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REPORT

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Guidance for assessing the validity of physical fire models for obtaining fire effluent toxicity data for fire hazard and risk assessment —

Part 2:
Evaluation of individual physical fire models

Lignes directrices pour évaluer la validité des modèles de feu physiques pour l'obtention de données sur les effluents du feu en vue de l'évaluation des risques et dangers —

Partie 2: Évaluation des différents modèles de feu physiques

Reference number
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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. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In exceptional circumstances, 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), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/TR 16312-2 was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 3, *Fire threat to people and environment*.

ISO 16312 consists of the following parts, under the general title *Guidance for assessing the validity of physical fire models for obtaining fire effluent toxicity data for fire hazard and risk assessment*:

- *Part 1: Criteria*
- *Part 2: Evaluation of individual physical fire models* [Technical Report]

Introduction

Providing the desired degree of life safety for an occupancy increasingly involves an explicit fire hazard or risk assessment. This assessment includes such components as information on the room/building properties, the nature of the occupancy, the nature of the occupants, the types of potential fires, the outcomes to be avoided, etc.

This type of determination also requires information on the potential for harm to people due to the effluent produced in the fire. Because of the prohibitive cost of real-scale product testing under the wide range of fire conditions, most estimates of the potential harm from the fire effluent depend on data generated from a physical fire model, a reduced-scale test apparatus and procedure for its use.

The role of a physical fire model for generating accurate toxic effluent composition is to simulate the essential features of the complex thermal and reactive chemical environment in full-scale fires. These environments vary with the physical characteristics of the fire scenario and with time during the course of the fire, and close representation of some phenomena occurring in full-scale fires can be difficult or even not possible at the small scale. The accuracy of the physical fire model, then, depends on two features:

a) degree to which the combustion conditions in the bench-scale apparatus mirror those in the fire stage being simulated;

b) degree to which the yields of the important combustion products obtained from burning of the commercial product at full scale are matched by the yields from burning specimens of the product in the small-scale model. This measure is generally performed for a small set of products, and the derived accuracy is then presumed to extend to other test subjects. At least one methodology for effecting this comparison has been developed.[1]

This part of ISO 16312 provides a set of technical criteria for evaluating physical fire models used to obtain composition and toxic potency data on the effluent from products and materials under fire conditions relevant to life safety. This Technical Report comprises the application by experts of these criteria to currently used test methods that are used for generating data on smoke effluent from burning materials and commercial products.

There are 12 physical fire models discussed in this part of ISO 16312. Additional apparatus can be added as they are developed or adapted with the intent of generating information regarding the toxic potency of smoke.

For the 12 models in this part of ISO 16312, the first five are closed systems. In these, no external air is introduced and the combustion (or pyrolysis) products remain within the apparatus except for the fraction removed for chemical analysis. The second seven are open apparatus, with air continuously flowing past the combusting sample and exiting the apparatus, along with the combustion products.

To make use of this part of ISO 16312, it is necessary for the user to have present a copy of ISO 16312-1, which contains much of the context and definitions for the present document. It is also necessary to make reference to ISO 19701[33], ISO 19702[34], ISO 19703, ISO 13344[31], and ISO 13571[32] for discussions of analytical methods, bioassay procedures, and prediction of the toxic effects of fire effluents.

Guidance for assessing the validity of physical fire models for obtaining fire effluent toxicity data for fire hazard and risk assessment —

Part 2:
Evaluation of individual physical fire models

1 Scope

This part of ISO 16312 assesses the utility of physical fire models that have been standardized, are commonly used and/or are cited in national or international standards, for generating fire effluent toxicity data of known accuracy. It does so using the criteria established in ISO 16312-1 and the guidelines established in ISO 19706. The aspects of the models that are considered are the intended application of the model, the combustion principles it manifests, the fire stage(s) that the model attempts to replicate, the types of data generated, the nature and appropriateness of the combustion conditions to which test specimens are exposed and the degree of validity established for the model.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 13943, *Fire safety — Vocabulary*

ISO 16312-1, *Guidelines for assessing the validity of physical fire models for obtaining fire effluent toxicity data for fire hazard and risk assessment — Part 1: Criteria*

ISO 19703, *Generation and analysis of toxic gases in fire — Calculation of species yields, equivalence ratios and combustion efficiency in experimental fires*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13943 and in ISO 19703 apply.

