Fire Technology, 40, 95–99, 2004

GUEST EDITORIAL

Sublethal Effects of Fire Smoke

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Abstract. Fire smoke toxicity has been a recurring theme for fire safety professionals for over four decades. There especially continue to be difficulty and controversy in assessing and addressing the contribution of the sublethal effects of smoke in hazard and risk analyses. The Fire Protection Research Foundation (FPRF), the National Institute of Standards and Technology (NIST), and NFPA have begun a private/public fire research initiative, the "International Study of the Sublethal Effects of Fire Smoke on Survival and Health" (SEFS) to provide scientific information on these effects for public policy makers. The papers in this issue of Fire Technology present results from the first phase of the project: estimates of the magnitude and impact of sublethal exposures to fire smoke on the U.S. population, the best available lethal and incapacitating toxic potency values for the smoke from commercial products, the potential for various sizes of fires to produce smoke yields that could result in sublethal health effects, and state-of-the-art information on the production of the condensed components of smoke from fires and their evolutionary changes during transport from the fire.

Key words: fire, fire research, smoke, toxicity, toxic hazard, fire hazard, fire risk

1. Introduction

Fire smoke toxicity has been a recurring theme for fire safety professionals for over four decades. This is because all combustible construction and furnishing products can produce harmful smoke, most U.S. fire victims succumb to smoke inhalation [1], and the problem of how to address smoke toxicity in standards and codes has not yet been "solved."

The danger from smoke is a function of the *toxic potency* of the smoke and the *exposure* a person experiences to the (changing) smoke concentration and thermal stress over the time they are in the vicinity of the fire. Some of the effects of smoke increase with continued exposure, others occur almost instantaneously.

The concentration and distribution of smoke in a burning home, public building or vehicle depends on such factors as the chemical composition and burning rates of the products (interior finish, furnishings, etc), the rate and direction of ventilation, and actuation of a suppression system. The time of exposure is a function of, e.g., the time of detection and alarm, the design of the building, the motor capability of the people, and the presence of rescuers. The severity of the outcome depends on all these plus the sensitivity of the occupants to the chemical components of the smoke.

2. Smoke Lethality

Of the effects that smoke can have on occupants or on fire service personnel responding to the fire, the most severe is the loss of life. This has driven the development, validation and adoption of a standard laboratory-scale method (NFPA 269 [2], ASTM E1678 [3]) for measuring the lethal toxic potency of smoke form burning products for use in hazard and risk analyses.

The capability of fire safety professionals to estimate potentially lethal smoke exposures has developed extensively over the past decade. Tools like HAZARD I enable combining all the above factors and predicting the outcome of a given fire. The EXITT routine in HAZARD I, EXIT 89 [4] and EXODUS [5], for example, offer the ability to simulate people movement through a burning facility. The Fire Protection Research Foundation has developed a method for calculating fire risk by combining scenario analysis with hazard analysis [6].

Numerous hazard calculations have been performed in which the survival of occupants is the predicted outcome. In many of these cases, the predictions are sufficiently in line with the actual occurrence and are sufficiently consistent with established fire physics that the community can have some degree of confidence in this predictive capability (a) when the analyses are performed by knowledgeable people and (b) when there are proper input data for the calculations.

3. Sublethal Effects of Smoke

There have also been anecdotal reports from fire survivors telling how smoke and heat impeded their progress toward exits, caused lingering health problems, or impaired fellow occupants' escape so that they did not survive. These are the consequences of a wide range of *sublethal* effects that smoke can have on people, short of causing death directly, during their exposure: incapacitation (inability to effect one's own escape); reduced egress speed due to, e.g., sensory (eye, lung) irritation, heat or radiation injury (beyond that from the flames themselves), reduced motor capability, and visual obscuration; choice of a longer egress path due to, e.g., decreased mental acuity and visual obscuration; and chronic health effects in fire fighters. Each can limit the ability to escape, to survive, and to continue in good health after the fire.

There continue to be difficulty and controversy in assessing and addressing the contribution of these sublethal effects of smoke in hazard and risk analyses. These result from:

- the unknown number of affected people, the fire conditions under which they are affected, and the severity of their afflictions;
- the confounding of assigning causation of any lingering effects because of, e.g., inhalation of dust and other irritants encountered in normal activities;
- the tendency to ascribe toxicity to each product potentially involved in a fire, even though other factors in the fire often affect smoke yield and toxic potency more than inherent product characteristics do, and even though there are many factors, unrelated to products, that affect the conversion of toxic smoke yield at the site of the burning product into toxic smoke exposure at the site of a potential victim;

- inadequate measurement methods for and inadequate or inaccessible data on the sublethal effects of smoke and inconsistent interpretation of the existing data;
- lack of consensus on a method for measuring smoke and smoke component yields for use in fire hazard analysis and lack of accepted, quantitative relationships between exposures based on these yields and the deleterious effects on escape and survival;
- misuse of toxicity data in the competition among products; and
- differing objectives for fire safety and the cost, both public and commercial, of providing a given degree of fire safety.

