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Industrial hygiene method for assessing toxic contamination in smoke and fire-damaged homes

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ABSTRACT
This article presents a new, more efficient and accurate method for assessing fire and toxic smoke losses to structures, the risks associated with such, and the scope necessary to restore an affected property to its pre-fire loss condition. While the commonly utilized field practice of handling fires, using the S700 as a guide, has been to focus on visible damage and particulate accumulations, to test for the presence of soot, char, and ash (sometimes referred to as fire residue), and to attempt remediation and cleaning of the property. The method proposed herein is to test for microscopic particulates commonly produced by fire, including heavy metals, dioxins, and furans, to determine if toxic levels of identified particulates are present. When toxic levels are present, standard airflow and waterflow dynamics, as well as secondary contamination circulate the toxic particles throughout the property rendering the property effectively totaled as a result of the impracticality of alternative handling methods.

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Structure fire; airflow dynamics; water flow dynamics; particulate matter; dioxin; furan; heavy metals; restoration of smoke damaged homes to pre-loss condition

Introduction

Fires, in addition to the heat and flames, also commonly involve two other hazards: the smoke with particulates produced, and the water or fire retardants used to put out the blaze. Each hazard has related toxicity. While smoke may sometimes leave visible particulate deposits, and while water may leave visible stains and related damage, these damages are often hidden. Combustion-based particulates are microscopic and capable of saturating every crack, crevice, seam, and texture of a structure by either airflow or waterflow. The human eye can see about 40 microns and larger while combustion-based particulates range in size from 0.01 to 10 microns (Baron 2010; Franks 2013). Combustion particles that tend to be hazardous are those which are 2.5 or less microns in size. Nonvisible particulate matter presents a huge risk that often prevents a structure from being returned to a pre-loss condition in the event of a fire with toxic smoke.

If a fire produces toxic smoke, that smoke will have generally contaminated the entirety of the home, all of its contents, and the other structures in close proximity to the home, regardless of the visibility of said contamination. In nearly all cases, there won't be visible discoloration or staining in most contaminated areas and a visual inspection of the area of loss should not be the only criteria utilized in an investigation. Industrial hygiene tests and analysis are critical to determining if toxic species are present. The elements that make up toxic smoke include heavy metals, dioxins and furans all of which can be carcinogenic to humans (Medina 2016; Scott 2017; Scott and Scott 2019; Fent et al. 2020; Gonzalez and Domingo 2021). These species are typically the risk assessment drivers that determine repair or replace from an insurance perspective.

Similar to smoke, water may accumulate in certain areas and be obvious upon visual inspection or due to dampness. Liquids have the ability to travel *via* a variety of means, identified later in this analysis, and cause damage *via* contamination that is not immediately identifiable or anticipated. One example of this would be where water is sprayed on or around a fire, absorbing toxic particulates, and thereafter transporting the toxins in the water throughout the house *via* electrical conduits, HVAC ductworks, and by zigzagging down the home levels. Water will travel all surfaces until it reaches openings to move downward into the lower levels continuously until a blockage is reached. Blockages will cause the water to reroute and travel

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new paths until new openings are reached allowing the water to reach the lowest areas of the home. Water which may have originated on one side of a house can end up on the other side of the house and where toxins that might have had heavier concentrations near a fire initially can be redistributed *via* water flow to other areas of the home which were not directly adjacent to the fire. In addition to air and waterflow dynamics, toxins are also distributed *via* secondary contamination methods including primary and secondary firefighting efforts, searches for life and interior operations to detect and address hotspots. Water evaporation and condensation post fire as well as mold can also influence property damage and restoration strategies following a structure fire.

The current method commonly used for handling fire damaged structures is to visually observe or test for soot, char, and ash, smell for fire based odors, and to address fires as a repairable circumstances with little to no regard for individual particulate testing or the hazards that toxic post fire particulates present outside of the mandated testing for lead and asbestos (ANSI/IICRC S700 1st Edition 2025). The new method proposed herein is to test for a variety of commonly identified combustion byproduct particulates which include metals, dioxins, furans, asbestos, Polycyclic Aromatic Hydrocarbons (PAHs), Volatile Organic Compounds (VOCs), and to weigh test results against individual toxic thresholds of those particulates. Data from multiple structure fires will be presented as levels of various metals, dioxins and furans to be compared with exposure limits for each toxic species. The presence or absence of these toxins determines the correct path forward to returning the property to pre-loss condition. This toxic threshold chart is combined with the professional judgment of a toxicologist to review the particulate levels and determine potential toxicity.

If particulate levels are identified as toxic post fire, then the application of airflow and waterflow dynamics, as well as consideration of secondary contamination associated with nearly all firefighting methods, to understand that the toxic particles identified will be distributed throughout all of the structure and its materials. The proposed method concludes that the most efficient and effective handling method is to treat the property as a total loss, tearing it down and fully rebuilding it. Repair is cost effective if it is addressing a smaller part of a larger system/structure, but the particulates produced by fire contaminate and damage essentially 100% of the property with no long term, like kind and quality method of repair that guarantees a preloss condition can be achieved when sufficient levels of toxic particulates are present. These conditions make replacement the only cost-effective method to guarantee the property is restored to its preloss condition.

Materials and methods

The airflow method was compiled utilizing standards and data provided by the US EPA, NIOSH/CDC, various governmental studies (State of Utah, City of Surrey, Airnow.gov, Osti.gov, etc.), scientific journals/magazines/sites (science.org, purewatergazette.com, engineeringtoolbox.com), and field knowledge derived from HVAC/Insulation companies.

The waterflow method was compiled utilizing standards and data from the USGS, National Library of Medicine, online resources from building consultants such as Copeland Building Consultants, and common understanding of water movement through structures from the construction and mitigation fields.

The medical history of home occupants is relevant to the risk assessment on the home and the strategy for repair or replacement of the home and contents. Ages of all occupants should be known, and a general and specific health background should be recorded. Any changes in health that have occurred around the time of the fire or smoke damage should be investigated for proximity of the occupant to areas of known contamination. A temporal relationship should be outlined to show any possible causation of medical symptoms from exposure to the smoked out or burned areas of the home. Acute and chronic medical conditions that could be exacerbated by exposure to ash, soot, char, heavy metals, dioxins or furans need to be considered as part of the risk assessment. Allergies, asthma, respiratory disorders, metabolic disorders, autoimmune conditions, skin conditions, multiple chemical sensitivity, and both acute and chronic conditions that will be exacerbated from toxic exposure following a fire and restoration should be included and documented.

Industrial hygiene methods for heavy metals, dioxins and furans utilize EPA methodology following a vacuum sample collection procedure and evaluation of samples by qualified and certified operations. EPA approved methods for sampling and analysis which could include combinations of air samples, surface wipe samples, vacuum samples, and tape lift samples, are utilized. Each sample will have to be analyzed with the corresponding EPA approved methods for each sample type. In most cases, Industrial Hygiene samples will utilize multiple sampling techniques and multiple methods of analysis. The wipe samples for heavy metals are usually EPA 6000 series methods specific to the analytical equipment of the laboratory. Industrial hygiene methods for heavy metals, dioxins, and furans utilize EPA methodology following a vacuum sample collection procedure and evaluation of samples by qualified and certified operations. The sample collection utilizes a vacuum sample that pulls particulate matter from the chosen sampling point(s) in the property for a specific amount of time onto filter media that is then sent to the appropriate laboratory. This interval can be 30 s up to several minutes per sample spot depending upon the sample spot and condition of the property. Analysis consists of EPA method 6010 for heavy metals and EPA 8090 for dioxins and furans. Results are quantitated and reported as picograms analyte per gram of sample by the analytical lab running the methods from the EPA or NIOSH.

