

Understanding the Hazards of Fire Residue Encountered During the Restoration Process

>> by Michael A. Pinto, CSP, CMP and David A. Batts

Abstract

An extensive literature review was undertaken to determine the types and levels of contaminants present in a building following a fire. A thorough review of currently available literature uncovered significant research regarding the sorts of contaminants that are produced during building fires, as well as the type and extent of airborne and surface contaminants that are produced in such conflagrations. A wide variety of noxious materials were identified from multiple studies, with the consistent warning that attempts to fully characterize hazards associated with fires are inherently limited due to the vast array of products that can be impacted by fire and the individual progression that each structure fire takes.

Introduction

The authors were contacted by a manufacturer of hydroxyl radical generators to assist in providing relevant information to the restoration industry regarding the air quality of post-fire environments and the potential risk to restoration contractors when working in such situations. In response, the authors recommended a two-phase approach be considered. The initial phase would be a review of existing literature related to indoor air quality (IAQ) and the risks associated with working in structures that have suffered fire and smoke damage.

The goal of the literature review was to answer important questions about the types and quantities of residual contaminants that may be present in structures at the time restoration work is undertaken. Specifically, given that smoke odor is often present and addressed

throughout the restoration process, the research was suggested to answer questions such as:

1. Does existing research suggest that certain harmful contaminants or intermediate compounds are typically present in a fire-damaged structure?
2. Does existing research suggest that environments subject to fire restoration are generally safe or generally unsafe during the various stages of restoration work?
3. Does existing research suggest certain types of fires or time periods after fires are more dangerous than others?
4. Is there consensus in the current body of knowledge regarding the use of personal protective equipment during the restoration of fire-damaged buildings—especially during the initial cleaning phases?
5. Is the risk to restoration workers and the utilization of personal protective equipment related to specific cleaning methods used during remediation?

Summary of Findings

There is no lack of information related to building fires. Codes and textbooks from organizations such as the National Fire Protection Association (NFPA) and the International Fire Service Training Association (IFSTA), research papers, restoration industry bulletins, and articles in the popular press all provide substantive information regarding fire science and firefighting. A substantially smaller subset of information focuses on the fire residue, health effects from such residue, and potential issues related to the breakdown of those residual contaminants.

Although many documents were reviewed regarding the science of airborne fire residue, eight of them seem to provide the widest array of applicable information. The salient parts of those documents are summarized below. The material is organized from the most general to the most specific in order to build on individual concepts.

“Why Professionals Should Clean Smoke Damage from a Fire”¹

As the title suggests, this basic document, published by the IICRC, is designed to educate the public about the value of using professionals for fire restoration and cleaning. While it is promotional in nature, it does touch on some of the basics related to ash and smoke residue. Specifically, it notes that, generally, ash is acidic and if left on surfaces for even relatively short periods it can cause extensive corrosion, etching and discoloration. It also emphasizes that ash residue is easily disturbed and can spread through a building, even into areas that were not originally impacted by fire or smoke.

From the standpoint of odor reduction, the IICRC document warns those dealing with fire-damaged properties that lingering powerful odors are usually present. The use of oxidizers in general, and hydroxyl radical generators in particular, are not mentioned. The basic understanding that source materials that are off-gassing must be removed is emphasized. The document explains the difficulty of the task in many situations by noting that ash builds up in layers, and may eventually develop into a lacquer-like consistency.

“The Hidden Hazards of Fire Soot”²

Because it was written as a primer for art conservators, this paper, produced by the American Institute for Conservation of Historic and Artistic Works (AIC), lays out significant information related to the types and potential hazards of fire residue. It includes clarification of terminology, noting that the term “fire soot” refers to smoke residue on surfaces, which is a complex mixture of substances. Similar to the information

Executive Summary

An extensive literature review was undertaken to determine the types and levels of contaminants in buildings following a fire. The review uncovered significant research regarding the sorts of airborne and surface contaminants produced. A wide variety of noxious materials were identified, with the consistent warning that attempts to fully characterize hazards associated with fires are limited due to the vast array of products impacted and the individual progression each structure fire takes.

