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Fire safety engineering — Assessment, verification and validation of calculation methods

Ingénierie de la sécurité incendie — Évaluation, vérification et validation des méthodes de calcul

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

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.

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 16730 was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 4, *Fire safety engineering*.

Introduction

The objective of fire safety engineering is to assist in the achievement of an acceptable predicted level of fire safety. Part of this work involves the use of calculation methods to predict the course of events that can potentially occur in case of a fire or as a consequence of a fire. This work involves the use of calculation methods to evaluate the ability of fire protection measures to mitigate the adverse effects of a fire on people, property, the environment and other objects. The main principles that are necessary to establish the credibility of these calculation methods are assessment, verification and validation.

There is a need for a standard as a technical basis to provide the developers and users of calculation methods and third parties with procedures to check whether the calculation method's accuracy for particular applications is sufficient.

This International Standard addresses the assessment, verification and validation of calculation methods for fire-safety engineering in general.

It is necessary that potential users of calculation methods and those who are asked to accept the results be assured that the calculation methods provide sufficiently accurate predictions of the course and consequences of the fire for the specific application planned. To provide this assurance, it is necessary that the calculation methods being considered be verified for mathematical accuracy and validated for capability to reproduce the phenomena.

There is no fixed requirement of accuracy that is applicable to all calculation methods. The accuracy level depends on the purposes for which a calculation method is being used. It is not necessary that all calculation methods demonstrate high accuracy as long as the error, uncertainty and limits of applicability of the calculation methods are known.

This International Standard focuses on the predictive accuracy of calculation methods. However, other factors such as ease of use, relevance, completeness and status of development play an important role in the assessment of the use of the most appropriate method for a particular application. The assessment of the suitability of a calculation method for a special purpose within the field of fire safety engineering is supported by the use of quality-assurance methodology to ensure that the requirements are being fulfilled. Guidance for establishing metrics for measuring attributes of the relevant quality characteristics is outlined in short form in this International Standard.

This International Standard is intended for use by

a) developers of calculation methods (individuals or organizations that perform development activities, including requirements analysis, design and testing of components), to document the usefulness of a particular calculation method, perhaps for specific applications. Part of the calculation method development includes the identification of precision and limits of applicability, and independent testing,

b) developers of calculation methods (individuals or organizations who maintain computer models, supply computer models, and for those who evaluate computer model quality as part of quality assurance and quality control), to document the software development process and assure users that appropriate development techniques are followed to assure quality of the application tools,

c) users of calculation methods (individuals or organizations that use calculation methods to perform an analysis), to assure themselves that they are using an appropriate method for a particular application and that it provides adequate accuracy,

d) developers of performance codes and standards, to determine whether a calculation method is appropriate for a given application,

e) approving bodies/officials (individuals or organizations that review or approve the use of assessment methods and tools), to ensure that the calculation methods submitted show clearly that the calculation method is used within its applicability limits and has an acceptable level of accuracy,

f) educators, to demonstrate the application and acceptability of calculation methods being taught.

It is necessary that users of this International Standard be appropriately qualified and competent in the fields of fire safety engineering and risk assessment. It is important that users understand the parameters within which specific methodologies can be used.

Fire safety engineering — Assessment, verification and validation of calculation methods

1 Scope

This International Standard provides a framework for assessment, verification and validation of all types of calculation methods used as tools for fire safety engineering. It does not address specific fire models, but is intended to be applicable to both analytical models and complex numerical models that are addressed as calculation methods in the context of this International Standard. It is not a step-by-step procedure, but does describe techniques for detecting errors and finding limitations in a calculation method.

This International Standard includes

— a process to ensure that the equations and calculation methods are implemented correctly (verification) and that the calculation method being considered is solving the appropriate problem (validation),

— requirements for documentation to demonstrate the adequacy of the scientific and technical basis of a calculation method,

— requirements for data against which a calculation method's predicted results shall be checked,

— guidance on use of this International Standard by developers and/or users of calculation methods, and by those assessing the results obtained by using calculation methods.

