UNDERWRITERS LABORATORIES INC.

UL 200C

GUIDANCE DOCUMENT

Guidance and Practical Strategies for Reducing Public Health Impacts of Wildland-Urban Interface (WUI) Fires on Community Populations

Guidance and Practical Strategies for Reducing Public Health Impacts of Wildland-Urban Interface (WUI) Fires on Community Populations, UL 200C

First Edition, Dated October 14, 2024

SUMMARY OF TOPICS

This guideline publication of UL 200C dated October 14, 2024 provides a resource to communities on Wildland-Urban Interface (WUI) fire hazards – outlining practical strategies to protect communities and reduce health risks before, during, and after a wildfire.

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First Edition

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These guidelines (The Guide) provides a resource to communities on Wildland-Urban Interface (WUI) fire hazards – outlining practical strategies to protect communities and reduce health risks before, during, and after a wildfire.

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About the Task Force

Wildfires in the United States (U.S.) are becoming larger, more frequent, and more destructive. Many of these fires occur at the WUI. Current knowledge on the WUI is limited and future research is needed to understand better the impact of wildland fuels, nearby structures, and system-wide factors on fire spread as well as on human health. Research shows that steps can be taken to mitigate these consequences and allow inhabitants to better prepare for fire events with fewer impacts on human health.

To address these issues and provide a resource for public health professionals, an expert group of volunteers was convened by Chemical Insights Research Institute (CIRI). This group is known as the CIRI Protecting Community Health Task Force. The Task Force consists of a wide range of professionals spanning from chemical/water exposure experts, fire experts, federal/state government officials, health experts, insurance and built environment professionals from a variety of organizations and academic universities in the U.S. One member of the Task Force survived the Marshall Fire in December 2021 and inspired the creation of this Guidance Document.

The following volunteers are acknowledged for their participation in the discussions, collaborations, and material reviews involved in the creation of this guidance document.

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PURPOSE OF THE GUIDANCE DOCUMENT

The purpose of this Task Force is to provide a resource to communities on Wildland-Urban Interface (WUI) fire hazards – outlining practical strategies to protect communities and reduce health risks before, during, and after a wildfire.

AUDIENCE FOR THE GUIDANCE DOCUMENT

The audience for the Guidance Document is primarily public health professionals and community organizations at national, state, and local levels. These professionals offer a variety of education and outreach vehicles to provide this valuable resource to the secondary audiences of community populations, particularly those who have health vulnerabilities.

KEY DEFINITIONS

Acute Exposure is contact with a substance that occurs once or for only a short time (up to 14 days).[1]

Air Quality Index (AQI) is the U.S. Environmental Protection Agency's (EPA's) index for reporting outdoor air quality. The EPA focuses on five major air pollutants that include ground-level ozone, particle pollution, carbon monoxide, sulfur dioxide, and nitrogen dioxide. The pollutant with the highest AQI determines the overall AQI for the specified time. Using this data for a specific location, the AQI defines air quality based on values of the index using six categories – good, moderate, unhealthy for sensitive groups, unhealthy, very unhealthy, and hazardous.[2]

Biomass is organic material derived from plants or animals.[3]

Clean Air Delivery Rate (CADR) is the measure of how much filtered (cleaned) air an air cleaner can deliver. CADR is measured in cubic feet per minute (cfm). The higher the CADR, the cleaner air the system can produce.[4]

Chronic exposure is the continuous or repeated contact with a toxic substance over a long period of time (months or years).[3]

Defensible area or defensible space is the space between the house or building and potential wildfire fuels to protect the building from ignition during a wildfire or WUI event.

Emissions are species emitted from a process into the air, water, soil, or other media, e.g., carbon dioxide is a common emission from a forest fire.[3]

Fire plume is the stream of heated air and combustion products, such as carbon dioxide, carbon monoxide, sulfur dioxide, nitrogen oxides, lead, and particulate matter, rising above the fire. Plumes may extend for many miles from the fire source.

Fuel breaks are strips of land on which the vegetation and fuels have been reduced or modified to decrease the risk of a fire crossing the strip of land.

High-Efficiency Particulate Air (HEPA) Filters are a type of air filter commonly used in commercially available stand-alone air cleaners. To be rated as HEPA, a filter must have a removal efficiency of at least 99.97 percent of dust, pollen, mold, bacteria, and any airborne particles with a size of 0.3 microns (µm).[4]

Ionization is the process by which an atom or a molecule acquires a negative or positive charge by gaining or losing electrons, often in conjunction with other chemical changes. An example of gas ionization is when ionization occurs within a fluorescent lamp or other electrical discharge lamps.

Minimum Efficiency Reporting Value (MERV) is the industry standard measurement of a heating, ventilation, and air conditioning (HVAC) filter's ability to capture particles. The higher the MERV rating, the better the filter is at capturing smaller particles. To effectively capture wildfire smoke particle emissions, look for filters rated MERV 13.[4,5]

Photoelectric is the emission of electrons from a material caused by electromagnetic radiation, such as ultraviolet light.

Particulate Matter (PM) is a mixture of solid particles and liquid droplets found in the air. Some particles, such as dust, dirt, soot, or smoke, are large enough to be seen with the naked eye. Others are so small they can only be detected using an electron microscope. Two sizes of concern are **PM_{10}** and **$PM_{2.5}$**: inhalable particles with diameters that are generally 10 microns and smaller; and fine inhalable particles with diameters that are generally 2.5 microns and smaller, respectively.[6]

Pollutants are chemicals or biological substances that harms water, air, or land quality.[3]

Respirators are worn over the mouth and nose to protect users. There are two types of respirators. One type of respirator supplies clean respirable air from another source. The other type of respirator includes those that filter out airborne particles and "gas masks," which filter out chemicals and gases.[7]

Social vulnerability refers to the potential negative effects on communities caused by external stresses on human health. Such stresses include natural or human-caused disasters, or disease outbreaks. Reducing social vulnerability can decrease both human suffering and economic loss.[8]

Structure fires are fires involving the structural components of buildings, such as residential, commercial, industrial, and institutional buildings. Structure fires are serious and potentially devastating occurrences that can have a significant impact on both property and human life.[9]

Semi-Volatile Organic Compounds (SVOCs) are organic compounds that tend to have a higher molecular weight and boiling point that volatile organic compounds (VOCs). SVOCs are more likely to be liquid or solid at lower temperatures. These chemicals are found in pesticides, oil-based products, and fire retardants. Potential health effects include eye, nose, and throat irritation, organ damage, and cancers, such as leukemia and lymphoma.[10] Examples include flame retardants and phthalates.

Toxic refers to harmful effects on the body by either breathing (inhalation), eating (ingestion), or skin (dermal) absorption of the chemical.[3]

Toxicants are any chemicals that can injure or kill humans, animals, or plants (i.e., poisons).[3]

Urban fires are fires that occur primarily in cities or town with the potential to rapidly spread through adjoining structures, damaging and destroying homes, schools, commercial or industrial buildings, and vehicles.[3]

Volatile Organic Compounds (VOCs) are chemical compounds that have a high vapor pressure and low water solubility, emitted as gases from certain solids or liquids. VOCs include a variety of chemicals, some of which may have short- and long-term adverse health effects.[11] Examples include benzene and formaldehyde.

Vulnerable populations are a group of individuals or communities at higher risk of adverse health effects from exposures – for instance, from greater pollutant exposure concentrations, higher health response to a given level of exposure, or reduced capacity to adapt.[3]

Wildfires are uncontrolled fires in an area of combustible vegetation that occur in the countryside or a wilderness area. Other descriptions of fires address types of vegetation, such as a brush fire, bushfire, forest fire, desert file, grass fire, hill fire, peat fire, and vegetation fire.[12]

Wildland fire is any non-structure fire that occurs in vegetation or natural fuels; it includes wildfires and prescribed fires.[3]

Wildland Urban Interface (WUI) is the zone of transition between unoccupied land and human development. It is the line, area, or zone where structures and other human development meet or intermingle with undeveloped wildland or vegetative fuels.[13]

WUI fire is a fire that breaches the WUI between unoccupied land and human development. WUI fires are different from wildfires or structure fires because it is the combination of those two types of fires that creates a different chemical profile than either the wildfire or structure fire.

AN OVERVIEW OF THE WUI AND HEALTH RISKS

Over the past 30 years, the WUI has grown rapidly across the U.S., putting more than 32 percent of all housing nationwide at risk. An estimated 70,000 communities and 45 million (M) residential buildings, valued at approximately $1.3 trillion (T), are at risk of destruction caused by wildfires.

Beyond economic impacts, WUI fires pose significant health risks. The combustion of structures releases harmful chemical and particle contaminants into the air, water, and ecosystem. Materials from the built environment, such as plastics, insulations, treatment chemicals, and electronics, burn to produce toxicants that pose acute and long-term human health risks through inhalation, ingestion, and skin absorption. These pollutants have the potential to infiltrate the human respiratory and circulatory systems and contribute to significant health risks that can include heart attacks, strokes, hypertension, asthma exacerbation, and even death. Smoke and ash resulting from WUI fires also can provoke eye inflammation, dermal irritation, redness, and discomfort, with exposures potentially leading to more severe ocular conditions. Less is known about the long-term health risks, but indicators of concern include chronic impairment of lung function and increased cancer vulnerability.

Exposure routes for contaminants from WUI fires can vary depending on factors, such as the type of emissions released, the distance from the fire, and prevailing environmental conditions. WUI fires have distinctive characteristics in different regions of the U.S., leading to differing risks. The chemistry of a WUI fire, involving the combination of natural and human-made fuels burned, results in toxic emissions not found in wildland fires. These toxic mixes of chemicals are largely uncharacterized and can lead to high human exposures due to their proximity to communities.

With wildfires in the U.S. becoming more frequent and destructive, resources, guidance, and practical strategies are critical for stakeholders residing in these communities. Evidence supports the need to protect people from WUI smoke and its residues. Since on average people spend approximately 90 percent of their time indoors, management and control of exposure to wildfire smoke and residues indoors can help reduce health impacts. **This document summarizes the current knowledge and aggregates recommendations to provide a comprehensive resource for communities at risk from WUI fire hazards.**

To assist stakeholders in prioritizing actionable steps to protect communities and reduce human health risks, this Guidance Document organizes the recommendations and practical strategies into three sections: before, during, and after a fire.

What is the WUI?

