

Where There's Fire, There's Soot and Smoke and . . .

By Neil McManus, CIH, ROH, CSP

Building restoration companies undertake the arduous task of restoring buildings following fire episodes. This activity involves removal and cleaning or disposal of contents, cleaning and partial or full demolition of the structure, and rebuilding. This kind of episode is traumatic for occupants, a truth to which anyone who has attended a fire scene can attest. Project managers easily can find themselves in the middle of disputes between the home or building owner and the insurance adjuster. A recent situation illustrates this point.

The Scene

The insulation on the windings of the fan motor in a gas furnace failed. This led to arcing and an electrical fire involving the insulation and other parts of the motor. Smoke migrated from the furnace through the supply ducts and spread throughout the house. Soot and smoke deposited on surfaces, especially metals. The homeowner fled and called 911.

The fire department arrived and cut the power to the furnace, put out the fire, ventilated the building using portable fans, and declared the building "safe," all within two hours of the start of the episode.

Smelling "smoke," the homeowner did not want to stay in the house during the cleanup and demanded that the insurance company pick up the tab for his hotel stay. The insurance adjuster, fearing out-of-control costs, said that the situation did not warrant such an extreme measure. After all, the fire was confined to the interior of the heating system, and there was no destruction of the structure or contents.

And, after all, it was *just* a fire. People willingly expose themselves to smoke from fireplaces, wood stoves and campfires, as well as cigarettes, pipes and cigars all the time. Campgrounds, parks and even urban areas often reek of wood and other smoke in cooler months of the year. What could be different in this circumstance?

Both parties turned to the project manager for support. The project manager started to wonder: What should be the company's position in arbitrating such situations? How should the company approach protection of its personnel during work in fire-damaged buildings? After all, building restoration personnel

often enter these structures when heavily protected firefighters leave after having declared the building "safe."

The preceding situation is real, as are the issues that it raises.

Fire: A Complex Chemical Event

Fires are complex chemical events, resulting from the right combination in time and space of a fuel, an oxidizer (usually oxygen) and a source of heat (Figure 1). Fire is a type of combustion process that leads to production of heat and light. Complete combustion results in production of gases, including carbon dioxide, steam, sulfur dioxide and nitrogen dioxide. Incomplete combustion leads to production of gases including carbon monoxide and nitric oxide, and depending on constituents of the fuel, ammonia, hydrogen chloride, hydrogen fluoride, hydrogen cyanide, hydrogen sulfide, and a wide array of vapors, and particles of smoke, soot and sometimes liquids, and melted and partly burned (charred) solid materials (Figure 2).

Fires in buildings can involve contents, furnishings and structural materials. At the most basic level, what burns in a fire are gases and vapors. Liquids, and especially solids, do not burn.

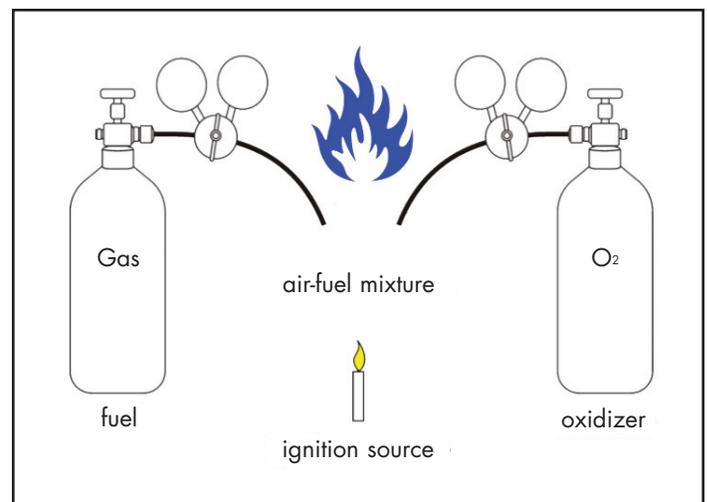


Figure 1. Fire is a series of complex chemical reactions that produce heat and light. Fire will occur only if heat, fuel and an oxidizer are present in the appropriate geometry in time and space. (The HazCom Training Program, NorthWest Occupational Health & Safety. North Vancouver, BC.)