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/TR 13387-1, *Fire safety engineering — Part 1: Application of fire performance concepts to design objectives*

ISO 13943, *Fire safety — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13943 and ISO/TR 13387-1 and the following apply.

NOTE Some of the definitions have been updated to illustrate the current understanding of the meaning of the terms in the field of fire-safety engineering.

3.1
accuracy
degree of exactness actually possessed by an approximation, measurement, etc.

NOTE In the context of this International Standard, the numerical (or mathematical) accuracy is part of the verification process for calculation methods, where a computer fire model may be such a calculation method. The accuracy may be expressed by indicating the uncertainty of a calculation or solution(s) of a model.

3.2
assessment
process of determining the degree to which a calculation method is an accurate representation of the real world from the perspective of the intended uses of the calculation method and the degree to which a calculation method implementation accurately represents the developer's conceptual description of the calculation method and the solution to the calculation method

NOTE Key processes in the assessment of suitability of a calculation method are verification and validation.

3.3
calculation method
mathematical procedure used to predict fire-related phenomena

NOTE Calculation methods may address behaviour of people as well as objects or fire; may be probabilistic as well as deterministic in form; and may be algebraic formulae as well as complex computer models.

3.4
calibration
⟨of a model⟩ process of adjusting modelling parameters in a computational model for the purpose of improving agreement with experimental data

3.5
computer(ized) model
operational computer program that implements a conceptual model

3.6
conceptual model
description composed of all the information, mathematical modelling data and mathematical equations that describe the (physical) system or process of interest

3.7
default value
standard setting or state to be taken by the program if no alternate setting or state is initiated by the system or the user

3.8
deterministic model
calculation method that uses science-based mathematical expressions to produce the same result each time the method is exercised with the same set of input data values

3.9
engineering judgment
process exercised by a professional who is qualified by way of education, experience and recognized skills to complement, supplement, accept or reject elements of a quantitative analysis

3.10
error
recognizable deficiency in any phase or activity of calculation that is not due to lack of knowledge

3.11
fire model
representation of a system or process related to fire development, including fire dynamics and fire impacts

3.12
mathematical model
sets of equations that describe the behaviour of a physical system

3.13
measure
variable to which a value is assigned as the result of measurement

3.14
measurement
set of operations having the object of determining a value of a measure

3.15
metric
measure, quantitative or qualitative, of relative achievement of a desired quality characteristic

3.16
modelling
process of construction or modification of a model

3.17
numerical model
numerical representation of a physical (fire) model

3.18
physical model
model that attempts to reproduce fire phenomena in a simplified physical situation, e.g. scale models

3.19
probabilistic model
model that treats phenomena as a series of sequential events or states, with mathematical rules to govern the transition from one event to another, e.g. from ignition to established burning, and probabilities assigned to each transfer point

3.20
simulation
exercise or use of a calculation method

3.21
simulation model
model that treats the dynamic relationships that are assumed to exist in the real situation as a series of elementary operations on the appropriate variables

3.22
uncertainty
potential deficiency in any phase or activity of the modelling process that is due to lack of knowledge

3.23
validation
process of determining the degree to which a calculation method is an accurate representation of the real world from the perspective of the intended uses of the calculation method

3.24
verification
process of determining that a calculation method implementation accurately represents the developer's conceptual description of the calculation method and the solution to the calculation method

NOTE The fundamental strategy of verification of computational models is the identification and quantification of error in the computational model and its solution.

4 Documentation

4.1 General

The technical documentation should be sufficiently detailed that all calculation results can be reproduced within the stated accuracy and precision by an appropriately qualified, independent individual or group. Sufficient documentation of calculation methods, including computer software, is essential to assess the adequacy of the scientific and technical basis of the calculation methods and the accuracy of computational procedures. Also, adequate documentation can assist in preventing the unintentional misuse of calculation methods. Reports on any assessment of a specific calculation method should become part of the documentation. The validity of a calculation method includes comparing results to data from real-world testing, from a survey or from real-world approximations and shall be stated by applying quality-assurance methodology. These give a measure or a set of measures that shall be compared to previously defined criteria to demonstrate whether agreed quality requirements are met.