The WUI refers to the area where human development meets or intermingles with undeveloped wildland and vegetation fuels.[3] This interface is characterized by the proximity and potential overlap between human communities and natural landscapes prone to wildfire hazards (Figure 1). In the WUI, there is an increased risk of wildfire ignition and spread due to the presence of flammable vegetation combined with human activities (like cigarettes, fireworks, burning debris, and malfunctioning equipment) and infrastructure (like buildings and vehicles). Managing the WUI involves strategies to mitigate wildfire risk, protect human health, and preserve natural ecosystems.[14]

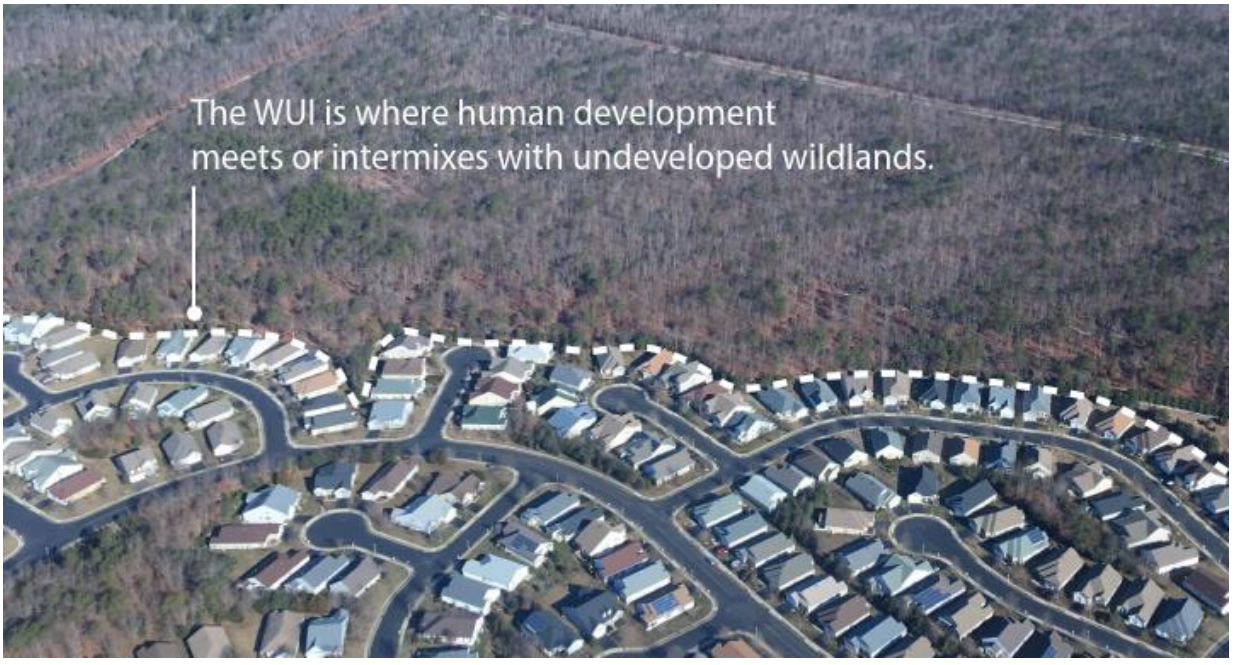

Figure 1

The WUI is the transition zone between unoccupied land and human development.

What are in the emissions from WUI fires?

The toxic emissions from a WUI fire are specific to the combination of the combustion of chemicals from natural and human-made burned fuels. A single home built in the WUI is a very condensed fuel package. It is estimated to have 38 tons of combustible fuel, which includes wood and structural subflooring, siding, insulation, wiring, plastics, flooring, interior furnishings, lubricants, and batteries. When all this complex material burns with biomass, complex fire emissions will result.

The smoke emitted by WUI fires, although not well characterized, likely contains a mixture of PM, organic and inorganic combustion gases, such as: carbon monoxide and nitrogen oxides; organic and inorganic metal complexes; VOCs, such as dioxins and furans, benzene, and formaldehyde; and SVOCs, such as organophosphorus and halogenated pesticides, phthalates, and numerous reaction products (Figure 2).[15-17] There is a limited data on the contaminants associated with WUI combustion smoke, so most current information is extrapolated from wildland-specific and structural fires.

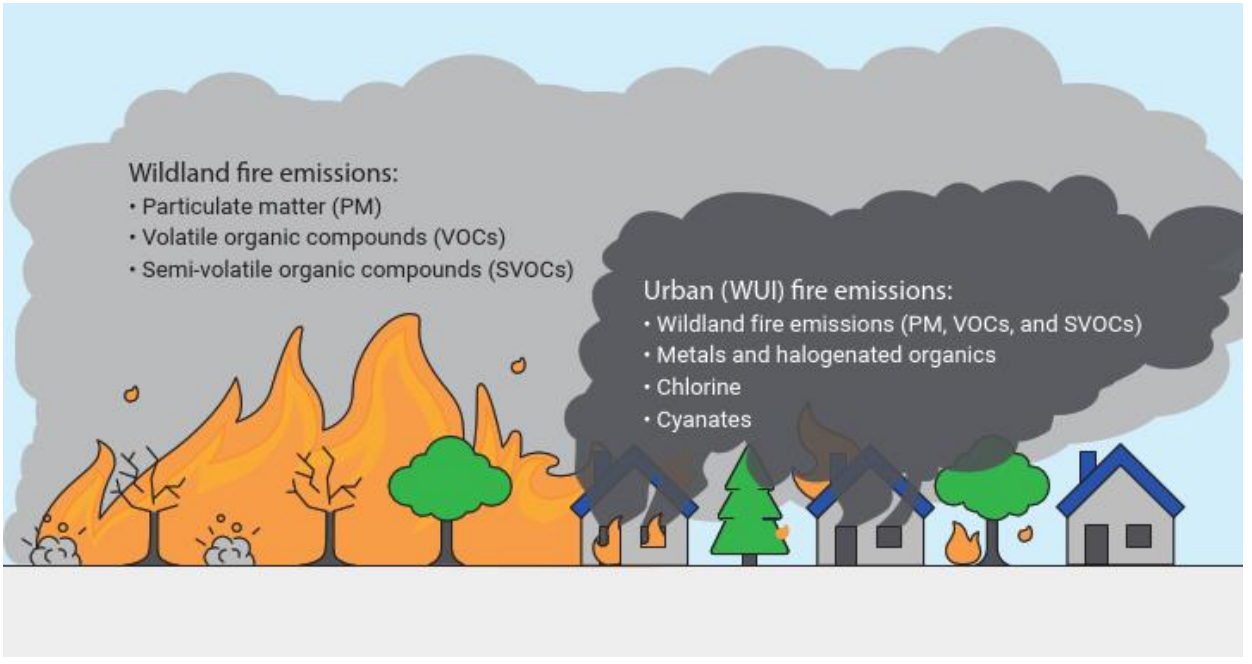

Figure 2

WUI fire emissions contain both the typical emissions of wildland fires (PM, VOCs, SVOCs) and additional urban fire emissions, such as metals and halogenated organics, chlorine, and cyanates.

What are the health risks?

WUI fires present multifaceted health hazards to residents inhabiting or adjacent to regions where wilderness interfaces with urban expansion, resulting in a mixture of fuels, contaminants, and particulates (Table 1).[15-18] People are primarily exposed to harmful substances through inhalation, ingestion, and skin absorption (Figure 3).[19] Smoke from WUI fires can worsen respiratory issues like asthma, bronchitis, allergies, chronic obstructive pulmonary disease (COPD), and pneumonia, and increase cardiovascular risks such as heart attacks, strokes, and hypertension, especially in those with existing conditions.[20] Asthma flare-ups and other respiratory problems can be triggered by allergens and irritants in the air, lack of access to treatment, and emotional stress.[21]

Smoke and ash from WUI fires can also cause eye inflammation, skin irritation, redness, and discomfort, potentially leading to more severe conditions, particularly in sensitive individuals.[3] Additionally, runoff from WUI fires can contaminate water sources with ash, debris, and other pollutants, posing risks to drinking water and aquatic ecosystems.[19]

Table 1
Examples of chemical pollutants related to WUI fire events and human exposures.

GROUP OF POLLUTANTS	COMMON EXAMPLES	ROUTES OF EXPOSURE	POTENTIAL HEALTH OUTCOMES
Asbestos	Fibrous asbestos, chrysotile	Inhalation Ingestion	Cancer; asbestosis; respiratory irritation; pleural disease
Asphyxiant gases	Carbon monoxide (CO), carbon dioxide (CO_2), hydrogen cyanide (HCN)	Inhalation	Depression of central nervous system and hypoxia; acute respiratory effects
Dioxins and furans (polychlorinated dibenzo dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs))	2,3,7,8-Tetrachloro-dibenzo-p dioxin/furan (TCDD/F)	Inhalation Ingestion Dermal (low penetration into skin by itself, but can cause skin lesions)	Cancer or predisposition to cancer; reproductive and developmental effects; immune suppression; dermal toxicity; endocrine disruption
Flame retardants	Tris(1-chloro-2-propyl) phosphate (TCPP), tris(2-chloroethyl) phosphate (TCEP), tris(iso-butylated triphenyl phosphate)(TBPP), methyl phenyl phosphate (MPP)	Inhalation Ingestion	Neurotoxicity or neurodevelopmental damage; reproduction and fetal development effects; endocrine and thyroid disruption
Inorganic acid gases	Hydrogen chloride (HCl), hydrogen fluoride (HF), phosphoric acid, oxides of sulfur (SO_x), oxides of nitrogen (NO_x)	Inhalation	Chemical burns; increased risk of laryngeal and lung cancer; cardiac arrhythmias and pulmonary edema
Inorganic and organic metals	Lead, lithium, iron, mercury, methylmercury, nickel, cadmium, palladium chloride	Inhalation Ingestion Dermal	Neurotoxicity; reproductive and developmental effects, dermal irritation or allergen; respiratory irritation
Isocyanates	Methyl isocyanate, methylene diphenyl diisocyanate, toluene diisocyanate	Inhalation	Irritation and pulmonary sensitivity
Organic and other gases	Phosgene ($COCl_2$), ammonia (NH_3)	Inhalation	Acute effects; pulmonary edema and irritation
Ozone (O_3)		Inhalation	Acute and chronic respiratory symptoms including coughing and exacerbation of chronic diseases such as bronchitis and asthma; increased risk of pulmonary infections
Particulate matter (PM)	PM is often classified by size, where the size is based on the aerodynamic diameter in micrometers (e.g., $PM_{2.5}$); smaller particles penetrate deeper into the respiratory system	Inhalation Ingestion Dermal	Cancer; cardiopulmonary toxicant; immunosuppressant; neurotoxicant; reproductive and developmental toxicity
Plasticizers	Ortho phthalates – dibutyl phthalate, terephthalates, adipates, benzoates	Inhalation Ingestion	Endocrine disruptors; reproductive and developmental toxicity
Polycyclic aromatic hydrocarbons (PAHs)	Benzo[a]pyrene, benzo[a]anthracene, benzo[b]fluoranthene, chrysene, pyrene, fluoranthene, naphthalene, anthracene	Inhalation Ingestion Dermal	Cancer; reproductive and developmental (teratogenic) toxicity; kidney and liver damage

GROUP OF POLLUTANTS	COMMON EXAMPLES	ROUTES OF EXPOSURE	POTENTIAL HEALTH OUTCOMES
Polychlorinated biphenyls (PCBs)	2-Chlorobiphenyl, 2,2-dichlorobiphenyl, 2,4,5-trichlorobiphenyl; PCBs typically occur as a mixture of PCB congeners (i.e., aroclors)	Inhalation Ingestion Dermal	Cancer; neurotoxicity; immune suppression; endocrine disruption; reproductive and developmental toxicity; respiratory toxicity
Volatile organic compounds (VOCs)	Formaldehyde, acetaldehyde, acrolein, benzene, toluene, ethylbenzene, para-xylene, ortho-xylene, meta-xylene, styrene, naphthalene; complex mixtures of VOCs are classified as total VOCs, and some are not toxic	Inhalation Ingestion	Cancer; reproductive and developmental toxicity; neurotoxicity; respiratory irritation; odorants
Other emission and transformation products that are currently unidentified	Per- or polyfluoroalkyl substances (PFAS), including perfluorooctane sulfate and perfluorooctanoic acid reactive oxygen species, including peroxides (R-O-O-R) and superoxides (O_2), environmentally persistent free radicals	Inhalation Ingestion	Cancer; respiratory and developmental toxicity

Source: National Academies of Sciences, Engineering, and Medicine. The Chemistry of Fires at the Wildland-Urban Interface. Health Effects of WUI Fires (2024).