The goal of the literature review was to answer questions about the residual contaminants present in structures at the time restoration work is undertaken. Specifically, to answer questions such as:

1. Are certain harmful contaminants or intermediate compounds typically present in a fire-damaged structure?
2. Are environments subject to fire restoration generally safe or generally unsafe during the various stages of restoration work?
3. Are certain types of fires or time periods after fires more dangerous than others?
4. Is there consensus regarding the use of personal protective equipment during the restoration of fire-damaged buildings?

There is no lack of information related to building fires. A smaller subset of information focuses on fire residue, health effects from said residue, and potential issues related to the breakdown of residual contaminants. Many documents were reviewed regarding the science of airborne fire residue, eight that provided a wide array of applicable information are discussed in this paper.

Substantial information was found about the types and extent of airborne contaminants versus surface contaminants. Several groups of chemicals were identified as potential airborne contaminants. Although many different processes create this mix of fire residue, the research is clear that most of the contaminants come from incomplete combustion of materials in the structures. Virtually all of the chemicals identified are considered hazardous.

In addition to the compounds identified as components of fire residue, the form of the residue is important. Exposure to

small-size particles creates the potential for more significant health problems than just exposure to the chemicals. These particles increase the ability of airborne contaminants to penetrate deep into the lungs.

In addition to information about airborne contaminant types, some studies evaluate the dissipation of hazardous airborne chemicals after a fire has been extinguished. Of concern is how quickly the hazardous compounds off-gas. One study showed that levels of hazardous chemicals dropped markedly within an hour of the fire being extinguished.

The research provides information regarding the use of personal protective equipment (PPE). Most of the research was directed toward firefighters. The literature emphasizes the importance of full-scale PPE (SCBA and full protective turnout gear) both during and immediately after a structure fire. Little information was found about levels of contamination that may require PPE after a fire has been out for several days or the structure has been extensively ventilated.

The picture that emerges is that prudence should be the primary approach when determining whether PPE should be worn. The levels and types of hazardous materials created lead to the recommendation that during demolition and disturbance of burned materials, and any activity, including initial cleaning, that results in exposure to soot and fire residue, PPE should be worn.

Applicable federal regulations must also be followed. The literature is clear that hazardous particles remain in a fire damaged structure. Knowing there is at least the possibility of solid hazardous particles remaining would fall under OSHA 1910.134(d)(1)(iii), which states, “The employer shall identify and evaluate the respiratory hazard(s) in the workplace; this evaluation shall include a reasonable estimate of employee exposures to respiratory hazard(s) and an identification of the contaminant’s chemical state and physical form.”

summarized above, this paper draws a connection between fire residue and the physical sciences, including the sense of smell. It notes that burnt organic material produces soot that is hard to see and often has a pungent odor (known as protein smoke). A number of hazardous byproducts are created by the burning of different materials (see Illustration 1).

Material Hazardous Fire Residue	
Wool	Hydrogen cyanide
Wood	Manganese and benzene
Carpet	Formaldehyde
Plastic	Chlorinated compounds
Rubber	Volatile organic compounds (VOCs)
Paint	Heavy metals

Illustration 1

The paper also addresses the hazards of exposure to fire soot. It emphasizes that fire soot should not be treated simply as “dirt.” It provides some historical context, noting that in 1775 Percivall Pott, an English surgeon, first documented an association between exposure to soot and a high incidence of scrotal cancer in chimney sweeps. The author notes that some chlorinated products become attached to airborne particulate matter. This phenomenon of gases and vapors adhering to airborne and settled soot suggests that fire residue is more than just a particulate hazard, and that some attached chemicals may desorb from skin contact, inhalation or ingestion.

Other areas of importance in this paper include the description of the burning process that produces smoke and a discussion of the sizes of the aerosolized carbon particles. The author notes that smoke residue can present a respiratory hazard because of the size of these particles. Particles approximately 10 microns or larger get trapped in the upper respiratory tract. Particles five microns or smaller can make it down to the lower lung where the gas exchange occurs in the alveoli. With the average particle size of soot being approximately 2.5 microns, most fire residue particulate can penetrate deep into the lungs.

This article, written for conservation professionals, provides a strong basis for understanding some of the hazards associated with fire residue. It identifies specific hazardous components of soot, links significant health effects to those components, and details the mechanisms that produce dangers for the respiratory system.