Documentation shall include

— technical documentation that explains the scientific basis of the calculation method; see 4.2;

— a user's manual, in the case of a computer program; see 4.3.

In 4.2 and 4.3 are described the necessary requirements for technical documentation and a user's manual. The list is quite lengthy, but is not intended to exclude other forms of information that can assist the user in assessing the applicability and usability of the calculation method.

4.2 Technical documentation

Technical documentation is needed to assess the scientific basis of the calculation method. The provision of technical documentation of a calculation method is a task done by the model developers. It is necessary that the technical documentation thoroughly describe the calculation method and its basis, demonstrate its ability to perform adequately, and provide users with the information they need to apply the calculation method correctly. In case of calculations that make use of algebraic equations derived from experimental results by regression or when analytical solutions are applied, the user shall rely on relevant documentation from standards or similar material, such as the scientific literature. When standards are developed that contain calculation methods for use in fire-safety engineering, the source(s) for the calculation methods being used, together with technical documentation as described below, shall be given where applicable.

a) The description of the calculation method shall include complete details on

1) purpose:

— define the problem solved or function performed;

— describe the results of the calculation method;

— include any feasibility studies and justification statements;

2) theory:

— describe the underlying conceptual model (governing phenomena), if applicable;

— describe the theoretical basis of the phenomena and physical laws on which the calculation method is based, if applicable;

3) implementation of theory, if applicable:

— present the governing equations;

— describe the mathematical techniques, procedures and computational algorithms employed and provide references to them;

— identify all the assumptions embedded in the logic, taking into account limitations on the input parameters that are caused by the range of applicability of the calculation method;

— discuss the precision of the results obtained by important algorithms and, in the case of computer models, any dependence on particular computer capabilities;

— describe results of the sensitivity analyses;

4) input:

— describe the input required;

— provide information on the source of the data required;

— for computer models, list any auxiliary programs or external data files required;

— provide information on the source, contents and use of data libraries for computer models.

b) It is necessary that the assessment (verification and validation) of the calculation method be completely described, with details on

— the results of any efforts to evaluate the predictive capabilities of the calculation method in accordance with Clause 5, which should be presented in a quantitative manner;

— references to reviews, analytical tests, comparison tests, experimental validation and code checking already performed. If, in the case of computer models, the validation of the calculation method is based on beta testing, the documentation should include a profile of those involved in the testing (e.g. were they involved to any degree in the development of the calculation method or were they naive users; were they given any extra instruction that is not available to the intended users of the final product, etc.);

— the extent to which the calculation method meets this International Standard.

The technical documentation shall be collected into one document such as a manual as far as computer models are concerned. Whenever explicit algebraic equations are used to solve a fire-safety engineering problem, relevant technical documentation may be cited from sources as indicated above.

Having prepared this documentation, however, the verification and validation processes are not considered finished until a third party has gone through the process independently ("third party auditing"). This auditing process is supported by the definition and use of relevant quality-assurance methods to arrive at a measure or a set of (derived) measures that allows scaling the quality of a calculation method and determines whether a calculation method is sufficiently accurate to meet the requirements of the intended user [see for example concept on internal and external metrics and on quality in use from the series of *Software Quality Requirements and Evaluation (SquaRE)* documents from the work of ISO/IEC JTC1]. For further information, see the series of ISO/IEC 25000 documents. The purpose of a calculation method's evaluation, in general, is to compare the quality of a calculation method against quality requirements that express user needs, or even to select a calculation method by comparing different calculation methods.

c) The technical documentation shall include at least one (or more) worked example(s). Worked examples may be required both for explicit algebraic formulae and for mathematical models. The latter is addressed in 4.3 h). The purpose of a worked example is to demonstrate what the required input data are and their limitations, and the range of applicability of the result(s) of the calculation method being considered. Examples for required input data and their intended range or limitations within which the calculation has been validated are, for example, geometry, material properties, and boundary conditions.