4 General principles

4.1 Physical fire model

A physical fire model is characterized by the requirements placed on the form of the test specimen, the operational combustion conditions and the capability of analysing the products of combustion.

4.2 Model validity

For use in providing data for effluent toxicity assessment, the validity of a physical fire model is determined by the degree of accuracy with which it reproduces the yields of the principal toxic components in real-scale fires.

4.3 Test specimens

Fire safety engineering requires data on commercial products or product components. In a reduced-scale test, the manner in which a specimen of the product is composed can affect the nature and yields of the combustion products. This is especially the case for products of non-uniform composition, such as those consisting of layered materials.

4.4 Combustion conditions

The yields of combustion products depend on such apparatus conditions as the fuel/air equivalence ratio, whether the decomposition is flaming or non-flaming, the persistence of flaming of the sample, the temperature of the specimen and the effluent produced, the thermal radiation incident on the specimen, the stability of the decomposition conditions and the interaction of the apparatus with the decomposition process, with the effluent and the flames.

4.5 Effluent characterization

4.5.1 For the effluent from most common materials, the major acute toxic effects have been shown to depend upon a small number of major asphyxiant gases and a somewhat wider range of inorganic and organic irritants. In ISO 13571[32], a base set of combustion products has been identified for routine analysis. Novel materials can evolve previously unidentified toxic products. Thus, a more detailed chemical analysis can be needed in order to provide a full assessment of acute effects and to assess chronic or environmental toxicants. A bioassay can provide guidance on the importance of toxicants not included in the base set. ISO 19706[35] contains a fuller discussion of the utility of bioassays.

4.5.2 It is essential that the physical fire model enable accurate determinations of chemical effluent composition.

4.5.3 It is desirable that the physical fire model accommodate a bioassay method.

4.5.4 The use of laboratory animals as test subjects is the only means of insuring inclusion of the impact of all combustion gases. However, it is recognized that the adoption and use of protocols using laboratory animals can be prohibited in some jurisdictions. An animal-free protocol captures the effects of known combustion gases but misses the impact of any uncommon and highly toxic species, those smoke components that are most in need of identification. Laboratory studies to date have shown that lethality from smoke inhalation results from the combined effects of a small number of gases and that none of the missing gases is “supertoxic.” There are also data that indicate incapacitation results from half the lethal exposure for a wide range of today’s materials, indicating that exotic gases do not affect incapacitation without affecting lethality as well. The decision to base hazard and risk assessments on analytical or animal-based measurements resides with the authority having jurisdiction.

5 Significance and use

5.1 Most computational models of fire hazard and risk require information regarding the potential of fire effluent (gases, heat and smoke) to cause harm to people and to affect their ability to escape or to seek refuge.

5.2 The quality of the data on fire effluent has a profound effect on the accuracy of the prediction of the degree of life safety offered by an occupancy design. Uncertainty in such predictions commonly leads to the use of safety factors that can compromise functionality and increase cost.

5.3 Fire safety engineering requires data on commercial products. Real-scale tests of such products generally provide accurate fire effluent data. However, due to the large number of available products, the high cost of performing real-scale tests of products and the small number of large-scale test facilities, information on effluent toxicity is most often obtained from physical fire models.

5.4 There are numerous physical fire models cited in national regulations. These apparatus vary in design and operation, as well as in their degree of characterization. The assessments of these models in this part of ISO 16312 provide product manufacturers, regulators and fire safety professionals with insight into appropriate and inappropriate sources of fire effluent data for their defined purposes.

5.5 None of the models in this part of ISO 16312 is appropriate for simulation of smouldering combustion.

5.6 The assessments of physical fire models in this part of ISO 16312 do not address means for combining the effluent component yields to estimate the effects on laboratory animals (see ISO 13344[31]) or for extrapolating the test results to people (see ISO 13571[32]).

6 Physical fire models

6.1 Cup-furnace smoke-toxicity test method

6.1.1 Application

This method[2] is designed to generate toxic potency data for materials and, perhaps, end products. It is not a national or international standard.

