

Physiological Effects of Smoke: Managing Escape

By *Frederic B. Clarke, Ph.D.*

The entire field of smoke toxicology is only about 25 years old (Clarke 1983), so there is not a great deal of difference between a historical review and the present state of the art. Still, a series of key technical facts (and uncertainties) underpins much of today's thinking. This paper covers how those facts emerged, their implications, the spin-off disciplines to which they have given rise, and how they have shaped the current issues in the field.

Patterns of Fire Fatalities

Until after World War II, most combustibles in buildings were based on wood, paper or cotton, which are varieties of the same basic substance—cellulose. This common origin had two important consequences. Since cellulose contains only carbon, hydrogen and oxygen, its combustion products are comparatively straightforward—mainly carbon monoxide (CO), carbon dioxide (CO₂) and water. Also, since the composition of common combustibles hadn't changed appreciably for as long as anyone could remember, smoke was a known quantity. Even though it might have been fairly toxic, it was the same from fire to fire because, by and large, so was the chemistry of what was burning.

This situation changed as man-made materials began to replace the traditional ones. Smoke in building fires lost its sameness, mirroring instead the chemistry of the fuel source. Strong acids, such as hydrochloric, began to appear routinely in smoke as chlorinated materials such as polyvinyl chloride (PVC) found increasing use. The appearance of large amounts of nitrogen in plastics—nylon and urethanes, for example—prompted worries about the possible appearance of hydrogen cyanide in the smoke. Fire retardants introduced bromine and phosphorus; smoke suppressants introduced heavy metals. It was clear to those in the fire protection professions that the character of the nation's fires was changing along with the chemistry of the burnable environment (NCFPC 1974).

Although it was originally thought that this change was associated with an increase in fire deaths, this turned out not to be the case. In fact, there has been a long-term decline in fire deaths, but the character of fatal fires has been altered. Smoke inhalation has replaced heat as the primary killer (NCFPC 1974). Indeed, two multiyear studies of fire fatalities, one in the U.K. (Anderson et al. 1981) and the other in the U.S. (Berl and Halpin 1979), showed that carbon monoxide poisoning was the clinical cause of death for the majority of fire victims, with burns a distant second. There were several unexpected additional discoveries, however:

- Measured amounts of carboxyhemoglobin, the signature of CO intoxication, in the blood of building fire victims were somewhat lower than those from fatalities due to other lethal CO exposures, such as from auto exhaust or furnace leaks.

- About half the victims had blood alcohol levels sufficient to be deemed intoxicating.

- The age distribution of the victims was not what would be expected from the population as a whole—those younger than 6 or older than 60 were disproportionately represented. In fact, healthy, unimpaired adults ages 20 to 60 were rarely found to be fire fatalities.

These findings prompted investigators to conclude that other toxic combustion products, i.e., those that appear when an assemblage of materials and products burns, play a contributory role, either exacerbating the effects of CO or producing their own toxic effects, which, when added to those of the CO, produce lethal effects at lower levels. It was also suggested that the key to surviving a fire is the ability to escape: healthy, unimpaired adults usually can, but too often the young, the old, the intoxicated, and those otherwise impaired cannot. If this is the case, then another important role of combustion-related toxicants may be their interference with escape, causing potential victims to remain in the fire environment long enough to be disabled and eventually killed by the carbon monoxide.