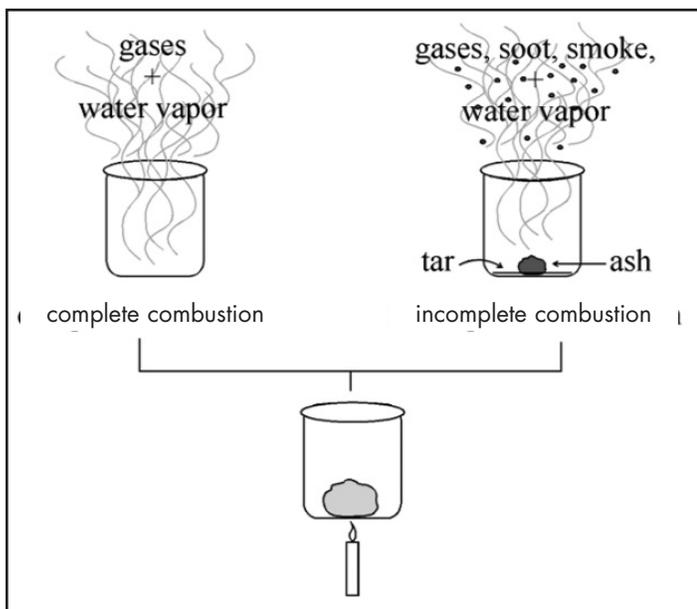


Figure 2. Combustion. Complete combustion produces only gases. Incomplete combustion produces gases, vapors, smoke and soot. (The HazCom Training Program, NorthWest Occupational Health & Safety, North Vancouver, BC.)

When we watch a fire consume logs in a fireplace, what we are observing is an overview of the breakdown of complex substances into small molecules that, in turn, break into the fragments that combine with oxygen (Figure 3). The process gives off heat and light and, if confined appropriately, remains self-sustaining so long as sufficient fuel is present.

This chemical event can be very romantic when it occurs in a fireplace. But when the fuel is the contents and structure of a building or when they become covered by ash and soot, the outcome is anything but romance and relaxation. Fire usually results in production of solid materials in the form of ash and soot. Ash contains the minerals left behind from the fuel. Soot is the partly burned solid that escapes from the containment of the fire.

So, the question then becomes: Exactly what does burn in a building fire? Almost all of the materials found in buildings and contents are composed of polymers, both natural and synthetic. Natural polymers include cellulose and protein. Products and materials containing cellulose include wood, paper, textiles and some plastics. Products and materials containing protein include meat, fur, skins, leathers, wool and silk.

Synthetic polymers comprise a huge list of substances including polyethylene, polypropylene, polyvinylchloride, nylon, rayon, plexiglass, polycarbonate, polytetrafluorethylene, polyester and polystyrene. These substances occur in all manner of plastics, textiles, structural materials and insulation, paints and coatings, and consumer goods. Note, the prefix "poly," which means many, appears in most of the names. This detail is important because most polymers contain one, two or three individual types of molecules attached end to end to form long chains. In some instances, the chains cross-link to each other.



Figure 3. Fire as observed in a fireplace, provides the overview of a complex chemical process: heat-induced decomposition of complex molecules into simpler molecules and fragments followed by reaction with oxygen. In building fires, the usual fuels are synthetic and naturally occurring polymers. Polymers are long chains of individual molecules that are joined end-to-end.

Synthetic polymers also contain plasticizers. Plasticizers are oil-like additives that impart properties of flexibility to otherwise brittle materials. The cells in closed-cell foams contain foaming agents. These agents expand the liquid to create the foam.

