Validation of Zone and Field Models to Support Fire Hazard Analysis and Fire PSA review of Fire Scenarios encountered in Nuclear Power Plants

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***Abstract*— This work aims at providing proper knowledge and methodologies for reviewing Fire Hazard Analysis and deterministic aspects of Fire Probabilistic Safety Assessments. In addition, the aspects of validation and sensitivity analysis have been applied to two models: the zone model CFAST and the CFD model ISIS.**

***Keywords*— Deterministic Fire Risk Assessment, Fire Hazard Analysis, Fire PSA, Review of Fire Risk Assessment, Code Validation**

I. Introduction

Within the fire safety assessment of nuclear installations, the modelling of the scenarios has improved significantly over the last decade. This allows plant operators to use fire modelling and fire risk information, along with prescriptive requirements to ensure that nuclear power plants can be safely shut down in the event of a fire. This evolution in the sometimes very complex fire modelling and associated uncertainties by many limitations creates the necessity for the authorities and the Technical Safety Organisations (TSO) to familiarize with those techniques in order to perform their regulatory and supervising activities. For the above reasons, this works aims to provide the Belgian TSO Bel V with proper knowledge and methodologies for reviewing Fire Hazard Analysis (FHA) and deterministic aspects of Fire PSA. Both FHA and Fire PSA will be conducted by Belgian NPP licensees in order to fulfil the requirements set by the Western European Nuclear Regulators' Association.

II. Chronological overview of the thesis content

A. *Fire modelling*

Firstly an overview of different types of fire modelling is drawn up. The reader who is unfamiliar with fire modelling is provided with enough background information of deterministic (computer) modelling and the associated sub models. When using models, care must be taken before using models for a particular purpose.

B. *Proposal of a methodology for deterministic fire risk assessment review*

At present, no clearly established methodology or knowledge base is available which covers the intended purpose of conducting a full independent Fire Risk Assessment (FRA) review as from a safety point of view. The verification of the proper use of fire models and review which also encompass fire modelling is however a necessity in the global safety assessment review conducted by the TSO. Therefore, a review methodology in order to support the review of deterministic aspects in FRA has been proposed.

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C. *Proposal of a methodology for the assessment of fire models*

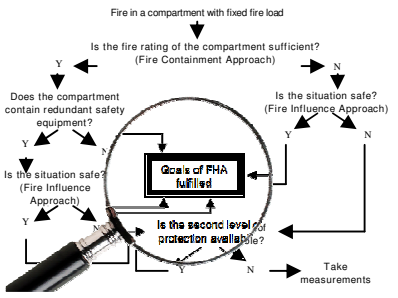
In the global process of safety assessments, the Belgian TSO has to verify if one makes use of deterministic fire models in a responsible manner, or make a direct review of assessments containing computer fire modelling. In order to perform this task, experience in fire modelling is necessary. In addition, maintaining skills in the determination of fire models limitations provide even more profound awareness. In order to fulfil these objectives, an assessment methodology for fire models has been proposed.

D. *Fire model validation application*

The aspects of validation and sensitivity analysis as stipulated in the assessment methodology are applied to two fire models used by the Belgian TSO (CFAST and ISIS). Two scenarios which cover important fire modelling parameters when considering NPP fire scenarios are elaborated.

III. Methodology for deterministic fire risk assessment review

In the proposed review approach, the review process is subdivided into three basic tasks: (1) regulatory review, (2) control of quality, and (3) evaluation of (minimal) technical requirements. The choice of partitioning this process is arbitrary and can subsequently be discussed. However, the choice is defended since the tasks are judged independent and complete for the intended purpose. The review methodology must be seen as complementary to the global TSO review work and therefore no specific site considerations have been described as this does not fit into a general methodology. These considerations are important to consider in a review. Nonetheless, the understanding of these site specific items is believed to be sufficiently established in the years of experience of the Belgian TSO.