Exposure limits for heavy metals were found in the scientific literature and references were included in the tables. Occupational Safety and Health Administration (OSHA) and National Institute for Occupational Safety and Health (NIOSH) values are set for workplace exposure for common workplace hazards. The Derived No Effect Level (DNEL) value is calculated by dividing a Point of Departure (POD) (like a NOAEL or LOAEL) by Assessment Factors (AFs). The formula can be summarized as: DNEL = POD/(AF1 * AF2 * …), where AFs represent factors for interspecies variation, intraspecies variation, and exposure duration (Boogaard et al. 2012). The DNEL can be an oral or inhalation value that is directly comparable to contaminant levels in a fire damaged property. DNELs are very useful for quick determination of toxicity in any exposure setting.

Results

Many restoration companies will claim a post-loss property is clean following a crew that washes surfaces, vacuums visible debris and deodorizes a property. The claim does little to cover the many toxic species invisible to the eye that permeate the property with smoke, steam, water, and airflow. Figure 1 visually depicts the size difference of various structures and particles. Both combustion and dust particles can be 2.5 microns or less in size. Particulate matter at 2.5 microns or smaller is noted to be 'the greatest concern to public health from wildfire smoke' (EPA: Office of Air and Radiation 2003). The same source goes on to note that 'Particles from smoke tend to be very small, with a size range near the wavelength of visible light (0.4–0.7 microns)'. Lead dust is as small as 0.1–0.7 microns, and combustion-related particles are 0.01–2.5 microns (The Engineering ToolBox 2005). A second source, from the CDC, notes that combustion particles tend to start out as 0.01-.05 microns in size but clarifies that they agglomerate into large particles. That source shows a chart range, found in Figure 2 for combustion particles being from 0.01 to 10 microns in size (Baron 2010). It may be helpful to note that dioxins and asbestos dust are also as small as 0.1 microns in size (Utah Department of Environmental Quality 2023).

The primary manner of transmission of hazardous particulates throughout a structure is airflow. Figure 3 illustrates airflow in a dwelling. If there is a crack, gap, joint, vent, light, plug, window, door, chimney, or HVAC/Plumbing-related opening in a wall, air is flowing through it from the outside (US EPA 2024). The same source notes that fresh air will enter a house through wall levels as low as the basement, and warm air inside the house will transition upward. In other words, air from the outside of the house will flow throughout the entire house. The EPA clarifies that air doesn't just transition through outer walls and roofing, but that infiltration is a 'process by which outdoor air

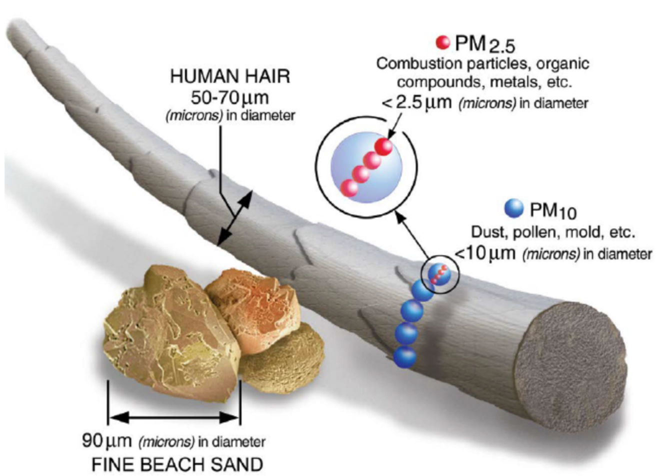

Figure 1. Visual representation of common structures versus toxic particle size. US EPA (2025).

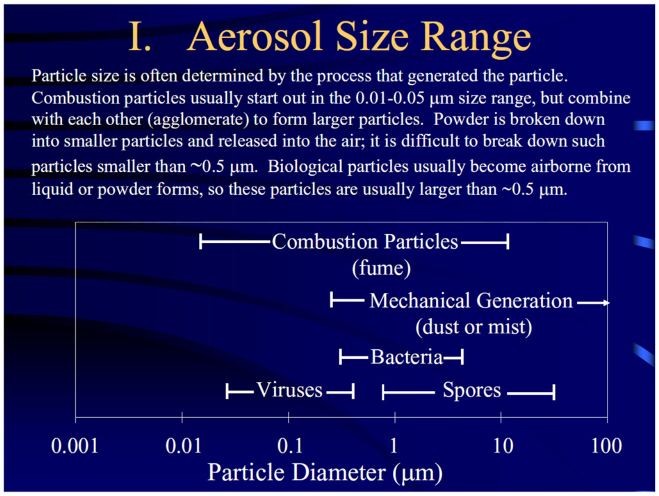

Figure 2. Aerosol size range. *Source*: CDC; Baron (2010).