6.1.2 Principle

A schematic of the apparatus is shown in Figure 1. The furnace is open to an 0,2 m^3 closed reservoir from which (air) oxygen is supplied by natural buoyancy. Vitiation in the reservoir is measured. The sample (approximately 10 g) is cut into pieces and heated conductively, convectively and (at higher temperatures) radiatively to just below or just above its auto-ignition temperature.

6.1.3 Fire stage(s)

The fire stage(s) from ISO 19706:2007[35], Table 1, are as follows:

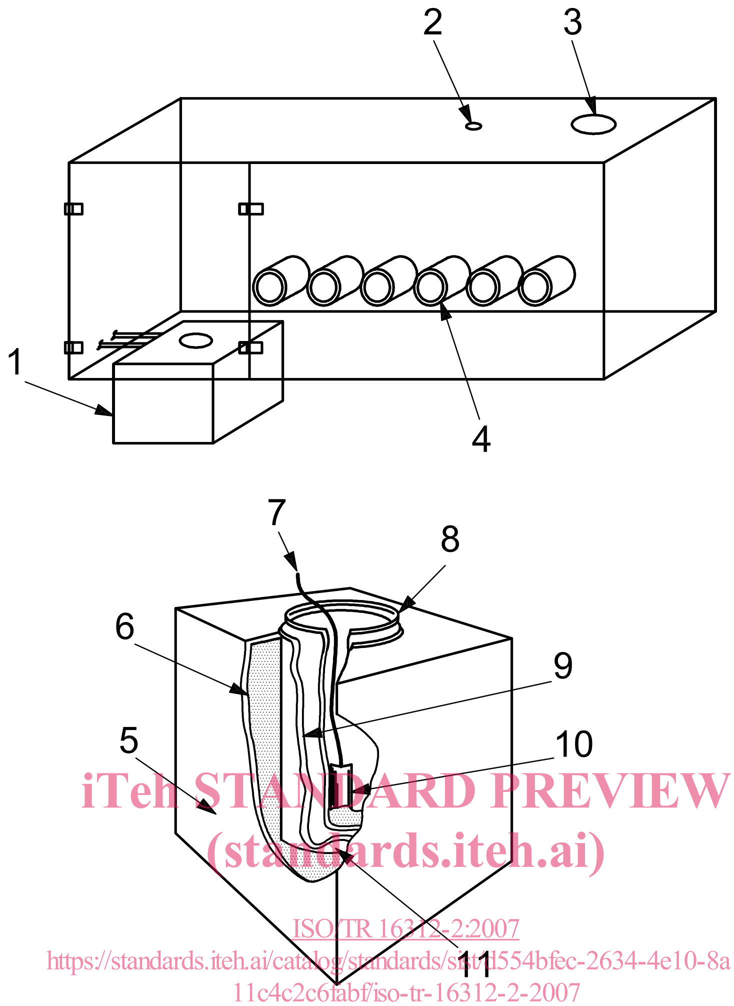
- 1.b, oxidative pyrolysis;
- 2, well-ventilated flaming.

6.1.4 Types of data

The standard procedure includes measurement of total mass loss, averaged mass consumed and mass charged concentrations, gas concentrations and gas yields. The gases to be measured are: CO_2, CO, O_2, HCN, HCl and HBr. In addition, the procedure includes measurement of the incapacitation (by hind-leg flexion or immobilization) and mortality of six rats, the times to these effects and documentation of any physiological harm, determined post-mortem. Blood samples are taken during and after exposure for subsequent analysis.

6.1.5 Presentation of results

Sufficient tests are performed, at different mass loadings, to determine LC_{50} and IC_{50} values and their confidence limits for within exposure and within-plus-post-exposure periods.



Key

1	furnace	7	thermocouple
2	gas-sampling port	8	1 000 ml quartz beaker
3	pressure-relief panel	9	ceramic
4	animal ports	10	thermocouple well
5	galvanized sheet	11	heating element in bottom
6	insulation		

Figure 1 — Schematic of the cup-furnace smoke-toxicity apparatus

6.1.6 Apparatus assessment

6.1.6.1 Advantages

Each test uses a small sample. The apparatus is inexpensive and easy to operate. Data for a wide range of materials and products have been published. There is a close similarity to the oxidative pyrolysis conditions in real-scale fires.