Standards on calculation methods shall include worked example(s) in an informative annex. By specifying the required components of a worked example in an International Standard on calculation methods (e.g. ISO 16734 through 16737), guidance is given on how to apply the International Standard correctly, together with information in the International Standard itself on requirements on limitations and input parameters. Examples taken from real-world problems include the temperature of a steel member or a fire insult to a cable in a nuclear power plant. Since there are examples available in the open literature, the requirement of the inclusion of worked examples in an informative annex to an International Standard on calculation methods may also be met by reference to textbooks that include such examples.

4.3 User's manual

A user's manual is required only in the case of computer models. The user's manual for a computer model should enable users to understand the model application and methodology, reproduce the computer operating environment and the results of sample problems included in the manual, modify data inputs and run the program for specified ranges of parameters and extreme cases. The manual should be sufficiently concise to serve as a reference document for the preparation of input data and the interpretation of results. Installation, maintenance and programming documentation may be included in the user's manual or may be provided separately. There should be sufficient information to install the program on a computer. All forms of documentation should include the name and sufficient information to define the specific version of the calculation method and identify the organization responsible for maintaining the calculation method and for providing further assistance.

In the case of computer models, it is necessary that the user's manual provide all the information necessary for a user to apply a computer model correctly. It should include

a) program description:

— a self-contained description of the model;

— a description of the basic processing tasks performed and the calculation methods and procedures employed (a flowchart can be useful);

— a description of the types of skills required to execute typical runs;

b) installation and operating instructions:

— identify the minimum hardware configuration required;

— identify the computer(s) on which the program has been executed successfully;

— identify the programming languages and software operating systems and version in use;

— provide instructions for installing the program;

— provide the typical personnel time and setup time to perform a typical run;

— provide information necessary to estimate the computer execution time on applicable computer systems for typical applications;

c) program considerations:

— describe the functions of each major option available for solving various problems with guidance for choosing these options;

— identify the limits of applicability (e.g. the range of scenarios over which the underlying theory is known or believed to be valid or the range of input data over which the calculation method was tested);

— list the restrictions and/or limitations of the software, including appropriate data ranges and the program's behaviour when the ranges are exceeded;

d) input data description:

— name and describe each input variable, its dimensional units, the default value (if any) and the source (if not widely available);

— describe any special input techniques;

— identify limits on input based on the stability, accuracy and practicality of the data and the applicability of the model, as well as their resulting limitations to output;

— describe any default variables and the process for setting those variables to user-defined values;

— if handling of consecutive cases is possible, explain the conditions of data retention or re-initialization from case to case;

e) external data files:

— describe the contents and organization of any external data files;

— provide references to any auxiliary programs that create, modify or edit these files;

f) system control requirements:

— detail the procedure required to set up and run the program;

— list the operating system control commands;

— list the program's prompts, with the ranges of appropriate responses;

— if possible to do so, describe how to halt the program during execution, how to resume or exit, and the status of the files and data after the interruption;

g) output information:

— describe the program output and any graphics display and plot routines;

— provide instructions on judging whether the program has converged to a good solution, where appropriate;

h) sample problems/worked examples:

— provide sample data files with associated outputs to allow the user to verify the correct operation of the program; these sample problems should exercise a large portion of the available programmed options; see, for comparison, 4.2 c);

i) error handling:

— list error messages that can be generated by the program;

— provide a list of instructions for appropriate actions when error messages occur;

— describe the program's behaviour when restrictions are violated;

— describe recovery procedures.

5 Methodology

5.1 General

Verification and validation of a calculation method are the processes used to determine the degree to which a calculation method is an accurate representation of the real world from the perspective of the intended uses of the calculation method and the degree to which a calculation method implementation accurately represents the developer's conceptual description of the calculation method and the solution to the calculation method. This is called the “assessment” of the calculation method (see the definitions). Verification is the process of determining whether the equations are being solved correctly. Presuming that the correct equations are being utilized, the next step is validation, which is to ensure that the results match what is expected in the real world.

