Evaluation of Fire Models for Nuclear Plant Fire Safety and Risk Analysis

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INTRODUCTION

This paper provides a summary of the author's work conducted as part of the International Collaborative Fire Model Project (ICFMP). The goal of the project was to evaluate state-of-the-art fire models for nuclear power plant applications. Dr. Dey led the ICFMP project from 1999 to 2006 while he was at the U.S. Nuclear Regulatory Commission (USNRC) and at the same time a guest researcher at the National Institute of Standards and Technology (NIST). The analyses conducted by the author to evaluate select fire models are presented here, along with conclusions on their reliability and applicability for nuclear plant fire safety and risk analysis.

INTERNATIONAL BENCHMARK EXERCISES

The ICFMP project consisted of five international benchmark exercises in which nuclear safety research organizations from five countries (Germany, UK, France, Finland, and USA) exercised state-of-the-art fire models developed in their respective countries to standard problems developed by the ICFMP. The 1st and 2nd international benchmark exercises included hypothetical exercises for fire scenarios in nuclear plants for which experimental data did not exist. The 3rd, 4th, and 5th international benchmark exercises consisted of tests conducted specifically for the ICFMP. Full-scale compartment fire experiments were conducted by the USNRC at NIST for ICFMP Benchmark Exercise No. 3 to simulate a cable room with various types of cables in different configurations [1]. Gesellschaft fur Anlagenund Reaktorsicherheit (GRS) in Germany conducted tests for ICFMP Benchmark Exercise No. 4 to simulate intense fire scenarios in a compartment [2], and ICFMP Benchmark Exercise No. 5 to simulate pool fires and cable flame spread [3]. The author exercised CFAST, a zone fire model, Fire Dynamics Simulator (FDS), a computational fluid dynamics model, and FDTs, a suite of fire correlations, to evaluate the abilities of the fire models or correlations to predict the experimental results.

RESULTS

The results presented here are based on blind predictions made by the fire models or correlations before the experiments were conducted. This was an important aspect of the benchmark exercises in order to determine the true predictive errors, and thereby the real limitations and capabilities of these fire models. Details of the experiments, fire model calculations, and predictive errors are discussed in References 1, 2, and 3.

The main goal of fire safety and risk analysis in nuclear plants is to predict damage to cables in various configurations as damage to power, control, or instrument cables could lead to the loss of reactor core cooling during accident conditions. Although the predictions of general compartment conditions, e.g. hot gas temperature, during a fire were reasonable (10-20 % errors) for most fire scenarios by the CFAST and FDS fire models, the prediction of the heat flux to and heat up of cable targets proved much more difficult. The compartment hot gas temperature is determined by mass and energy balances which are robust in the fire models and thereby result in reliable predictions. However, the heat flux to the cables is dependent on how cables are exposed to the fire, i.e. to the fire flame and/or hot gas, and algorithms for predicting convective and radiative heat fluxes. The ability to predict heat flux, especially when targets are close to the fire flame, was found to be particularly challenging (40 to > 100 % errors) as the algorithms for calculating heat flux and fire flame characteristics involve phenomena that are presently not well understood. Although the correlations for FDTs are suitable for simple fire scenarios and parameters, they are severely limited for most fire scenarios in nuclear plants. Fire models can be reliably used by first examining the flame characteristics in the fire scenario, and then making bounding calculations based on whether the cable target will be primarily exposed to the flame or only hot gases.

REFERENCES

1. M. DEY, "Validation of the CFAST and FDS Fire Models with Full-Scale Nuclear Power Plant Compartment Fire Experiments (ICFMP Benchmark Exercise No. 3), Technical Report Report No. 2009-01, Deytec, Inc., (2009). Available at www.deytecinc.com/FSA8.pdf

2. W. KLEIN-HESSLING (Ed), "Evaluation of Fire Models for Nuclear Power Plant Applications: Benchmark Exercise No. 4: Fuel Pool Fire Inside a Compartment - International Panel Report," GRS-213, Gesellschaft fur Anlagenund Reaktorsicherheit (GRS) (2006). Available at www.deytecinc.com/FSA10.pdf

3. O. RIESE (Ed), "Evaluation of Fire Models for Nuclear Power Plant Applications: Benchmark Exercise No. 5: Flame Spread in Cable Tray Fires – International

Panel Report," GRS-214, GRS, (2006). Available at www.deytecinc.com/FSA12.pdf