“Firefighters Sound Alarm on Toxic Chemicals”³

Written for the layperson, this press article written for the Huffington Post is an investigation of the health effects experienced by active and retired firefighters. The article provides an expansive listing of the types of hazardous materials recovered from fire residue. It points out that some of the most toxic fumes released in structure fires come from chemicals added to common contents in an effort to retard flames.

When flame-retardant materials burn, a variety of manmade byproducts are liberated, including dioxins, furans, and formaldehyde. Additionally, levels of polybrominated diphenyl ethers, or PBDEs—a common class of chemicals used as flame retardant—are so prevalent in smoke that they are recovered at elevated levels in the blood of firefighters.

Although the article focuses on firefighters, it has real relevance for the restoration industry. The article states that studies have shown that hazardous chemicals present in soot may linger on skin, uniforms, respirators, helmets, and other gear. It notes that transference of hazardous contaminants continues during the “overhaul” phase of work, when firefighters are moving debris and opening trapped spaces in order to confirm that no embers are active. This type of activity closely correlates with the demolition and cleanout phases of fire restoration.

“International Study of the Sublethal Effects of Fire Smoke on Survivability and Health (SEFS): Phase 1 Final Report”⁴

The National Institute of Standards and Technology (NIST) report is a massive study that provides data on many aspects

of the composition and movement of fire residue. The document distinguishes between gaseous and particulate portions of smoke. As noted previously, the compounds that are in the form of a gas dissipate rapidly, although some absorption into surfaces and airborne particulates does occur. The researchers documented that some types of fire gasses, such as halogen acids, actually dissolve into water droplets, which removes them from the air; but that process changes the composition of the water used to extinguish the fire.

The NIST report identified a wide range of dangerous gasses produced by structure fires:

- *Acrolein* from cellulosic materials such as wood, cotton, paper and polystyrenes.
- *Toluene diisocyanate* from flexible polyurethane foams.
- *Formaldehyde* from polypropylene materials.
- *Hydrogen cyanide* from nitrogen-containing materials such as wool, silk, acrylic fibers, nylons, urea/formaldehyde, melamine, polyurethanes, and polyacrylamide.
- *Nitrogen dioxide* from nitrogen-containing products such as those mentioned previously.
- *Hydrogen chloride* from PVC plastics and chlorinated additives.
- *Hydrogen fluoride* from PTFE plastics and other fluorinated compounds and additives.
- *Hydrogen bromide* from brominated compounds and additives.
- *Sulfur dioxide* from sulfur-containing materials such as wool and vulcanized rubbers.
- *Hydrogen sulfide* also from sulfur-containing materials.
- *Ammonia* from nitrogen-containing materials.
- *Styrene* from polystyrenes.
- *Toluene* from polystyrenes, PVC plastic, and polyurethane foams.
- *Benzene* from polystyrenes, PVC plastic, polyesters, and nylons.

Another aspect of fire residue investigated by the NIST team was the toxicology of ultrafine particles. The study confirmed that smaller-size particles create more health problems because of their ability to penetrate deeper into the lungs. It noted that health problems occurred even with chemically inert materials due to the adsorption of the types of hazardous gasses detailed in their research.

“Polychlorinated Biphenyls (PCB’s): Current Intelligence Bulletin 45”⁵

This bulletin, published by the National Institute for Occupational Safety and Health (NIOSH), focuses on another concern with residue from fires: the potential for contamination by polychlorinated biphenyls (PCBs). Although PCBs were phased out of consumer products by 1977, commercial electrical service equipment was still found with these materials in North America up until 1990. Because of the effectiveness of these products and resiliency of the PCBs, houses and commercial structures can still be impacted by PCBs nearly 40 years after the products were initially banned.

Specifically, small capacitors containing PCBs were commonly used in household appliances such as television sets, air conditioners, and fluorescent light fixtures. Many of those products still reside in structures, and numerous fire-related incidents involving electrical equipment containing PCBs have resulted in widespread contamination. The bulletin also points out that a wide variety of chemical configurations were utilized and that secondary byproducts can develop in reaction to the heat and flames. Fire residue may contain polychlorinated dibenzofurans (PCDFs) and polychlorinated dibenzo-p-dioxins (PCDDs) in addition to standard PCBs.

