TECHNICAL REPORT

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Toxicity testing of fire effluents —

Part 6:
Guidance for regulators and specifiers on the assessment of toxic hazard in fires in buildings and transport

Essais de toxicité des effluents du feu —

Partie 6: Directives destinées aux législateurs et aux spécificateurs pour l'évaluation du risque de toxicité des incendies dans les bâtiments et dans le transport

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Foreword

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

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

— type 2, when the subject is still under technical development or where for any other reason there is the future but not immediate possibility of an agreement on an International Standard;

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 Technical Reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

ISO/TR 9122-6, which is a Technical Report of type 2, was prepared by Technical Committee ISO/TC 92, *Fire tests on building materials, components and structures*, Subcommittee SC 3, *Toxic hazards in fire*.

This document is being issued in the type 2 Technical Report series of publications (according to subclause G.4.2.2 of part 1 of the ISO/IEC Directives) as a "prospective standard for provisional application" in the field of toxicity testing of fire effluents because there is an urgent need for guidance on how standards in this field should be used to meet an identified need.

International Organization for Standardization
Case Postale 56 • CH-1211 Genève 20 • Switzerland

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This document is not to be regarded as an "International Standard". It is proposed for provisional application so that information and experience of its use in practice may be gathered. Comments on the content of this document should be sent to the ISO Central Secretariat.

A review of this type 2 Technical Report will be carried out not later than two years after its publication with the options of: extension for another two years; conversion into an International Standard; or withdrawal.

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

- *Part 1: General*
- *Part 2: Guidelines for biological assays to determine the acute inhalation toxicity of fire effluents (basic principles, criteria and methodology)*
- *Part 3: Methods for the analysis of gases and vapours in fire effluents*
- *Part 4: The fire model (furnaces and combustion apparatus used in small-scale testing)*
- *Part 5: Prediction of toxic effects of fire effluents*
- *Part 6: Guidance for regulators and specifiers on the assessment of toxic hazards in fires in buildings and transport*

Annex A of this part of ISO/TR 9122 is for information only.

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Toxicity testing of fire effluents —

Part 6:
Guidance for regulators and specifiers on the assessment of toxic hazard in fires in buildings and transport

1 Scope

This part of ISO/TR 9122 is intended to provide guidance for the regulator and specifier on the assessment of toxic hazards in fires in buildings and transport. This is done by describing a series of logical steps to assess a particular fire scenario.

2 Background

The life threat hazard from fires continues to be a source of concern in many countries[1]. Of major concern is exposure to toxic gases which together with heat and visual obscuration from smoke are responsible for the majority of deaths and serious injury in fires. The increasing use of novel materials and innovative design in buildings and transport vehicles and their contents, can create new potential hazards as well as new opportunities for the reduction of hazard. There is therefore a great need for effective methods for the assessment of life threat hazard and its regulation. This has stimulated wide ranging research over many years whose aim has been to understand the nature and biological effects of fire effluent atmospheres and provide guidance on the mitigation of their effects.

2.1 Regulatory use of data from small-scale toxicity tests

The initial thrust internationally was to develop a small-scale test for toxic potency of materials which could be used by regulators, specifiers and fire safety practitioners in much the same way as other small-scale fire tests have been used for the control of materials. This perceived need for small-scale toxic potency tests arose from concern about the increasing incidence of fire deaths resulting from smoke exposure. There was a feeling that the most important factor in toxic hazard was the toxic potency of combustion products and that modern materials evolved products which had a much greater toxic potency than traditional materials. This fear was increased by the discovery of a small number of materials evolving products with an unusually high toxic potency in small-scale tests. These concerns led to pressure for small-scale tests to measure the toxic potency of combustion products so that materials could be ranked and on that basis, "bad" materials could be identified. Experience with these tests over many years coupled with a growing understanding from research of the life threatening properties of "real" fires has resulted in the general consensus that such small-scale test data independent of other fire performance data, are insufficient for assessing life threat hazard. Also, examples of unusually high toxic potency have proven to be rare and in most fires the major toxic effects are known to be caused by a small number of well known products. It follows that attempts to regulate on the basis of toxic potency values alone such as those required to be submitted by the State of New York (U. Pitt test[2]), or to specify materials based upon unrealistic tests such as the NES713[3] or controls based solely upon elemental composition of synthetic materials[4] may be considered counterproductive.

