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Toxicity testing of fire effluents -- Part 1: General

Essais de toxicité des effluents du feu -- Partie 1: Généralités

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TECHNICAL REPORT

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Toxicity testing of fire effluents —

Part 1 : General

Essais de toxicité des effluents du feu —

Partie 1 : Généralités

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Contents

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work.

The main task of ISO technical committees is to prepare International Standards. In exceptional circumstances a technical committee may propose the publication of a Technical Report of one of the following types:

— type 1, when the necessary support within the technical committee cannot be obtained for the publication of an International Standard, despite repeated efforts;

— type 2, when the subject is still under technical development requiring wider exposure;

— type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standards ("state of the art", for example).

Technical Reports are accepted for publication directly by ISO Council. Technical Reports types 1 and 2 are subject to review within three years of publication, to decide if they can be transformed into International Standards. Technical Reports type 3 do not necessarily have to be reviewed until the data they provide is considered no longer valid or useful.

ISO/TR 9122 was prepared by Technical Committee ISO/TC 92, *Fire tests on building materials, components and structures.*

The reasons which led to the decision to publish this document in the form of a technical Report type 3 are explained in the Introduction.

ISO/TR 9122 will consist of the following parts, under the general title *Toxicity testing of fire effluents*:

— *Part 1: General*

— *Part 2: Guidelines for biological assays to determine acute inhalation toxicity of fire effluents: basic principles, criteria and methodology*

— *Part 3: Methods for analysis of gases and vapours*

— *Part 4: Fire models*

Annexes A and B of this Technical Report are for information only.

Introduction

This Technical Report is intended as useful background information regarding the current state of the art of the development of tests for assessing the toxicity of fire effluents.

It outlines the current philosophy behind the development of tests and indicates how the tests might be used as a contribution in determining the overall toxic hazard, drawing attention to the essential need to take account of information from other fire tests to assess the overall fire hazard.

The report is designed to replace ISO/TR 6543 [1] prepared by an earlier Working Group (WG-12) reporting directly to ISO/TC 92 and published in 1979. The technical report format is retained as being appropriate within ISO for a subject which continues to be under discussion and where the possibility exists of agreement for the preparation of an International Standard at a future date.

The document describes the evolution of thinking on the question of toxic hazards since the publication of the ISO/TR 6543 [1], and attempts to identify clearly those areas where general agreement has been reached and those where divergencies in expert opinions continue to be expressed.

At the time of preparation of this Technical Report, advances are being made within ISO/TC 92/SC3 in identifying the criteria and considering appropriate methods for producing fire atmospheres (fire models), in the biological assessment of toxicity (bioassay methods), in bioanalytical modelling and in analytical techniques for assessing known toxic species in fire gases and laboratory methods.

Considerable emphasis has been directed towards the philosophies expressed within WG-12 of ISO/TC 92 and the more recent WG-4 of ISO/TC 92/SC3. It is recognized that these Working Groups have provided fora for debate by experts nominated by Standards Bodies throughout the world and with international reputations. Knowledge of the differing viewpoints which have been expressed by these experts is essential background to all those who are involved in any way with possible test procedures for assessing the toxicity of fire effluents.

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Toxicity testing of fire effluents —

Part 1: General

1 Scope

The purpose of this part of ISO/TR 9122 is to provide an up-to-date review of the philosophies prevailing on the question of the development of tests for assessing toxic hazards in fire. It presents the state of the art in 1987.

This present report is designed to provide essential information to all those involved with the evaluation of the toxicity of fire effluents not only in the development of meaningful test procedures but also in their use for mitigating hazards.

2 Definitions and abbreviations

For the purposes of this Technical Report, the following definitions apply.

2.1 fire effluent: Total gaseous, particulate or aerosol effluent from combustion or pyrolysis.

2.2 toxicity: Nature (effect) and extent (potency) of adverse effects of a substance upon a living organism.

2.3 toxic hazard: Danger caused to people in fire situations by the formation of toxic products with respect to their nature, quantity, rate of production and concentrations.