Reviewing the data from a number of fires where electrical equipment was involved, NIOSH researchers showed that PCB contamination in fire residues can be extensive — up to 5,000

micrograms of PCBs per gram of soot. At such levels, emergency response personnel, maintenance staff, restoration crew members, or building occupants may be exposed to the compounds by inhalation, ingestion or skin contact. Therefore, the government research group recommended that all workers who may be exposed to PCBs, PCDFs, or PCDDs should be equipped with chemical protective clothing to ensure their protection.

Researchers recommended disposable apparel because of the uncertainty of properly decontaminating reusable clothing. Specifically, the bulletin recommended that outer protective garments should consist of a zippered coverall with attached hood and draw string, elastic cuffs, gloves, and protective boots. If exposure to soot is anticipated, workers should wear outer coveralls made of a nonwoven fabric such as spunbond Tyvek® to exclude particulates. From a respiratory protection standpoint, they indicated that disturbance of burnt materials in large quantities of visible soot can create airborne exposure levels of PCBs. In such cases, a supplied air or powered air-purifying respirator should be used. When cleanup operations have advanced to a point where airborne PCBs can no longer be detected, air-purifying full face-piece respirators equipped with a high-efficiency particulate air filter and organic vapor cartridge should be used as a precaution until final decontamination is completed.

“Hazardous Substances after Fire Damage”⁶

This Belfor document provides an international perspective. Belfor is a global restoration company with much of its technical support based in Germany. The bulletin provides a distinction between the gaseous contaminants present while the fire is burning and the damaged structure is still hot, and those in a particulate form that are present after the fire scene is cold. The authors note that while the

gaseous compounds are of a significant hazard to firefighters and others present in the building immediately after its control, restoration work is typically impacted by contaminants present in soot and particulates.

Specifically, the pamphlet notes that PCBs are still considered potential fire-residue contaminants despite their phase-out from industrial operations many years ago, particularly from the burning of elastic expansion joints and sealing compounds in a building. The document also demonstrates that polycyclic aromatic hydrocarbons (abbreviated as PAH in some documents and PAK in others) and dioxins are possible contaminants as well.

The pamphlet notes that more than 200 individual substances fall into the dioxin category, including the most well known of that chemical class, the polyhalogenated dibenzodioxins (PHDD). It also explains that the entire group of fire residues typically arises through incomplete combustion of chlorine and bromine-containing materials, in conjunction with other organic substances. Consequently, a source of dioxins, such as an old container of pesticides, does not have to be present for soot and other fire residues to contain dioxins. In addition, carbonic acids, aldehydes, alcohols, and aliphatic and aromatic hydrocarbons are also possible fire residue contaminants.

The bulletin also notes that both dioxins and PAHs are deposited in the condensate on surfaces and are also bound by adsorption to soot or fire residues. A large number of PAHs are known to be cancer-causing compounds, with benzo(a)pyrene as a marker. Benzo(a)pyrene itself is classified as a toxic, carcinogenic, mutagenic substance that also has a damaging effect on reproduction. It states that the acute and chronic toxicity of the large number of individual compounds varies considerably, by a factor of up to 10,000. Given the unstructured nature of the creation of dioxins (as well as many of the aromatic hydrocarbons), and the wildly varying toxicity of the

contaminants, the safe approach is to assume that such hazardous materials will be part of fire residue.

“Toxic Chlorinated and Polyaromatic Hydrocarbons and Simulated House Fires”⁷

This document, published by the Department of Environmental Sciences at the University of Kuopio in Finland, looked at the presence of a number of toxic products, particularly those arising from chlorinated hydrocarbons. As in previous documents, the Finnish study identified polychlorinated biphenyls (PCBs), benzenes, and dioxins as hazardous contaminants of note. They also explain that furans (a class of chemicals often used as insecticides) are also present in combustion gas and deposited in soot collected from simulated house fires. Their measurements confirmed that large amounts of organic compounds may be released in house fires. As a result, there is a need for careful personal protection of firefighters and remediation workers against combustion gases during a fire and contaminated surfaces after it.

