Swedish PRISME project – Part 2 - Use of test results from PRISME for practical applications in Sweden

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Abstract

Fires in nuclear power plants can be an important hazard for the overall safety of the facility. One of the important aspects is the effect of ventilation on the fire and vice-versa. Research was with this aspect in mind performed in the PRISME project supported by OECD/NEA. As part of the project also a Swedish research project was initiated. This report is the part, which summarizes the work performed at Lund University to interpret and use the tests results from the experiments performed at the facilities of IRSN.

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Preface

This report, part 2, is one of the reports within the Swedish research project of the PRISME project. The different reports are:

- Swedish PRISME project – Part 1 – Overview and Summary of Tests and Results – Report 3154
- Swedish PRISME project – Part 2 – Use of test results from PRISME for practical applications in Sweden – Report 3155
- Swedish PRISME project – Part 3 – Results and use of overall benchmark exercises in PRISME – Report 3156
- Swedish PRISME project – Part 4 – Results of benchmark exercises at LTH – Report 3157
- Swedish PRISME project – Part 5 – Results of benchmark exercises from other partners in PRISME – Report 3158

Due to the OECD/NEA rules some of these reports can only be published 3 years after finishing of the contract and are as such confidential until January 1st 2015.

This report deals with the application of the test results for the Swedish nuclear power plants. This part also contains a short summary of LTH report nr 3159, which is a Swedish subreport in the project "Varför blir små brander stora?" (Why do some small fires become large?). This report also does not include the benchmark exercises, as this is reported in Part 3-5.

This report would not have been possible without support from all partners in the OECD partners and especially IRSN who was willing to allow us to use pictures and photos from their publications.

The Swedish part of the PRISME project was possible thanks to financial support from Brandforsk (Swedish Board for Fire Research) and NBSG (National Fire safety Group, with representation of Strålsäkerhetsmyndigheten (SSM), Svenskt Kärnbränsle (SKB) and the nuclear power plants in Forsmark, Oskarshamn and Ringhals). Also parts of the validation work were possible thanks to support of SSF (Strategic Research Fund).

Lund, 15 december 2011.

Patrick van Hees

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Jonathan Wahlqvist

Contents

1. Introduction

1.1. Background

The PRISME project [1] is an OECD/NEA project with participation of the following countries:

- Belgium
- Canada
- Finland
- France
- Germany
- Japan
- Netherlands
- Republic of Korea
- Spain
- Sweden.
- United Kingdom
- United States

The budget of the project was 7 M€ and the project time of the project was from January 2006 to June 2011. The major PRISME project financed fire tests at IRSN (France). A project and management group was installed by means of the contract and had meetings at least twice a year. During the meetings the technical content and scope of the project was discussed.

PRISME is the French acronym for "**Pr**opagation de l'**I**ncendie lors de **S**cénarios **M**ulti-locaux **E**lémentaires" which is translated to "Fire Propagation in Elementary Multi-room Scenarios". The project mainly aims on studying smoke and hot gases propagation in full scale, well confined and mechanically ventilated fire compartments.

The PRISME project consisted of a series of fire and smoke propagation tests in a dedicated facility at the French *Institut de radioprotection et de sûreté nucléaire* (IRSN) centre at Cadarache, France. The facility is used to investigate room-to-room heat and smoke propagation, the effect of network ventilation and the resulting thermal stresses to sensitive safety equipment of such room configurations. It is also planned to use data from the project to study multi-room fires and for validating fire computer codes and this is described in another sub-report in this series (Part 3).

Several propagation modes were being studied: through a door; along a ventilation duct that crosses the room containing the fire and that ventilates an adjacent room; along a ventilation duct when flow is reversed within and through leakages between several rooms.