2.4 toxic risk: Likelihood that a toxic hazard will occur.

2.5 specific toxicity: Particular adverse effect caused by a toxicant, e.g. narcosis, irritancy.

2.6 toxic potency: Measure of the amount of toxicant required to elicit a specific toxic effect: the smaller the amount required the greater the potency.

2.7 fire model: Means for the decomposition and/or combustion of test specimens under defined conditions to represent (a) known stage(s) of fire in order to generate fire effluents for toxicity assessments. (This term is also used by the fire science community in the mathematical simulation of fire characteristics.)

2.8 pyrolysis: Irreversible chemical decomposition caused by heat, usually without oxidation.

NOTE — This is the 1980 ASTM definition. In the USA, this term is often used to refer to both oxidative and non-oxidative non-flaming conditions when an external heat source is present.

The following abbreviations are used in the text:

Carbon monoxide	CO
Carbon dioxide	CO_2
Oxygen	O_2
Hydrogen chloride	HCl
Water	H_2O
Hydrogen cyanide	HCN

3 General

3.1 Historical background

The toxic effects of exposure to fire effluents were probably observed by prehistoric man on the first attempt to move fire into a cave. The contribution of carbon monoxide to the toxicity of fire effluents has been recognized for more than a century, but it was not until 1951 that an extensive medical-physiological investigation on *The Toxicology of Fire* was reported by Zapp [2]. Animal experiments were directed towards distinguishing quantitatively between the effects of direct flame exposure (skin burns and respiratory burns), generalized heat stress, and toxic factors — including carbon monoxide, carbon dioxide, oxygen depletion, and other toxicants. While carbon monoxide was found to exert the predominant physiological effect in a wide range of natural and synthesized fire effluents, the experiments showed strong evidence of interactions among all chemical and thermal stress factors including simple heat stress.

Rapid expansion of research in polymer science during the 1950's resulted in a substantial growth in chemical and toxicological information relating to fire. A 1963 *Survey of Available Information on the Toxicity of the Combustion and Thermal Decomposition Products of Certain Building Materials under Fire Conditions* [3] listed 297 references. Further expansion of this data base has continued to the present day with major emphasis, from a philosophical point of view, on supplying the fundamental facts upon which any science depends.

In the late 1960's and early 1970's research was increasingly devoted to study of laboratory test methodologies. While fundamental understanding of fire remained as an implicit goal of combustion toxicology, increased emphasis was directed toward attempts to define specific test procedures which might serve to rank, rate, or classify materials with respect to fire safety. Significant studies have been undertaken for example in Germany by Reploh and co-workers [4] and Hofmann and Oettel [5]. A fundamental contribution to the acute inhalation toxicology of combustion products was given by Kimmerle at the 1973 Polymer Series Conferences of the University of Utah [6]. The dual objectives — understanding fire threat and testing materials — were clearly evident in the range of papers presented at the "International Symposium on Toxicology of Combustion Products" held at the University of Utah in 1976. By this time, more than a dozen significant studies had been reported [7] originating in Belgium, France, Germany, F.R., Japan, United Kingdom and United States. The general test philosophy of this period was reviewed by Birky in 1976 [8].

Following publication of the studies noted above, several independent assessments, including one by the US National Academy of Sciences [9], expressed a need to make sure that any projected use of test results should be consistent with an understanding of the shortcomings and limitations of this type of testing. This philosophy has superseded the previously held view that results of toxicity tests could be used directly to provide a ranking order of toxic hazards in fire.

There is also increasing emphasis of the role of toxicological testing as a contributor to hazard analysis/risk assessment for materials rather than as a direct decision-making fire standard. This is consistent with the clear distinction between toxicity and hazard in classical toxicology [10] and is generally embraced by combustion toxicologists, as expressed by Anderson and Alarie in 1978 [11].