The researchers found that concentrations of toxic organic compounds released in residential fires are high even when there are no hazardous substances present in the fire, as the compounds are produced by incomplete combustion of building materials, surfaces, and contents typically found in homes.

Researchers concluded that substantial amounts of toxic chlorinated and polyaromatic hydrocarbons may be released during fires, but no emission factors could be estimated on the basis of their sampling, since the amount of material actually burned and the total amount of combustion gases in an uncontrolled setting like a house fire remain unknown. In actual structure fires, the variety of furniture and interior decoration material available as the fire loads is much greater than in a simulated fire, thus PAH and dioxin concentrations in the combustion gases may be higher.

For firefighters and reconstruction workers who may be exposed to combustion gases, it is not only important

to be equipped with respirators and protective clothing during the fire (typically self-contained breathing apparatus [SCBA] for fire fighting), but it is also necessary to be aware of the possibility of many types of toxic contamination from particulate soot on surfaces after the fire. The use of proper personal protective equipment (PPE) during renovation work is recommended.

A Study on Chemicals found in the Overhaul Phase of Structure Fires using Advanced Portable Air Monitoring available for Chemical Speciation⁸

This Oregon study used real-time portable gas detection instruments together with corresponding sampling and laboratory analysis to validate the information from the portable equipment. Data was collected from 38 different fires over an eight-month period, representing real-world situations. Even so, testing at actual fire scenes during firefighting and overhaul activities (conducted after the majority of the fire has been put out but during a time when there may be smoldering materials and the possibility of small flare-ups) introduced variability into the research that could not be controlled. As the authors noted, “... it was performed in the field with unpredictable conditions and circumstances. This was compounded by the fact that structure fires present a mixture of chemicals and synergistic effects. Concentrations, and even chemicals present, may depend on what’s burning.”

Because of the type of instrumentation used during the study, only 21 specific chemicals, along with miscellaneous unidentified particulates, were reviewed:

Acrolein, Total aliphatic aldehydes, Ammonia, Arsenic, Benzene, Benzyl chloride, Carbon disulfide, Carbon monoxide, Formaldehyde, Fufural, Glutaraldehyde, Hydrogen chloride, Mercury vapor, Naphthalene, Nitrogen dioxide, Nitrogen monoxide, Ozone, Phenol, Sulfur dioxide, Styrene, Toluene

Researchers found that many of these chemicals were present in various fires in

concentrations that exceeded the established permissible exposure limits, with some greater than recommended short-term exposure limits. Concentrations of specific chemicals—such as arsenic, carbon monoxide, mercury vapor, and nitrogen dioxide—exceeded levels that were considered to be immediately dangerous to life and health.

The Oregon report provides useful information about the types of hazardous materials involved in structure fires as well as how fast the airborne concentrations of those materials dissipate. In this respect, it was unique among all the resources reviewed for this research.

Of particular interest, the study demonstrated a natural dissipation of chemical levels detected over the first 45 minutes after a fire was extinguished. As monitoring continued, once the fire was out the contents of the structures cooled and either natural or mechanical ventilation had commenced. Somewhat surprisingly, the researchers noted that by one hour after the fire had been extinguished, most of the fire residue products had completely dissipated. Monitoring was typically discontinued about one hour after completion of the primary firefighting activities.

The key information regarding reduction in airborne levels of hazardous contaminants was summarized in Illustration 2 and Illustration 3 to allow a careful review of the data. It is interesting to note that concentrations of specific “toxic chemical levels” shown in the report’s Illustration 2 were measured in parts per million (ppm), with the illustrative graph scale describing a logarithmic fashion that presents concentrations from nearly 1,000 ppm to 1/1000 ppm. The accelerated decrease shown in the graph from 45 minutes to 65 minutes after the fire is extinguished is dramatic.

In a similar fashion, Illustration 3 presents the airborne chemical data on a percentage basis from the various field instruments and laboratory results. It also confirms a steep decline in airborne chemical concentrations as soon as the burning stops, with levels that are close

to undetectable (utilizing field instruments and basic sampling protocols) by the time one hour has passed.