6.1.6.2 Disadvantages

The realism of sample exposure is questionable due to the cutting up of the sample, especially for non-homogeneous products. For well-ventilated combustion, the simulation of real-scale heating, which is primarily radiative, is poor. Mixing by natural buoyancy makes values of the global equivalence ratio somewhat uncertain. In common with many physical fire models, no indication is given about the rate of burning;

therefore, additional data input on burning rates at different fire stages are needed for fire safety engineering calculations.

6.1.6.3 Repeatability and reproducibility

A successful inter-laboratory evaluation of this method has been performed[3].

6.1.7 Toxicological results

6.1.7.1 Advantages

The method produces true measures of smoke lethality and incapacitation and identifies instances of extreme and unusual smoke toxic potency. It also produces data enabling calculation of the yields of measured toxicants. It can identify cases where unusual toxicity occurs as a result of constituents not identified by the analytical procedures applied.

6.1.7.2 Disadvantages

The relationship between data for a finished product and data for its component materials has not been determined. The concentration of combustion products is not truly uniform over the entire animal-exposure period, introducing some reduction in the precision of the lethality and incapacitation measures.

6.1.8 Miscellaneous

This is primarily an animal-exposure test with chemical instrumentation to quantify the expected major toxicants. Additional analytical instrumentation can be added with little interference with the standard method. The apparatus can be used without test animals, but it then loses the ability to identify the principal cases of real interest.

6.1.9 Validation

The toxic potency and gas yield data did not replicate real-scale post-flashover test data well[1]. The method has not been assessed against real-scale test data for oxidative pyrolysis or well-ventilated flaming.

6.1.10 Conclusion

This method is potentially a useful test for screening the toxic potency of materials and homogeneous products. However, cutting the specimen into pieces makes it unlikely that the test results relate to the real fire exposure of heterogeneous end products. Thus, with validation, it can produce useful information for hazard models for oxidative pyrolysis and well-ventilated flaming of homogeneous materials, but not of complex commercial products.

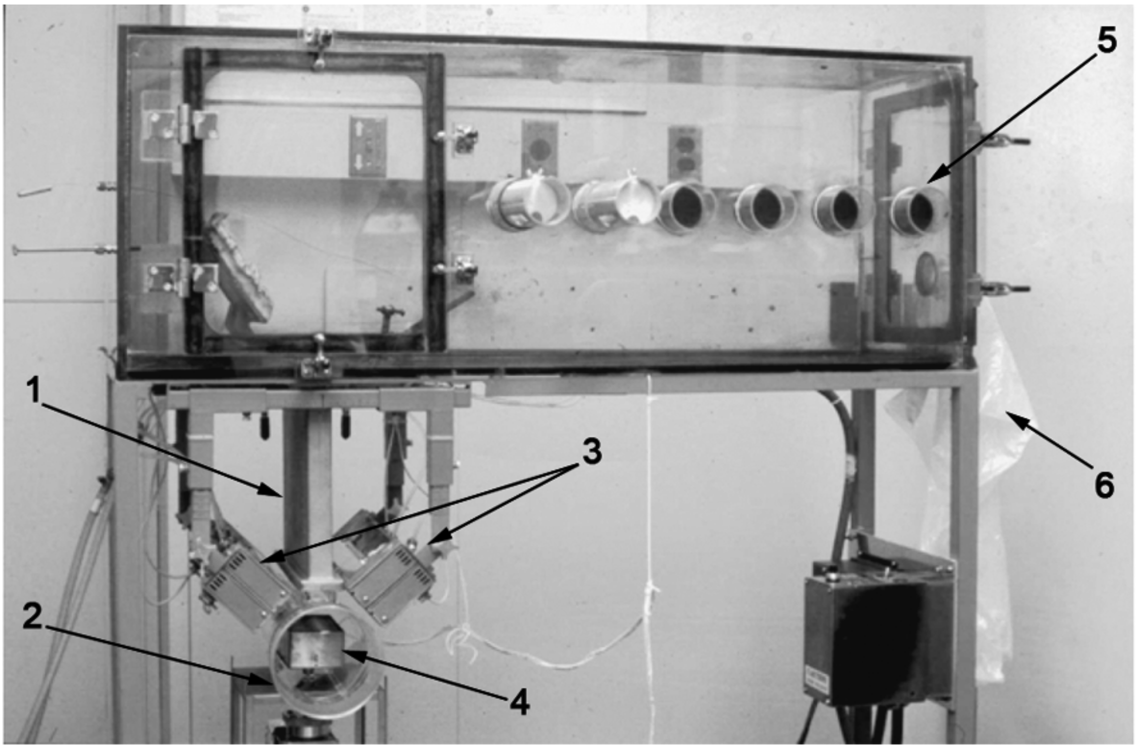
6.2 Radiant furnace toxicity test method (United States)

