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Evaluating the Toxic Hazard of Fires

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Please note

Fire statistics reveal that inhalation of thermal decomposition products (smoke, gases and vapours) is responsible for the majority of fire deaths. Many new materials release harmful decomposition products very rapidly, and some of them are much more toxic than those generated by traditional materials. With their increased use as both building materials and furnishings, the problem of toxic products of combustion has become a subject of very real concern. This Digest briefly discusses two major types of laboratory assessment of fire toxicity and some of the problems encountered in developing standard methods of evaluation.

Background

General information regarding toxic products of combustion presented in an earlier Digest (**CBD 144**) is condensed in Table I. Smoke and toxic gases and vapours usually occur together at fires, so that it is difficult to distinguish the contribution of the two types of combustion product to the hazard. It is useful, however, to define them. Smoke is particulate matter consisting of very fine solid particles and condensed vapour. It constitutes most of the visible part of the products of combustion observed at a fire. Gas is a product of combustion that remains in a gaseous state even when cooled to normal building temperatures. Vapour is a product of combustion that is gas when produced but reverts to solid or liquid at normal temperatures. Vapours gradually condense on cool surfaces as they migrate from the fire.

Table I. Main Harmful Products of Materials and General Harmful Effect*(*More details in CBD 144)

Material	Harmful Product	Harmful Effects
Wood and paper	Carbon Monoxide(CO)	Dangerous concentration 4000 ppm of air (30 min)

Polystyrene	CO	also styrene, but present in smaller quantities	
Polyvinyl Chloride (PVC)	HCl CO	also corrosive	Dangerous for even short exposure 1000-2000 ppm
Plexiglas or perspex	CO	also methylmethacrylate, which is as toxic as CO but produced in smaller quantities	
Polyethylene	CO		
Acrylic Fibres Wool Nylon	Hydrogen Cyanide (HCN) CO		120 - 150 ppm

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The main danger from smoke is reduced visibility; that from toxic gases and vapours, their adverse effect on body functions. Smoke can impede the escape of occupants from a burning building, prolonging exposure to the harmful effects of toxic products. Toxic gases and vapours can cause death if they are present in sufficient quantities and for a sufficient time. Some can also trap occupants by acting as irritants. For example, small concentrations of hydrogen chloride and ammonia cause direct irritation of the respiratory tract and the eyes. Although irritants may serve as warning agents and alert occupants to fire, they can under certain circumstances prevent victims from finding an exit even before reduced visibility from smoke traps them.

The life hazard associated with toxic combustion products was recognized by the fire service many years ago and almost all modern fire departments are now equipped with self-breathing apparatus. The danger to occupants of buildings is also recognized, but so far it has appeared impractical to reduce this risk by limiting the use of materials that have a high propensity for releasing harmful products. In recent years various new materials, especially synthetic polymers, have found increasing use in buildings and their introduction has heightened the concern of fire authorities with reference to toxic combustion products. Part of this increased concern has risen because of the lack of information on toxic combustion products and the problem of assessing their potential hazard.

Laboratory Studies

At present, two main types of laboratory study of fire toxicity are undertaken: chemical analysis of decomposition products and biological tests involving animals. The two approaches complement each other in the development of information relevant to toxic hazard at fires.

Chemical Analysis

The types and quantities of toxic gases and vapours produced by combustion depend on the materials involved and on environmental conditions. Some toxic products are already known; others can often be predicted from a knowledge of the chemical composition and molecular structure of the organic compounds.

Detailed analysis of decomposition products from synthetic materials is very difficult because the materials break down into many compounds. Analysis of the pyrolysis products of cellulose, for example, has revealed some 175 different organic compounds. Because of this the researcher must arbitrarily decide how detailed the analysis should be, and despite recent advances in analytical techniques the work continues to be very time-consuming. At present, detailed analysis cannot keep pace with the rapid development of new organic materials.

Comprehensive chemical analysis is necessary for the identification of unusual toxicants, and is usually undertaken following evidence that a given material is capable of releasing extremely harmful decomposition products. For most practical applications, however, it is not necessary. Testing for a few of the most important known toxicants often gives sufficient information. Some compounds such as carbon monoxide, hydrogen chloride, hydrogen cyanide, sulphur dioxide and oxides of nitrogen are recognized as harmful products; others such as water vapour and the hydrocarbons contribute little or no toxic hazard. It is usually sufficient to decompose materials under specified conditions and determine the resulting concentrations of a few of the most important toxicants. From this information a reasonable indication of the toxicity of the mixture of products can be obtained. This is the essence of the toxicity index concept.[1]

Biological Assessment

The evaluation of fire toxicity of materials by exposing small animals, notably mice and rats, to decomposition products is being undertaken in several countries, but not in Canada at the present time. Such studies include both sophisticated research dealing with the effects of harmful decomposition products on the biological system and simple screening tests using animals for evaluation of toxicity.

Fire toxicology is much less advanced than many other areas of toxicology. Although standard approaches have been developed for evaluating toxicity of food additives, drugs, cosmetics and pesticides, no standard method is yet available for evaluating the combustion/pyrolysis products released by materials. Experimental data show that ranking of relative toxicity based on biological assessment is significantly different for different decomposition procedures, a fact that should not be surprising since the influence of experimental conditions on ranking of materials has been observed in studies of other fire characteristics such as rate of heat release, spread of flame, and smoke density. The development of a test that will rank materials according to toxic hazard in actual fires is needed, but it does not seem possible at present. A test that will determine toxic hazard under one or more specified conditions, with little relevance to actual fires, may be the best that can be hoped for in the near future.