Apart from the project, which incorporated the fire test, a separate project dealing with validation was conducted. This project was not covered by a contract but has been conducted based on national resources. However it uses the test data from the OECD/NEA PRISME project

1.2. Scope

1.2.1. PRISME OECD project

The project (citation from reference 1) aims to provide such critical information as the time that elapses before target equipment malfunctions and to qualify computer codes modelling heat and smoke propagation phenomena. The objective is to answer questions concerning smoke and heat propagation inside an installation, by means of experiments tailored for code validation purposes. In particular, the project aims to provide answers to the following questions:

- What is, for a given fire scenario, the failure time for equipment situated in the nearby rooms that communicate with the fire room by the ventilation network and/or by a door (which is open before the fire or opens during the fire)?
- Is it valid to assume that no propagation occurs beyond the second room from the fire room when the rooms communicate through doors, and beyond the first room when rooms communicate only by the ventilation network?
- What are the safety consequences of the damper or door failing to close, or of an intervention delay which is too long?
- What is the best way to operate the ventilation network in order to limit pressure-driven phenomena and releases to nearby rooms?
- Is it the admission damper closing following fire detection? Is it the extraction damper closing when the temperature threshold of filters has been reached or when the filters are plugged?

The results obtained will be used as a basis for qualifying fire codes (either simplified zone model codes or computerised fluid dynamics codes used in the fire safety analysis of nuclear installations and plants). After qualification, these codes could be applied for simulating other fire propagation scenarios in various room configurations with a good degree of confidence. The information will be useful for designers in order to select the best fire protection strategy. For the operators, this data could be useful for establishing the suitable operation of the plant, such as the operation of the ventilation network (e.g. closing dampers to reduce the ventilation flow rate or to stop the ventilation) in case of a fire.

1.2.2. Swedish PRISME project

The main scope of the Swedish PRISME project was mainly to assess and determine the CFD tools used for fire safety evaluations in buildings and constructions where similar fire scenarios will occur as in the PRISME project.

The objectives were covering three parts:

1. Validation of CFD tools in the scenarios within the PRISME project (mainly FDS but possibly also other CFD tools e.g. Ansys-CFX). This will be limited to the scenarios and exercises within the PRISME project. The results will give further input and improvement of the quality manual for fire safety evaluations.

2. Dissemination of the test results within the PRISME project to the Swedish fire community by reporting to the NBSG and presenting at the NBSG meetings.
3. Participate in the benchmark group meetings and other PRISME meetings.

The project consisted of three work packages:

1. Validation of CFD codes.
2. Dissemination of the results
3. Reporting

1.2.3. Scope of this report

The scope of this report is to summarize the application of the test data of PRISME for Swedish nuclear power plants and will be covering objective number 2 and work packages number 2 and 3.

2. Interpretation of the different Prisme tests Source

2.1. PRISME Source

The PRISME source tests were mainly test to obtain data from the different items, which would be used in the later tests.

First a series of pool fires were conducted with the TPH liquid. The reason for this was that this type of liquid fuel was not so well known. The choice of the type of fuel was taken in the beginning of the project with the motivation to obtain a fuel with high soot production. The soot production was namely higher than liquids like heptane etc.

However a problem for the validation work occurred quickly in the project since it became apparent that the combustion characteristics of the fuel were not so easy to model. THP burns with a clear multi reaction scheme and as such has not one single heat of combustion.

Another disadvantage of using this fuel was the fact that little correlation data was available for the prediction of the HRR for different pool diameters. These types of correlations formulas are available for other known liquids like e.g. heptane, kerosene, etc. The first source tests in an open calorimeter gave this type of correlation data, which is rather unique on one hand, but on the other hand it would have been better to choose a more realistic liquid.

Another important part of the PRISME Source tests was the single room tests with closed doors but with mechanical ventilation. These tests are important as it gave unique test data of under-ventilated fire with mechanical ventilation. This data is as such not only important for nuclear power plant but also for building applications where mechanical ventilation is used. The tests are therefore a challenge for CFD models as there is an interaction between HRR and ventilation due to the overpressure but there is also an interaction between the ventilation and the HRR due to possible limitation of air supply. During a majority of the test reversed flow in the ventilation ducts were observed which makes the data interesting for increased understanding of ventilation systems in fire conditions.

The tests were also used for benchmarking exercises 1 and 2.