6.2.1 Application

This apparatus, used in NFPA 269[4] and ASTM E 1678[5], was designed to generate toxic potency data for building and furnishing materials and end products for use in fire and hazard analyses.

6.2.2 Principle

A photograph of the apparatus is shown in Figure 2. A sample, up to 76 mm x 127 mm in area and up to 50 mm in thickness and representative of the end-use configuration of the finished product, is exposed to thermal radiation. Buoyancy from the burning sample entrains air from a closed reservoir similar to that described in 6.1.



Key

1	chimney	4	specimen holder
2	combustion cell	5	animal ports
3	radiant heaters	6	expansion bag

Figure 2 — Photograph of the NFPA 269 apparatus

6.2.3 Fire stage(s)

The fire stage(s) from ISO 19706:2007[35], Table 1, are as follows:

- 2, well-ventilated flaming combustion;
- 3, under-ventilated flaming (using a post-flashover correction for the yield of CO);
- 1.b, oxidative pyrolysis, if the sample does not auto-ignite.

6.2.4 Types of data

The standard procedure includes continuous measurement of mass loss and gas concentrations, gas yields, and atmosphere vitiation. In addition, the procedure includes measurement of the mortality of six rats and documentation of any physiological harm, determined post-mortem.

6.2.5 Presentation of results

Sufficient tests are performed, at different sample surface areas, to determine LC_{50} values and their confidence limits for within exposure and within-plus-post-exposure periods.

6.2.6 Apparatus assessment

6.2.6.1 Advantages

The representation and exposure of finished products is accurate. The mass burning rate is recorded, enabling direct use of the yield data in engineering calculations.

6.2.6.2 Disadvantages

Mixing by natural buoyancy makes values of global equivalence ratio somewhat uncertain. Limited sample intumescence can be tolerated.

6.2.6.3 Repeatability and reproducibility

No inter-laboratory evaluation of this method has been performed.

6.2.7 Toxicological results

6.2.7.1 Advantages

The method produces a true measure of smoke lethality and identifies instances of extreme and unusual smoke toxic potency. It also produces data enabling calculation of the yields of measured toxicants. The method can be adapted to measure incapacitation (hind-leg flexion or immobilization).

6.2.7.2 Disadvantages

The use of an empirically derived correction for CO introduces some uncertainty into the LC_{50} values. Furthermore, altered yields of other product gases are not included. However, these factors are included in the comparison of LC_{50} values with room-scale test data in Reference [1]. This correction limits the value of this method for other sublethal effects in which the uncorrected gas yields play a prominent role.

6.2.8 Miscellaneous

This is primarily an animal-exposure test with limited chemical instrumentation. However, additional analytical instrumentation can be added with little interference with the standard method. The apparatus can be used without test animals, but it then loses the ability to identify the principal cases of real interest.

Using a generic, experimentally observed carbon monoxide yield correction, accurate post-flashover LC_{50} values have been obtained relative to real-scale fire tests of the same combustibles[1].

6.2.9 Validation

The output of this method for three products has been compared to room-scale data for the same products (wall lining configuration)[1]. The post-flashover LC_{50} values were well within a factor of 2. No data were taken for pre-flashover combustion.

6.2.10 Conclusion

This is a useful test for obtaining quantitative toxic potency information for materials and end products for input to fire hazard models.