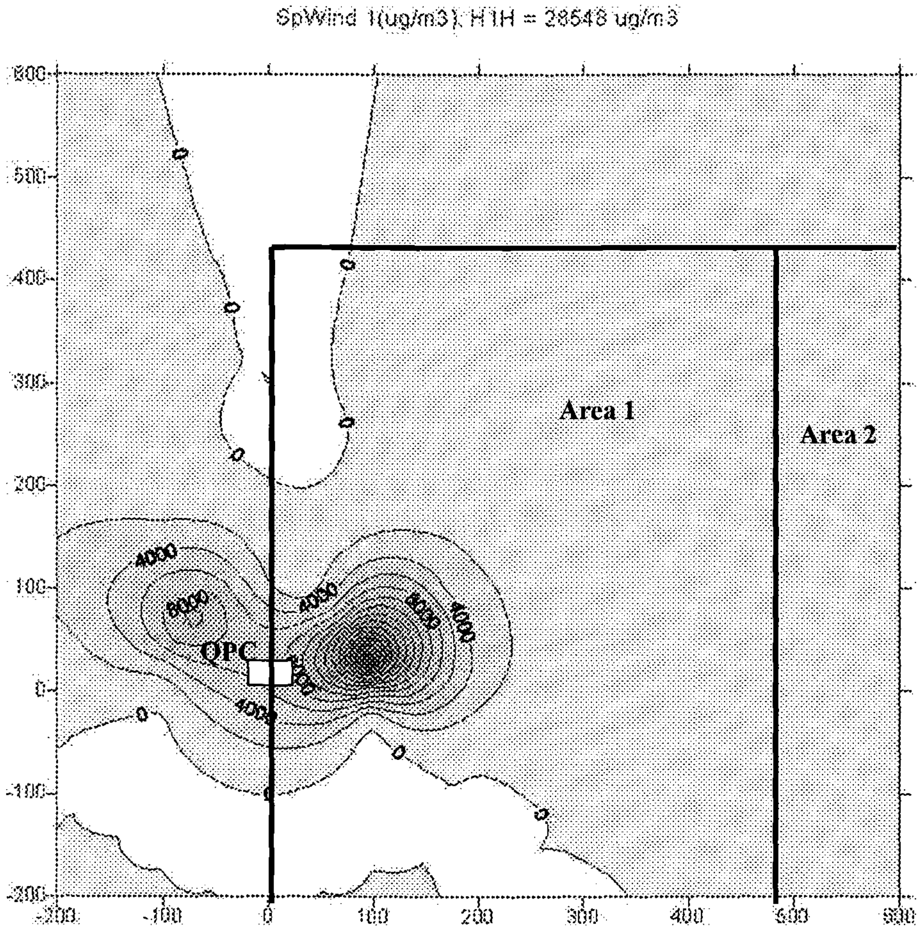


Figure 13: QPC fire plume assuming constant wind speed of 4.1m/s

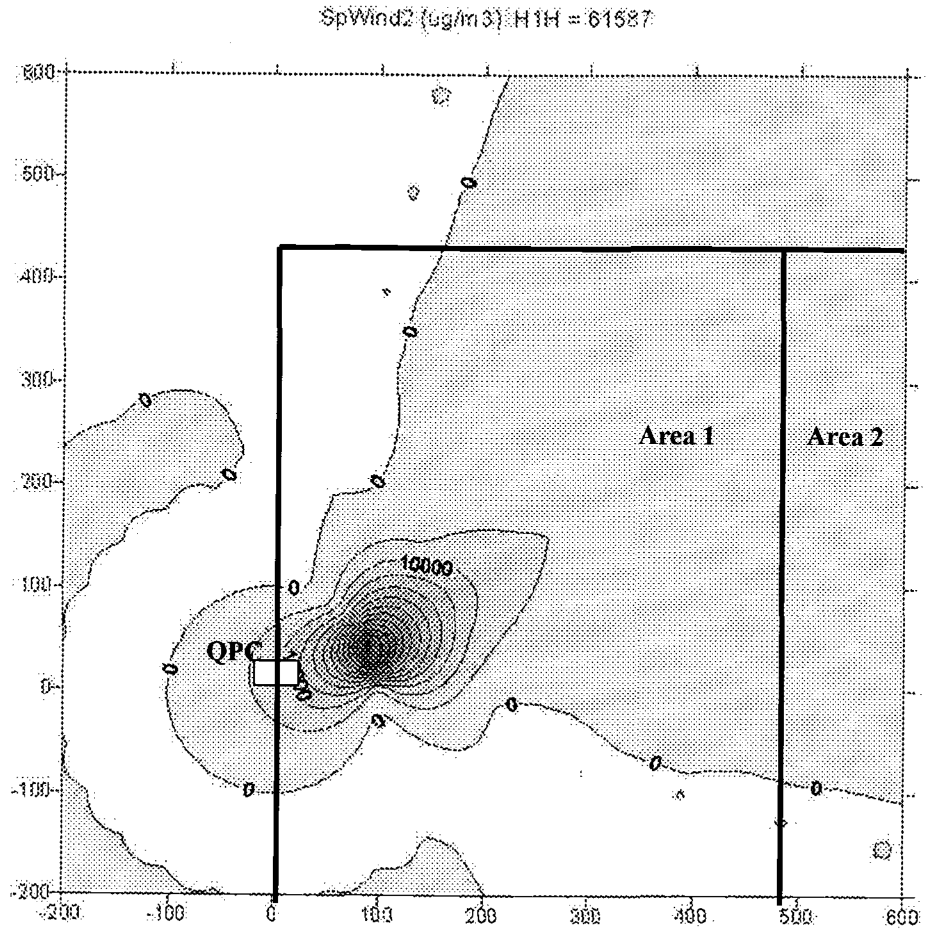


Figure 14: QPC fire plume assuming constant wind direction of 60 degrees east of direct north and a constant wind speed of 4.1m/s