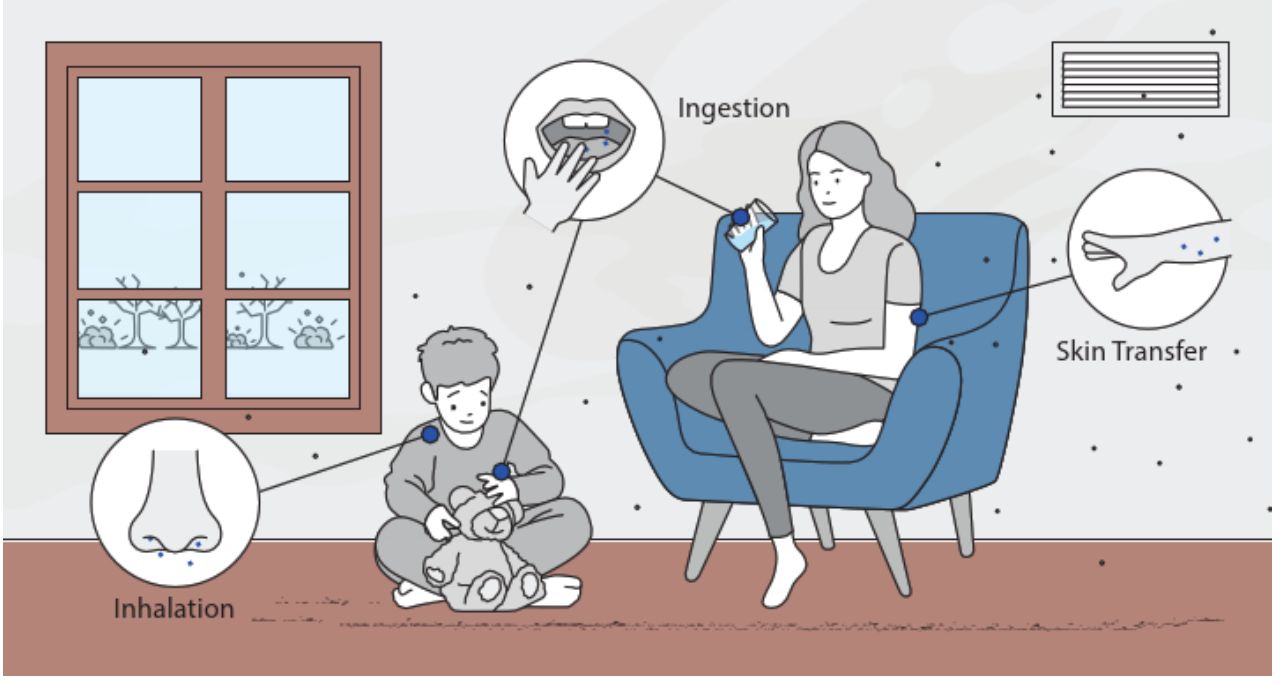

Figure 3

Human exposure to emissions and residues from a WUI fire can occur through inhalation, ingestion, and skin transfer (absorption).

Who are most impacted by these health risks?

Vulnerable populations – like children, older adults, the immunocompromised, pregnant people, and those without healthcare access – are more susceptible to negative health effects from WUI fire emissions.[16]

Children face numerous health issues due to their developing bodies and unique vulnerabilities, especially because of more frequent hand to mouth behaviors, which increases settled dust ingestion. They are prone to respiratory problems like asthma, bronchitis, and infections from WUI fire smoke. Their developing physiology makes them more susceptible to irritation and inflammation caused by PM and other pollutants. Prolonged exposure can lead to long-term respiratory and cardiovascular issues.[22] This can increase the risk of chronic respiratory conditions later in life. Additionally, children can experience eye and skin irritation, rashes, and allergic reactions.[23] They are also at higher risk of injuries due to their size, limited mobility, and dependency on caregivers. The stress and trauma from WUI fires can severely impact their mental health and well-being.[24] Witnessing the destruction of homes, displacement, and experiencing uncertainty about the future can lead to emotional distress and psychological trauma.[25] Protecting children and the vulnerable requires reducing their exposure to smoke, ash, and toxins, and providing appropriate physical and mental health support during and after such events.

What are the costs of WUI fires?

In 2021, WUI fires across the U.S. destroyed almost 4,300 buildings despite spending $4.4 billion (B) in suppression costs.[15] The estimated economic impact of wildfire related premature deaths and respiratory hospital admissions from fine PM ($PM_{2.5}$) is $11B – $20B annually for short-term exposures and $76B – $130B annually for long-term exposures (Figure 4).[16] These costs are associated with premature mortality, health care utilization, lost productivity, and impacts on quality of life.[17]

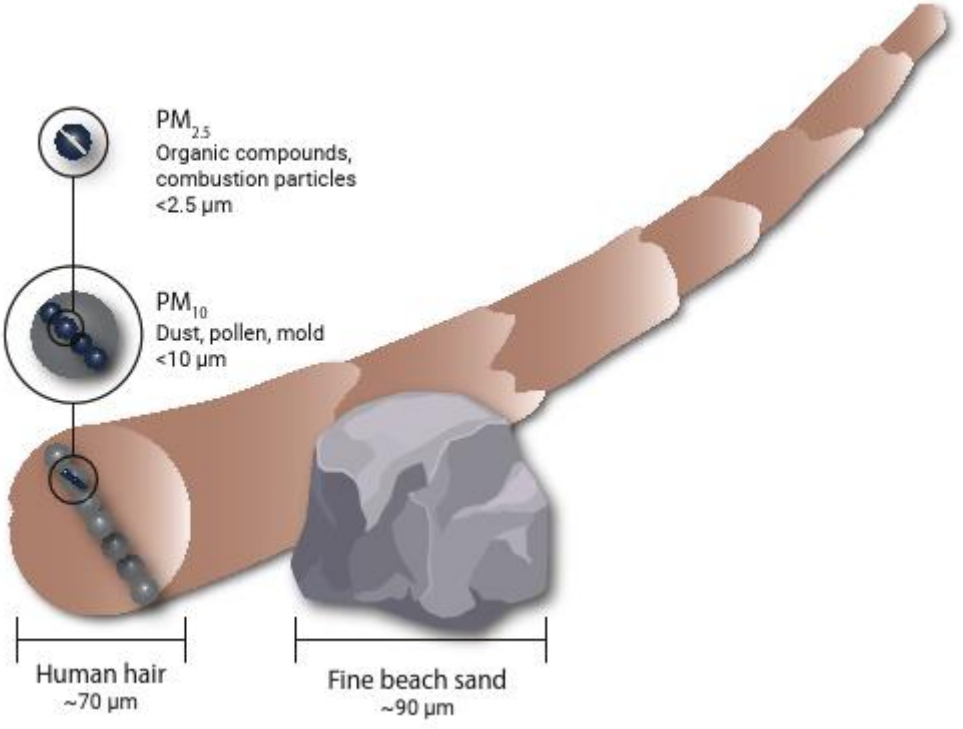

Figure 4

$PM_{2.5}$ are particles that are 2.5 microns or less in diameter. By comparison, the average human hair is approximately 70 microns and fine beach sand is approximately 90 microns.

Reducing Health Risks

This guidance document assembles recommendations from a range of resources aimed at minimizing damage and associated health risks related to WUI fires and is organized in three sections: before, during, and after a fire. Each section offers practical steps for each stage of a WUI fire for protecting your and your family's health, your home or building, and your property.

Before a Fire focuses on prevention to minimize health effects and property damage.

During a Fire addresses practical means of staying apprised of your situation and taking steps to reduce health risks.

After a Fire provides steps for a safe return to your home or building and practical measures to remedy fire-related damage and prevent long-term or chronic health impacts.

BEFORE A FIRE

Understanding Risk

• To assess your risk, start **by checking your location on the** U.S. Federal Emergency Management Agency (FEMA) Map of the National Risk Index. This interactive map shows the potential risk of wildfires and wildfire emissions in each county and is based on census data, where red indicates a higher risk and blue indicates lower risk. The risk index is evaluated based on expected annual loss, social vulnerability, and community resilience, which can also be found on the website. This map provides an overview of where the wildfire prone regions are and helps users to assess the potential wildfire risk in the areas where they reside. FEMA also has two tools to **assess your risk: the** WUI Fire Property Awareness Explorer **and the** WUI Fire Community Awareness Explorer.

• **Evaluate your family's health vulnerability to wildfire emissions.** Do you have pre-existing conditions or a weakened immune system? Are you or someone in your household a sensitive individual, such as a young child, pregnant person, or older adult?

• **Consider your access to safe places to shelter and healthcare resources.** Do you have nearby healthcare professionals or facilities? If not, consider how would you reach them in an emergency and is it feasible?

• **Consider your home or building's vulnerability to WUI fire and capability to mitigate risks from WUI fire emissions.** How is the building situated on the site, and how is it constructed? For instance, is it wood frame on pier and beam or is it constructed of brick on a concrete foundation? Has the home been weather proofed and checked for air leaks? Does the home have a centralized HVAC system that would help reduce indoor wildfire contaminant levels? Is it operating and do you understand how it operates? Can it recirculate the air without any outdoor air being brought in? Is it equipped with MERV rated filters to remove fine particles?

Protecting Health

There are steps you can take to reduce the potential hazards of a wildfire and exposure to its smoke and debris.

• **Ensure** smoke alarms **work throughout the home.**[26] Follow the guidance of the U.S. Fire Administration (USFA) and use both ionization and photoelectric smoke alarms or dual-sensor smoke alarms that contain both ionization and photoelectric smoke sensors. An alarm during a wildfire indicates that flames are imminent, or smoke is getting into your home and people need to be evacuated or protected.

• **Purchase and have available respirators[27] or National Institute for Occupational Safety and Health (NIOSH) – approved P100, N95 masks; or KN95 masks**, which are more effective than surgical masks for use if smoke is expected.[28,29] Children 7 years of age and older are likely

to fit an adult small N95 face mask, but for children aged 2 to 7 years of age, look for a child-size medical or surgical mask to fit their face better. Do not mask a child two years old and younger.[20,28,30] To check the fit of the mask, perform a seal check by cupping the hands around the edges of the face mask. Adjust the fit of the mask if you feel air leaking out or sucking in around the edges of the face mask.

• **Draft and have an** escape and evacuation plan **accessible to safely exit your building, home, and/or community** in case of a wildfire. Test the effectiveness and preparedness of the plans for every member of your family and communicate the plans with family and friends.[31]

• **If you have children in childcare or school, request access to review their emergency preparations and evacuation plans** in the event of a wildfire and determine how you will stay connected or retrieve your children during and/or after a fire.