2.2. PRISME Door

In the PRISME Door series the same type of liquid pool fires where used to determine mass and heat transport between different rooms with mechanical ventilation. It was an extension from the PRISME Source tests since the number of room was extended. Similar to the SOURCE tests, these data gave unique data for flows between e.g. two rooms were both inlet and outlet ventilation was present. One of the tests was used for the benchmark exercises and the tests were also used as input in the Swedish part of using the PRISME data for practical situations.

2.3. PRISME Leak

Important information on leakages between rooms (not doors) is available in the PRISME leak tests. These tests are also of importance for further use in the validation exercises as they include new challenges for the CFD models. Small circular openings, vertical slot and a fire door were used as possible leakages between two rooms. A final test with a complex ventilation duct in the fire room exiting in a neighbouring room concluded this test series. These tests are again of value for validation although that much of this work is not yet done and certainly will be picked up in the PRISME 2 project.

The data could also be used for functional performance of cables. Important to mention is that the data has been used in order to validate the functional performance model for cables developed by Andersson and Van Hees [2]. The validation of this model was performed by Dreisback, Nowlen and Hostikka and was published as a paper [3] at the Interflam 2010 conference. It could be seen in this validation work that this model, originally developed in Sweden, worked satisfactory for the cables tested in the PRISME leak tests.

2.4. PRISME Integral

The analysis report has not yet been published by IRSN when the report was submitted to NBSG.

3. Use of PRISME Data

This paragraph summarises the way in which the data of PRISME could be applied for a typical fire safety problem in nuclear power plants in order to assess risk of loss of functional performance of critical components. More detailed information on methods and results is given in LTH report 3159 [4].

3.1. Scope of the work

A correlation for predicting gas temperatures in a room adjacent to a room involved in a pre-flashover fire is discussed in this paragraph. A correlation has namely been derived from computer simulation results and validated with data from fire experiments. This paragraph is only a summary of the work reported in report the LTH report 3159 [4].

3.2. Background

Advanced computer modeling software, that can predict smoke spread and compartment temperatures, has been developed during the last decays. With zone models and computational fluid dynamics (CFD) it is possible to e.g. calculate smoke layer heights, species and temperatures in a multi-room geometry. The programs are generally good tools for fire engineering purposes, but they do not remove the need for simple engineering correlations. Simple correlations can be used for hand-calculations to get a first estimate of e.g. smoke layer temperatures in performance based design of a building and help the fire engineer to determine if it is necessary to perform a detailed CFD calculation. Simple correlations can also be a useful tool to use in sensitivity analysis or in fire risk analysis.

Correlations that predict compartment temperatures for single room enclosures date back to the early eighties [5, 6] and are still used for different purposes by fire engineers. These correlations are rough and less accurate compared to computer simulations but they have the benefit of being simple and giving a good description of the hazard. The method that McCaffrey et al presented [5] (MQH-correlation) is based on a simple conservation of energy expression. The MQH-correlation gives the gas temperature as a function of the heat release rate, ventilation conditions, enclosure geometry and thermal properties of the enclosure. The MQH correlation has a set of limitations, which the user must be aware of, but it has been shown to give good predictions of room fire temperatures [7]. The correlation has even been developed further and modified [6,7]. Lately new models for predicting compartment fire temperatures have been presented [8, 9]. However there are few correlations that can predict temperatures outside the room of fire origin. Thus such predictions have to be done with the help of zone or CFD models. A simple correlation that would predict temperatures outside a compartment is something that could be useful to get a first estimate when for example evaluating conditions for evacuees in a room next to the room of fire origin.

3.3. Method

The work presented here has been performed in three steps.

In the first step numerous CFD simulations with the computer software FDS 5 [10] have been conducted. Input files to FDS, with randomly sized two-room configurations, were created with a MATLAB script. Approximately 140 FDS files with different, geometries, openings, wall materials, fuels and heat release rates were simulated on the Lund cluster. In all simulations the fire was placed in the centre of the fire room as illustrated in Figure 1.

The various inputs are e.g. size of the door-opening, size of the room, HRR, fuel, properties of the wall and wall thickness. The mesh size near the fire was determined by following the recommendations of characteristic fire diameter D*, which varied between 0.61 and 1.27 m.