Another complication of designing screening tests is that of controlling the temperature and oxygen concentration to which animals are exposed. It is important to ensure that the test determines the effect of toxic products alone, and that complications introduced by temperature stress or reduced oxygen concentration are avoided. Separating the apparatus that produces the thermal decomposition products from the animals is probably the best means of coping with the problem. Its disadvantage is the possible loss of important toxic components during transfer of the combustion products to the animals.

In exposing small rodents to decomposition products and observing their response, the most common endpoints of the experiments are death or incapacitation. Incapacitation seems a more meaningful endpoint than death since it is related to escape capability. The experimental results are often reported on the basis of LD_{50} or LC_{50}, the dose or concentration of products required to kill or incapacitate, respectively, 50 per cent of the animals. Various methods of assessing incapacitation have been reported, but at the present time there is no agreement as to the best way to determine it.

Comparison of Methods of Assessing Fire Toxicity

The principal advantage of the chemical method of assessing toxicity is its convenience. Any laboratory engaged in fire research will be equipped to duplicate the very wide range of

environmental conditions under which materials are decomposed in actual fires. As conditions can be reproduced exactly, results can be verified. The method holds potential for limiting specific elements in various products. For example, it could be used to control the amounts of chlorine or nitrogen in materials for specific applications.

There are limitations, however. As toxicological data are not available for many of the compounds produced as thermal decomposition products, it is not always possible to assess toxicity adequately. Neither is it possible to analyse all the combustion products found in a fire atmosphere, and small quantities of extremely harmful products may be overlooked. Another unknown factor is the effect of any interaction of decomposition products on the over-all toxicity of a mixture of products.

It is for these reasons that there is need for animal exposure tests, for which special facilities and expertise outside the usual range are necessary. This method permits comparison of all materials and study of all toxic components generated under specified conditions. Such an approach could identify materials that generate extremely harmful decomposition products when they burn and thus provide a basis for ensuring that they will not be marketed. It is difficult, however, to develop a method of ranking materials in order of toxic hazard by means of animal exposure tests.

Regulation of Fire Toxicity

There are no regulations in Canada limiting the use of materials that generate large amounts of toxic decomposition products. Two organizations are, however, expected to play an important role in any consideration of the regulations on this subject: the Department of Consumer and Corporate Affairs and the National Research Council of Canada. The former, through the Hazardous Products Act, has a mandate to withdraw from the market any goods considered a danger to public safety. The latter sponsors the Associate Committees on the National Building Code and the National Fire Code. Both agencies will consider the promulgation of regulations on fire toxicity if evidence can be shown of need for such requirements and if a suitable method of assessing the hazard becomes available.

In the United States, both the Uniform Building Code 1976 and the BOCA Basic Building Code 1975 have toxicity requirements. Initially, the Uniform Building Code requirement was applied only to plastics, but this has been extended to other interior finishes for walls and ceilings. It reads, "The products of combustion shall be no more toxic than those of untreated wood when burned under similar conditions." The BOCA Basic Building Code requirement is similar. Unfortunately, enforcement of toxicity regulations in both Codes is handicapped by the lack of a standard test method that can verify whether a material will meet the specified requirements.

A new toxicity regulation limiting the use of certain materials and products in public establishments was announced in France in January 1977. It is intended to control the production of hydrogen chloride (HCl) and hydrogen cyanide (HCN) during fires in buildings by limiting the use of materials containing chlorine and nitrogen. The regulations apply to decorative materials, to curtains, interior finishes for walls, ceilings and floors, fixed furniture and elements making up false ceilings. They do not apply to insulation materials covered with a thermal barrier having a finish rating of not less than 15 minutes, to movable furniture, or to electric and telephone fittings.

In Japan the use of materials for building construction is controlled by the Building Law. Certain materials to be used in fire-resistive buildings must comply with heat release, smoke density, and fire toxicity requirements before they can be certified by the Ministry of Construction. This toxicity regulation has been in the Building Law since 1969, but there was no test to enforce the requirement until April 1977 when a new test based on biological assessment was adopted. The specimen material is heated in a furnace and the decomposition products are transferred to a mixing chamber before being fed into an animal exposure chamber where mice are placed in individual rotary cages. The test determines time to incapacitation, which is defined as the time at which the test animal ceases to rotate the cage. The test specifies that the combustion

products generated by a material under specified conditions must be less toxic than those generated by red lauan board, which is the reference standard.

Regulatory authorities are handicapped by a lack of recognized standard methods of assessing the toxic hazard of materials involved in fire. The Committee on Fire Toxicology of the U.S. National Academy of Sciences has reviewed the methods of studying toxicity of combustion products of polymeric materials used on aircraft, spacecraft and other transportation systems.[2] It has observed that acceptable screening tests to evaluate the toxicity of pyrolysis and combustion products of aircraft materials are not currently available; all the methods examined have one or more shortcomings. The Committee has concluded that "the state-of-the-knowledge in fire toxicology precludes the establishment of a standard protocol for screening materials."

The International Organization for Standardization (ISO) has also been concerned with the problem of developing test methods and recommended practices for evaluating the toxic hazard associated with fires. A working group of Technical Committee 92 on Fire Tests on Building Materials and Structures has prepared a state-of-the-art review of combustion toxicology and recommended the establishment of an ISO committee through which suitable standards can be developed. This recommendation was accepted by TC 92 at the Plenary Session held in September 1977. The Technical Committee has agreed to give priority to the preparation of a test method for the toxicological assessment of combustion products to assist in identifying materials capable of producing acute toxicity in fire.

Summary

Although considerable effort is being directed towards developing recommended procedures or standard methods of evaluating the fire toxicity of materials, there is as yet no accepted standard method. Until it becomes available it is difficult to have definite recommendations and regulations concerning the use of materials known to generate significant amounts of toxic decomposition products.

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