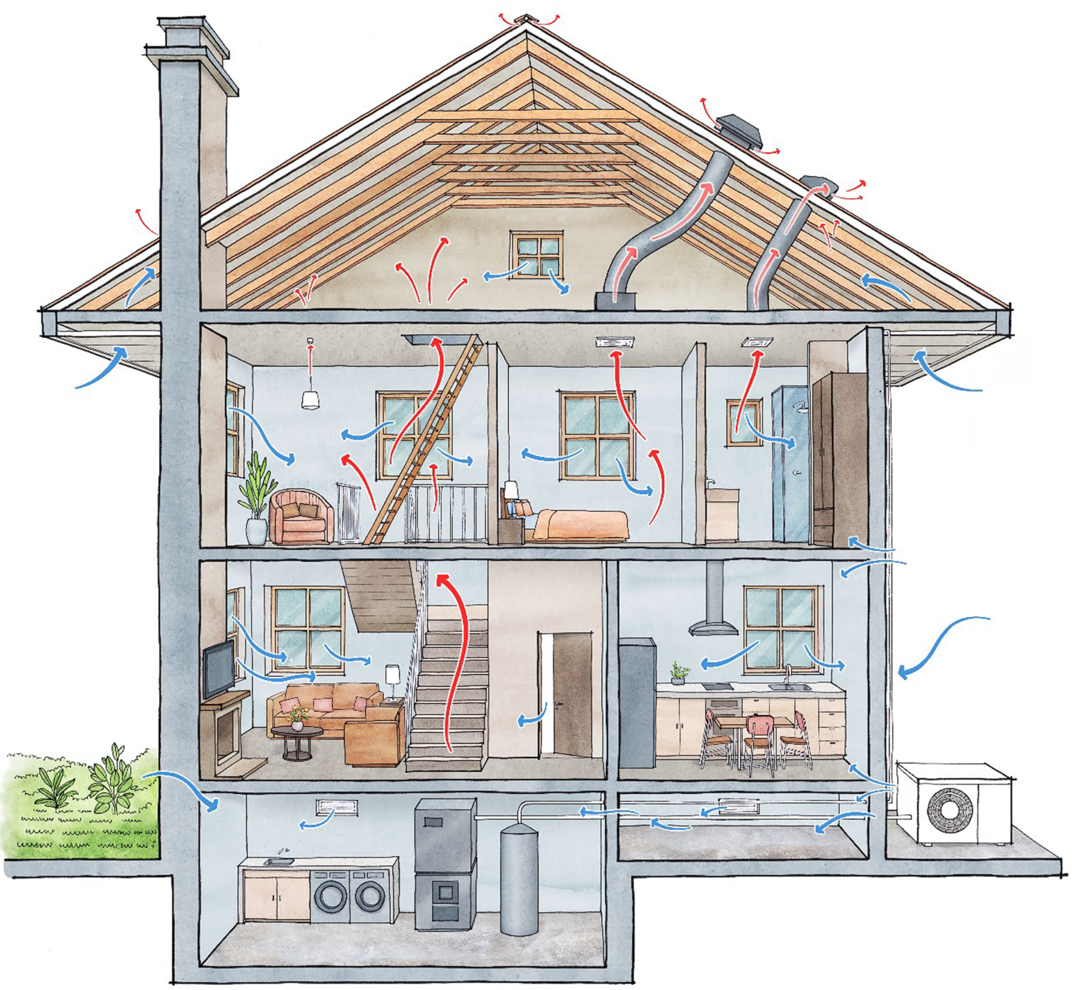

Figure 3. Airflow in a structure. This figure shows methods of fresh air (blue arrows) entry into a residential home and shows warming air (red arrows) moving upward into the attic and out the roof level. In particular, one may see fresh air entering the structure through soffit vents, around piping/spigots/external HVAC system ducts, through level transitions (seams/under & overhangs), though walls (siding/sheathing gaps/vents/exterior light fixtures/etc.), and through windows, and exterior doors. Air comes through openings and around the edges of the openings.

flows into the house through openings, joints and cracks in walls, floors and ceilings, and around windows and doors' (US EPA 2024). Said another way, air will move through every structural component of a house, including floors, ceilings, and interior walls. Why is this important? Because it logically follows that incomplete combustion byproducts, namely toxins, soot, char, and ash, can enter all the same places that air will flow, starting from outside the home as it is blown into and infiltrates the house with the assistance of any wind in the area. When there are other harmful particulates from hazardous materials that might be on the outside of the structure and which are damaged by fire/water/wind/or impacts, it also means that hazardous particulates will transition from the outside to the inside of the home *via* these airflow dynamics. When the hazardous particulates begin inside a structure or enter a structure from outside sources, we can also see how the particulates would flow throughout the structure (generally from bottom to top but not exclusively), and one can imagine how hazardous particulates which may have started in one small area of a structure would easily spread through the entire structure itself.

As a structure is heated by fire, it is only natural to understand that airflow would intensify throughout the structure. Even without the added assistance of fire, a home's structure is designed to facilitate fresh air entering from the outside with cooler air currents flowing downward and warming air currents flowing upward throughout the structure where it eventually collects in the attic and flows out of the structure through the roofing level vents and membranes. Figure 4 shows how air in the home will transition through light switches, plugs, ventilation, and vertical gaps in the walls as well. The figure further shows how outside air sweeps horizontally across floors as well, and this makes it reasonable to suggest that air that enters into a building would travel virtually everywhere within a house, inside and out. Additionally, buildings are designed to circulate air as depicted in Figure 5. Buildings have HVAC systems and ductworks that are very carefully installed so as to productively transfer air throughout a structure. Figure 5 diagram from Science Magazine helps visualize how outside air and pollutants enter through an HVAC system and distribute those pollutants through an office room, but the concept applies to all structures. While the diagram notations that speak on common pollutants are not addressing combustion-centric pollutants/hazardous particulate matter, those toxic particulates are generally equal to or much smaller than common pollutants and would toxify rooms in a similar manner.

Fresh air and outdoor pollutants/hazardous particulates enter through the ductworks, disperse themselves within the room and its surfaces where they are disturbed and transitioned through everyday movement and that pollutants and hazardous particulates are then recycled back through the air return. In most cases, there may be an air filter in the furnace, but common air filters found in HVAC systems are not HEPA filters which are designed to filter out most particles as small as combustion-related/hazardous particulate matter (Custom Comfort Air 2025). Further, even if a HEPA filter was present, these filters tend to quickly become overwhelmed by large quantities of smoke/particulates, which would then cause them to no longer work effectively (MontanaWildFireSmoke.org 2025). With purification processes of air flowing through ductworks quickly diminishing, more toxic particulates would remain unfiltered and would recirculate and spread throughout the already toxified, particulate laden building as a result (Bakies 2023). There are also typically gaps, screw holes, and seems in ductworks that also allow for toxin transmission *via* these systems despite the potential presence of HEPA filtration.

The second method of hazardous particulate matter transmission throughout a structure is waterflow. Water being sprayed onto burning materials, through smoke, or onto surfaces or water which travels through those areas indirectly will capture hazardous particulate matter and deposit them wherever water ends up. The dynamics of waterflow are generally simple and are illustrated in Figure 6. Water flows from higher locations to lower locations (i.e. if there is a leak on the top floor, the water from that leak will move downward toward the lowest floors). Water also diffuses from areas of high concentration to areas of low concentration (i.e. if there is a room filled with water but surrounding rooms have nearly no water, the water will generally diffuse from the filled room to the unfilled rooms) (Copeland and Rrc 2020). Water will absorb into permeable and porous materials. Finally, water will move *via* osmosis and capillary action and may be pulled horizontally or even vertically into smaller spaces where layers of flooring or wall material create tight channels and the opportunity for water pressure dynamics to occur (Water Science School 2018; Lopez and Hall 2023).

In addition to standard water flow dynamics, one must keep in mind that water evaporates as it warms and can then condense on surfaces which can cause dripping off of ceilings and water trails down walls, thereby creating further damage, degradation, and contamination as it continues to absorb and deposit hazardous particulate matter along with it. Finally, if