In the second step a statistical analysis has been conducted with the statistical software package SPSS (Statistical Package for the Social Sciences) [11]. The smoke layer temperature in the adjacent room was retrieved from the FDS simulations and was used as dependent variable in the statistical analysis. The heat release rate, area of boundary surfaces of both enclosures, ventilation factors for both openings and heat transfer coefficient were used as independent variables. A multiple linear regression analysis of the logarithmic values of the variables were conducted in SPSS.

In the third step the correlation was tested and validated against results from full-scale experiments both found in literature. A review of such data has been made within the PRISME project [12] and it has been valuable to find suitable data for validation.

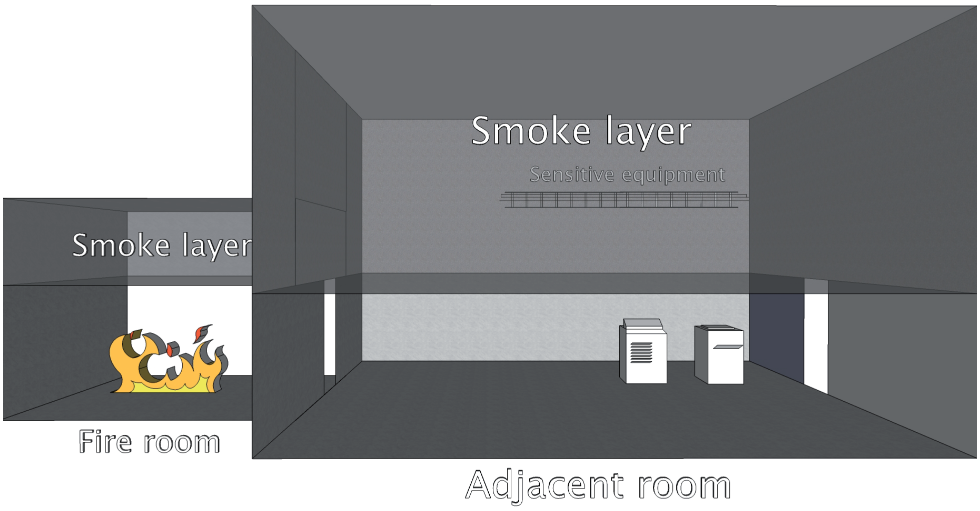

Figure 1 Room set-up for the simulations.

3.4. Results

All included variables were statistical significant and the correlation had a correlations coefficient, R^2-value, of approximately 0.9 with respect to the data from the simulations (Figure 2). The most important variable was the heat release rate. A validity check was preformed by studying data from real fire tests [13,14]. Three sets of experimental data were studied and the result of the validity check can be found in Figure 3. It is considered to be a good agreement between the calculated and measured temperatures since the maximum difference is less than 20%.

A reliability check was preformed by looking at the grid sensitivity of six of the preformed simulations, when decreasing the grid size from 0.1 to 0.05 m.

The presented work is based on FDS simulations of well-ventilated pre-flashover fires. Thus are the results only valid for such conditions. This could be seen be when the PRISME data was introduced in the correlation at the beginning of the project. The test results needed of course to be adapted in order to fit the mechanical ventilation within the correlation formulae. It then showed that the tests were in fact outliers in the correlation formulae because they represented under-ventilated conditions. This showed in fact that the PRISME data represent a unique set of data.