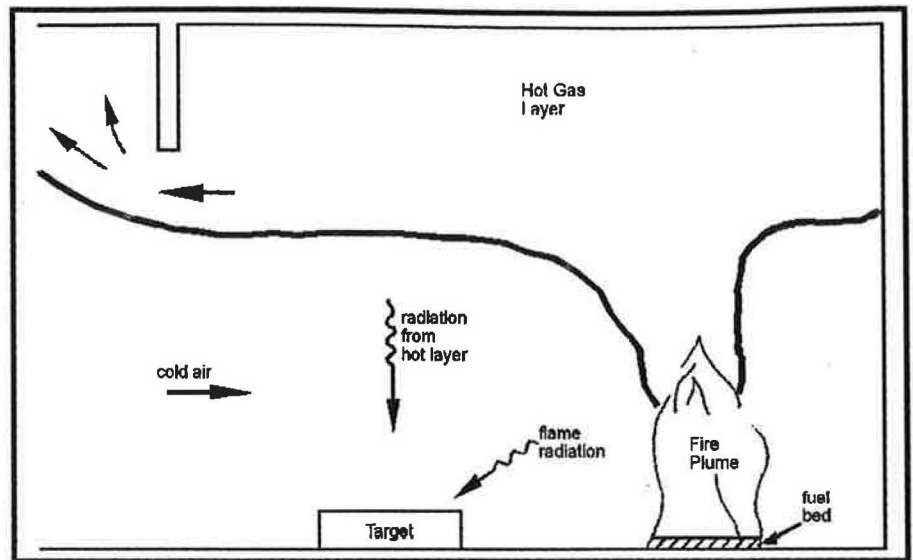
Technical Issues

In the mid-1970s, the first concerted research effort was undertaken, primarily by the federal government, to characterize smoke toxicity and to understand its connection with the U.S. "fire problem," as the nation's fire record was often called. This effort was part of a systematic program designed to reduce fire losses but to do so based on the underlying science of fire. The United States was not alone. Other nations, most notably Japan and the United Kingdom, also had sizable

About the Author

Frederic B. Clarke, Ph.D., has served since 1981 as president of Benjamin Clarke Associates, Inc., a consulting firm in Arlington, Va. that specializes in the hazards and risks associated with fire and smoke. Previously, he was director of the Center for Fire Research at the National Bureau of Standards (now the National Institute of Standards and Technology), science advisor to the U.S. Fire Administration, and on the staff of the U.S. Senate. He is a member of numerous standards committees in NFPA and ASTM, and served in the mid-1980s on the National Academy of Sciences Committee on Fire Toxicology.

Figure 1: Schematic of room fire shows the development of the hot upper layer and the flow of hot gases and air through a vent.



research efforts under way at this time. By the early 1980s, some results began to emerge that (at first, anyway) raised as many new questions as they provided answers.

Toxicological Results

It was initially supposed that wood and cellulose offered a suitable benchmark of smoke toxicity, and so, beginning in the late 1960s, some building codes carried language that smoke from building materials be "no more toxic than that from wood or paper when burned in a similar manner." As a result, much of the early research centered on a screening test, using laboratory animals, that would be suitable for making this determination.

Two test concepts were advanced more or less simultaneously: one at a U.S. university and the National Bureau of Standards' Center for Fire Research (Levin et al. 1982) and the other at another U.S. university (Alarie and Anderson (1979). Investigators were surprised to discover, however, that the two tests often gave different results for the same materials.

There are a number of reasons why this is so. First, the toxic potency of wood smoke, the standard, is not the same in the two tests. Second, different animal species have different sensitivities to smoke components, so if one test uses mice and the other rats (which was the case) the results reflect this difference. A third reason is that both tests originally tried to employ a more sensitive indicator of toxicity than lethality, reflecting the concern with escape impairment.

The result was that the "end points" of the two tests were different and not directly comparable. By far the most important reason, however, is that the smoke chemistry of most materials is strongly influenced by the details of how the material is burned (Clarke 1983). These details differ considerably in the two tests and so does the character of the smoke.

Although matching test method conditions to each other and to the full-scale conditions they are supposed to represent remains a key concern, some of the other difficulties appeared less troublesome as more was learned. For example, it was found that the sophisticated indicators of incapacitation thought necessary to model escape capability offered little information beyond what could be learned from simply measuring the combustion products' lethal toxic potency (Levin et

al. 1982), commonly called the LC_{50} (the lethal concentration for 50% of the exposed population of subjects, i.e., the smoke concentration at which half of the exposed animals die in a specified time period, usually 30 minutes).

Another important simplification was gained when experience showed that toxicity is usually controlled by one or two of the smoke's components. In other words, even though a sample might produce hundreds of different products on burning, and even though many of those in principle might be toxic, only a small number are present in high enough concentrations to contribute to the overall toxicity (Purser 1988). These gases are the same from fire to fire: carbon monoxide from the hydrocarbon moieties, hydrogen cyanide and NO_x arising from organic nitrogen, hydrogen halides from any halogenated fraction, sulfur dioxide from any sulfur present, and so forth.

The gases to look for in the burning of any specific material can usually be determined simply by examining its empirical formula. Once this is done, chemical analysis to determine the levels present and a computational scheme that corrects for binary interactions (Levin et al. 1985) are all that is required to estimate the toxic potency of the smoke. Hence, the routine use of large numbers of test animals is unnecessary.