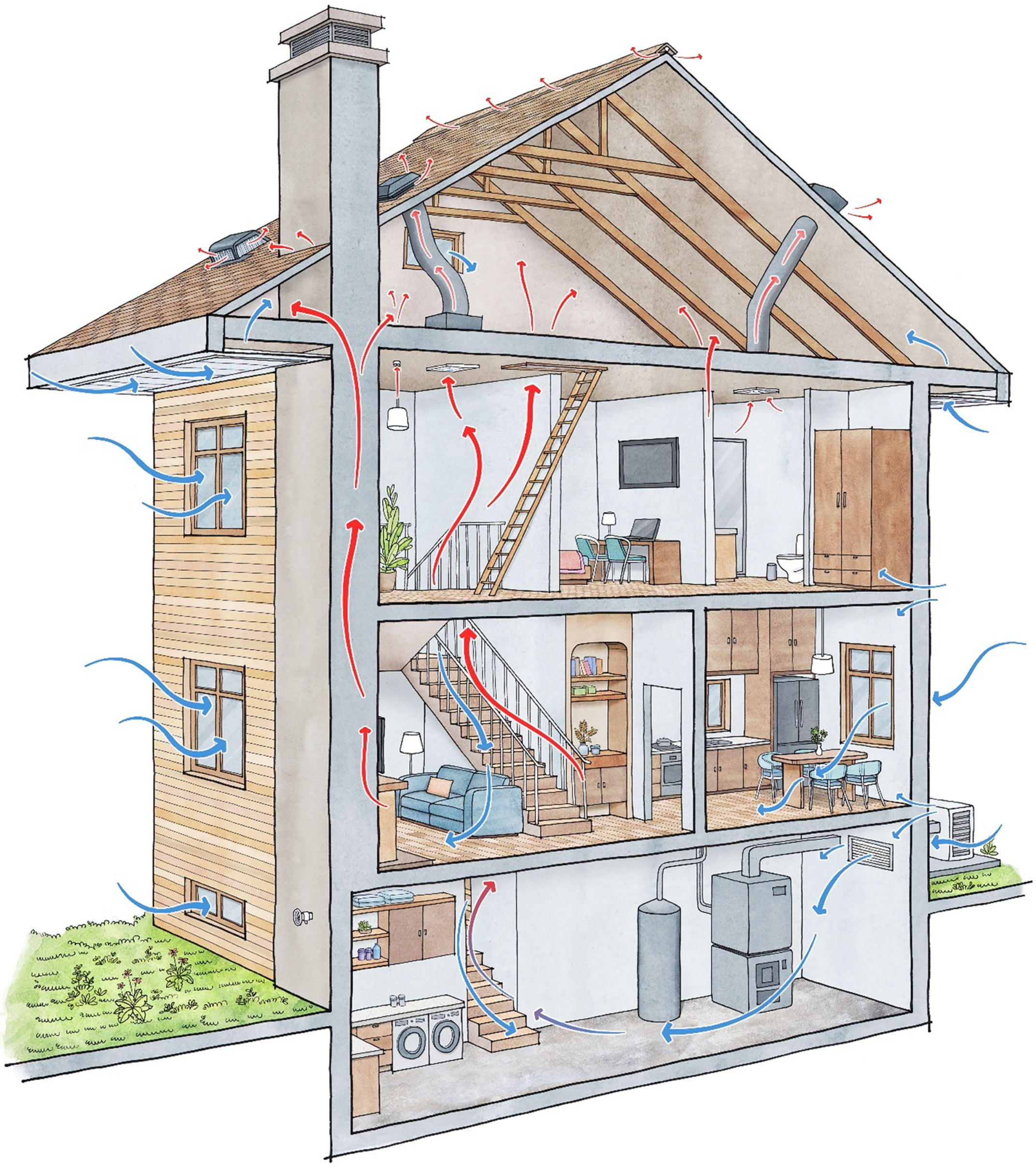

Figure 4. Warm airflow in a structure. This figure shows *cool* fresh air entering the building (show falling blue arrows). One can see that the cool air comes in as fresh air via standard pathways (windows, doors, openings, walls, vents, gaps, seams, fixtures, piping, etc.) and falls toward the floors while moving toward the lowest levels of the home. In addition to fresh cool air, some air inside the home may cool and move downward via walls/stairs or other gaps and openings. Cool fresh air entering the building is shown warming (red arrows) and moving upward via walls (often utilizing openings in walls and floors around ductworks/plumbing/conduits), vents/whole house fans/bathroom fans, chimney stacks or areas around the chimney, electrical fixtures (a light fixture in this case, but warm air will also enter walls through light switches and plugs, where it will then move toward the roof level), conduits and the spaces around them in the walls and floors), and the attic access. Once the hot air accumulates in or around the roof level/attic, it then exfiltrates via flashed openings through the roof (such as around chimneys, wall transitions, pipe jacks, furnace vents, turtle/box vents), through ridge vents, directly out through ducted openings (such as furnace ducts, whole house fan ducts, or bathroom fan/kitchen hood ducts). Some of the warmer air will also seep through the roof level via gaps in the sheathing or spaced decking and will flow through the roofing membranes (be it shingles, tile, wood shakes, or even low slope roofing membranes such as Thermoplastic Polyolefin or Ethylene Propylene Diene Monomer).

water is present in a structure from burst pipes (or water from a highly pressurized firehose), the water jets from the pressurized water source will erode wall/ceiling materials such as asbestos while also damaging lead paint that might be found on surfaces. As those materials are splattered or deposited in areas that then dry, they will also become airborne and flow throughout the structure more freely. These hazardous

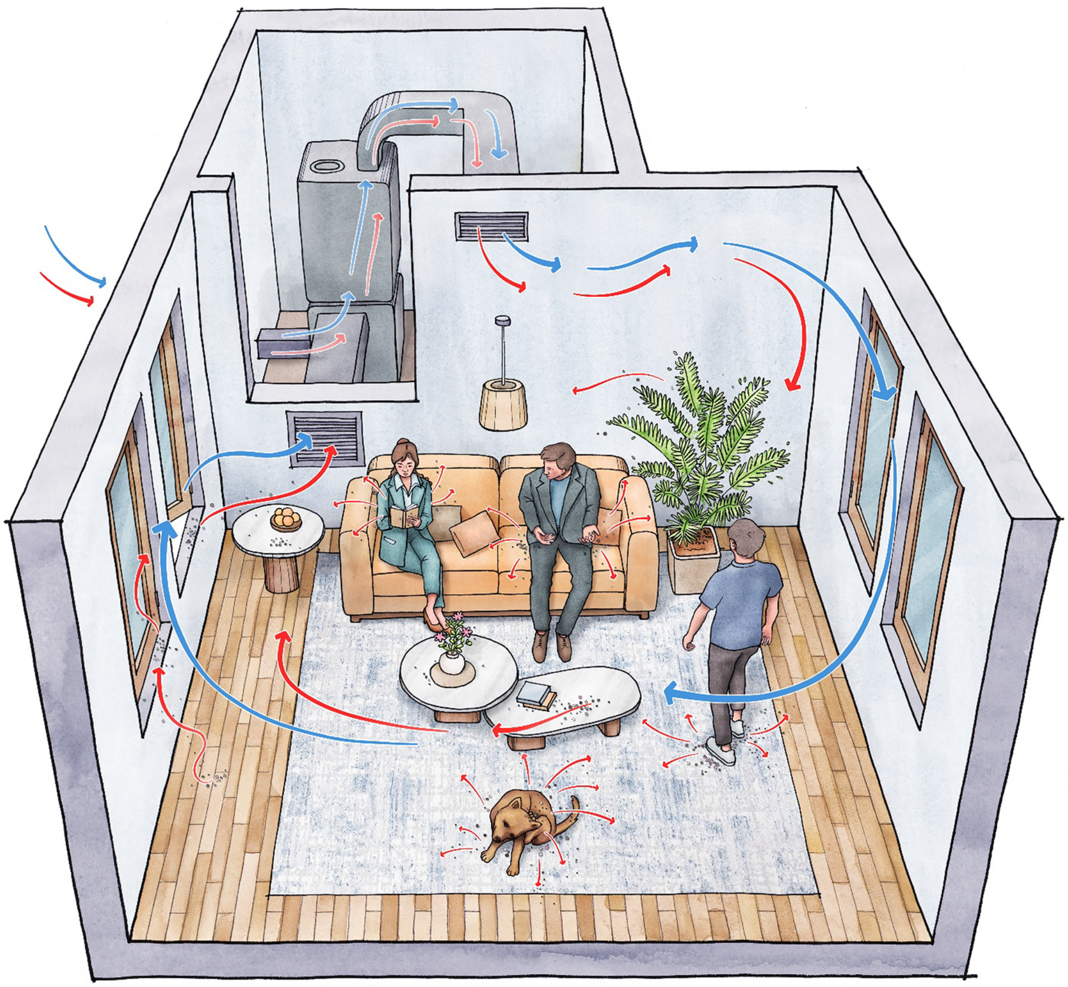

Figure 5. Recirculation of air in a structure. This figure shows outside air with contaminants (such as those produced by fires) pulled into a room via the furnace and HVAC system. Fresh air (shown as blue arrows) containing contaminants (represented by red arrows) enters via a furnace vent in the wall. The air and the contaminants circulate around the room and drop particulates on plants, furnishings, floors and windowsills before some of the air is eventually pulled back into the furnace via the air return vent. While some particulates remain aloft in the air, other particulates are deposited on surfaces, people, and pets, only to be disturbed by movement across the floors, scratching or shaking of furred animals, sitting on furniture, handling and moving objects (such as book), brushing up against plants, or opening windows or doors which would cause new air movement and send many settled contaminants aloft yet again.

particulates will not only be on the visible surfaces of a structure but will also drain into the walls and between levels which will not be able to be sealed off, meaning the particulate matter will contaminate the structure *via* its walls, ceilings, and floors.