Despite the substantial evidence showing that chemical levels from fires dissipated rapidly after the burning had stopped, the authors did note that due to the fact that hazardous airborne toxicants were documented many hours and sometimes days after extinguishment, this study could not conclude that time alone was a reliable determinate of safe atmospheric levels. The data did show that allowing more time after knock-down was beneficial and should be an important consideration when determining the best practices for firefighters during overhaul. This prompted them to give a cautionary warning that even with strong evidence for rapid reduction of hazardous substances, time alone was not a reliable method of determining safe atmospheric levels.

Another interesting discussion in the study involved the impact of natural or mechanical ventilation on the airborne levels of some hazardous materials. The authors noted that ventilation seemed to improve conditions; however, the time lapse between the fire being extinguished and the collection of samples had a more pronounced effect in improving the quality of the air inside the structure. They added, “Ventilation was evaluated as it relates to the levels of toxicants and did assist in the reduction of airborne levels; however, toxicant levels rapidly increased when ventilation was discontinued.”

Another germane aspect of the study dealt with personal protective equipment. Given the types and levels of hazardous materials in the air while the structures were burning, the authors were adamant that self-contained breathing apparatus should continue to be utilized as the primary respiratory protection for firefighters even when the blaze has been brought under control. They noted that other types of positive-pressure supplied air respirators might be more feasible for overhaul and fire investigation activities, but cautioned against going to

air-purifying respirators soon after a fire was put out or for any activity that might overturn hot spots or smoldering embers.

Although the study did not address restoration activities, these precautions may be applicable for restoration workers