The main limitations of small-scale tests are:

a) the tests do not address the problem of the rate of fire growth and toxic product generation which are essential in toxic hazard assessment;

b) the decomposition conditions used in the tests are easily relatable to those existing in actual fires;

c) some methods do not utilize animals, but rely solely on chemical analytical data. As far as can be determined with the current state of knowledge, such data can never be comprehensive in assessing toxicity;

d) for toxic potency tests using animals, the LC_{50} end point (a measure of lethal exposure concentration) is too simplistic; sublethal effects which might prevent escape from fire should also be considered;

e) the tests do not normally allow the testing of materials in their end-use configuration, i.e. as composites or in conjunction with other materials;

f) the tests are not capable of addressing the environmental aspects of fires which may influence escape and therefore the overall hazard, i.e. building design and fire protection measures;

g) the use of data from animals (mostly rodents) can be regarded as representing effects on humans only to the extent that the rat is correlated with humans as a biological system. Failure to allow for differences between species may introduce errors with respect to important aspects of fire atmosphere toxicity in human subjects.

2.2 Importance of fire growth characteristics in toxic hazard assessment

It is now recognised that data from small-scale toxicity tests are useful in toxic hazard assessments in conjunction with other input data on fire growth characteristics. The most important variable in the development of toxic hazard in fires is the rate of fire growth and the rate of evolution of the common fire gases. The point in any fire when a victim becomes incapacitated or dies therefore depends strongly upon the growth curve of the fire and the points in time where an incapacitating or lethal dose of products has been inhaled.

This is not to say that toxicity is no longer a problem, since it is the toxic effects that ultimately cause incapacitation or death in the majority of fires, and it is therefore important to know what will cause toxic effects in order to predict the potential hazard in any particular fire. Also, toxicity data for individual materials can be used to screen for rare products of unusually high toxic potency, and to improve the accuracy of fire performance predictions based upon hazard assessments. It follows that an individual material can be assessed in terms of its contribution to toxic hazard only as part of a system rather than in isolation. Its suitability will depend on its contribution to the overall ignition and growth characteristics of fires as well as the toxic potency of its products. This has led to the development of models which combine several aspects of life threat for the overall assessment of hazard and a code of practice approach rather than the use of simple pass/fail criteria.

2.3 Integrated assessment methods

These methods require a detailed analysis of given scenarios. The stages of hazard development need to be determined, enabling a series of logical steps to be identified and used as a basis for a hazard assessment of particular scenarios. Within these steps there are still areas for which it is possible to give only general advice, and where assumptions have to be made. Ongoing and future research is aimed at improving capabilities in these areas.

The magnitude of the toxic, or more completely the life threat, hazard depends upon the complex interaction of many parameters, starting with an ignition source and ending with possible toxic or other hazards affecting potential victims present in the system. When a system is designed, it is necessary to consider the effects of all these component parameters in assessing the overall life threat hazard.

The toxic hazard in any fire becomes predictable if two sets of information are known:

a) the time/concentration profiles of the important toxic products in the fire;

b) the time/concentration/toxicity relationships of these products in humans.

The first set of data may be obtained from mathematical modelling of fire growth using small-scale test results as input data, or from large-scale fire test results. The second set of data is derived from toxicity studies of combustion products and individual fire gases in animals and humans.

This approach is the basis of toxic hazard assessment methods being developed in ISO/TC 92/SC3, and in BSI Publication DD180[5], in the National Institute for Standards and Technology Hazard 1.1 models[6] and in the Fire Research Station "ASKFRS" model[7].

There are many ways in which the development of life threat hazard may be controlled. Historically, the main approach to fire control has been to control the ignition and flame spread properties of materials and other factors relating to the structural design of buildings and transport systems. The implementation of these measures has resulted in some control of the development of life threat hazard.

3 Position of the regulator

While existing regulations already contribute to fire safety in occupied buildings and transport, the specific problem of toxic hazard (the major cause of death and serious injury in fires) is yet to be fully addressed.

Regulation can be achieved through the application of voluntary codes of practice. This has the advantage that it is flexible both in its application and in that it does not inhibit continued development of assessment methodology.

However, regulation becomes necessary when consensus to conform to standards voluntarily can no longer be maintained. The realities of the market place can lead to unsafe practices which can only be controlled in a fair and effective manner by regulation. For a regulatory system to be defensible and effective however, it must satisfy certain basic principles. Any regulation must be enforceable, such that those responsible for its implementation can be satisfied that materials and products meet approved standards based on relatively expedient tests and/or criteria.