Fire Phenomena: Flashover

Along with the toxicological work, studies were proceeding on the phenomenology of building fires, concentrating particularly on what happens as the result of fire buildup in a room. It was recognized quickly that, whether or not the smoke from modern materials was any worse than that from traditional ones, the intensity of the fires they caused certainly was. Modern building contents (upholstered furniture, for example) are characterized by heat release rates as much as 10 times those of earlier times (Babrauskas and Krasny 1985). Smoke production rates are usually much higher as well. Perhaps, the most dramatic difference occurs as a result of how these materials affect a fire's ventilation.

Because a rapid burning rate means rapid consumption of the available oxygen in the compartment, uncontrolled room fires typically reach a stage where their burning rate is governed by the rate at which new air is supplied through the doors

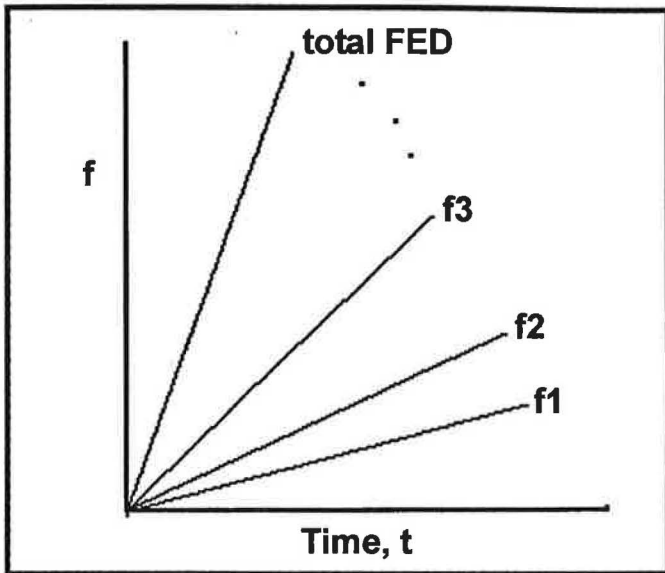


Figure 2: The time dependence of fractional and total Fractional Effective Dose (FED).

and windows. For a fire supplied with air by a typical 203 cm (80 in.) doorway, the limiting fire intensity is 2 to 3 MW (Kawagoe 1958).

The availability of air influences the products of combustion as well as the intensity of a fire. When a fire is relatively small and excess air is available, relatively little CO is formed. As the fire grows, it becomes more difficult for air to reach all parts of the flame, while the vaporizing fuel and partially oxidized products are still hot enough for further reaction. As the fire approaches its maximum size, O₂ depletion becomes pronounced, the fraction of CO in the smoke shoots up, and complex pyrolytic products are likely to appear (in particular, products that would be oxidized further if more O₂ were available).

For this reason, the toxicity of smoke from a fire usually depends on the intensity of the fire and certainly on the availability of air. A small fire might produce mostly CO₂ and water vapor and little else; smoke from the same material burning near flashover conditions can contain large quantities of CO and unoxidized pyrolytic products. Assuming adequate fuel, the amount of ventilation, not the size of the compartment, controls the fire's eventual rate of energy output.

Compartmental size does, however, influence the rate at which the fire grows and the likelihood that it will spread beyond the compartment. As the upper part of a room becomes filled with very hot combustion products, this hot layer, like the flame itself, radiates energy to the fuel bed. Figure 1 is a schematic of a room fire showing the development of the hot upper layer and the flow of hot gases and air through a vent. As the room's surfaces become hotter, they themselves begin to radiate heat back into the room.

The net result is that all combustible materials in the room are heated. If their ignition temperatures are reached before the initial fuel supply is exhausted or the fire is extinguished, burning will no longer be confined to one item; the whole room will become involved in flames. This phenomenon, called flashover, is the typical result of an unchecked fire in a residence or a commercial occupancy that contains an abundance of combustible materials. At flashover, more combustible fuel vapor