Tests were directed in the past to identifying materials which on burning give rise to unusually toxic products[1]. These terms were subject to different interpretations and have been replaced by two more precise terms: products of

— "unusual specific toxicity" which refers to products exerting types of toxic effect not normally encountered in fires (i.e. other than narcosis or irritance); and

— "extreme toxic potency" when the toxicity of the products is much greater on a mass/mass basis than the toxic potency of products usually encountered in fires.

3.2 State of the art reviews of combustion toxicology

An extensive review of the state of the art of combustion toxicology has recently been completed by members of the staff of the Department of Fire Technology at Southwest Research Institute, San Antonio, Texas. Results of this comprehensive study (174 pages) have been published under the title *Combustion Toxicology — Principles and Test Methods* [14]. This document is an expanded version of a report submitted to ASTM Committee E-5 on Fire Standards *A Critical Review of the State of the Art of Combustion Toxicology.* The review of test methods is international in scope and contains extensive comments on advantages and disadvantages of each method as seen by the authors. While the opinions and conclusions presented have not been submitted to consensus processes within either ASTM or ISO, the factual content alone should be very valuable to anyone seeking a better understanding of what can — or cannot — be expected from test data in combustion toxicology.

Another study of similar scope and depth entitled *An Analysis of Current Knowledge in Toxicity of the Products of Combustion* [15] has been recently made available by NFPA (National Fire Protection Association). This study provided background for a summary report from the NFPA Committee on the Toxicity of the Products of Combustion to the NFPA Standards Council.

Both the Southwest Research Institute and the NFPA studies concurred in the conclusions that "the current tests for toxicity of products of combustion are inadequate for regulatory purposes" and "toxicity should be a part of a fire hazard assessment" [16].

3.3 Current position

At the end of 1982, a consensus was reached in WG 4 that there was a need to attempt to integrate toxicity and combustibility information (and not to use toxicity information by itself as a basis for decisions on materials).

No consensus has been reached regarding suitable timing, or, more appropriately, what must be accomplished before it would be wise to propose that a toxicity test procedure be put forward as a Draft International Standard. Despite this there has been agreement that the ISO Working Groups should continue to work towards a DIS dealing with problems as appropriate.

4 Life threat in fire

4.1 General aspects

Although this Technical Report is concerned primarily with the toxic hazards associated with fire, the inability of victims to escape from fire atmospheres is often considered in terms of three major hazard factors:

a) smoke: obscuration of vision;

b) heat;

c) toxic factors: narcosis and irritancy.

Attempts have been made to define the limits of human ability to function and ultimately to survive fires in terms of "tenability limits" for each of the toxic factors (see annex B). It has been suggested that the point at which life or death is determined in a fire is the point at which the first tenability limit is reached. Thus some experimental room fires have been reported in which the tenability limits were reached in a definite sequence and in the order shown above.

However for many fires, there is a considerable question as to the feasibility of dealing precisely with the above factors as separate entities when there is evidence that they usually function in combination.

1) Formerly referred to as "super toxicants".

Thus smoke, which impairs escape ability by obscuration, also contains toxic products which irritate the eyes causing further impairment of vision. Similarly heat stress, severe irritation and narcosis may occur simultaneously in flaming room fires causing profound physical incapacitation, while ultimately the effects of narcotic gases, hypoxia due to oxygen depletion, or heat may cause death.

Thus we can conceive of "toxic hazard" in a general way as that aspect of hazard arising from toxic factors, but it is not at all clear that toxic hazard can ultimately be differentiated quantitatively from overall fire hazard.

In addition the life threat of fire atmospheres is greatly aggravated by special circumstances. Fire is especially hazardous to infants and children, the elderly, invalids, and those whose abilities are impaired by alcohol or drugs. Fire is also a special problem for people in unfamiliar surroundings and in locations where escape is physically blocked or impeded.

4.2 Trends in fire statistics

Fire statistics from the UK covering the years from 1955 to 1971 showed a significant increase in the number of fatal and non-fatal casualties reported as "overcome by toxic gas or smoke". Specifically, Bowes [17] reported a fourfold increase in fatal casualties arising from toxic gas and smoke over that period. Comparable statistics from other countries over these particular years are not available. Historically, however, the UK statistics raised the question of whether the increase in smoke inhalation casualties might have been related to an increased use of modern synthetic materials in furnishings over the same interval.