• **If you have pets, include them in evacuation planning.** Identify emergency shelters that accept pets.[32]

• **Keep an emergency bag or "go-bag" packed in case an evacuation is necessary.** Include items from The U.S. Department of Homeland Security's Ready: Wildfires website or use this list:

- Water: estimate one gallon per person per day (3-day supply for evacuation, 2-week supply for home)
- Non-perishable, easy-to-prepare food items (3-day supply for evacuation, 2-week supply for home)
- Medications (7-10-day supply) and medical items
- Sanitation and personal hygiene items
- Cell phone with charger
- Family and emergency contact information
- Copies of personal documents (medication list and pertinent medical information, proof of address, deed/lease to home, passports, birth certificates, insurance policies)
- Extra cash (automated teller machines [ATMs] might be inoperable)
- Extra fuel for generators and vehicles
- First aid kit
- Respirators and masks
- A hammer or hatchet
- Flashlight
- Multi-purpose tool like a Swiss Army knife
- Battery-powered or hand-crank radio (National Oceanic and Atmospheric Administration [NOAA] Weather Radio, if possible)
- Extra batteries
- Depending on your family's requirements, you may need to include medical-care items, baby supplies, pet supplies, and other things, such as extra sets of vehicle and house keys
- Additional supplies might include towels, plastic sheeting, duct tape, scissors, and work gloves

Protecting Indoor Air Quality

• **Develop a Smoke Management Plan**,[31] which outlines how to modify and maintain the HVAC system to limit and/or remove smoke from incoming outside air and to filter $PM_{2.5}$. (Figure 5).

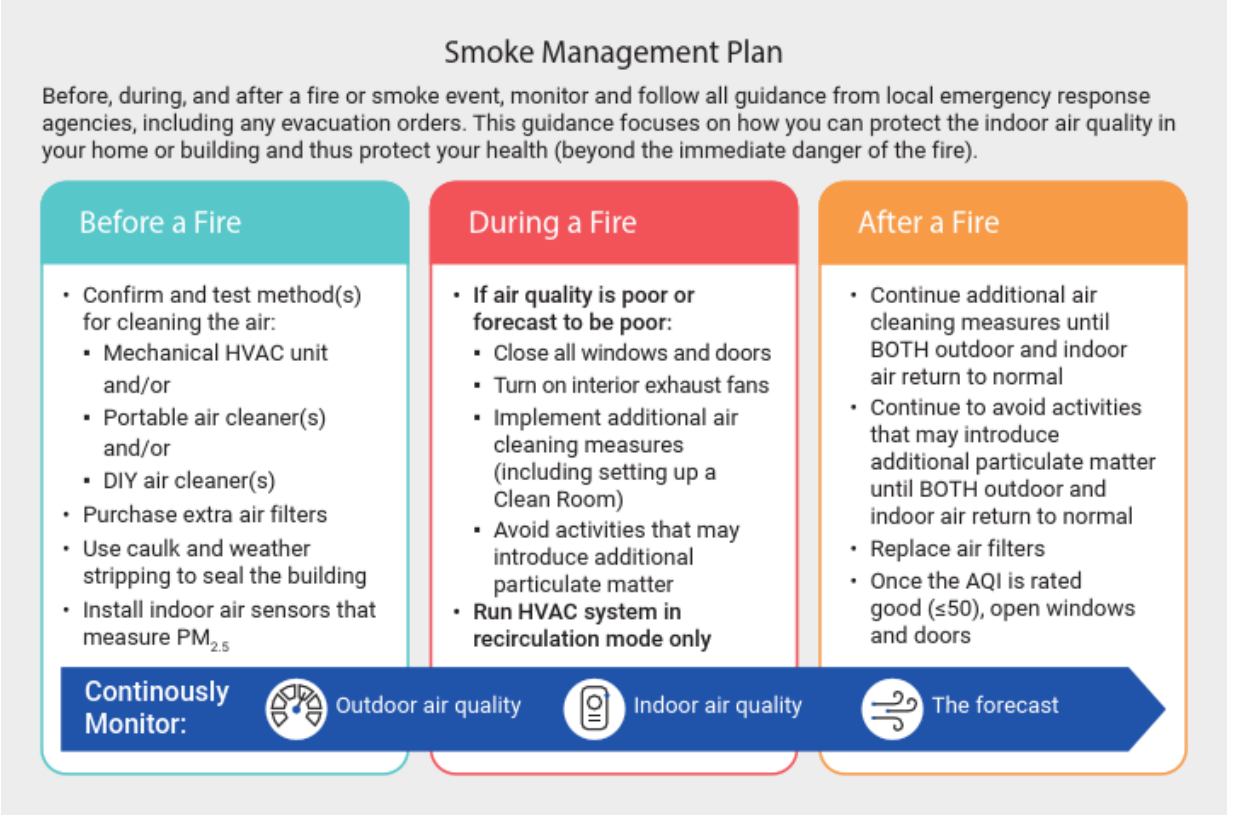

Figure 5

Overview of key actions to take before, during, and after a fire to protect indoor air quality from smoke.

• **Check manufacturer information to determine if a MERV filter is allowed for your HVAC system.** If allowed, install the highest-rated MERV filter possible to reduce fine PM concentrations in the air.[5] A MERV 13 (or better) rated filter is recommended for $PM_{2.5}$ removal. Purchase spare filters, as supplies may be limited during a smoke event (Figure 6).

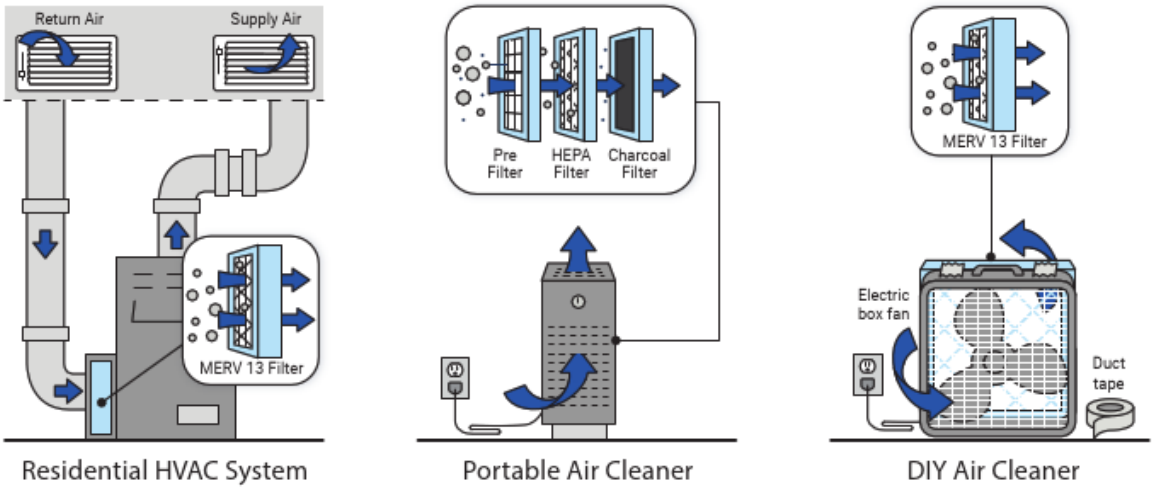

Figure 6

There are several options for filtering (or cleaning) indoor air in a residence or building.

• **If your HVAC system does not allow a MERV filter, consider installing new mechanical equipment** that would accommodate MERV 13 (or better) filters or HEPA-style filters. Keep spare filters on site and ensure you know how to replace them.

• **Ensure that windows and doors are closed and provide a tight seal** to keep out smoke and dust. Also look for additional openings and seal. Use caulk to seal gaps along the baseboards, lighting and plumbing fixtures, switches and electrical outlets, and use weather stripping for windows and doors. Sealing air leaks will prevent unwanted smoke from entering the home and improve energy saving efficiencies from 10 to 20 percent per year.

• If you do not have a central HVAC system or would like to have additional air cleaning, **consider purchasing and having available one or more portable air cleaners (PACs)**. Before selecting a suitable air cleaner, determine a CADR aligned with the square footage and volume of the space needing filtration. CADR quantifies the volume of air that can be filtered and delivered per minute – the higher the CADR rating, the quicker clean air is being generated. The Harvard Healthy Buildings Program recommends filtering the air within an indoor space at least five times per hour to maintain good air quality.[33] For example, a room of 450 square feet (with 8-foot ceilings) would need a PAC with a CADR of 300 cfm.[33] In general, follow the 2/3 rule – the CADR of the air cleaner should be equal to at least two-thirds of the room's area.[34]

  ○ Only purchase PACs that are certified by the California Air Resources Board (CARB) to not contribute to O_3 emissions. It is also recommended that the PACs be certified by Association of Home Appliance Manufacturers (AHAM) for removal of tobacco smoke, dust, and pollen with a CADR.[31,35] Avoid those that have additive technology, such as ionization and plasma.[35-37]

• If PACs are unavailable or not economically feasible, **consider constructing a do-it-yourself (DIY) air cleaner**. Gather the required materials: a box fan (20 inches x 20 inches), an HVAC filter (20 inches x 20 inches) with a MERV rating of 13 or higher, and duct tape.[38] Follow these instructions on How to Make a DIY Air Cleaner along with other helpful information provided by CIRI. Follow these Safety Tips when using a DIY air cleaner. It is important to use box fans manufactured after 2012 and verified by an accredited third party to meet the Underwriters Laboratories (UL) 507 safety standard (or equivalent) for electric fans or equipment, marked with a UL or Electrical Testing Laboratories (ETL) safety label.[26]

• **Consider purchasing and installing one or a few low-cost indoor air sensor(s) that measures $PM_{2.5}$.** Readings from these sensors can help when determining whether a Smoke Management Plan (see Figure 5) needs to be implemented and will also help determine how well your filtration is working and the effectiveness of any other steps taken to reduce the intrusion of $PM_{2.5}$ into the indoor air. An example of commercially available low-cost sensors is Purple Air, which also provides a cloud-based network of measured air-quality data. Follow manufacturer guidance for installation and operation.

Protecting a Home or Building

To meaningfully reduce risk, property loss, and suffering, the Insurance Institute for Business & Home Safety (IBHS) advocates for a two-tiered approach to homes and other buildings, providing protection against both embers and flames.[39] As with most strategies intended to reduce risk, many of these suggested guidelines require continued assessment, preparedness, and routine maintenance.

Steps to Protect an Existing Building or Home

• **Regularly inspect your home and any additional structures** for deterioration and identify all potential hazards.[40] Regularly clean the roof and gutters, removing debris, such as leaves and pine needles.[41] Seal and weatherize the building envelope.[6] Protect vulnerable areas easily ignited by embers, flames, and/or radiant heat; enclose the underside of eaves,[25] the underside of bay windows, and low decks.[23] Install ember-resistant vents or cover existing vents with 1/8-inch metal wire mesh. Replace plastic or vinyl gutters with metal gutters, such as aluminum or steel.

• **Create an immediate defensible zone adjacent to property structures by eliminating fuels from the immediate area surrounding the building.** Utilize fuel breaks in the design of driveways, walkways, and lawns,[42] and keep combustible materials, particularly firewood, at least 100 feet away from any structure or attachment, such as a fence or deck.[28]

• **Eliminate, at a minimum, all combustible landscape and/or vegetation, including tree limbs, within five feet of the primary structure.** Create and maintain at least a 30-foot buffer of defensible space around all structures, removing any material, vegetation included, that would transmit fire to a structure.[27,43]

• **Provide at least six inches of clearance between the base of the exterior wall and the ground.**[39] Use a masonry or metal fence as a protective barrier between an all-wood fence and the primary structure.[42] Limit accessory structures like sheds and playsets in the defensible area.