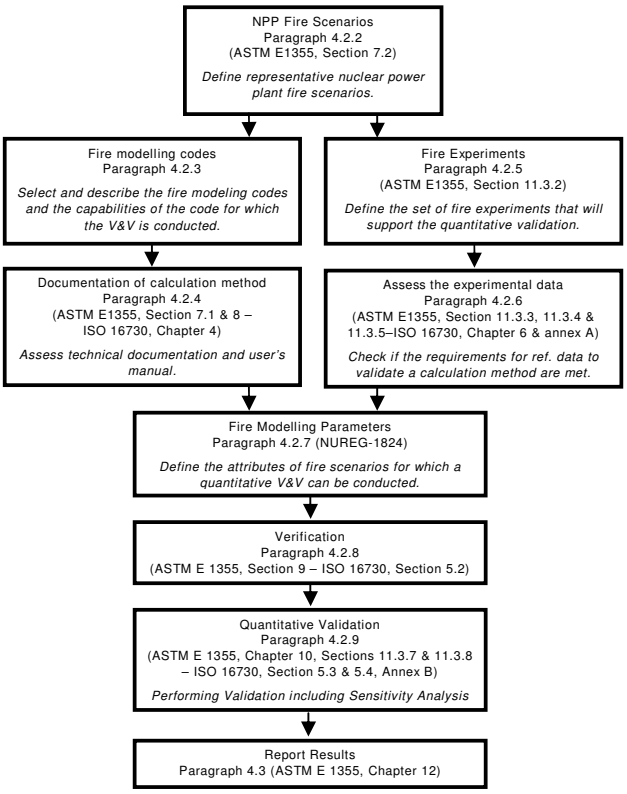


A structured database with information needed to adequately perform an independent review is presented. The proposed Knowledge Base, supplemented by the Technical Application Base, provides a comparative framework for the reviewer of proposed methodologies, developments and computations made by the licensee in the framework of deterministic FRA analyses. The tables with their explanation are intended to identify possible defects or lacks of treatment when being confronted with reviewing FRA methodologies, studies and (sub)analyses. It is the task of the reviewer whether or not to launch appropriate actions in the larger framework of the TSO

review work when deficiencies are encountered, taking into account the general and more detailed aspects of the analysis.

IV. Methodology for the Assessment of Fire Models

Since it is desirable to reflect on both the ability of the numerical fire models to adequately simulate the different fire scenarios, and how the numerical results should be interpreted, the complementary use of two documents is proposed here: ASTM E1355 "Evaluating the Predictive Capability of Deterministic fire Models" and ISO 16730 "FSE – Assessment, verification and validation of calculation methods". Because both documents assess the same aspects, such an approach is feasible. Moreover, it is also convenient to have a methodology that meets the requirements of two commonly used standards. The methodology for the assessment of fire models proposed in this work is as follows:



Each step of this new approach is elaborated in more detail. Furthermore, the aspect of quantitative validation is investigated thoroughly and applied on two scenarios.

In order to quantify the differences between model predictions and experimental measurements, often qualitative comparisons were made in the past. In this work the Euclidean, Hellinger, Secant and Hybrid normalized norm and the associated inner product cosines are presented in order to quantify more properly the differences between experimental data and numerical result.

V. Fire Model Validation Application

A. *Scen. 1: Closed room equipped with ventilation blowing and exhaust branch providing an air renewal rate of $1.5h^{-1}$.*

The zone model CFAST and the field model ISIS have been used to simulate the scenario and subsequently make a quantitative validation. In parallel to the quantitative comparison, a sensitivity study was performed. Among other things grid convergence, behaviour on parallel processing, near wall region, heat release rate, soot production, radiation modelling, wall emissivity, turbulence modelling and branch flow resistance have been considered. In CFAST, leakages had to be chosen such that the calculated pressure resembled the measured pressure. After this trial-and-error, pressure predictions by CFAST are acceptable. In ISIS however, semi-blind simulations without the addition of leaks provided reliable pressure predictions. In ISIS, a pipe-junction boundary condition is available which is intended to be applied in the case of a confined domain which is connected to a ventilation network. This pipe-junction boundary condition also relies on measured pressures, but only at steady state before ignition.

B. *Scen. 2: Two rooms connected by an open door equipped with cable targets. Each room contains ventilation blowing and exhaust branch providing an air renewal rate of $4.7h^{-1}$.*

The zone model CFAST and the field model ISIS have been used to simulate the scenario and subsequently make a quantitative validation for both codes. In parallel to the quantitative comparison, a sensitivity study has been performed. Lessons were learnt from the single room configuration and among other things grid convergence, near wall region, soot production, and wall emissivity were regarded. No specific boundary condition is available in ISIS to model cables. Consequently, the use of a wall conduction boundary condition has been investigated.

As for scenario 1, the use of the Moss two-equation model to model soot production is investigated. This model takes into account the processes of nucleation, surface growth and coagulation. It was found that the Moss model can adequately be used for predicting soot yields and the parameters influenced by the soot (e.g. heat fluxes and temperatures). Nevertheless, the moss model constants can be set. It was found that the constants based on ethylene are suited to represent the fuel.

VI. Closing Remark

The author believes that through this work, the onset is given to make specific considerations towards applicability of validation results. Therefore, the author suggests that it would be beneficial to establish a transition to the applied field (including consideration of NPP safety practices and room configurations in Belgium) of the available knowledge regarding the validation of models and the existing data. Expanding the knowledge in the fields of the above subjects and establishing a structured approach is believed to be indispensable in the process of reviewing safety analysis in the vein of FHA and Fire PSA.

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