If firefighting activities occur and water is being sprayed at a structure, that water will also absorb hazardous particulate matter that is in the air or on building surfaces and will actually force that particulate matter into the structure *via* the pressure of the water, which then causes contamination inside the structure wherever the water runs, finally causing secondary contamination as the water dries and the contaminants then move throughout the structure's walls, ceilings, floors, and rooms *via* airflow. It is not uncommon for mold or similar water-based biological hazards to spring up as a result of the water-laden nature of a given structure. As noted previously, water will also traverse exterior surfaces which have various fire-based byproducts and will absorb those often-toxic byproducts. The toxic water will then contaminate the structure as it saturates and transitions through the structure, depositing those toxins which will eventually dry and become airborne again (though some toxins may be absorbed within the materials themselves).

Common fire related toxic species are ash, soot and char. These toxic particles present a health risk from compounds of incomplete combustion known to contain polycyclic aromatic hydrocarbons (PAHs) and volatile organic compounds (VOCs) that have become

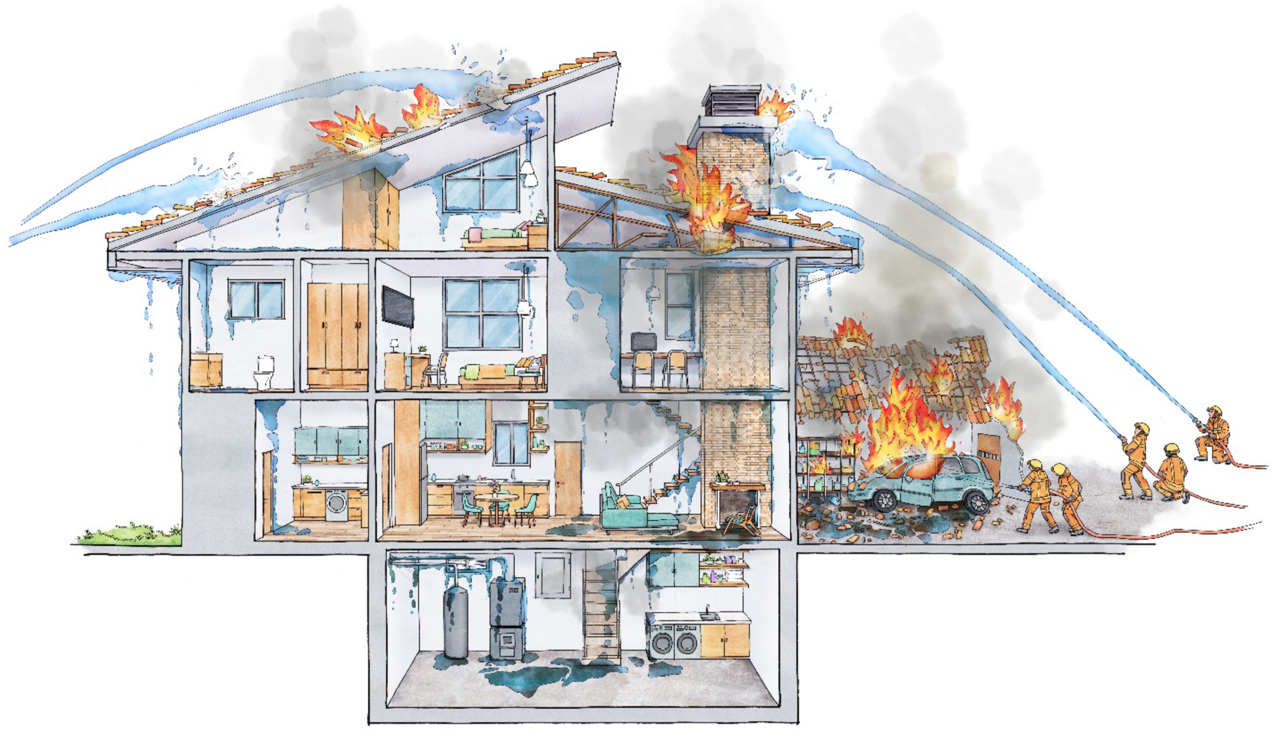

Figure 6. Waterflow in a structure. This Figure shows how waterflow can toxify a home. This home is on fire with firefighting efforts underway. The garage is ablaze with the vehicle and various shelved chemicals ignited. The upper roofing is also burning. Smoke and steam permeate the house and exterior while water is entering the building by being blasted at soffits (which often have vents that pressurized water can enter through), through rooftop openings (which may be holes burned through the roof or rooftop vents such as turtle/box vents, furnace vents, pipe jacks, whole house fan ducts, chimney flues), and any area with a gap or crack that pressurized water can access. Water is moving across surfaces that have been affected by toxic smoke (created by everything that burns including household chemicals, building components, and vehicles), and that water is becoming more and more toxic as it picks up contaminants found in the toxic smoke and deposited throughout the surfaces of the home's exterior and interior. The water transitions from the attic/roof level downward using wall and ceiling gaps, holes cut in ceiling and floors (typically for light fixtures, floor vents, ceiling fans, and related), via stairs, and via interior walls spaces (which tend to have a variety of holes and openings cut throughout them to facilitate ductworks, piping, and electrical lines). If the fire/smoke is toxic, this will result in the water entering the home being toxic from the very beginning and getting more and more dirty and contaminated as it moves downward through the home, zigzagging along the path of least resistance from the uppermost areas of the home to the lowermost areas and further toxifying everything wetted along the way.

adsorbed onto surfaces in the structure. House fire smoke is a veritable cocktail of products of incomplete combustion. Ash and char, the main components of fires, usually contain heavy metals, PAHs, and dioxins and furans (Medina 2016, Scott 2017). This particulate matter was created by incomplete combustion of materials in the structure. Dioxins are extremely toxic environmental pollutants known to science as persistent organic pollutants or (POPs). Dioxins, especially 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) has been called the most toxic man-made compound on Earth. Scientists say it is exceeded in toxicity only by radioactive waste. A characterization by the National Institute of Standards and Technology of cancer causing potential evaluated dioxin as over 10,000 times more potent than the next highest chemical (diethanol amine), half a million times more than arsenic and a million or more times greater than all others (Scott 2017).

The factor that drives the process of repair versus replace is potential toxicity to inhabitants. Toxicity is driven by dose and exposure to various fire byproducts and include heavy metals, dioxins and furans. Table 1 lists potential heavy metals found in a smoke damaged property an acceptable workplace exposure limit associated with those metals and a DNEL. The DNEL is the important exposure limit to compare to the actual values of heavy metals found in actual fires. The DNEL is the level of that chemical at which there should be no risk of adverse effects of exposure. This exposure limit is for exposure to just that single chemical and there are no provisions made for exposure to a mixture. Real world exposure to toxic chemicals can

Table 1. Potential metals -toxic species found in smoke, ash, soot, char and particulates.