• **Plant trees and shrubs in well-spaced groupings, prune tree limbs and branches to provide six feet of clearance above the ground, and space trees so that their crown edges are at least ten feet apart.** If planted on a slope, increase the minimum distance between crowns to slow a faster-moving fire with longer flame lengths.[44]

Steps to Protect New Construction and/or Renovation

• **Review any relevant state and/or local government hazard mitigation policies** intended to reduce risks.[45]

• **Evaluate the site**, overall terrain, the direction of prevailing winds, seasonal weather conditions, and property boundaries. Build on the most level portion of available land to avoid faster wildfires moving up a slope.[42]

• **Use ignition-resistant, noncombustible construction materials on the exterior.**[43] Specifically, ensure the roof and its sub-roofing are constructed using non-combustible or fire-resistant Class A fire-rated roofing materials, like metal, asphalt shingle, slate, clay, or terracotta tiles.[39]

• **Ensure all doors and windows, including skylights, are fire-rated with noncombustible frames**, such as aluminum, with weather-stripping seals that meet or exceed American Society for Testing and Materials (ASTM) D638 or UL 94 V-2.[46] Use noncombustible window covers or shutters, particularly those that are operable and can be used to protect both the frame and window from radiant heat.[46]

• **Ensure any exterior-mounted equipment, including the HVAC system**, uses noncombustible conduit and support systems, noncombustible frames, and louvered mechanical screens covered with 1/8-inch noncombustible, corrosion-resistant mesh screening.[46]

• **Protect water lines coming into the house** by burying pipes at least two feet deep and utilizing backflow prevention devices. Clear vegetation and trees from around the water meter box if present.

• **Protect power lines coming into the house** and install backup power systems, such as generators, to reduce the chance of plumbing depressurization and chemical contamination.[24] When using generators, operate in a well-ventilated area to reduce the risk of CO poisoning, follow manufacturer's instructions, monitor the unit periodically during operation, and do not fuel the generator while it is hot. Additional information on the safe use of a generator, especially with regard to its location, can be found at South Coast Air Quality Management District (AQDM) and Health Canada. Ask the power company to clear branches from the power lines, if applicable.[42]

• **If using a solar panel system to provide power**, install an isolating switch to disconnect the system from the power grid.[47]

Steps for Readiness

• **Contact your insurance agent and confirm you have appropriate coverage.** Discuss the replacement value of your home, additional structure(s), and personal property, including vehicles.[21] In addition, review deductibles, allowances for expenses incurred if displaced, and coverage for special items (like jewelry) and/or collectibles (like artwork). Record a video of contents and upload to the cloud.

• **Keep a 7 to 10-day supply of prescription medications on hand**, particularly those necessary to improve asthma and other respiratory conditions, and store these medications in a waterproof, childproof container for ease if evacuation is required.[32]

• **Obtain copies of valuable documents and records** that could be lost in a fire, such as personal identification (driver's license, passport, social security card as well as birth, death, and marriage certificates), auto registration, stocks and bonds, income tax records, titles and deeds, insurance policies, wills, divorce papers, medical records, etc.[48]

• **Maintain an accurate set of house and site plans**, if available, and keep a copy in a safe location. When possible, on the plans, include the location of important gas pipelines, water lines, drainage systems on the property, and any stored hazardous materials or chemicals.[49,50]

DURING A FIRE

The U.S. Forest Service (USFS) Interagency Wildland Fire Air Quality Response Program and the U.S. EPA monitor existing conditions, measure air quality, and report on rapidly changing situations. In response, state Departments of Health and the CDC offer guidelines to limit risk while regional and local disaster relief services mobilize to aid residents.

Understanding Risk

• **Pay close attention to increasing heat and monitor the air quality** using resources like the interactive AirNow Fire and Smoke Map, which measures the current AQI by zip code, city, or state and provides recommended actions to avoid risk (Figure 7).[36] When conditions are changing rapidly, use resources such as Smoke Advisories | AirNow.gov or Real-Time Air Quality Map | PurpleAir.

• In general, **if the smell of smoke is detectable, then avoid outdoor activity**. If visibility is less than 5 miles, then assume outdoor air quality levels are unhealthy.[41]

Air Quality Index (AQI)			
Green	Good	0 to 50	Air quality is satisfactory, and air pollution poses little or no risk.
Yellow	Moderate	51 to 100	Air quality is acceptable. However, there may be a risk for some people, particularly those who are unusually sensitive to air pollution.
Orange	Unhealthy for Sensitive Groups	101 to 150	Members of sensitive groups may experience health effects. The general public is less likely to be affected.
Red	Unhealthy	151 to 200	Some members of the general public may experience health effects; members of sensitive groups may experience more serious health effects.
Purple	Very Unhealthy	201 to 300	Health alert: The risk of health effects is increased for everyone.
Maroon	Hazardous	301 and higher	Health warning of emergency conditions: Everyone is more likely to be affected.

Figure 7

The U.S. Air Quality Index (AQI) is the U.S. EPA's index for reporting air quality. The higher the AQI, the greater the level of air pollution and the greater the health concern. Source: Image adapted from the U.S. EPA.

Steps to Minimize Smoke Risks

Based on reported and monitored smoke conditions, determine when to initiate the Smoke Management Plan (Figure 8) and implement smoke mitigation measures.

• **In some situations, to protect indoor air quality and reduce exposure to unhealthy smoke, authorities advise setting up a Clean Room.** This requires keeping doors and windows closed and sealed, running the HVAC system in a recirculation mode without outside air entry if available, filtering the air using MERV (13 preferred) or HEPA rated filters in the HVAC system and/or using PACs with a certified CADR, and avoiding any activity that creates additional PM, like burning candles, operating 3D printers, or cooking.[51]

• **Use additional PACs and/or DIY air cleaners to filter the indoor air in a Clean Room area or rooms with extended occupancy.**[26] Ensure the fan has open space around it with good air movement prior to use. Keep the fan and cords away from water sources, curtains, and loose clothing.[26] During use, do not use an extension cord or leave the fan unattended, particularly around children or pets.[26]

• **Keep all windows and doors closed.**[36] Turn on all interior exhaust fans to reduce elevated levels of fine PM ($PM_{2.5}$ or less).[52]

• **Limit the intensity**[42] **and duration of outdoor activity when the** AQI **reaches a moderate level (51 – 100** AQI**). When possible, cancel outdoor activities when the** AQI **reaches an unhealthy or hazardous level (≥ 151** AQI**).**[20] If canceling outdoor activities is not possible, wear a respirator to limit exposure and health risk.

• **If possible, when evacuating**, contact the police department to let them know that you will be away from your home.[48]

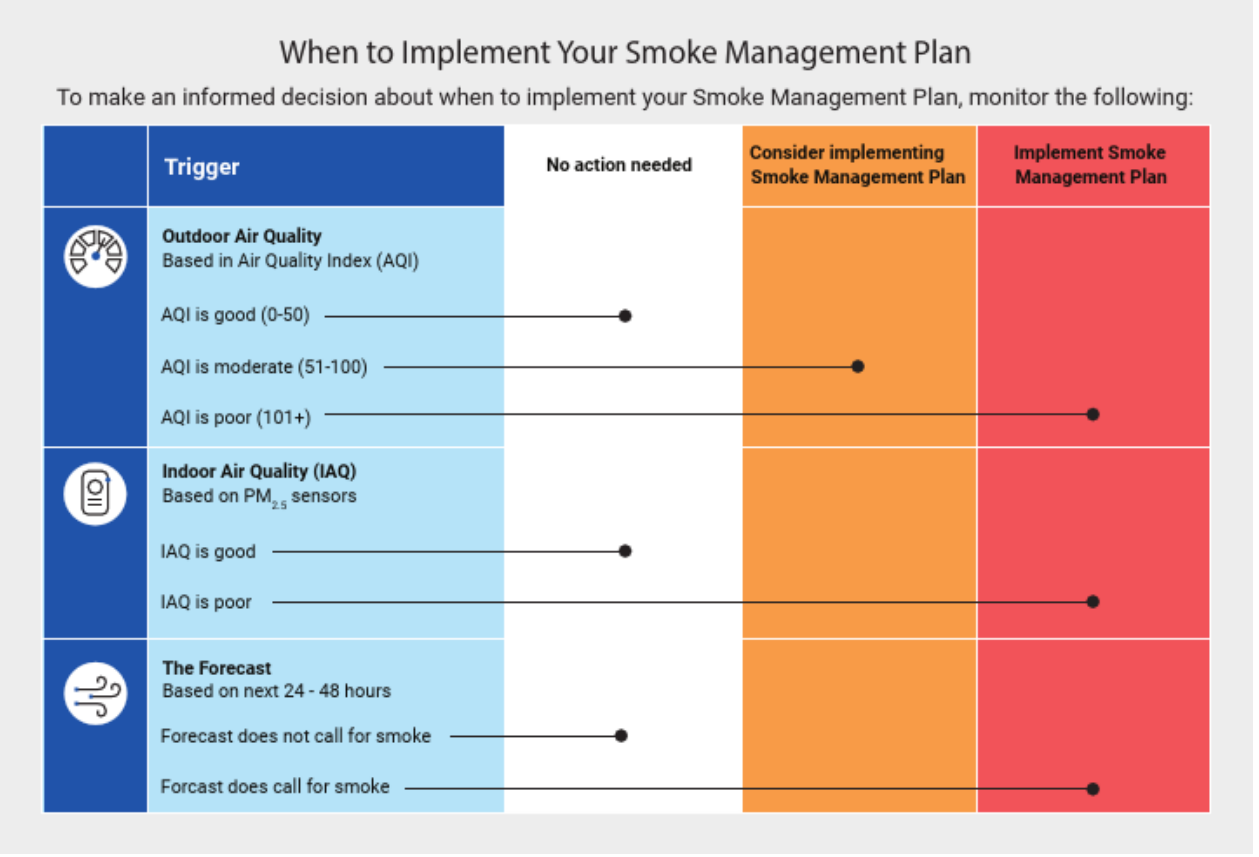

Figure 8

Guidance on when to implement your Smoke Management Plan.

Steps to Minimize Fire Risk

• **Never attempt to extinguish the fire yourself** due to potential electrical hazards.[47] Remove yourself, your family, and your pets from the home and call the fire department (911).

• **If there is a fire involving solar panels, contact your local fire station so the firefighters can take the necessary precautions and evacuate the area, maintaining a safe distance.**[47] Solar panels will continue to produce potentially lethal amounts of direct current (DC) electricity, even if the electricity has been isolated elsewhere in the building.[53]

• **Save all evacuation-related receipts, which may later be reimbursed and claimed on annual tax returns.**[48]

AFTER A FIRE

A Case Study: Surviving the Marshall Fire and Its Aftermath

On December 30, 2021, the Marshall Fire tore through Boulder County, Colorado, destroying over 1,000 structures and killing two people (Figure 9). A Louisville, Colorado resident and her family evacuated quickly and were lucky to have a home that remained standing after the fire. But upon their return, they faced a new challenge: the ashes, settled dust, and other pollutants the fire left behind. A professional interior designer with a specialization in healthy spaces, she had the knowledge and understanding about the importance of making sure their home was safe to inhabit. In this brief video, this interior designer shares her family's seven-month journey to remediate their home and lessons learned along the way. Watch this video to see her story.

Figure 9

In December 2021, the Marshall Fire erupted into the costliest wildfire in Colorado history, destroying over 1,000 homes in the suburbs of Boulder.

The U.S. Department of Homeland Security (DHS), FEMA, and USFA provide guidance on when it is safe to return to an impacted area. Many organizations, including the American Academy of Pediatrics (AAP), recommend waiting to bring children and pregnant people back to an affected area until water and sewer conditions are secure, roads are clear, debris has been removed, and residences are structurally sound. Once returning, proceed with caution to avoid potentially hazardous dust, contaminated water, and/or soil when cleaning and disposing of ash and debris.