Polymers play an important role in building fires. Many polymers are poor fuel sources. The molecules are long and possibly cross-linked; they must be broken into small fragments in order to burn and this requires heat. Polymers often melt, forming a tarry mass rather than burning. Melting the material causes release of unreacted monomer, plasticizers and foaming agents, as well as production of decomposition products.

Decomposition products are molecules formed from the breakdown and sometimes reforming and rearrangement of

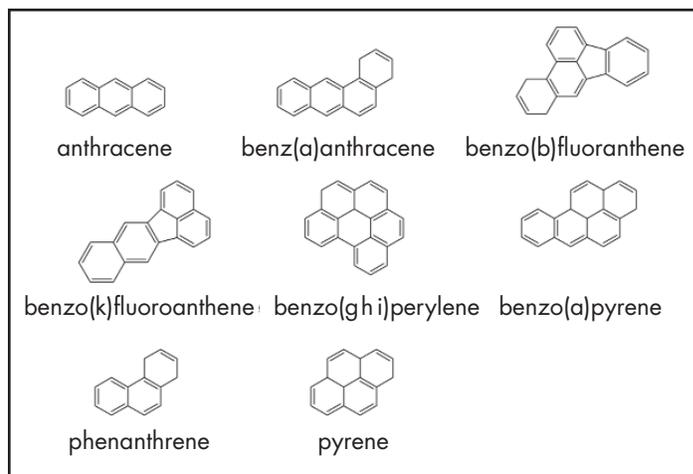
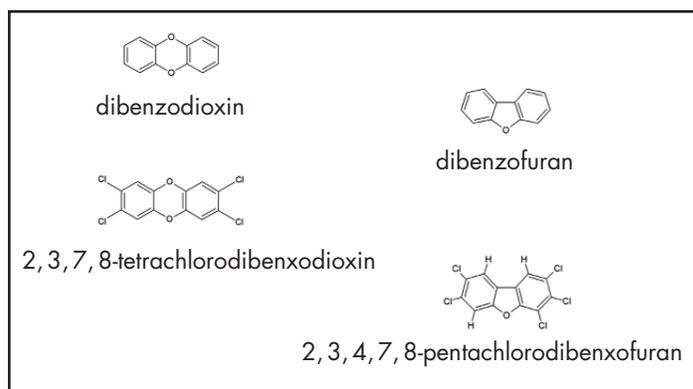


Figure 4. Polycyclic Aromatic Hydrocarbons. These structures show the organic chemists' abbreviations when drawing molecules. Carbon atoms form the rings. Each carbon atom has four covalent chemical bonds. Hydrogen atoms are present on the outside of the rings and are not shown. Each hydrogen atom forms one bond.

Figure 5. Dibenzofurans and dibenzodioxins. These complex ring structures also form during fires. Chlorine-substitutions for hydrogen atoms occur on the outer rings.



other molecules. These decomposition products can be simple molecules or complex ones, and they often have no obvious relationship to the substances from which they are formed. As a result, their production is difficult to predict and is usually determined in controlled lab experiments. But what occurs in a controlled experiment is not necessarily what occurs in a real-world fire situation.

Substances undergoing decomposition induced by heat form new substances. These can include complex ring structures where only simpler molecules existed. Two classes among these complex ring-structured molecules have important implications for building restoration. These include polycyclic aromatic hydrocarbons (PAHs) and chlorinated dibenzofurans and dibenzodioxins.

These substances are known to be formed wherever uncontrolled and partially controlled combustion occurs. Sources include incinerators, home fireplaces, crematoria, forest fires, cigarette smoke, gasoline and diesel engines, and building fires. (Formation of chlorinated dibenzofurans and dibenzodioxins also requires the presence of a source of chlorine.) These substances occur every-

where in the environment and, as illustrated, occur through naturally occurring processes.

To make these substances a little less intimidating, a brief lesson in organic chemistry might help. Carbon atoms always form four covalent chemical bonds with other atoms. Covalent chemical bonds involve the sharing of electrons in the space between the atoms. Each hydrogen atom can form one bond. Chlorine atoms can form several bonds, but one is found in organic molecules. Oxygen forms two covalent bonds, and nitrogen, three.