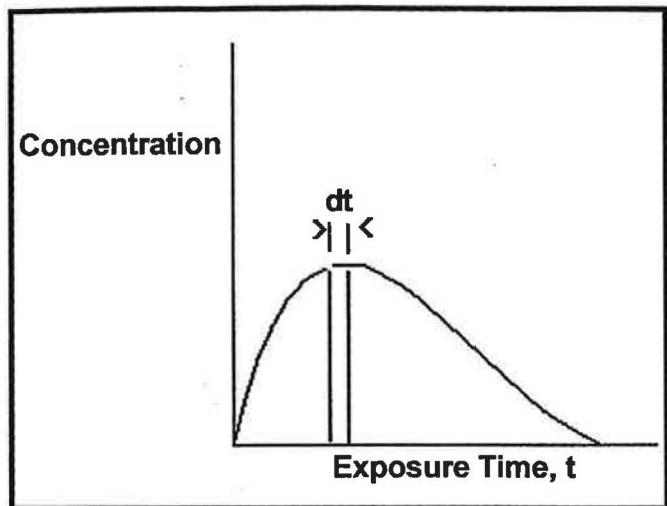


Figure 3: Typical time dependence of smoke concentration. Area under the curve is the exposure dose.

is being produced than can be consumed by the air coming in, so hot vapors are carried out the doorway, where they burn as they encounter more air. Combustible materials in adjacent spaces can then be ignited by flames emerging from the original fire compartment.

Even where such additional combustible material is not available, the production of heat will increase dramatically because additional air is available. Obviously, a flashed-over room is difficult for firefighters to approach, so there is often little opportunity to apply water to the burning fuel in the room of origin.

The consequences of any large room fire are potentially serious. The temperature of the hot gases coming out of the room as the fire approaches flashover typically exceeds 700°C (1292°F). CO content of the smoke can be as much as 10%—high enough for a few breaths to be disabling or lethal. Such a fire produces hot gases at several cubic meters per second, so an entire floor of a building can be filled with smoke within a few minutes. In such a situation, the magnitude of the hazard is dominated by the size of the fire. No matter what materials are burning, the threat is acute.

Smoke Toxicity in Large Fires

When burned under well-ventilated conditions, materials vary widely in the amount of carbon monoxide they produce. This is one of the main reasons for differences observed in toxic potencies in laboratory-scale smoke toxicity tests. When materials are burned under oxygen-deficient conditions, the amount of CO in the smoke always goes up but the differences between materials goes down. Eventually, the CO fraction approaches what appears to be a common limit of about 0.2 kg CO/kg of fuel burned (0.44 lb CO/lb of fuel burned). Thus, as a fire approaches the ventilation-limited conditions that typify flashover, the fraction of carbon monoxide in the smoke approaches the same value regardless of the detailed chemistry of the (organic) fuel (Babrauskas et al. 1991). This finding provided one of the crucial elements in a coherent scheme for managing smoke toxicity.

The other pieces fell into place when it was recognized that fires that reach flashover are approximately 10 times as dan-