Understanding Risk

- **After a wildfire, air and water quality should be monitored to determine when an area is safe to re-enter after an evacuation.** Contact your local health department to learn more about the current conditions and allow them to drive decisions about when it is safe to return.

- In addition to the health department, **contact the local fire department to ensure that buildings are safe to occupy and that the utilities (water, electricity, and gas) have been restored and are safe to use**. If the property has its own water source and system, consult the local health department for advice and determine whether inspection and further testing are necessary before restoring the system and assuming it is safe to use. If the property has propane and/or heating oil tanks, contact your supplier to ensure that the system is inspected and properly turned back on, given tanks, fittings, and lines may have been damaged from the heat.[47]

• **Before returning to the area, ensure medical treatment facilities are accessible[54], and determine available resources for assistance.** Contact local disaster relief services, such as the American Red Cross, Salvation Army, religious organizations, and nonprofit crisis-counseling centers, for food, clothing, medicine, and temporary housing.[48]

• **When you return, assess the damage and contact your landlord or mortgage company to report the fire.**[48] Contact credit card companies to report any lost credit cards in the fire,[48] and start the process of replacing any lost valuable documents and records.[48]

• **To determine the appropriate process for restoring/replacing the structure and property, contact your insurance agent and ask for recommendations on reputable companies specializing in cleaning and restoration, including your personal items.**[48] Independent of the insurance company, consider seeking the services of an industrial hygienist or environmental health professional to determine the extent of residual smoke and soot contamination,[55] which, according to the National Cancer Institute, may contain a number of carcinogens, such as arsenic, cadmium, and chromium.[56]

• **Before reoccupying the property, use a professional to test, restore, and clean the home's exterior and interior.**[45,46] Locate a Fire and Smoke Damage Restoration Technician (FSRT) certified to clean and restore properties after fire and smoke damage. Given their recognized standards, find a legitimate restorationist using the Institute of Inspection Cleaning and Restoration Certification (IICRC) Global Locator Tool.

Steps to Protect Health

• **When returning be careful of broken glass, exposed electrical wires, contaminated soils, and hot spots.**[57] Avoid ash pits or holes full of hot ashes created by burned trees and stumps, given that these can cause serious burns.[54]

• **Assess ash and smoke contamination.** Both indoor and outdoor surfaces may have residue from hazardous substances.[54] Ash and debris may contain toxic substances, such as asbestos and lead in older structures,[57] and vinyl chloride in the polyvinyl chloride (PVC) of newer structures.[23] All indoor surfaces will need to be cleaned.

• **Wear a properly fitted N95 or P100 face mask, latex or nitrile gloves, and eye protection when cleaning up ash inside and outside the structure.**[37,57] Children over 2 years old[28] and vulnerable populations should wear a mask to avoid inhaling wildfire smoke and particles of ash and dust.[20,58] To check the fit of the mask, perform a seal check by cupping the hands around the edges of the face mask. Adjust the fit of the mask if you feel air leaking out or sucking in around the edges of the mask.[28] People with heart or lung disease should consult with their physicians before using a mask during post-fire cleanup.[37,59]

• **Evaluate the HVAC system before starting to ensure it is not damaged and is clean and free of fire residues.** Remove the existing filter and replace it with a new filter. Professional cleaning may be needed.

• **Watch for symptoms of $PM_{2.5}$ exposure**, including burning eyes, coughing, throat and nose irritation, fatigue, headache, wheezing, and shortness of breath,[36,37] given that ash can be inhaled and ingested, irritating the nose and throat, causing coughing and/or triggering asthma attacks, and irritating the skin.[37,59] Watch for symptoms of $PM_{2.5}$ exposure in pets and be sure to wash or wipe off any ash that they may pick up.[60]

• **Assess the water quality at both the tap and the onsite source** (e.g., well, spring, ground, reservoirs, aquifer) and seek guidance from the local and state public health departments. Some studies suggest that exposure to VOCs from contaminated potable water supply networks and building plumbing is a possibility.[3] Guidance for insurance companies about plumbing damage, contamination, inspection, and testing is available.[61]

• **For properties that receive water from formal public water systems, seek information from the supplier about the safety of water being delivered to the property and if it could be contaminated.** Follow the recommendations issued about using that water.

• **Be aware of any buried septic tanks on the property.** Septic tanks could have burned or become unstable and thus pose a serious physical hazard.

• **Solar panels exposed to light during the day can continue to produce dangerous amounts of DC electricity and may be connected to the grid or battery energy storage on-site.** Look for damaged solar panels and avoid any exposed solar cells, given that they may have emitted highly toxic substances when burned.[62]

Cleaning Strategies to Mitigate Contaminate Exposure

Carefully clean and remove debris and damaged materials to limit exposure to fire ash,[3] dust, and VOCs off-gassing (Figure 10). Use appropriate personal protective equipment (PPE) – gloves, mask or respirator, eye protection, and clothing. To minimize ash and dust indoors, remove shoes when coming into the home, use walk-off mats on either side of the door,[57] and wash clothes separately.[63] Wear long-sleeved shirts and long pants. If the skin comes in contact with the ash, wash it off as soon as possible.[59] Check the fit of the mask by performing a seal check by cupping the hands around the edges of the face mask. Adjust the fit of the mask if you feel air leaking out or sucking in around the edges of the mask.[28]

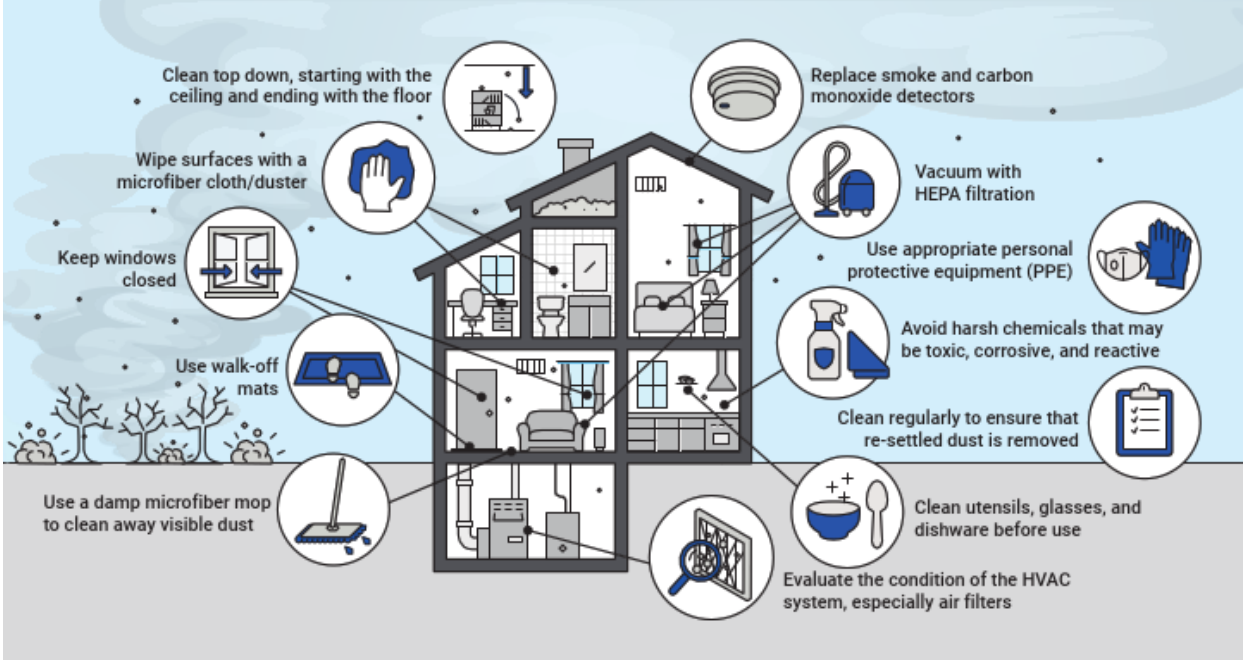

Figure 10

Key cleaning strategies for removing ash and dust indoors after a fire.

• **Clean top down, starting with the ceiling and ending with the floor.** Soap and water are adequate to clean ash from hard surfaces.[37,57]

• **Avoid harsh chemicals that may be toxic, corrosive, and reactive**; and/or vinegar that can react with chemicals in the ash. Select safe cleaning materials, referencing the list of the U.S. EPA Safer Choice Cleaning Products to minimize chemical load and limit increased exposure.

• **In some cases, using a damp microfiber mop to clean away visible dust could be adequate.**[57] In other instances, vacuuming may be required. Do not use a shop vacuum; instead, use a vacuum equipped with a HEPA filter system.[37,57] Once all visible dust has been removed, use a microfiber cleaning cloth, which is more effective in capturing smaller particles.

• **When cleaning furniture, artwork, and accessories, use a damp cloth to clean away visible dust**, like other surfaces. Wash soft surfaces and fabrics. Discard these items if they cannot be laundered.[57]

• **When cleaning utensils, glasses, and dishware, wash in a detergent solution and then soak for 15 minutes in a bleach solution of one teaspoon of bleach per quart of water.** If the dishwasher is debris-free, run a long wash cycle, heat the water to at least 140 degrees Fahrenheit and utilize the heated drying cycle.[57]

• **Avoid consuming food, beverages, or medication exposed to burn debris or ash.** Continue to wash any harvested home-grown fruits and vegetables thoroughly before eating, and assess the soil for contamination.[58]

• **Handle burnt money as little as possible, placing each bill in plastic to help preserve it.** Depending on its condition, the regional Federal Reserve Banks can replace damaged bills.[48]

• **Look for leaking or compromised containers and reactive household cleaners**, such as caustic drain cleaners and chlorine bleach, and keep children and pets away from leaking or spilled chemicals.[57]

• **Carefully dispose of household chemicals**, such as cleaners, fertilizers, and pesticides, which contain dangerous chemicals that may have spilled in or near the structure during the fire response. When disposing of chemicals, do not burn, combine, pour down drains, storm sewers, or toilets, or put them in the trash.

• **When focusing on the outdoors, refrain from using a leaf blower following a fire to reduce airborne contaminants.** When cleaning outdoor play areas, do not sweep ash.[57] Instead, spray it lightly with water and remove.[57]

• **Evaluate the condition of the HVAC system.** Clean it of all dust and debris and replace filters. Specialized cleaning of all associated HVAC ductwork will be needed with brush and vacuum systems.

• **Replace smoke and CO detectors.**[37]

• **Replace any internal exhaust fan filters**, such as those over range hoods and in bathrooms.

Steps to Monitor and Protect Air Quality

Steps should be taken to monitor the outdoor air quality and IAQ, so that personal protection can be advised and used as appropriate. The time to return to a typical background environment after a fire can depend on a wide range of environmental and building parameters and cannot be predicted or taken for granted (Figure 11).