PAHs contain at least two six-membered, aromatic carbon rings (Figure 4). (The six-membered, aromatic carbon ring is the structure of the benzene molecule.) PAHs containing more than two rings are some of the suspected cancer-causing agents mentioned in connection with cigarette smoking and air pollution.

Chlorinated dibenzofurans and dibenzodioxins are well-recognized environmental contaminants (Figure 5). They too are universal in their distribution and form during fires of various types when a chlorine source is present. Chlorine sources include inorganic chloride, which is present in almost all living cells and



Figure 6. Debris resulting from a building fire. This material is a highly heterogeneous collection of contents, furnishings and furniture, and building material. Debris from building fires can contain soot, partly-burned particulate material to which PAHs are attached and possibly chlorinated dibenzofurans and dibenzodioxins. This debris also can contain asbestos-containing materials. The presence of asbestos-containing materials depends on the age of the building.

tissues, and plastics and chemical products containing chlorine. Hence, contrary to popular opinion, plastics and chemical products containing chlorine are not required for the formation of chlorinated dibenzofurans and dibenzodioxins to occur.

Investigating the production and occurrence of chlorinated dibenzofurans and dibenzodioxins requires considerable finesse and is very expensive. These substances normally are present only in picogram quantities (one billionth of a crystal of white sugar which weighs about two milligrams). Chlorinated dibenzofurans and dibenzodioxins are referenced to the most toxic substance in the group, 2,3,7,8-tetrachlorodibenzodioxin or TCDD.

PAHs and chlorinated dibenzofurans and dibenzodioxins are very heavy molecules. They stick tightly to particulate and solid materials in soot, smoke and char, and as a result are present in the air as free molecules in concentrations much lower than otherwise expected. They enter the body only through ingestion and inhalation of particles and do not readily dissolve in body fluids. They do not pass through the skin. These characteristics have major implications from the perspective of the personal hygiene and protection of restoration workers, and health concerns of building occupants regarding reoccupancy.

Soot particles are the source of emission of volatile compounds. They off-gas for a period of time following the cessation of burning. These substances include aldehydes such as formaldehyde, acetaldehyde and acrolein. They contribute to the “fire” odor and are highly irritating to the eyes and nose. Firefighters remove these substances during the initial purge of the building. Further ventilation using negative airmovers helps to reduce the level of particulates and these substances.

Building materials, structure and contents contain other hazardous materials. Principal among them is asbestos. Asbestos is present in many applications in older buildings including thermal insulation on piping, fireproofing, drywall mud and textured ceiling materials and flooring. Resins and other polymers usually bind the asbestos in place. Strong heating, as occurs in a fire, could convert nonfriable forms into the friable state. Friability refers to the ability to crumble the material to release the fiber into the air. The presence and range of applications of asbestos in a building depend on its age. Asbestos-containing material easily could be part of the debris created in a destructive fire.

Electrical switches, thermostats and fluorescent lights can contain mercury, albeit in small quantities. Destruction of these devices in a fire can lead to release of the mercury into the debris. At trauma scenes there is the risk of blood and sharps.

A Protection Strategy

Post-fire scenes are workplaces. Buildings do not demolish, clean, repair or rebuild themselves without human intervention. People other than firefighters work in the post-fire environment every day. The fire episode is not the end of the story for many buildings. Rather, it is an event in a much longer story.

Post-fire scenes pose a challenge to the protection of workers. The scene presents a highly heterogeneous situation often containing soot- and smoke-covered debris of unrecognizable origin and composition (Figure 6). The debris may be wet from use of hoses in fire suppression and firefighting. Walls and structures may be partially destroyed by the fire or by the use of demolition tools by firefighters.