Toxic metal	Exposure limit	Exposure limit	Reference
Cobalt[a]	0.1 mg/m^3 OSHA	DNEL General Population inhalation 8.1 μg/m^3	https://chem.echa.europa.eu/100.028.325/dossier-view/08bdffd9-57d4-4685-afd8-4956205ebc25/a8784087-d0c1-4109-811c-2ddef838ad1b_1e81eacd-da8e-46c7-a312-0ad9b5054098
Chromium	0.005 mg/m^3 OSHA	DNEL General Population Repeated Dose Toxicity 0.027 mg/m^3	https://chem.echa.europa.eu/100.028.324/dossier-view/d6d66265-7a8e-414c-af96-aeb34c3b078a/IUC5-70607c6e-8523-4c23-9132-00244241c512_2e5e06a1-3050-454d-a362-125fc3c00779?searchText=chromium
Cadmium	0.005 mg/m^3 OSHA	DNEL General Population Repeated Dose Toxicity 1 μg/kg bw/day	https://chem.echa.europa.eu/100.028.320/dossier-view/6ecb88d5-fa0d-432b-802c-97a9998bd681/27982e86-7e7a-490f-a000-fb4dce02f87d_63199495-977d-435d-9d68-69a2b084838c?searchText=cadmium
Silver	0.01 mg/m^3 OSHA	DNEL General Population inhalation 0.002 mg/m^3	https://chem.echa.europa.eu/100.028.301/dossier-view/b43d6b46-c045-45c9-9cff-f7f664e55bec/56b74590-cfcf-45cd-95b6-fd17d9ab7c5d_1bb13f1a-69ec-46a9-96cf-50f2310fc909?searchText=silver
Lead	0.05 mg/m^3 OSHA	DNELs Child 2 μg/dL Preg women 5 μg/dL Adults 20 μg/dL (blood levels)	https://chem.echa.europa.eu/100.028.273/dossier-view/c0464cff-4dfa-43ef-a4d3-e569a82803bf/8020ca43-4f4d-491d-93e7-24fb71b326df_cb5ea1e3-cfc2-451b-8772-946ab058121f?searchText=lead
Vanadium	0.05 mg/m^3 NIOSH	Rat oral repeat dose NOAEL 1000 mg/kg/day	https://chem.echa.europa.eu/100.028.337/dossier-view/ae11d0d0-78d9-465f-b8fe-92a5e1c88118/IUC5-96be1274-0d7d-44cc-a21a-d24fd48d4c43_5928507d-dbff-40ce-b071-607cb2406722?searchText=vanadium
Zinc	5 mg/m^3 OSHA	Rat NOAEC 1.48 mg/m^3	https://chem.echa.europa.eu/100.028.341/dossier-view/a2d9b11c-d84f-4f16-976e-57fb2d16463d/d3dbfe8d-29df-4047-bae7-35d291fdb315_e4bf1037-6718-4f93-8583-2c67b42dbcf7?searchText=zinc
Arsenic[a]	0.01 mg/m^3 OSHA	DNEL General Population inhalation 2 μg/m^3	https://chem.echa.europa.eu/100.028.316/dossier-view/104a4e33-e910-49c5-a114-50666e771ff8/d173c76a-df81-47c8-9578-02c1dae9b1d6_600b5ff6-8ed1-4037-8119-9fc661f0bd7b?searchText=arsenic
Copper	0.1 mg/m^3 OSHA	Acute short-term exposure LOAEC 1,240 mg/m^3	https://chem.echa.europa.eu/100.028.326/dossier-view/769a3561-67ad-491f-9696-f2addc049add/IUC5-132ec672-34bd-4a30-87d9-fcb990ae015d_50f830c2-19e3-4a12-ac36-5d2d9f515eaf?searchText=copper
Nickel	1 mg/m^3 OSHA	DNEL General Population inhalation 60 ng/m^3	https://chem.echa.europa.eu/100.028.283/dossier-view/4077cd76-ccb2-49ca-88fb-061e09fb6eff/aae27b55-6e16-49fb-966f-86c05b9f1076_da7e6236-8e36-40d9-bb16-52aa19176982?searchText=nickel

DNEL: derived no effect level; NOAEL: no observed adverse effect level; NOAEC: no observed adverse effect concentration; LOAEC: lowest observed adverse effect concentration.adenotes carcinogen.

Table 2. Potential dioxins and furans -toxic species found in smoke, ash, soot, char and particulates.

Analyte dioxin and furan species	Exposure limit	Reference
Total tetrachlorodibenzo-p-dioxins (TCDD)	Carcinogen – as low as possible to zero	
Total pentachlorodibenzo-p-dioxins (PCDD)	70 picogram/kg per month	WHO
Total hexachlorodibenzo-p-dioxins (HxCDD)	70 picogram/kg per month	WHO
Total heptachlorodibenzo-p-dioxins (HCDD)	70 picogram/kg per month	WHO
Total octochlorodibenzo-p-dioxins (OCDD)	70 picogram/kg per month	WHO
Total tetrachlorodibenzofurans (TCDF)	Carcinogen – as low as possible to zero	
Total pentachlorodibenzofurans (PCDF)	70 picogram/kg per month	WHO
Total hexachlorodibenzofurans (HxCDF)	70 picogram/kg per month	WHO
Total heptachlorodibenzofurans (HCDF)	70 picogram/kg per month	WHO
Total octochlorodibenzofurans (OCDF)	70 picogram/kg per month	WHO

The World Health Organization (WHO) has reported a provisional tolerable monthly intake (PTMI) for dioxins of 70 picogram/kg per month. This level is the amount of dioxins that can be ingested over a lifetime without detectable health effects.

be assumed to be exposure to a mixture of chemicals and not a single toxic chemical. Table 2 lists potential dioxins and furans found in a smoke damaged property. The heavy metals, dioxins and furans are found in the ash, soot and char that can be seen after a fire. The metals, dioxins and furans are all over in a fire or smoke damaged dwelling and cannot be seen with the naked eye. Industrial hygiene (IH) analysis of a dwelling has to go beyond ash, soot, and char to include a quantitative analysis of the heavy metals, dioxins and furans. These, as well as select metals, are the potentially carcinogenic species to humans and need to be in any analysis that will be used to determine decisions on loss management.

Case specific levels of heavy metals, dioxins and furans are dependent on the proximity of the wildfire or structure fire. Tables 3 and 4 show different levels of heavy metals per smoke or fire damaged house. Not every metal was detected in each fire case and to keep the comparability of the tables, nondetected (ND) results were left as placeholders in the tables. The trend, but not always the case, is that higher levels occur when the fire is in the house or nearer to the house than if there was just smoke inundation of the structure. Tables 5 and 6 show dioxin and furan levels per smoke or fire damaged house. The trend, but not always the case, is that higher levels occur when the fire is in the house or nearer to the house than if there was just smoke inundation of the structure. Each smoke or fire damaged case is unique and the IH sampling and analysis will show the data and extent of

Table 3. Shows different heavy metals levels per smoke damaged house.