The essential features are:

a) an argued and defensible case for regulations;

b) a scientifically valid basis for the quantification and qualification of the identified hazards;

c) precision and clarity in the way in which the regulations are intended to be applied;

d) practical and relatively simple methods for enforcement, i.e. rapid and inexpensive tests.

If any of these features is not met, then the regulations themselves could be discredited. Therefore, regulators are heavily dependent upon the expert not only to identify the problem for which the regulation is necessary, but also to provide the most practical tests to provide information upon which the implementation will be based.

4 Steps to be considered

In applying this clause, the user will require access to particular information for each scenario being assessed. For some steps, general guidance on sources of information is given, while for others specific information is provided on toxicity and toxic hazard assessment in clauses 4 and 5.

4.1 Definition of system and likelihood of possible fire scenarios

4.1.1 Definition of the circumstances

Before a hazard assessment can be made, it is necessary first to make a detailed assessment of the use of the building or transport system in terms of type and number of occupants and activities carried out. In addition, the provision of warnings and escape procedure should be recorded. The contents and their location should be defined, particularly with reference to the local environment. The different fire scenarios which could occur should be selected. Loss patterns and life threats related to experience and historical data should be identified and examined.

4.1.2 Assessment of the likelihood of each chosen scenario occurring

A three-tier assessment is suggested, i.e. "likely to occur", "unlikely to occur" and "very unlikely to occur".

4.2 Toxic hazard analysis for chosen scenarios

The toxic hazard in any fire depends upon:

a) the time/concentration profiles of the important toxic products in the fire representing the dose of toxicants to which a potential victim may be exposed;

b) the toxicity of the products and in particular the exposure dose required to cause toxic effects.

4.2.1 Description of fire growth

The first essential in assessing the toxic hazard presented by a particular fire is to determine the exposure dose of toxic products delivered to a potential victim over a period of time during the fire. This has two major elements from which the exposure dose can be calculated:

a) the fire growth curve in terms of the mass loss profile of the burning materials and the volume into which the products are dispersed;

b) the yields of the different toxic products.

During the early local growth, the fire can be smouldering or flaming, and information on the initial behaviour can be obtained from standardized reaction to fire tests and from special tests related to the situation under consideration. For the later stages, as a flaming fire grows into a developed fire, large-scale tests can be used to provide information. Mathematical modelling also becomes a more practical possibility during the later stages, for the calculation of fire growth and transport of toxic products.

4.2.2 Determination of the toxic potency of the products

The next item of information required is the toxic potency of the products, i.e. the exposure dose needed to cause toxic effects. This is discussed in this subclause, and more detailed guidance is given in ISO/TR 9122-5[8].

In practice, the exposure dose in a particular scenario will depend upon a number of factors such as:

a) fire growth and yield of toxic products;

b) size of fire compartment and ventilation;

c) routes of spread of toxic products, distribution, dilution and loss of products prior to inhalation;

d) building or compartment features e.g. fire alarms, active fire suppression systems, smoke control systems;

e) nature of passive fire protection, i.e. fire resistance rating of vertical and horizontal fire separations and burning characteristics of surfaces;

f) position of occupants relative to the fire and means of escape;

g) exposure time and time required for escape.

4.2.3 Calculation of toxic hazard

Once the exposure dose and toxic potency have been determined, it is possible to calculate the time when potential victims will have received an incapacitating or lethal exposure to toxic products in the fire. This can then be compared to the time required for escape. Where an assessment of full life threat hazard is being performed, the effects of heat exposure and visual obscuration by smoke must also be considered.

5 Toxic products and mechanisms of toxicity in fires

Combustion products cause incapacitation and death in fires by two main mechanisms — narcosis and irritancy.

5.1 Effects of narcotic gases

Narcotic gases affect the brain and circulatory system, causing confusion followed by loss of consciousness and death depending upon the exposure dose inhaled. The only narcotic gases found to be important in fires are CO, HCN, CO_2 and low oxygen. The effects of these gases on humans and the ways in which they interact are reasonably well known. Also it has been found that incapacitation becomes significant at a well defined endpoint, when a victim passes from a near normal to an unconscious state following a brief period of confusion[9]. It is therefore possible to develop effective mathematical models based upon data obtained from humans and other primates[9], to predict when a victim will become incapacitated in a fire due to the effects of narcotic gases, if the concentration/time curves for these gases in a fire are known. Details of such models are given in ISO/TR 9122-5[8].