As a result, product manufacturers and specifiers, building and vehicle designers, regulatory officials, and consumers are faced with persistence of this issue with little momentum toward resolution, inconsistent or inaccurate representation in the marketplace, and continuing liability concerns.

4. Need for Resolution

There is little doubt that the sublethal effects of fire smoke continue to affect life safety and that the professional community does not yet have the knowledge to develop technically sound tools to include these effects in hazard and risk analysis. This inability has severe consequences for all parties. Underestimating smoke effects could result in not providing the intended degree of safety. Erring on the conservative side could inappropriately bias the distribution and regulation of construction and furnishing materials, constrain and distort building design options, and drive up construction costs. Meanwhile, competition in the marketplace is already being affected by poorly substantiated or misleading claims regarding smoke toxicity.

5. The SEFS Project

In May 2000, the Fire Protection Research Foundation (FPRF), the National Institute of Standards and Technology (NIST), and the National Fire Protection Association (NFPA) began a major private/public fire research initiative to provide scientific guidance for public policy makers. Entitled the "International Study of the Sublethal Effects of Fire Smoke on Survival and Health" (SEFS), the project objectives are to:

1. identify fire scenarios where sublethal exposures to smoke lead to significant harm;
2. compile the best available toxicological data on heat and smoke, and their effects on escape and survival of people of differing age and physical condition, identifying where existing data are insufficient for use in fire hazard analysis;
3. develop a validated method to generate product smoke data for fire hazard and risk analysis; and
4. generate practical guidance for using these data correctly in fire safety decisions.

The project is composed of a number of research tasks under the headings of: Toxicological Data, Smoke Transport Data, Behavioral Data, Fire Data, Risk Calculations, Product Characterization, Societal Analysis, and Dissemination. The initial focus would be on incapacitation (the inability to effect one's own escape), since it is the most serious sublethal effect and since there is more quantitative information on this effect than the other sublethal effects. The five tasks in the first phase of the research were to:

- assess the potential for using available data sets (a) to bound the magnitude of the U.S. population who are harmed by sublethal exposures to fire smoke and (b) to estimate the link between exposure dose and resulting health effects;
- provide a candidate scenario and intervention strategy structure for future calculations of the survivability and health risk from sublethal exposures to smoke from building fires;
- determine the potential for various types of fires to produce smoke yields from 1/2 (incapacitating) to 1/100 (very low harm potential) of those that result in lethal exposures in selected scenarios;
- provide decision-makers with the best available lethal and incapacitating toxic potency values for the smoke from commercial products for use in quantifying the effects of smoke on people's survival in fires; and
- provide state-of-the-art information on the production of the condensed phase components of smoke from fires and their evolutionary changes that could affect their transport and their toxicological effect on people.

The six papers in this issue of Fire Technology accomplish these tasks. The authors also identify the most important research elements in an agenda to enable accurate use of toxicity information in the assessment of fire hazard and risk:

- reduction in the uncertainties in the source term for the combustibles, including rate of heat release, mass burning rate, and yields of toxic species (especially irritant gases and aerosols);
- understanding of the relationships between physiological effects of smoke exposure and escape behavior;
- enhanced information on the subsequent health of people exposed to fires;
- time-dependent yield data for typical fire-generated gases, especially irritant gases, from room-scale fires;
- toxic potency data for rats for smoke from a wide range of materials and products obtained using a validated bench-scale apparatus;
- quantitative information on the losses of toxicants for a range of realistic fires;
- identification of whether nanometer smoke aerosol can be generated in realistic fire scenarios; and
- determination of whether a cloud of water droplets forms during a fire and, if so, the conditions under which it may form and the size distribution of the droplets.

Acknowledgments

The authors thank the sponsors of Phase I of the SEFS Project: the Alliance for the Polyurethane Industry, the American Plastics Council, DuPont, Lamson & Sessions, NASA, the National Institute of Standards and Technology, Solvay, the Society of the Plastics Industry (SPI), the SPI Fluorocarbon Products Division, Swiss Institute of Safety and Security, Underwriters Laboratories, the U.S. Access Board, and the Vinyl Institute.

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