The conditions of destruction that exist in these workplaces do not provide the comfort level for certainty and predictability preferred by health and safety practitioners. Yet, despite the seeming uncertainty, some things are predictable at the macro level, but perhaps not at the micro one.

In addition to putting out the fire in materials, wetting suppresses dust formation in materials that have suffered drying and degradation due to extreme heat. This would include asbestos in materials made friable by the heat.

In assessing how to protect restoration workers, the foremost questions are:

- What is or could be present?
- In what quantity?
- How could exposure occur?

Oxygen level and the level of carbon monoxide and other hazardous gases in a post-fire scene should be predictable and should be present at normally encountered levels. The fire service does not turn over the building until these levels have been achieved. Fire overhaul is the investigation performed by firefighters at the end of firefighting to ensure that all materials are extinguished. A study of this activity determined that there was little or no smoke, and that the concentration of gases and vapors decreased in the order aldehydes > CO > SO₂ > NO₂ > PAHs. As mentioned previously, aldehydes create the “odor” of fire.

Firefighters routinely use fans to purge smoke from buildings during and after firefighting. At the end of a fire, contaminant generation and oxygen consumption cease. (Left, however, for a prolonged period, other mechanisms such as biodecomposition then occur.) That is, the concentration of contaminants will trend downward toward zero and the oxygen level will trend upward to the normal level of 20.9 percent.

Oxygen and carbon monoxide can be easily checked using instruments routinely used for confined space entry. By the time workers other than firefighters enter, gases associated with fire should not be present and the oxygen level should be normal. The only volatile contaminants present are those that remain attached to the soot, which off-gases over a continuing period, causing a fire odor.

Building restoration companies routinely use differential pressure to control emissions from work zones into occupied areas. Negative pressure that draws air into the contained area provides a means to continue the purge initiated by the firefighters with discharge in a controlled manner. This purge will promote off-gassing of residual volatiles capable of forming vapor. This will reduce the concentration in the air at time of remediation.

These considerations indicate that the main concerns for which protection is required are aldehydes and other volatiles off-gassing from the soot and asbestos. Soot particles are oily and acidic (pH ≈ 4) and are readily trapped in the filters used in respirators. Large and heavy molecules, such as PAHs and chlorinated dibenzofurans and dibenzodioxins, adhere tightly to soot, as mentioned, and also to the activated charcoal used in respirator cartridges. Airborne soot particles and asbestos fibers in air are suppressible through use of mist or fogging equipment and amended water, and removed from the air by negative airmovers containing HEPA (High Efficiency Particulate Air) filtration.

Workers require skin protection to prevent contact with soot and other materials. Disposable suits made from Tyvek® or Kleenguard® or other impervious fabrics provide a means to prevent skin contact. Remediation workers routinely wear disposable suits of this type coupled with gloves and full-facepiece PAPRs (Powered Air Purifying Respirators) containing HEPA plus acid gas/organic vapor cartridges during asbestos work. The gloves and facepiece are routinely taped to the suit. This combi-



Figure 7. Suggested protective ensemble for restoration worker at a post fire scene. The combination of the disposable suit + PAPR (HEPA + acid gas/organic vapor cartridges) + gloves + safety footwear taped together forms a sealed unit. This ensemble is common to other remediation work including asbestos removal and bloodborne pathogens and must be selected and assembled with consideration given to ease of removal to prevent spread of contamination to underclothing and the skin.

nation creates a sealed unit. The fabric of the suit, the facepiece and the gloves are impervious to asbestos and soot (Figure 7).

Anytime a restorer enters a building after a fire, risk is involved. But when armed with a greater understanding about the complexities of this chemical event, workers can be better protected and then address pertinent issues more quickly. ■

Acknowledgement

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In addition to having written numerous articles and short publications, he is the author of Safety and Health in Confined Spaces, Portable Ventilation Systems Handbook, The Confined Space Training Program and coauthor of The Hazcom Training Program and The WHMIS Training Program. He also teaches courses on these subjects and courses on topics of specific interest to the restoration industry.