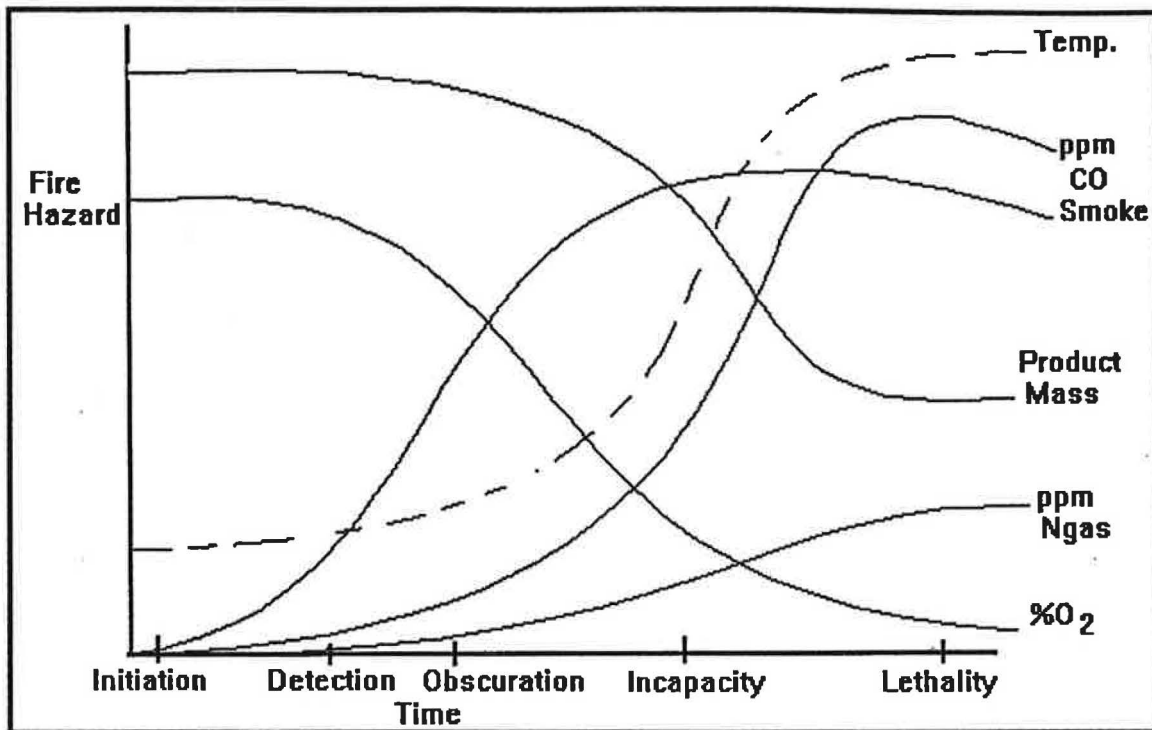


Figure 4: Typical time dependence of fire hazard components.

gerous as those that do not. By restricting their attention to this class of fire, investigators were able to reason as follows (Babrauskas et al. 1991):

- The toxicity of smoke generated in post-flashover room fires is dominated by the large amounts of carbon monoxide present.
- In such fires, all organic materials appear to produce roughly the same fraction of carbon monoxide.
- Therefore, in large fires where carbon monoxide is the dominant toxicant, there is no significant difference in the smoke toxicity of materials.

This dictum has several important corollaries (Babrauskas et al. 1991):

1. Since in most fires of real interest there is little difference in the toxicity of the smoke from one material to another, any differences in the *hazard* produced by the smoke are due to the materials' fire properties, such as ignitability, flame spread, and burning intensity, which control the amount of smoke produced.
2. Differences in the smoke toxicity of materials that are measured in the laboratory are only likely to be important in real fires if they are due to the presence of noncarbon elements, such as halogens, nitrogen, and sulfur.
3. Materials producing only CO as a toxicant should have an LC₅₀ at flashover near 25 g/m³. Since laboratory toxicity data only correlate with full-scale toxicity data within a factor of about three, a material's smoke is significantly more toxic than the norm at full scale only if its LC₅₀ is less than a third of 25, or about 8.

It is important to remember that this analysis applies only to post-flashover fires and lethal smoke conditions, not to the more subtle issues of incapacitation, which will be discussed further in the final section of this paper. Nevertheless, it provides a background against which the most important aspects of smoke toxicity can be evaluated and clears the way for a discussion of how toxic smoke hazards are assessed.

TOXIC HAZARD ASSESSMENT Overall Approach

The approach of toxic hazard assessment (IEC 1995) is to calculate the fractional effective dose (FED) of smoke associated with a fire involving the material or product whose toxic hazard is being assessed. The first step is to describe the material and how it is used. The second is to identify the detailed circumstances of the fire, including descriptions of the enclosing structure, how the fire starts and how it involves the material, the location of those persons exposed, and how they are expected to escape. The collective descriptors of a given fire constitute a "fire scenario." There is often more than one scenario that can be envisioned for a given product, and a distinct toxic hazard is associated with each scenario. (The combination of results from multiple scenarios involving their probability of occurrence is the province of risk assessment.) Once a given scenario has been identified, the bulk of the effort of toxic hazard assessment is the calculation and analysis of the FED, described below.

Fractional Effective Dose (FED)

The adverse effect of an inhaled toxicant is roughly proportional to the product of its concentration, C , and the time of exposure, t . This quantity is the "exposure dose" of the smoke produced. If the concentration of toxicant is doubled and the exposure time is halved, the exposure dose is unchanged and the toxic effect on an exposed organism is usually about the same (Alexeef and Packham 1984). The units of exposure dose are concentration \times time, usually expressed as g/m³ · min or ppm · min.

Toxic hazard assessment techniques are designed to compute the exposure dose, usually as a function of time, and to

See Clarke, Page 52

Clarke

Continued from Page 50

compare it to the toxic potency. The ratio of the two is the fractional effective dose, or FED.

$$FED = \frac{\text{exposure dose}}{\text{toxic potency } L(C+)_{50}} \quad (1)$$

The numerator is the exposure dose. The denominator is the only place in the exercise where toxic potency appears. Toxic potency data can be derived (in order of increasing confidence) from generic values, by chemical analysis, and by biological evaluations. When the actual exposure dose at the victim's location equals unity (i.e., when FED = 1), the defined toxic effect, incapacity or death, is assumed to occur.