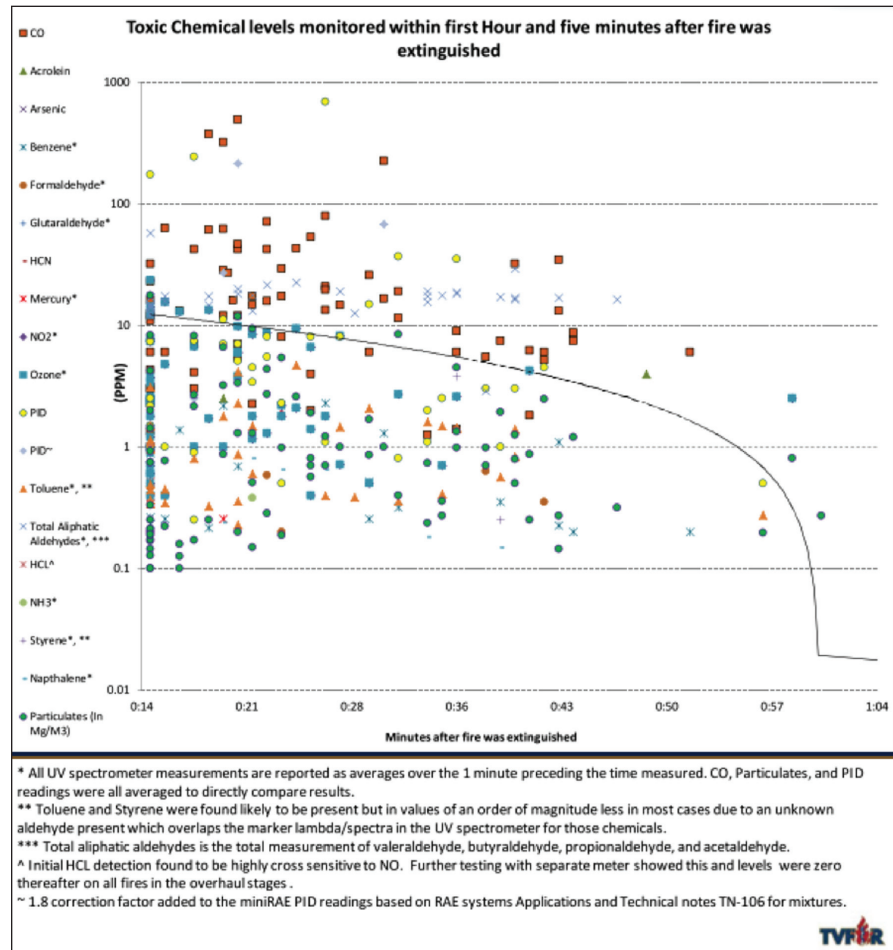


Illustration 2

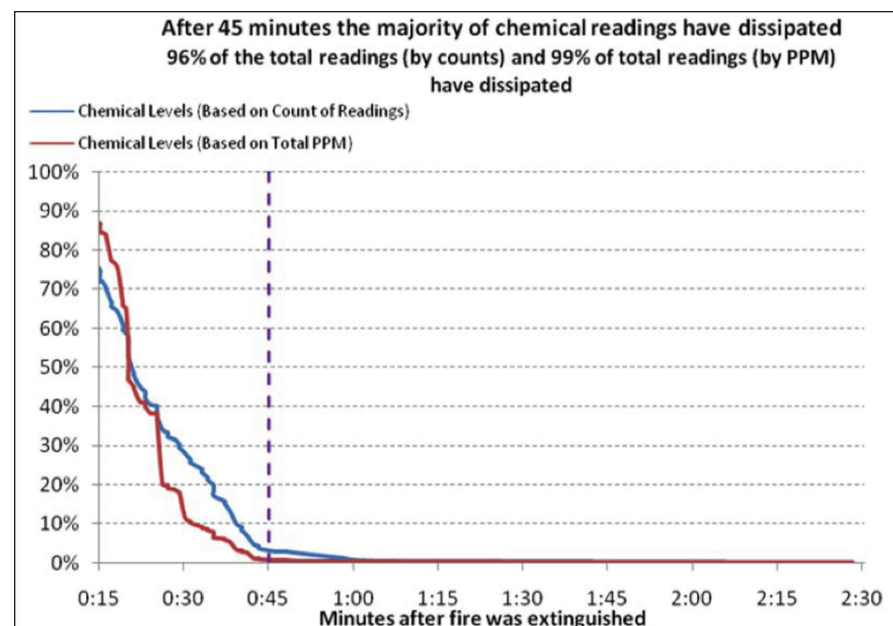


Illustration 3

involved in activities which take place immediately following a fire being extinguished, such as board-up, immediate pump out, initial content salvaging, etc. However, lower levels of personal protective equipment would seem to be indicated by the data collected for this report for individuals that are involved in restoration work taking place one or more days after the fire has been extinguished. Nevertheless, the author's comments about levels of toxicants going up after ventilation was stopped emphasizes the need for continued ventilation during restoration work, especially if lower levels of PPE are considered.

Conclusions and Recommendations

As noted, extensive research has been conducted regarding contaminants produced during building fires. Substantial scientific information was found about the types and extent of airborne contaminants as compared to surface contaminants. Several groups of chemicals were identified as potential airborne contaminants in fire-damaged buildings, including solid particles, volatile organic compounds (aldehydes, esters, halogenated alcohols, hydrocarbons, nitro-nitriles, ketones, aromatics, sulfides, etc.), polycyclic aromatic hydrocarbons, polychlorinated biphenyls, and dioxins. Although many different chemical processes create this chemical mix of fire residue, the overall research is clear that most of the contaminants come from incomplete combustion of materials in the structures. Virtually all of the chemicals identified in the various studies are considered hazardous by both regulatory agencies and safety/health professionals.

In addition to the specific compounds identified as components of fire residue, the physical form of the residue is important. Exposure to the small-size particles created during a fire creates the potential for more significant health problems than just exposure to the chemicals themselves. The tiny particles increase the ability of the airborne contaminants to penetrate deep into the lungs. This has an added negative impact related to health, because hazardous gasses that

might dissipate before being inhaled are adsorbed by many of the particulates and released on contact with the fluid in lung sacs.

In addition to information describing the types of airborne contaminants following a fire, there are also studies that evaluate the dissipation of hazardous airborne chemicals after a fire has been extinguished. Of primary concern to firefighters and restoration professionals is how quickly the hazardous compounds off-gas, especially the time that elapses between the fire being extinguished and airborne levels of hazardous contaminants dissipate. One study showed that levels of hazardous chemicals dropped off markedly within an hour of the fire being extinguished. Still, the authors noted that many factors influence any particular case, including the amount of damage and subsequent natural airflow, use of artificial ventilation, firefighting methods, and how long the building is exposed prior to installation of protective coverings.