5.2 Effects of irritants

Irritant fire products have two principal effects:

a) they cause immediate painful sensory stimulation of the eyes, nose, throat and lungs;

b) they cause lung inflammation and oedema which may lead to death due to impairment of respiration, usually a few hours after exposure.

Irritant effects during a fire lie on a continuum from mild eye irritation to severe eye and respiratory tract pain, and ultimately death during or after exposure. All fire atmospheres are irritant and contain many irritating chemical species. Some twenty of so have been identified in combustion product atmospheres, and there is evidence that other, unknown, irritant species are also present[9]. For these reasons the irritancy of combustion product atmospheres cannot, as yet, be predicted fully from even a comprehensive chemical analysis, and the only way to estimate irritancy is by animal exposure. Two test parameters can be used in rodent tests; sensory irritancy can be estimated by measuring the RD_{50} (the concentration causing a 50 % decrease in breathing rate in mice) and lung irritation by measuring the LC_{50} in terms of the concentration causing postexposure deaths due to lung damage. However, care must be taken in using rodent data to predict effects in humans[9].

5.3 Variations in yields of narcotic and irritant products under different fire conditions

The yields of different narcotic and irritant products from even an individual material in a fire can vary greatly depending upon the thermal decomposition conditions under which it is decomposed. It is therefore very important in any small-scale test using chemical analysis of combustion products, or using direct animal toxicity measurement, that the decomposition conditions are similar to those of the fire being modelled. It is also important to understand that no small-scale test can model the changing conditions of growth and development occurring in large-scale fires.

5.4 Effects of visual obscuration by smoke and exposure to heat

In addition to the effects of narcotic and irritant products, consideration also needs to be given to the effects of visual obscuration by smoke, which reduces escape efficiency or renders a victim unwilling to enter a smoke-filled escape route, and of heat which initially hinders or prevents escape due to skin pain and burns or hyperthermia, and can cause death either during or after exposure.

6 Methods of toxic hazard assessment

There are essentially two types of method which can be used for assessing toxic fire hazard:

a) from a battery of small-scale tests on individual materials or composite samples, the results of which are used as inputs to mathematical fire models, or from simple large-scale tests where only mass loss or heat release rates are measured. The essential components are

   1) the toxic potency data for the materials (lethal mass loss exposure dose) obtained from small-scale combustion toxicity tests using animal exposures (or increasingly from calculation methods using chemical analytical data from small-scale toxicity tests),

   2) the mass loss/concentration curve for the fire, obtained from a combination of small-scale tests and mathematical fire models, or from simple large-scale tests;

b) from large-scale fire tests which include measurements by chemical analysis of the concentration/time profiles of the major toxic fire gases and smoke particulates. These are combined with existing knowledge of the toxicity of these gases and particulates derived originally from human and animal exposures.

The advantages of the first approach are that it can be based upon small-scale test data alone, and that when animal exposures are used it is possible to detect any unusual toxic effects which cannot be predicted from a solely chemical analysis of combustion products. The reliance on animal exposure data can be considered a disadvantage of the first approach in some countries. However, with the advancing knowledge in this field, the need for animal experimentation is decreasing, so that in many cases a toxic potency estimation can be based upon analytical data from small-scale experiments.

The advantage of the second approach is that the concentration/time curves for the toxic fire products are measured directly, and data based upon the effects of exposure of humans can be used to calculate time to incapacitation or death.

In practice, for a full analysis of any given scenario, it is preferable to use data from both of these approaches in making a hazard assessment, but the methods used will depend upon the data available and the type of hazard assessment required.

The aim of both types of methods is to calculate the fractional effective dose (FED) of toxic products presented to potential victims during the fire. This is achieved by calculating the exposure dose received each minute during the fire and expressing it as a fraction of the dose required to cause incapacitation or death. These FEDs are then summed until a time is reached when the fraction reaches unity, and incapacitation or death is predicted to occur. Details of the procedures used to calculate FEDs are presented in ISO/TR 9122-5[8]. Applications of the these methods in toxic hazard assessments are described in the following subclauses.

6.1 Toxic hazard assessment based on mass loss exposure dose toxicity data

6.1.1 Simple assessment using a single mass loss exposure dose toxic potency figure for all materials

The simplest form of toxic hazard assessment could be based upon mass loss concentration data for the fire and an average value for the toxic potency of combustion products from materials considered to be of "normal" toxicity. In practice, this would include nearly all common materials. Examples of such