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Toxicity testing of fire effluents —

Part 1 : General

iTeh STANDARD PREVIEW

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Partie 1 : Généralités

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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 Standard ("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 Technical Reports type 3 do not necessarily have to be reviewed until the data they provide is considered no longer valid or useful.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 ₂ O
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 products¹⁾. 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 irritation); 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 irritation 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

must be remembered that although most fatal victims have burns or high blood carboxyhaemoglobin concentrations, this does not prove that either agent was responsible for the initial incapacitation. Nevertheless the evidence from real fires and fire casualties, when taken with data from experimental fire and combustion toxicity studies, suggests that substances of unusual specific toxicity are not important. The major toxic product formed in fires causing incapacitation and subsequent death is CO, with a possible contribution from HCN in some cases [18]. In addition, irritants are likely to play an important part in delaying escape by effects on the eyes and upper respiratory tract and possibly also on the lungs. Also there has been no significant change in the toxicity of fire products that could account for the increased incidence of incapacitation and deaths. The problem in understanding this most probably lies in the way in which the basic products (including carbon monoxide) evolve in modern fires.

4.3 Fire scenarios and victim incapacitation

Data from fire statistics show that the vast majority of fire injuries and deaths occur in domestic dwellings (80 % in both the UK and US) while a small proportion of injuries (20 %) and deaths (10 %) occur in other buildings such as shops, hotels, hospitals and clubs.

There are two different circumstances in which casualties due to toxic combustion products occur, those in the compartment of origin of the fire and those remote from it. In each case the hazards may arise from non-flaming or flaming combustion.

Statistics in the UK indicate that, with fires in domestic premises and in transport fires, most of the casualties occur in the compartment of origin of the fire. For fires in dwellings in the UK this class of fire is responsible for the highest incidence of deaths (60 %) and a high incidence of injuries (39 %) and these fires occur mostly in living rooms or bedrooms and in upholstery or bedding. In these cases the material first ignited may be responsible for the toxic environment, the fire not yet having spread to other materials, there is no thermal flux external to the burning material and the burning or smouldering is sustained by its exothermic nature.

The USA statistics for the years 1980 to 1983 indicate that most of the fatalities from smoke only occur outside the room of fire origin (21 % in the room of fire origin and 77 % outside the room). The reason for this may be linked to differences in the reporting procedures between the UK and USA, due to the inclusion of "joint burn and smoke" victims with "smoke" victims in the UK.

The toxic hazard in such fires depends upon whether there is a long period of smouldering, or whether there is a rapidly growing flaming fire.

With smouldering fires there may be ample time for escape if alerted sufficiently early but persons may be overcome by fumes, particularly carbon monoxide, after a long period of time, if unaware of the danger. It is not possible from fire statistics to determine how common this type of fire is, since in many cases smouldering fires become flaming fires before they are detected. However it is likely that fires which are estimated to have burned for 30 min or more before discovery have involved long-term smouldering and it may be significant that deaths are much more likely in this class of fire.

For flaming fires where the person is in the compartment of origin, the hazard relates to the early stages of fire growth. The most rapidly developing experimental fire takes only a few minutes to reach levels of heat and gases hazardous to life [24], [25].

The inability of persons to escape from such fires seems to depend upon a number of factors. Casualties include a higher proportion of children and old people than does the general population and people who are incapacitated by a previous period of smouldering (see above) or by some other infirmity are obviously more at risk. However there seem to be two other factors of importance, the behaviour of the victim and the exponential rate of fire development.

In many cases there is only a short period during which it is possible to carry out the correct actions enabling escape, after which a person may be rapidly trapped. Some persons may be asleep during this critical escape "window" but there are also reports of situations where the victim was aware of the fire from ignition, but remained to attempt to extinguish the fire or for some other reason failed to attempt to leave before the phase of very rapid fire growth, when heat and CO very quickly reach life-threatening levels.

The second scenario is where casualties occur remote from the source of the fire. Apart from being a common occurrence in domestic dwellings such situations often occur in public buildings where the situation involves a developed fire which has spread from the first ignited material to others. Materials in such fires are subject to substantial external thermal flux and in some cases to oxygen deficient environments. In these cases large quantities of material may be involved in flaming combustion or pyrolysis producing large quantities of toxic smoke and gases.

Fires where the victim is remote from the compartment of origin are responsible for the highest incidence of non-fatal casualties (48 %) in the UK and a large proportion of deaths (37 %). Here the victim is five times more likely to be killed by smoke than by burns and is often unaware of the fire during the crucial early phase, so that the gases may not penetrate to the victim until the fire has reached its rapid growth phase and the victim is already trapped. The major causes of incapacitation and death in this type of fire are almost certainly fumes, particularly carbon monoxide, which can build up rapidly to high concentrations and the role of irritants in causing incapacitation and impeding escape attempts may be crucial.

5 Chemical nature of fire effluents

5.1 Mechanisms of product formation

Knowledge of the main routes leading to the formation of combustion products [25], [26], [27] is an essential part of the wider understanding of the chemical aspects of combustion toxicology of fires.