While fire fatalities attributed to smoke and toxic gases in the UK have continued to increase, the rise has been less dramatic since 1971. Japanese statistics since 1968 and USA statistics since 1977 have not reflected a rise in smoke inhalation fatalities in the recent past.

The early UK statistics, however, have had significant historical impact. There are two views typically advanced in explanation of the 1955 to 1971 UK data:

a) that the composition of fire products has changed so that the smoke from "modern" fires is more toxic on a mass/mass basis than is the smoke produced by "traditional" materials (e.g. wood, wool, cotton), and that the presence of unknown toxicants may account for the fact that persons are now more likely to be overcome and fail to escape from a fire;

b) that the composition and toxicity of fire products has changed little, if at all, but that the rate of fire growth is much more rapid and the rate of evolution of products is much greater than previously.

However in considering these views it should be borne in mind that fire loads may have increased in typical residential living spaces. Also it has been suggested that the statistics may be influenced by changes in the reporting of fires, and that actual fires may not have changed as much as appears.

Information which might be of use in understanding the causes of fire death and injury derive from a number of sources. The information gathered by fire agencies consists mainly of information on the origin and extent of fires and the position of victims, which is of limited use in the understanding of toxic hazard in fires, but when this information is taken in conjunction with data from large scale experimental fires it is possible to make some assessment of effects on fire victims. Other data are derived from pathological studies of fire fatalities [18]. Accounts by fire survivors and the experiences of fire-fighters are promising potential sources of information for understanding the toxic effects of fire atmospheres, although no systematic studies have been published and such information is largely anecdotal.

The main toxic products identified in fires fall into two classes: narcotic gases, which can cause narcosis and death, and irritants which cause incapacitation mainly by effects on the eyes and upper respiratory tract. The latter effect may impair escape capability and sometimes cause death in victims surviving the immediate exposure due to lung damage.

Both of the main narcotic gases known to appear in fires, CO and HCN, have been measured in the blood of both fatal [18] and non-fatal [19] fire casualties. Relatively little is known of exposure to irritant products since these are difficult to identify in the blood as having come from a fire (e.g. HCl, aldehydes). However Treitman et al. and other workers have detected high concentrations of acrolein in some real fire atmospheres [20], [21].

Of the narcotic gases, CO is undoubtedly the most important and produced lethal blood concentrations of carboxyhaemoglobin (> 50 %) in 54 % of fire fatalities in the recent pathology study [18] at Glasgow of the Strathclyde region of Scotland, while some 70 % of victims had carboxyhaemoglobin concentrations capable of causing incapacitation (> 30 % carboxyhaemoglobin), and all the remaining cases except two had burns sufficient to cause death. The contribution of HCN to fire deaths was more difficult to assess since high blood cyanide concentrations were almost always accompanied by high blood carboxyhaemoglobin concentrations in victims, but the blood of 24 % of victims contained sufficient cyanide (> 50 μmol/l) to have had some incapacitative effects and in 5 % of cases to have been life threatening (> 100 μmol/l) [22]. The other major factor associated with fire deaths in this study was a high blood alcohol concentration (42 % of victims), although this factor was found to be less significant in the United Kingdom as a whole.

Some 40 % of fatalities in the Glasgow study had pulmonary haemorrhage which may have been caused by chemical irritants rather than by heat. However, the role of irritants in producing incapacitation in fires is poorly understood, and there is little published human data on the effects of eye and respiratory tract irritance on escape capability, particularly in fires. Combinations of GC-mass spectrometer analysis of combustion product atmospheres with animal exposures are beginning to identify some of the important components [23].

However, another point that emerges from the Glasgow study is that there was no significant group of fatal victims for which death could not be attributed to either CO or burns. There was no evidence that substances of unusual specific toxicity are important in fires, although their existence cannot be ruled out. It