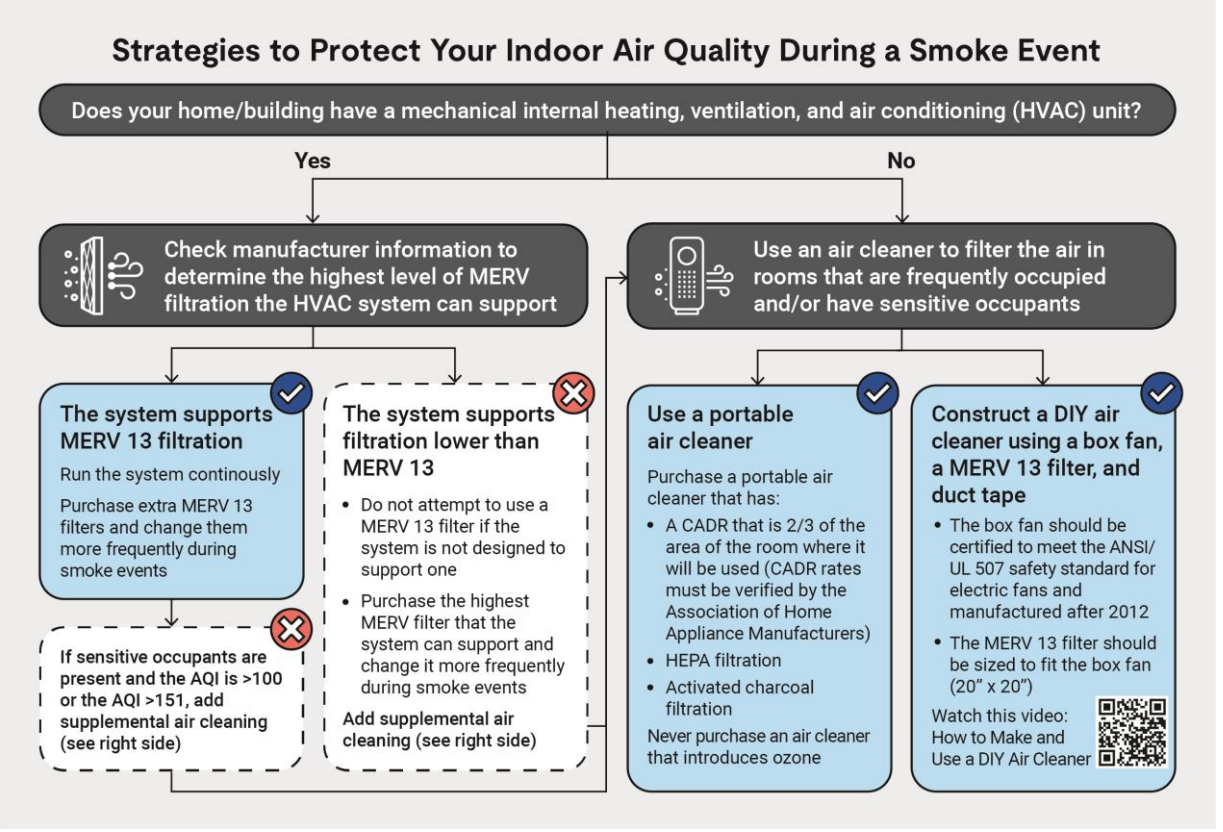

Figure 11

Decision tree providing guidance on how to protect indoor air quality during a smoke event.

• **After a fire, it is still important to continue monitoring the outdoor** AQI, using resources like AirNow.gov, which measures current air quality by zip code, city, or state, and forecasts conditions for the following day. Modify the duration of outdoor activities according to the outside AQI, using resources like AirNow.gov, particularly for children and those with health conditions, including asthma and other lung diseases, heart disease, and diabetes.[36] When possible, avoid the burn areas where there are residual dust and debris, particularly when conditions are windy.[57]

• **Continue to minimize or eliminate additional sources of indoor air pollutants until normalcy is obtained.** This includes avoiding using combustion appliances (e.g., gas stoves and fireplaces), burning candles, using harsh cleaning products, and smoking.

• **HVAC or PAC filters may soil more quickly after a fire, so check and replace with new filters,[37] especially when visibly soiled.**[52] Unplug PACs when not in use and keep the fan and motor clean.[26]

• **Continue to practice good hand hygiene, especially before eating or preparing food.**

• **Measure IAQ using a low-cost stationary sensor for long-term data on IAQ, including $PM_{2.5}$ and CO, and a portable handheld sensor to check for variations within the home.** If these sensors are not economically feasible to measure indoor pollutants, assume they match the outdoor AQI and take steps to reduce risks. If the outdoor AQI is rated "good," increase fresh air intake by opening windows and doors. For detailed monitoring, an industrial hygienist can assess a broader range of IAQ parameters.[36]

Steps to Monitor Water Quality

- **Avoid contaminated water.** Seek advice from the public health department about property water safety investigations and testing.

- **If contaminated water is suspected or confirmed to have entered infrastructure on the property, monitor the water quality at both the tap and the onsite source, if applicable, with periodic testing.**[64] Such testing must be well-designed as water quality can change with time as a result of the incident. Additional resources for households and businesses provides guidance for water system inspections, testing, and repair.

Understanding the risks associated with a WUI fire is crucial for effective preparedness and response. Take proactive measures before a fire, such as creating defensible space and having an evacuation plan. Stay informed and follow official guidance during the fire to ensure safety. After the fire, assess and address any damage, and be vigilant about air quality and potential health risks. Being well-prepared and informed can significantly reduce the impact of WUI fires on your home or building and health.

AN INFORMATIVE APPENDIX

Current State of the WUI

The WUI refers to the area where human development meets or intermingles with undeveloped wildland and vegetation fuels.[3] This interface is characterized by the proximity and potential overlap between human communities and natural landscapes prone to wildfire hazards. In the U.S., 9.4 percent of the land area is in the WUI, home to more than 32 percent of all housing nationwide.[65] The WUI grew rapidly between 1990 and 2020 both in the number of new homes (47 percent growth) and land area (31 percent growth), making it the fastest growing land use type and affecting more than one-third of the U.S. population now living in the WUI.[66,67] In the WUI, there is an increased risk of wildfire ignition and spread due to the presence of flammable vegetation, combined with human activities and infrastructure. It is estimated that more than 48M residential buildings across the U.S. are at risk of destruction from wildfires, resulting from historic population growth, unregulated building in wildfire exposed areas, overgrowth of forests and rangelands, aging infrastructure, and the effects of climate change.[66,67] At risk are more than 70,000 communities with an estimated value of $1.3T from the impact of wildfire.[68] Wildfire disproportionately affects some communities. More than 60 percent of counties in Washington and Oregon have high wildfire risk; nearly 75 percent of people living in tribal areas live in places with high risk; 20 percent of places with high wildfire risk have a greater percentage of people over the age of 65; and nearly 20 percent of places with high wildfire risk have a large number of mobile homes, putting a significant portion of affordable housing and the people who live there at much greater risk.[67] As communities continue to expand into previously undeveloped areas, fires are changing, driven in part by the burning of homes, cars, and other human-made structures in addition to vegetation. The interaction of wildfires and structure fires may lead to public health effects that are unique to WUI fires, affecting the local area as well as communities hundreds of miles away.

Wildfires in the U.S. are becoming larger, more frequent, and more destructive. Many of these fires occur at the WUI. Current knowledge on the WUI is limited and future research is needed to understand better the impact of wildland fuels, nearby structures, and system-wide factors on fire spread as well as on human health.[69,70] Most current information is not specific to WUI fires, but rather on wildfires. Managing the WUI involves strategies to mitigate wildfire risk, protect human health, and preserve natural ecosystems.[14] This Guidance Document aims to delineate the scope of issues associated with the WUI and provide pertinent details for stakeholders residing in communities where WUI fires pose a significant risk.

Human Health Risks Associated with WUI Fires

What is in WUI fire emissions and residues?

WUI fires present multifaceted health hazards to residents inhabiting or adjacent to regions where wilderness interfaces with urban expansion, resulting in a mixture of fuels, organic and inorganic contaminants, and particulates.[15-17] The smoke emitted by WUI fires contains a mixture of PM, CO, inorganic gases (e.g., nitrous and sulfur oxides), organic and inorganic metal complexes, VOCs and SVOCs, and complex mixtures of these emissions and combustion products.

There is a paucity of data on the contaminants associated with WUI combustion smoke so most current information is extrapolated from wildland-specific and structural fires.

What are the health risks from WUI emissions?

Both acute and chronic exposure to WUI smoke is expected to exacerbate respiratory ailments, such as asthma, bronchitis, and allergies.[71] Moreover, fine PM from WUI fires has the potential to infiltrate the circulatory system through inhalation, incidental ingestion, and dermal routes of exposure, contributing to cardiovascular risks, including heart attacks, strokes, and hypertension, particularly impacting individuals with pre-existing cardiovascular conditions.[72] Other health effects include asthma, COPD, bronchitis, and pneumonia. Asthma flare ups and other respiratory health concerns during a WUI event can happen because of allergens (e.g., pollen, mold) and irritants (e.g., dust, smoke) in the air, losing access to treatment, and strong emotions (e.g., fear, anxiety).[73]

Additionally, smoke and ash resulting from WUI fires can provoke eye inflammation, dermal irritation, redness, and discomfort, with exposures potentially leading to more severe ocular conditions.[71] Direct contact with ash and soot may induce skin irritation, rashes, and allergic reactions, particularly affecting those with heightened sensitivity. The combustion of structures within WUI fires releases harmful toxins from household materials such as plastics, chemicals, and treated wood, posing acute and long-term health risks through inhalation, ingestion, or skin absorption.[15] Exposure may occur from air contamination and residual dust that infiltrates the built environment, leading to dermal transfer or ingestion by building occupants. Contaminated air and water can be drawn into depressurized water systems (after the water treatment plant inside the water distribution system) and contaminate drinking water. Plastic infrastructure materials can be heat damaged causing and generating VOCs, which can contaminate drinking water as well.[64,74] Furthermore, the aftermath of WUI fires can result in water contamination as runoff carries ash, debris, and contaminants into water sources, jeopardizing both drinking water[18] and aquatic ecosystems.[75]

The ecological impact extends to alterations in ecosystems and biodiversity, which can disrupt the distribution and abundance of vector species like mosquitoes and ticks, potentially heightening the prevalence of vector-borne diseases, such as West Nile virus and other zoonotic diseases. Environmental, animal, and human health are connected and interdependent.[76]

Susceptible Populations to WUI Health Risks

Various populations are more susceptible to WUI fire emissions including children, older adults, immunocompromised people, those who are on drug therapies, those who are pregnant, persons with one or more disabilities, and those without access to assistance and healthcare. For example, children exposed to WUI fires face a range of specific health effects because of their developing bodies and unique vulnerabilities.[17,24,71] Children are particularly susceptible to respiratory problems caused by WUI fire smoke, such as asthma exacerbation, bronchitis, and other respiratory infections.[24,51,71] Their developing physiology makes children more vulnerable to irritation and inflammation caused by PM and other pollutants present in the smoke.[54,58] Prolonged exposure to WUI fire smoke during childhood can lead to long-term respiratory issues, potentially affecting lung function and development.[71] This can increase the risk of chronic respiratory conditions later in life. Like adults, children can experience cardiovascular effects from exposure to WUI fire smoke, including an increased risk of heart attacks, strokes, and hypertension. Fine PM from the smoke can enter their bloodstream and contribute to these issues.[17,24,71]

Children also experience eye irritation, redness, and discomfort from exposure to smoke and ash. Prolonged exposure can lead to more severe eye conditions.[17,25,51,58,63,71] Similarly, contact with ash and soot can cause skin irritation, rashes, and allergic reactions, which may be more pronounced in children with sensitive skin.[63] Inhalation or skin contact with toxins from burning household items can have acute and long-term health effects, including neurological and developmental issues.[17,25,51,58,71] Children are at a higher risk of injuries during WUI fires due to their size, limited mobility, and dependency on caregivers. They may be more prone to accidents during evacuation or while navigating hazardous conditions during and after the fire.