Other reviewed material indicates that off-gassing is not the only process at work on fire residue following fire suppression. Many chemical contaminants are broken down into other substances through oxidation, and even by sunlight. However, the release and natural breakdown of components of fire residue does create other compounds, some of which can also be hazardous.⁹

Data garnered from the research provides useful information regarding the appropriate use of personal protective equipment. However, most of the research was directed toward firefighters who are in the structure during the actual conflagration and immediately afterward as well. Current literature, which focuses on fire suppression, overhaul, and investigation, continues to emphasize the importance of full-scale personal protective equipment (SCBA and full protective turnout gear) both during and immediately after a structure fire. From that perspective, the need for personal protective equipment would appear to drop off substantially within an hour of the fire being extinguished. In contrast,

there is little information about levels of contamination that may require protective equipment after the fire has been out for several days and/or the structure has been ventilated to remove a significant portion of the odors.

Although restoration professionals could look at only one study — the Oregon Fire Marshal document that shows a rapid reduction in airborne chemicals after the fire is out — and feel justified in putting workers in fire-damaged structures without personal protective equipment, such a decision clearly oversimplifies the actual situations encountered during such work. Virtually all of the reviewed literature emphasized that fire residue, and the hazards associated with it, is difficult to properly evaluate because of the incredible diversity in the types of materials that are burned and how the fire progresses.

The picture that emerges from this literature review is that prudence should be the primary approach when restoration professionals determine whether personal protective equipment should be worn by restoration workers in fire-damaged buildings. The levels and types of hazardous materials created during a structure fire lead to the recommendation that during the demolition and disturbance of burned materials, and during any activity that creates exposure to soot and other fire residue, personal protective equipment should be worn. Similarly, during initial cleaning activities that can liberate settled materials and propel smaller particles into the air, appropriate personal protective equipment should be worn. At a minimum, this should include respiratory protection and gloves to reduce the potential for inhalation and skin absorption of dangerous compounds.

Restoration contractors also need to remember that there are applicable federal regulations that must be followed. As noted by this literature review, there are very few studies that relate to the restoration industry; especially when it comes to fire damage restoration and respiratory protection. The bulk of the reviewed literature makes it clear that

there are hazardous particles that remain in a fire damaged structure. Knowing that there is at least the possibility of these solid hazardous particles remaining, this would fall under OSHA 1910.134(d)(1)(iii) which states, "The employer shall identify and evaluate the respiratory hazard(s) in the workplace; this evaluation shall include a reasonable estimate of employee exposures to respiratory hazard(s) and an identification of the contaminant's chemical state and physical form."

Additional Research Recommendation

While the recommendation to utilize personal protective equipment is based on the types of hazardous materials that may be encountered and the inability of the contractor to know the actual mix of chemicals to which his workers may be exposed, additional research in this area would be valuable. Since cleaning and the utilization of air scrubbers and hydroxyl radical generators have become a standard method for addressing fire residue and smoke odors, further research or testing is recommended to determine if the use of hydroxyl radical treatments to eliminate smoke odors may also create harmful intermediary compounds. As such, testing in actual or simulated fire conditions to determine if the cascade

effect produced by hydroxyl radical generators as part of the contaminant/odor reduction process puts restoration workers at any further risk would offer valuable information to the restoration industry. Such testing should be supported as Part Two of this research. ●

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>> ABOUT THE AUTHORS



DAVID A. BATTS currently serves as Director of Environmental Services for Wonder Makers Environmental. His background includes education in the liberal arts and a variety of life experiences. Dave is a certified Mold Remediation Supervisor and also holds other certifications related to indoor air quality investigations and abatement. He has been involved in remediation of hazardous indoor environments as a contractor, inspector, project manager, asbestos instructor, and laboratory analyst since 1971.



MICHAEL PINTO provided oversight and generated the report for this study. Mr. Pinto's post-graduate training is in Public Administration and Environmental Engineering. In addition to his scholastic achievements, he holds the titles of Certified Safety Professional and Certified Mold Professional. He is a member of the American Society of Safety Engineers, Restoration Industry Association, American Industrial Hygiene Association, Indoor Air Quality Association, and the Cleaning Industry Research Institute. Mr. Pinto is the author of over 215 published technical articles and has successfully conducted industrial hygiene/indoor air quality investigations since 1988.