Under the action of heat, organic polymeric materials decompose and release volatile products. If a sufficient concentration of these products is attained and ignited then a flame may develop and feed back to the polymer to continue the process.

The primary step in product formation therefore involves the thermal decomposition of the polymeric material and may take place in fires over a wide temperature range in oxidative or inert (pyrolytic) conditions. Most of the chemical products present in fire atmospheres are species which have been produced from the decomposition of polymeric materials and which have escaped flame destruction. At relatively low temperatures (up to about 400 °C) a polymeric material decomposes to give a restricted number of complex chemical products. It is at medium temperatures (400 °C to 700 °C) that the greatest variety and often the greatest quantities of products, which may include hydrocarbons, oxygenated species (aldehydes, ketones), etc., are produced. This is also the main region where polymers which are sensitive to oxygen may form oxygenated species by incorporation of atmospheric oxygen.

At high temperatures (in excess of about 700 °C), organic and organometallic compounds which are unstable under the normal contact times achieved under these conditions may decompose. Also present are complex polycyclic hydrocarbons and other stable products of low molecular weight such as hydrogen cyanide and certain organic nitriles. By contrast, combustion with flame tends to destroy these products with the formation of a small range of simple combustion products. For example, with a polymer containing carbon, hydrogen and oxygen, the combustion products will be carbon monoxide, carbon dioxide and water; if nitrogen is also present, then molecular nitrogen and oxides of nitrogen may also be formed.

In addition to CO, CO₂ and H₂O, a wide variety of products are formed in fire effluents. For example, the chemical species produced during the burning of wood and polypropylene (40 kg) in a room-corridor are shown in table 1. Also shown is a summary of the main chemical groups.

5.2 Characterization of fire atmospheres

During recent years, major advances have been made in the analysis of fire effluents [27]. It is recognised that the overall nature of the products is dependent particularly upon the type of polymeric material, temperatures and ventilation conditions. A number of factors are important in defining fire atmospheres both for toxicological considerations and in comparing atmospheres between laboratory and full scale fire studies.

These factors include

- a) the yields of oxides of carbon (and CO₂/CO ratio) and reduction in oxygen as a measure of the basic combustion conditions;
- b) the concentration of additional specific toxic gases (in relation to carbon monoxide) which may be important for the specific polymers burnt (e.g. hydrogen cyanide, hydrogen chloride);
- c) types and concentrations of "unburnt" organic products (chemical fingerprints) including:
 - 1) total concentrations relative to carbon monoxide,
 - 2) percentage distribution of important groups, e.g. aromatic and aliphatic hydrocarbons, oxygenated species, amines, nitriles, halides, etc.;
- d) rate of production of total quantities of the major products of toxicological significance.

Other important aspects regarding the fire effluent include

- a) obscuration (usually optical density per metre), rate of production and total amount of smoke produced;
- b) temperature of the effluent and radiation from the effluent.

5.3 Classification of fires

Recent research has shown that in spite of the enormous complexity of fire effluents, the oxygen concentration and the relative concentrations of carbon dioxide and carbon monoxide (CO₂/CO ratio) can provide a simple means of characterization. This arises because the relative conversion of oxygen to carbon monoxide and carbon dioxide depends markedly on the oxygen concentration, with high oxygen concentrations favouring complete combustion to carbon dioxide and conversely restricted oxygen giving rise to carbon monoxide.

By combining CO₂/CO ratios with oxygen concentration and expected fire "severity" as based on expected temperatures (or irradiance), a number of different fire types can be classified, as summarized in table 2. These fire types are:

1 a) Smouldering (self-sustained)

Although often misunderstood, smouldering is generally defined as a self-sustaining exothermic decomposition sometimes accompanied by glowing. Smouldering is initiated by a local high temperature source in the absence of area heating. It takes place mostly in natural materials and some synthetic-natural composites, involving a smouldering front which propagates across the material (as in cotton, fibreboard) or within a bulk (e.g. polyurethane initiated by smouldering cotton). Since complex balances between heat generation and loss are involved, particularly with bulk materials, the phenomenon is not always easy to produce.

Local temperatures at the smouldering front may range from about 400 °C (polyurethane foam) to 800 °C (cotton) and in some cases considerably higher. Oxygen concentrations near to the front may be below ambient but the overall demand on oxygen is low and long periods usually elapse before surrounding oxygen concentrations fall significantly. Smouldering will often continue in closed surroundings to a few percent oxygen. Since the condition is essentially a non-flaming one, CO₂/CO ratios have little significance. Temperatures of the general environment rarely exceed around 100 °C.

The phenomenon of smouldering is important as a process which continues to lead to loss of life, with early types of furniture and beds/bedding set into smouldering from sources such as smoker's materials. In the room of fire origin, carbon monoxide concentrations may be of the order of 0 ppm to 1 500 ppm with irritants present. The time to incapacitation is often long (hours rather than a few minutes) usually with ample time for escape if alerted.

1 b) Non-flaming (oxidative) decomposition

During fires and related circumstances (e.g. overheating), materials and composites can be heated under conditions where ample oxygen exists and toxic decomposition products can be formed. Examples include the radiative transfer of heat