The stress, anxiety, and trauma associated with WUI fires can have a significant impact, including access to safe drinking water and other resources as well as on children's mental health and well-being.[58,63,77] Witnessing the destruction of homes, displacement, and experiencing uncertainty about the future can lead to emotional distress and psychological trauma.[25] Overall, protecting children from the health effects of WUI fires requires proactive measures to reduce their exposure to smoke, ash, and toxins, as well as providing appropriate support for their physical and mental well-being during and after such events.

Human Exposure Routes for Fire Emissions

Exposure routes for contaminants from WUI fires can vary depending on factors such as the type of contaminants released, the distance from the fire, and prevailing environmental conditions. Direct measures of exposure within the immediate and near-field zones during fires have yet to be reported in the literature.[3,78] However, farther away in the regional and continental zones, the chemistry of the fire plume continues to change with additional mixing of PM and complex gas mixtures. WUI fires have distinctive characteristics in different regions of the U.S. likely leading to differing risks, however a comprehensive mapping of communities at risk of fire indicating the severity of that risk is not available.[6]

Currently, studies are investigating the distance of smoke plumes from the source fire related to impacts on human health.[79] In a systematic review,[17] it was noted that the source of the fire (area burnt) is not a suitable proxy for wildfire smoke exposure because exposure is relative to the population's distance to the wildfire, wind speed, direction, and atmospheric mixing depth. Wildfire smoke also varies with vegetation type[17] and when considering the WUI, other toxic emission from burned structures, vehicles, and other material contents influence the smoke mixture.[80]

Exposure from the WUI fire plume in the immediate and near field (up to six miles from the fire site) may have concentrations of $PM_{2.5}$ averaging in the hundreds to thousands of micrograms per cubic meter with risks of inhalation of dust and ash, ingestion of settled dust and contaminated potable water, and dermal absorption of settle dust and ash.[3] People within the local and regional area, defined as between 600 and 700 miles may risk exposure of polluted air through inhalation, contaminated water through ingestion, and dermal exposure of settled dust.[3] Further from the fire site in excess of 600 miles, the smoke plume dilutes and ages, resulting in different inhalation exposure considerations from those near field. While concentrations may drop off rapidly away from the fire, it may impact large populations affecting a far greater number of people than the near field fire site with an ever-changing chemistry through inhalation of polluted air.[3]

Specific routes of exposure include:

Inhalation

Heat and gas damage to the epithelium are the two mechanisms in inhalation injury. Of the two, the latter is considered more severe, since toxic gasses set free by the fire can inflict severe damage.[81] In addition, inhalation injury may arise from immune reactions triggered by these elements, systemic repercussions of inhaled chemicals, accumulation of debris within the airways, and subsequent secondary infections. Smoke generated from structural fires is known to contain a diverse mixture of chemicals, incomplete combustion byproducts, and aerosolized debris, with a wide range of particle sizes. WUI specific smoke is expected to be more complicated with the addition of biomass fuels.

Ingestion

Ingestion exposure of smoke particulates, debris, and chemical contaminants in settled dust and water sources is a concern, particularly for infants and toddlers, due to the potential exposure to indoor contaminants after a fire.[82-84] All the contents within a WUI fire, including wildfire and structure fires, may be present in settled dust on indoor surfaces. This contamination often ends up on hands, which then results in ingestion from oral contact. Furthermore, ingestion exposure to fire smoke can occur when smoke particles settle on food or beverages, or when individuals inadvertently swallow smoke particles while breathing in smoky air. Ingestion risk from smoke in gardens after a fire depends on the extent of contamination and the substances present in the smoke, such as toxic residue contamination and airborne particles. Fruits, vegetables, and other garden produce that were exposed to smoke or ash may be contaminated and could pose ingestion risks if consumed without proper cleaning or disposal of contaminated items.[83] Following a fire, it's crucial to keep track of air quality updates provided by local health authorities concerning outdoor activities and precautions for food safety.

Dermal

Dermal exposure to fire smoke refers to contact between the skin and smoke particles generated during a fire event. Direct exposure may occur when individuals are near a fire, while indirect exposure happens when smoke settles on surfaces like clothing and other surfaces, facilitating cross-contamination.[85]

The Impact of the WUI on the Built Environment

Three thousand homes are lost annually in the WUI.[70] The development continuum from wildland to urban areas start with wildlands, then rural, continuing to suburban, then residential and urban, both located in the ember zone.[86] Most of the WUI fire disasters begin in undeveloped areas where fire maintenance programs are not consistent, forests are denser, fuel loads are higher, vegetation species distributions have shifted, and forest age has left these areas more vulnerable to wide-spread disturbances, including fire, insects, and disease. In WUI environments, fire propagation is a multi-scale and multi-dimensional problem, creating a more complex phenomenon than a structure fire or wildfire.[70] The built environment and its surroundings suffer significant damaging impacts affecting the safety of those living in the WUI along with the loss of material assets such as damaged and collapsed structures.[87]

The WUI Fire Environmental Contamination Impact

Environmental contamination stemming from WUI fires encompasses diverse forms of pollution that impact air, water, soil, and ecosystems. These fires emit smoke laden with PM, chemicals, heavy metals, and other pollutants, degrading air quality and precipitating respiratory issues for humans and wildlife. Furthermore, fine PM can disperse over long distances (1,000 miles or more), affecting air quality in regions remote from the fire.[80] Most of the research on how wildfire smoke can impact human health has been based on people living or working near fires in the Western U.S. One recent study found that wildfires in the Pacific Northwest were linked to increased respiratory problems in Colorado.[88] More research is needed to understand how smoke affects population centers far from the wildfires.

Runoff from WUI fires transports ash, debris, and contaminants into water bodies like rivers, lakes, and streams. Consequently, ash and charred vegetation introduce nutrients and toxins into waterways, potentially endangering aquatic life and compromising water quality.[75] The altered soil properties resulting from WUI fires render it more susceptible to erosion and diminish its capacity to sustain vegetation growth. The fire's heat can sterilize soil, deplete organic matter, disrupt nutrient cycling, and diminish soil fertility. Subsequent soil erosion exacerbates water quality concerns by leading to sedimentation in waterways.[89]

Burning structures during WUI fires release an array of toxic chemicals from building materials, household products, and vehicles. Some of these chemicals, encompassing heavy metals, asbestos, PAHs, and other hazardous substances, endure in the environment, posing health risks to both humans and wildlife.[74,90] Moreover, WUI fires disrupt ecosystems by ravaging vegetation, altering wildlife habitats, and perturbing ecological processes. Some plant and animal species may struggle to rebound from the

fire, resulting in shifts in species composition and biodiversity loss. Additionally, invasive species may exploit post-fire environments, further unsettling ecosystem dynamics.[60]

The Role of Climate Change

Climate change with extreme heat has increased the frequency and length of droughts, which dry out soil and vegetation, making wildland vegetation more likely to ignite and burn rapidly, reaching more communities at the WUI.[91] In the short term, increases in atmospheric CO_2 concentrations have decreased the amount of precipitation in the air at the same time that droughts have become more common making it easier for fires to spread and reducing the likelihood of a precipitation event that would control or extinguish the fire.[92] In the long term, climate impacts are more complex. Over years, even decades, climate can affect factors, such as fuel buildup, while increased temperatures lead to decreased vegetation and increased fuel decomposition, which reduces fuels and area burned.[92] In addition, nearly a century of aggressive fire suppression policies have also contributed to increased fuel loads, and fire danger is then further exacerbated by climate change. Recent history has shown that after the cycle of increased fuel loads begins, larger fire years occurred in subsequent burns, creating a feedback loop where fires at the WUI become more likely, more frequent, and more dangerous.[93,94]

COMMUNITY POPULATIONS

Numerous populations are affected by WUI fires. General community groups include the following:

Residents. All people living within the WUI area at risk of catastrophic wildfire losses.

Offices and Business. All people working in business enterprises within the WUI area at risk of catastrophic wildfire losses.

Domestic Workers. Indoor and outdoor workers providing services of a household nature in or about a private home, such as yard maintenance, home care workers, house cleaners, and nannies.

Community Centers. A place where people from a particular community can meet for social, educational, or recreational activities. Community centers may be facilitators of communication before, during, and after a WUI fire or potentially serve as emergency shelters.

Faith-Based Organizations. Organizations whose values are based on faith and have a mission based on social values of a particular faith. Faith-based organizations may be facilitators of communication before, during, and after a WUI fire.

Schools and Child Care Facilities. Public or private institutions for educating children from kindergarten through high school and early childhood childcare facilities. Schools and childcare facilities may be facilitators of communication before, during, and after a WUI fire.

Colleges and Universities. Higher education institutions designed for instruction and examination of students in many areas of advanced learning and conferring degrees. Colleges and universities have existing systems for relaying information and may be facilitators of communication before, during, and after a WUI fire.

VULNERABLE POPULATIONS

In every community, certain populations are more susceptible to the consequences of disasters than others. Social factors like poverty, transportation limitations, and housing inadequacies already pose challenges for residents in these areas.[95] When disasters strike, these vulnerabilities are exacerbated, further complicating response and recovery efforts for these communities. Emergency managers must recognize the interplay between risk and social vulnerability to ensure equitable support and meet the diverse needs of all individuals affected.[95] The Centers for Disease Control/Agency for Toxic Substances and Disease Registry Social Vulnerability Index (CDC/ATSDR SVI) was developed to help emergency response planners and public health officials identify and map the communities that need support before,

during, and after a hazardous event, considering factors such as socio-economic status, household characteristics, racial and ethnic minority status, housing type, and transportation.[8] The CDC/ATSDR SVI can help communities be better prepared to estimate the amount of needed supplies (e.g., food, water, medicine, and bedding), how many emergency personnel are required, identify areas in need of emergency shelters, and plan the best way to evacuate people. Vulnerable populations are defined as those with increased exposure, inability to adapt, and specific health response.[3] The following is a brief description of vulnerable populations affected by WUI fires[3]:

Children. Higher respiratory rate and more water ingested per body weight than adults.

Older Adults. Preexisting conditions, limited mobility, compromised immune response, and social isolation.

Immunocompromised. Unable to stop invasion and colonization by foreign intruders like bacterial and viral pathogens.

Pregnant People. Physiological changes, such as higher respiratory rates, increase in blood and lung volumes.

People with Respiratory and Cardiovascular Disease. Fine particle pollution further exacerbates disease and triggers symptoms.

People with One or More Disabilities. Fewer resources and less means to evacuate, inadequate community infrastructure, less mobility, and ability to assess risks.

Communities of Color, Immigrant, Migrant, and Refugee Communities, and Tribal Communities. Structural racism, disproportionate health burdens from environmental conditions, existing health disparities, less access to resources, and barriers to receiving culturally appropriate care.

Low-Income Communities. Fewer resources and means to evacuate, less access to indoor spaces with air cleaners and air cooling, higher burden of asthma and cardiovascular disease, existing health disparities, and lack of safety nets for missing work.

Rural Communities. Less municipal infrastructure, including access to drinking water and safe spaces, lack of extensive evaluation routes, fewer environmental monitoring units available, less access to indoor spaces with air cleaners and cooling, and existing health disparities.

Unhoused Communities. Lack of access to multiple basic resources and existing health disparities.

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