	Case 1 mg/kg	Case 2 mg/kg	Case 3 mg/kg	Case 4 mg/kg	Case 5 mg/kg	Case 6 mg/kg	Case 7 mg/kg	Case 8 mg/kg	Case 9 mg/kg	Case 10 Mg/kg
Cobalt[a]	3.19	4.13	4.01	4.11	ND	4.16	1.95	4.18	ND	2.40
Chromium	14.3	17.7	48.1	21.1	17.9	13.4	9.6	22.6	1.83	10.7
Silver	ND	ND	ND	ND	70.1	ND	0.79	ND	ND	ND
Lead	8.82	24.2	12.0	13.9	29.8	62.3	10.5	16.9	0.616	20.2
Vanadium	9.17	18.3	56.0	14.5	5.92	19.2	7.88	13.3	ND	8.56
Zinc	299	439	2540	1100	6430	329	255	407	49.5	8260
Arsenic[a]	ND	7.57	7.63	2.86	5.43	5.44	1.98	6.04	ND	2.25
Copper	ND	118	342	47.6	1890	59.7	92.8	ND	ND	856
Nickel	ND	10.5	25.6	16.9	24.6	10.4	8.74	14.6	ND	5.82
Cadmium	ND	ND	1.43	ND	2.0	ND	ND	1.68	ND	ND

adenotes carcinogen.

Table 4. Shows different heavy metals levels per fire and smoke damaged house.

	Case 11 mg/kg	Case 12 mg/kg	Case 13 mg/kg
Cobalt[a]	0.299	ND	11.8
Chromium	1.58	ND	28.7
Silver	ND	ND	1.18
Lead	5.11	ND	36.5
Vanadium	0.577	ND	5.12
Zinc	30.3	ND	2070
Arsenic[a]	ND	ND	ND
Copper	3.98	ND	40.3
Nickel	0.682	ND	6.85
Cadmium	ND	ND	6.04

[a]denotes carcinogen.

toxic species that are at the site of loss. These data will drive the decisions for repair or replace based on the presence of toxic levels of metals, especially those known to be carcinogens, and more importantly, the levels of the dioxin and furan species detected at the property.

The World Health Organization (WHO) has reported a provisional tolerable monthly intake (PTMI) for dioxins of 70 picogram/kg per month (WHO 2019). This level is the amount of total dioxin species that can be ingested over a lifetime without detectable health effects. The level of 70 pg/kg per month calculates to 2.3 pg/kg/day and kids from 4 to 8 years old typically weight between 40 and 60 pounds. Using 30 pounds to stay on the conservative side, this would be 13.6 kg. Multiply the 2.3 pg/kg/day times the 13.6 kg equals 31.3 pg/day as a safe level of ingestion with no detectable health effects. These limits are extraordinarily conservative in nature by how they are set and the level in the home can be compared to this consumption limit set by WHO where nothing would happen over a lifetime, even if a child were to consume 100% of dioxin every day that they were in the house. These potentially toxic species associated with the particulate matter observed in the home can result in adverse health effects. All potential exposures including inhalation, ingestion and skin contact would contribute to this daily limit set by the WHO (2019). The total level of dioxins and the total level of furans is the important figure in the decision to repair or replace. The sum total of the five dioxins added together and compared to the WHO threshold limit before adverse effects are expected is the main point of decision for repair or replace. Dioxins and furans are the ultimate toxic species in fire and smoke damaged structures and contain multiple known human carcinogens. All species of dioxins and furans share a mechanism of toxicity, and all species have potential to be human carcinogens. Science has proven that TCDD and TCDF are human carcinogens. In time, science will likely prove that the remains species are also human carcinogens. This WHO limit is limit is for exposure to just that single chemical and there are no provisions made for exposure to a mixture. Real world exposure to toxic chemicals can be assumed to be exposure to a mixture of chemicals and not a single toxic chemical. Adding the dioxin and furan species to get a total dioxin or furan exposure provides a more realistic approach as all the species are considered. Keep in mind there are other hazards in this toxic mixture that occupants are exposed to daily.

Discussion

Contaminants from combustion and related hazardous materials are very small. This means that those contaminants can reasonably be anticipated to be carried through the air during a fire, to be pulled into the various gaps and openings in a house, and to be able to flow through any and all internal spaces within a house because there is effectively no gap, cut, groove, hole, joint, and so on which would be too small for said particles to flow through. Remember that if the human eye can see a gap, it has to be at least 40 microns or larger, and hazardous particulate matter/ combustion-based particulates are as small as 0.01 microns in size, which means that visible gap is typically hundreds of times larger than required for hazardous particulates to freely move through it (Franks 2013). Since air circulates throughout the entirety of a

Table 5. Shows dioxin and furan levels per smoke damaged house.

	Case 1 pg/g	Case 2 pg/g	Case 3 pg/g	Case 4 pg/g	Case 5 pg/g	Case 6 pg/g	Case 7 pg/g	Case 8 pg/g	Case 9 pg/g	Case 10 pg/g
TCDD	ND	ND	ND	ND	1.73	17.1	ND	ND	4.60	1.87
PCDD	ND	ND	ND	ND	ND	14.7	9.53	ND	5.59	ND
HxCDD	ND	1.77	ND	ND	19.1	23.6	ND	2.27	1.31	ND
HCDD	ND	26.6	ND	7.12	34.8	46.6	9.60	23.0	5.24	34.2
OCDD	14.3	149	ND	31.0	214.0	115	81.4	106	46.9	189
TCDF	ND	ND	ND	ND	ND	145.8	ND	1.02	29.1	ND
PCDF	ND	0.214	ND	ND	ND	34.9	ND	ND	ND	ND
HxCDF	ND	1.64	ND	ND	3.5	30.3	ND	1.15	ND	1.62
HCDF	ND	9.50	ND	ND	8.71	32.4	ND	6.22	ND	8.79
OCDF	ND	10.4	ND	ND	8.99	18.6	ND	6.23	ND	7.99

Table 6. Shows dioxin and furan levels per fire and smoke damaged house.

	Case 1 pg/g	Case 2 pg/g	Case 3 pg/g
TCDD	ND	ND	7.0
PCDD	ND	ND	14.5
HxCDD	0.270	ND	37.2
HCDD	ND	762	70.4
OCDD	ND	ND	146
TCDF	0.246	ND	1340
PCDF	ND	ND	464
HxCDF	0.183	ND	151
HCDF	ND	774	31.0
OCDF	ND	ND	7.76

structure, that would mean that hazardous particulates/contaminants would circulate and be deposited throughout the entirety of a structure.

Particles are carried by airflow throughout a structure during a fire. We can also see that without the added assistance of fire-related, increase airflows, a home's structure itself is designed to facilitate fresh air entering from the outside with cooler air currents moving toward lower levels and warmer air currents flowing upward through the structure until hot air generally accumulates at the roofing level and exfiltrates *via* roof level vents and membranes. The bottom line is that most structures are made to move air through them, and this is only intensified with heat. Toxic particulates, heavy metals, dioxins, furans, and so on, are carried *via* common structural airflow dynamic throughout buildings. In the case of toxic contamination, it is often fiscally or effectively impractical to remediate losses and there can be no reasonable guarantee that a pre-loss condition can be achieved for the building owner.

It is also important to understand that structures have intervening components such as ductworks, electrical wires or conduits, floors, vents, supports, cracks, fixtures, piping, and multiple layers of sheathing/flooring/wall materials. These sorts of components and their configurations allow air and water to alter course or may block water, forcing it to pool in some areas while flowing more freely in others. The gist is that water doesn't just flow in straight lines through a building, it tends to zigzag its way from top to bottom. The harder the wall and ceiling materials are, the more likely water is to not permeate through it, and the water will be forced to pool and divert as it moves throughout the structure. As an example, ceilings covered in just drywall are likely to get saturated and have the water breach through the ceiling's seam tape or the ceiling drywall may collapse under the water weight, thereby creating a more streamlined water flow path. In a structure where the ceilings are plaster, the plaster will tend to hold water for prolonged periods and cause it to divert throughout the structure first before eventually weakening, cracking, and crumbling, resulting in more direct water flow paths.

