Advances in Fire Modeling for Nuclear Power Plant Applications

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INTRODUCTION

The results of the Individual Plant Examination of External Events (IPEEE) program and actual fire events indicate that fire can be a significant contributor to nuclear power plant (NPP) risk depending on design and operational conditions. Fire models can evaluate fire scenarios in risk assessments, determine damage to critical electric cables and other systems and components important to safety, and characterize the progression of fire beyond initial targets. Used in these ways, fire models are important tools in determining the contribution of fire to the overall risk in NPPs.

ACTIVITIES

In 2004, the U.S. Nuclear Regulatory Commission (NRC) amended its fire protection requirements to allow existing reactor licensees to voluntarily adopt the fire protection requirements contained in National Fire Protection Association (NFPA) Standard 805. This allows licensees to use fire models as part of their fire protection programs. The standard requires fire models to be verified and validated (V&V) and to be acceptable to NRC to ensure the quality and integrity of the modeling. NRC's Office of Nuclear Regulatory Research (RES), along with the Electric Power Research Institute (EPRI) and the National Institute of Standards and Technology (NIST), conducted an extensive V&V study of fire models used to analyze NPP fire scenarios. This study resulted in NUREG-1824, "Verification and Validation of Selected Fire Models for Nuclear Power Plant Applications," a seven-volume report issued in May 2007. NRC and its licensees use the results in NUREG-1824 to provide confidence in the predictive capabilities of the various models evaluated.

NRC completed a Phenomena Identification and Ranking Table (PIRT) study of fire modeling (NUREG/CR-6978) that was issued in November 2008. The PIRT study identified important fire-modeling capabilities needed to improve NRC's confidence in the results. This study helps define future research priorities in fire modeling.

NPP fire risk assessments often need to determine when cables will fail during a fire. In the past, cable-damage models have been vague and have not been validated. Recently, as part of the Cable Response to Live Fire (CAROLFIRE) NUREG/CR-6931 program, NRC and the National Institute of Standards and Technology (NIST) developed a simple cable damage model named Thermally-Induced Electrical Failure (THIEF). This model uses empirical information about cable electrical function failure temperatures and calculations of the thermal response of a cable to predict the time to cable damage. NRC validated the THIEF model against real cable failure and thermal data acquired during the CAROLFIRE program.

NIST added the THIEF model in both two-zone and computational fluid dynamics (CFD) models. In addition, NRC incorporated the THIEF model in Supplement 1 to its fire dynamics tools spreadsheets (NUREG-1805) originally issued in December 2004. The THIEF spreadsheet is a useful tool for inspectors and licensees to quickly determine the likelihood of cable damage given a fire or to indicate the need for further analysis. NRC and NIST are currently working on a project examining the fire hazards of grouped electrical cables. The first phase of the CHRISTIFIRE project (NUREG/CR-7010, vol. 1) reports measurements of heat release rate and flame obtained from burning cables in horizontal trays.

Currently, NRC is again working with EPRI and NIST to develop technical guidance to assist those who conduct fire-modeling analyses of NPPs. This guidance will continue to expand on NUREG-1824 by providing users with best practices from experts in fire modeling and NPP fire safety.

This application guide discusses five commonly available fire modeling tools (i.e., fire dynamics tools, Fire-Induced Vulnerability Evaluation (FIVE)-Rev1, Consolidated Fire Growth and Smoke Transport Model (CFAST), MAGIC, and fire dynamics simulator) that were developed by nuclear power stakeholders or that

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were applied to NPP fire scenarios. Previously, RES, EPRI, and NIST used these same models in the V&V study documented in NUREG-1824. Fig. 1 illustrates an isometric view of a room in an NPP showing the temperature profile above an electrical cabinet fire in a fire dynamics simulation.

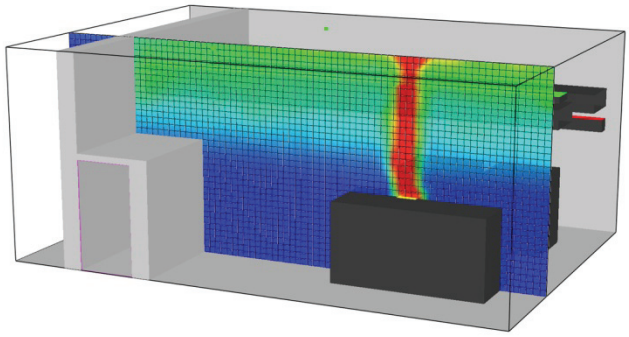

Fig. 1. Graphical output from FDS/Smokeview fire model.

RESULTS

NRC released draft NUREG-1934, "Nuclear Power Plant Fire Modeling Application Guide (NPP FIRE MAG)," for public comment in early 2010. It received numerous comments and suggestions during the public comment period on ways to expand and improve it to better support the model users and reviewers. NRC is currently working with EPRI and NIST on revising the draft and expects to publish it in early 2011. This report will assist both the user performing the calculation and the reviewers. It includes guidance on selecting appropriate models for a given fire scenario and on understanding the levels of confidence that can be attributed to the model results. The report also will form the foundation for future fire model training being developed by RES and EPRI.

NRC is continuing to update the fire modeling tools, expand the V&V effort, and develop additional model input data.

REFERENCES

1. U.S. NRC, "Verification and Validation of Selected Fire Models for Nuclear Power Plant Applications," NUREG-1824 (EPRI 1011999) vols. 1 to 7, Washington, D.C., May (2007).
2. U.S. NRC, "A Phenomena Identification and Ranking Table (PIRT) Exercise for Nuclear Power Plant Fire Modeling Applications," NUREG/CR-6978, Washington, D.C., December (2007).
3. U.S. NRC, "Cable Response to Live Fire (CAROLFIRE) Volume 3: Thermally-Induced Electrical Failure (THIEF) Model," NUREG/CR-6931 vol. 3, Washington, D.C., January (2008).
4. U.S. NRC, "Nuclear Power Plant Fire Modeling Application Guide (NPP FIRE MAG) – Draft Report for Comment," NUREG-1934 (EPRI 1019195), Washington, D.C., January (2010).
5. U.S. NRC, "Cable Heat Release, Ignition, and Spread In Tray Installations during Fire (CHRISTIFIRE) Volume 1: Horizontal Trays," NUREG/CR-7010 vol. 1, Washington, D.C., February (2011).