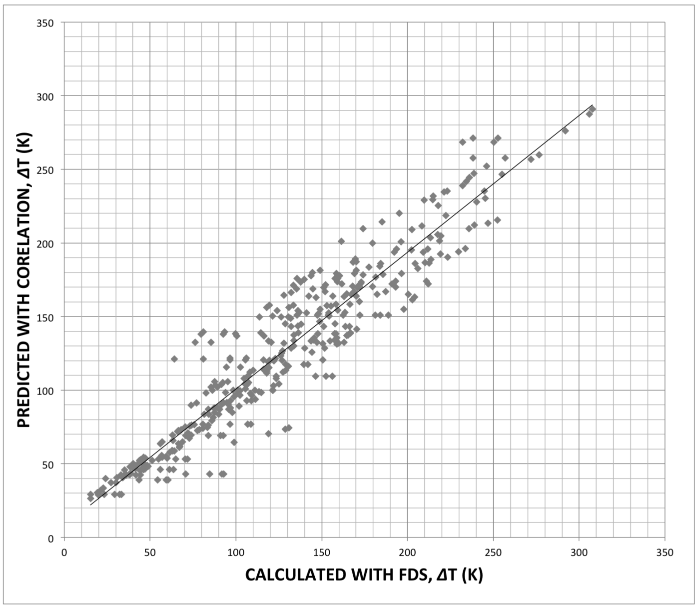

Figure 2 Correlation graph between calculated and simulated temperature increase

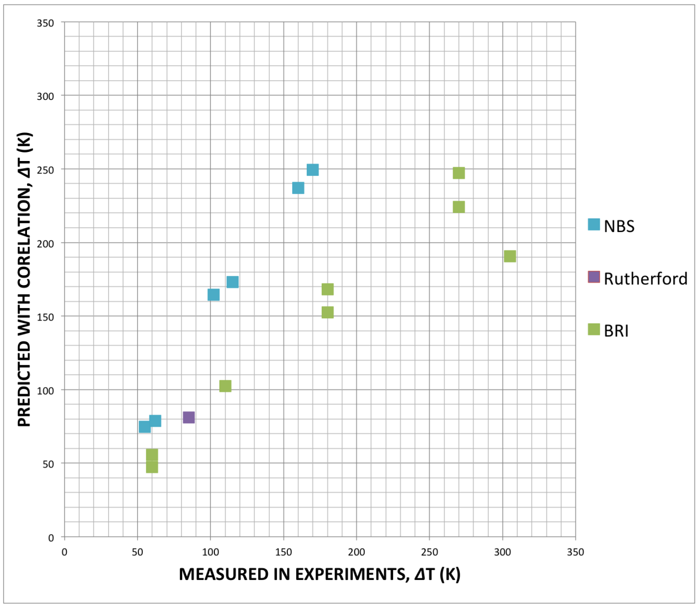

Figure 3 Comparison between calculated and measured temperature increase.

3.5. Discussion

The method used to find a simple correlation was very successfully and could possibly be applied to other areas in fire science to be able to find other simple correlations that can be used by engineers in an initial stage of their design. Some more experimental data is necessary to fully validate the developed empirical formulae.

4. Conclusions

The test data of the PRISME project consist of a number of unique sets of data, which can be used to further study and understand the behaviour of under-ventilated fires. These fires will become more and more important when more air-tight buildings are built, both for industrial and residential application. The data is therefore of importance for a broad field of fire engineers, regulators and industry.
The Swedish part of the project was also extended by developing a simple model for predicting the temperature in a room adjacent to the fire room. This will reduce the number of time expensive simulation when investigating e.g. the functional performance of electrical components and cables.

The test data of the PRISME project is so large that it is important for the whole project group that executive reports will be available in the next PRISME project. Else the data can be difficult to overview.

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Acronyms

Brandforsk: Swedish Board for Fire Research

CFD: Computational Fluid Dynamics

FDS: Fire Dynamics Simulator software programme

HRR: Heat release rate

IRSN: Institut de radioprotection et de sûreté nucléaire

MQH: Method of McCaffrey, Quintiere, and Harkleroad (MQH) for temperature prediction in the fire room.

NBSG: National Fire safety group (composed of SSM, SKB and nuclear power plants at Oscarshamn, Forsmark and Ringhals)

NEA: Nuclear energy agency

OECD: Organisation for Economic Co-operation and Development

PRISME: **Pr**opagation de l'**I**ncendie lors de **S**cénarios **M**ulti-locaux **E**lémentaires" which is translated to "Fire Propagation in Elementary Multi-room Scenarios"

SKB: Svensk kärnbränslehantering AB (Swedish Nuclear Fuel and Waste Management Company)

SSM: Strålsäkerhetsmyndigheten (Swedish Radiation Protection Agency)

SPSS: Statistical Package for the Social Sciences

TS: Technical Specification