Properties of Component and Total FED

FED is a function of:

- Fire type, stage, and size;
- Exposure time;
- Location of those exposed in comparison to that of the fire; and
- Volume of the compartment into which the effluent is dispersed.

For a given scenario, the FEDs of each burning material add up to the total FED, the toxic contribution of all burning materials to the fire effluent. Each contribution, f_i , is in turn given by:

$$f_i = \frac{[Ct]_i}{[LCt_{50}]_i} = \frac{\text{Exposure Dose Due to Material } i}{\text{Toxic Potency of Smoke from Material } i} \quad (2)$$

and total FED = $f_1 + f_2 + f_3 + \dots$ (see Figure 2).

- The relative contribution of a given material to the total toxic hazard is thus f_i/FED .
- The toxic contribution of a given material in comparison to that of a reference is $f_i/[f_s]$, where $[f_s]$ is the toxic contribution of the reference material.

Examples of the Uses of FED

- By designers of a structure or occupancy: Requiring total FED < 1 for a specified length of time provides tenability for continuity of operation escape or rescue.
- By material/product specifiers: Requiring $f_i < [f_s]$, where $[f_s]$ is the value of f for a reference material or product. Reference may be another product with toxic contribution defined as necessary.
- By regulators: Requiring $f_i < [f_o]$, where $[f_o]$ is the value of f for a reference standard or a specific design fire.

Approaches to Estimating Exposure Dose, Ct

The exposure dose is the cumulative inhaled amount of smoke from the fire. It is, strictly speaking, an integrated quantity, since the smoke concentration itself is generally dependent on the exposure time, t . (see Figure 3).

$$\text{Exposure Dose, } Ct = \int_{\text{exposure time}} C dt \quad (3)$$

There are two possible ways to determine the time profile of C :

- By direct measurement of C in a full-scale simulation of the fire scenario;
- By computing the mass loss rate of the fuels and knowing the volume into which the effluent is being discharged. (See Figure 4).

The computational method often makes use of computer-based mathematical models. These models have so far been developed for simple environments and usually require as input not only the characteristics of the fire scenario but also the time-based mass loss rate of all combustible materials exposed to the fire.

The mass loss rate of each exposed product is proportional to the exposed surface area and the radiant heat load imposed by the fire. The proportionality constant is determined for each material by laboratory measurements of the mass loss rate per unit of exposed surface area at a series of known radiant fluxes. Mass loss for a given material begins when its previously determined ignition conditions (radiant flux or temperature) are reached. Mass loss ceases when the material has been consumed (consumption time = product mass/mass loss rate).

Using mass loss rates and scenario-specific information as input, the computer code takes into account the effects of the structure, ventilation, and victim location and returns effluent concentrations with time in the compartment where the victim is located.

APPROACHES TO EXPRESSING TOXIC POTENCY

Generic Values of Toxic Potency

If one is willing to tolerate a sizable amount of uncertainty in the result, it is possible to use generic values for the toxic potency of fire effluents because the fire effluents from most materials are, within approximately an order of magnitude, the same. It has been suggested in the U.K. that 200 g-min/m³ be used as reference for predicting incapacitation and 500 g-min/m³ for predicting lethality (Purser n.d.).

Toxic Potencies from Chemical Analyses

The reference toxic potencies of the major fire gases are known from previous biological tests. These data support hazard assessment based on chemical analyses of fire effluents that avoids routine use of animals, relying upon the fact that the toxic potencies of all common individual gases generated in fires have already been determined by animal exposure.

Specific Toxic Potencies from Animal Tests

The foregoing are both only approximations of toxic potency. In reality a typical material, when burning, produces a mixture of toxic substances. These combustion products can interact chemically with one another and biologically once inhaled. Burning the material and exposing the animal to the effluent captures the effects from any such interactions, most of which are not predictable from chemical analysis. In large fires near flashover, however, chemical analysis is, as already described, usually "close enough."

CURRENT ISSUES

Technical

Most of the work done on smoke toxicity to date has concentrated on agents that do biological damage when inhaled,

See Clarke, Page 54

Clarke

Continued from Page 52

and so dose (concentration \times time) is the appropriate quantity to control. This is even true if the effect one seeks to monitor is incapacitation, i.e., the impairment of escape, so long as the route to incapacitation is inhalation.