Dioxins are extremely toxic environmental pollutants known to science as persistent organic pollutants or (POPs). Dioxins, especially 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) has been called the most toxic man-made compound on Earth Scientists say it is exceeded in toxicity only by radioactive waste. A characterization by the National Institute of Standards and Technology of cancer causing potential evaluated dioxin as over 10,000 times more potent than the next highest chemical (diethanol amine), half a million times more than arsenic and a million or more times greater than all others (Medina 2016; Scott 2017).

Burning of waste materials, such as in backyard burn barrels, creates higher levels of dioxins than industrial incinerators and is particularly dangerous because it releases pollutants at ground level where they are more readily inhaled or incorporated into the food chain. In comparison, the sheer volume of household products and building materials that combust in a typical structure fire can produce the equivalent of literally hundreds or even thousands of burn barrels (Scott 2017). Dioxins are formed when products containing carbon and chlorine are burned, such as plastics containing polyvinyl chloride. Even very small amounts of chlorine can produce dioxins. During a structure fire, dioxins attach themselves to particles of soot and dust, where they spread efficiently into the air as the hot gases rise. When a fire is extinguished, and the air begins to cool, the dioxin-laden particles settle and become part of the soot, ash, and particulate matter. Burning 1 kilogram of wood can produce as much as 160 micrograms of total dioxins (Scott 2017).

Short-term exposure of humans to high levels of dioxins may result in skin lesions, such as chloracne, patchy darkening of the skin, and altered liver function. Long-term exposure is linked to impairment of the immune system, the developing nervous system, the endocrine system and reproductive functions. Other adverse health effects may include cardiovascular disease, diabetes, cancer, porphyria, endometriosis, early menopause, reduced testosterone and thyroid hormones, altered immunologic response, skin, tooth, and nail abnormalities, altered growth factor signaling, and altered metabolism (Scott 2017).

Dioxin, even in picograms (parts per trillion) is associated with severe health damage that can shorten the lives of people exposed to it, and potentially that of their offspring and future generations. Dioxin is chemically stable and retained in human fatty tissue, where it alters the complex cellular and chemical balances involved in bodily functioning and reproductive processes. The genetic effects may skip a generation and reappear in third or subsequent generations. Diseases which have been linked to dioxin seem endless. Ingesting dioxin can also result in congenital malformations, spontaneous abortions, and a slow wasting syndrome followed by death similar to the AIDS syndrome. Dioxin is strongly suspected of contributing to pathology of the urinary and hematological systems, growths in the colon, gall bladder complications, multiple myeloma, and lung, larynx and prostate cancer (Scott 2017).

IH analysis will fall short and incomplete data sets will be used to base loss decisions on and force families back into toxic environments. Bad plans of analysis, not enough samples, wrong sampling techniques and manipulation of how the samples are collected in an effort to 'miss' the contamination and make a bad assessment that a dwelling is safe for occupancy are commonly encountered after fires. Every situation is different with the health history of the occupying family and the proximity of the fire to the dwelling (smoke damage but not destroyed) and the levels of the heavy metals, dioxins and furans in the dwelling.

How clean is clean? There is an issue with what to use as an appropriate background for baseline contamination of dwellings based on the area of the catastrophic event. How this scientific concept is handled will affect every case as the background is potentially different for each site of a loss. Cancer theories will also weigh into the equation. The two theories for carcinogenesis include the one hit theory and the threshold theory. The one hit theory is based on the potential for a tumor to arise after one exposure to one carcinogen and is the most conservative theory to adhere to when picking levels for clean following any type of chemical exposure event. Threshold theory states that the body can endure exposure to some carcinogens up to a certain level or concentration before there are irreversible biological events that then set the path toward tumors in the exposed individual. In addition to these two leading theories for carcinogenesis, the concept of voluntary verses involuntary risk comes into play. The distinguishing factor between these two types of risk is whether or not a person chooses to accept the risk of whatever exposure scenario is at hand. Smoking, drinking, illicit drug use and even eating poorly are all voluntary risks. Occupational or environmental exposure to toxins is involuntary in that someone else is making the decision that a person has to endure some exposure.

While repair is often considered with many forms of losses, fires which produce toxic byproducts tend to render this approach moot. Research utilizing Xactimate, a fair market valuation system, shows that the cost of repairing a roof is between 284% and 643% more expensive per shingle than replacement per shingle. In essence, when 30% or more of a structure's square footage is being repaired, there is a significant and increasing likelihood that replacement of the property would be a less expensive method to apply. In the event that equal to or more than 50% of a structure's square footage is being repaired, it will essentially always be less expensive to replace the property (for standard structures) than it would be to repair the property. Yet, structures affected by toxic smoke are typically 100% saturated by the toxins as a result of the air and water flow dynamics for said structures. This means that effectively 100% of the structure would need to be repaired. As repair per square foot is essentially always more expensive than replacement, the only practical method for handling toxified standard structures similar to single family homes and structures equal to or under 25,000 square feet of floor space would be to tear down and replace those structures in totality.

It should be understood that there are unique property circumstances which may not cause a fire with toxic smoke to fully saturate the structure due to the size or the uniqueness of the building's construction (separate utility systems/fire barriers/hermetically sealed areas). Examples of structures that may fall under unique property circumstances include, but are not limited to, buildings with greater than 25,000 square feet of floor space, very high value properties, track homes, condos, skyscrapers, hospitals, laboratories, or similar structures. Even with unique property circumstances where not 100% of the structure is laden with toxic smoke, it may still be fiscally impractical to conduct repairs, and, even if it is fiscally practical, there is also the risk that toxins are missed in the repair/remediation process, which then re-contaminates freshly repaired areas.

Methods such as 'encapsulation' where a sealant is applied to all surfaces that are thought to be affected by toxins as a means of keeping said toxins trapped beneath the sealed surface are largely ineffective (surface imperfections or inaccessible locations prevent proper application in the first place), degrade over time (seasonal thermal expansion and contraction, and compressive forces of humans moving throughout the structure flex the sealant membrane in vulnerable areas like a paperclip that will initially bend but will eventually break while environmental and aging based effects weaken the membrane material itself), and do not remove toxins but instead localize those toxins to be an issue for future construction with the property or for future inhabitants.

With dioxins, the only way to remediate the presence of these species is to remove them physically from the site, property, structure or site of loss and incinerate them at very high temperatures. There is currently no acceptable method to 'clean' or 'encapsulate' dioxins at a site of loss (Scott 2017).

The dwelling after a fire or smoke inundation that contaminates the structure with measurable toxic species is a serious exposure situation for the occupants. This is due to the occupants being exposed to a mixture rather than to a single toxic agent. Each toxic species will have an adverse effect on the cells and cause a depletion in cellular defenses. When there are multiple toxic species, consumption of cellular defenses occurs more rapidly. When cellular defenses are depleted, exposure results in mutations, enzyme inactivation, unrepaired damage to genetic materials, irritation, inflammation and eventually cancer. There is no known safe level of exposure to known carcinogens and all exposure should be eliminated or minimized to remove or reduce potential risk, respectively. A person's home should not be the reason for developing health issues in the near or long term. If proper IH analysis is conducted to gauge the true contamination level of toxins, proper decisions can be made regarding the path of remediation or replacement in these smoke damaged residences.

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