However, there is another type of impairment as well: that caused by irritation of sensitive tissues, such as the eyes or the lungs. These effects are not the result of uptake but rather of the

concentration of the agent in the smoke. It has long been suspected that such irritants have important effects on escape, but quantifying them and setting allowable limits on irritant gases has been difficult and is still under active investigation (Kaplan et al. 1985).

Regulatory: Control of Materials

In the past it was common to promote toxicity testing as a means of identifying materials that, when subjected to thermal decomposition, yield combustion effluents characterized by "unusually" high toxic potency (Clarke 1983; NCFPC 1974).

Such instances now appear to be rare, unknown in fact, outside the laboratory.

The presence or absence of specific chemical elements such as nitrogen, halogen, or phosphorus in the product is no indicator, by itself, of the level of toxic hazard. It is now recognized that lethally toxic environments are almost always caused by elevated concentrations of fire effluents rather than by specific components of the effluent with unusually high or extremely toxic potencies.

The conclusion generally is the same whether the toxic potencies of individual components fall in a normal range or elevated range. Therefore, no conclusions should be drawn from the presence or absence of a particular toxic chemical species in the fire effluent. Conclusions on the significance of the threat posed by a fire and its effluent require hazard assessment to evaluate and integrate all threat factors such as heat, smoke, toxicity, and oxygen depletion in a time-dependent, quantitative way.

Indeed, toxic potency test results should not be interpreted directly to rank materials. No conclusions can be drawn or safety decisions made until after all relevant fire test and fire scenario data have been incorporated into an appropriate quantitative hazard assessment framework.

References

Alarie, Y., and R.C. Anderson. 1979. Toxicologic and acute lethal hazard evaluation of thermal decomposition products of synthetic and natural polymers. *Toxicol. Appl. Pharmacol.* 57: 181-188.

Alexeef, G.V., and S.C. Packham. 1984. Evaluation of smoke toxicity using concentration-time products. *Journal of Fire Science* 2: 362-779.

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See Clarke, Page 56

March, 1997

Clarke
Continued from Page 54

Anderson, R.A., A.A. Watson, and W.A. Harland. 1981. Fire deaths in the Glasscow area II. The role of carbon monoxide. *Med. Sci. Law* 21: 288-294.

Babrauskas, V., and J. Krasny. 1985. Fire behavior of upholstered furniture. *NBS Monograph* 173, 101 pp. Gaithersburg, Md.: National Bureau of Standards (now NIST).

Babrauskas, V., et. al. 1991. Toxic potency measurement for fire hazard analysis. NIST Special Publication 827, 103 pp. Gaithersburg, Md.: National Institute of Standards and Technology.

Berl, W., and B. Halpin. 1979. NBS grant/contract report. NBS GCR 169. Gaithersburg, Md.: National Bureau of Standards (now NIST).

Clarke, F.B. 1983. Toxicity of combustion products: Current knowledge. *NFPA Fire Journal* 77(5).

IEC. 1995. IEC 695-1-1. Geneva: International Electrotechnical Commission.

Kaplan, H., et al. 1985. Effect of combustion gases on the escape performance of the baboon and the rat. *Journal of Fire Science* 3: 288-344. Kawagoe, K. 1958. Fire behavior in rooms. *Report of the Building Research Institute*, no. 27, 72 pp. Tokyo: Building Research Institute.

Levin, B.C., A.J. Fowell, M.M. Birky, M. Paabo, A. Stolte, and D. Malek. 1982. Further development of a test method for the assessment of

the acute inhalation toxicity of combustion products. NBSIR 82-2532, 133 pp. Gaithersburg, Md.: National Bureau of Standards (now NIST).

Levin, B.C., M. Paabo, C. Bailey, S.E. Harris, and J.L. Gurman. 1985. Toxicological effects of the interactions of fire gases and their use in a toxic hazard assessment computer model. *The Toxicologist* 5: 127.

NCFFPC. 1974. American burning, the report of the National Commission on Fire Prevention and Control, 186 pp. Washington, D.C.: National Commission on Fire Prevention and Control (available from U.S. Government Printing Office).

Purser, D.A. 1988. In *SFPE handbook of fire protection engineering*, 1st ed., pp. 1-201. Quincy, Mass.: National Fire Protection Association.

Purser, D. n.d. Draft guidance document (in press). London: British Standards Institute

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