UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, DC 20555 - 0001

ACRSR-2219

October 25, 2006

Mr. Luis Reyes
Executive Director for Operations
U.S. Nuclear Regulatory Commission
Washington DC 20555-0001

SUBJECT: DRAFT FINAL NUREG-1824, "VERIFICATION AND VALIDATION OF SELECTED FIRE MODELS FOR NUCLEAR POWER PLANT APPLICATIONS"

Dear Mr. Reyes:

During the 536th meeting of the Advisory Committee on Reactor Safeguards, October 4-6, 2006, we met with representatives of the NRC staff, Electric Power Research Institute (EPRI), and the National Institute of Standards and Technology (NIST) to discuss the draft final NUREG-1824 (EPRI 1011999), "Verification and Validation of Selected Fire Models for Nuclear Power Plant Applications." Our Subcommittee on Reliability and Probabilistic Risk Assessment (PRA) also reviewed this matter during its meeting on September 21, 2006. During our review, we had the benefit of the documents referenced.

CONCLUSION AND RECOMMENDATIONS

1. The report provides a systematic evaluation of the predictive capability of five commonly used compartment fire models. It should be published.

2. The user's guide to be developed by the staff should include:

   a. Estimates of the ranges of normalized parameters to be expected in nuclear plant applications.
   b. Quantitative estimates of the uncertainties associated with each model's predictions, preferably in the form of probability distributions.

BACKGROUND

Fire models are used in a number of safety evaluations, including fire risk analysis; demonstrating compliance with, and exemptions to, the regulatory requirements for fire protection in 10 CFR Part 50, Appendix R; the significance determination process of the Reactor Oversight Process; and establishing the risk-informed, performance-based voluntary

fire protection licensing basis under 10 CFR 50.48(c) and the referenced 2001 Edition of the National Fire Protection Association (NFPA) Standard, NFPA 805, "Performance-Based Standard for Fire Protection for Light-Water Reactor Electric Generating Stations." NFPA 805 requires that "only fire models that are acceptable to the authority having jurisdiction shall be used in fire modeling calculations." NFPA 805 further requires that the fire models be verified and validated, and be applied only within their domains of validity.

The NRC Office of Nuclear Regulatory Research (RES) and EPRI sponsored a collaborative project for the verification and validation of selected fire models that are commonly used in the nuclear industry. NIST participated in this work. Report NUREG-1824 (EPRI 1011999) is the result of this collaborative project.

The selected models are:

- Fire Dynamics Tools (FDTs) developed by the NRC
- Fire-Induced Vulnerability Evaluation, Revision 1 (FIVE-Rev1) developed by EPRI
- Consolidated Model of Fire Growth and Smoke Transport (CFAST) developed by NIST
- MAGIC developed by Electricité de France (EdF)
- Fire Dynamics Simulator (FDS) developed by NIST

The verification and validation study was based on the methodology described in the American Society for Testing and Materials (ASTM) International Standard E 1355 - 05a "Standard Guide for Evaluating the Predictive Capability of Deterministic Fire Models."

A draft version of NUREG-1824 was issued for public comment on January 31, 2006. The comment period closed on March 31, 2006. The project team responded to all of the public comments.

DISCUSSION OF THE NUREG REPORT

Ever since the Browns Ferry fire in 1975 and the publication of several PRAs that demonstrated the risk significance of fires, there has been a great deal of interest in modeling the effects of fire on nuclear power plants. A number of deterministic models have been proposed focusing primarily on compartment fires. These are based on varying assumptions and calculational methods ranging from simple hand calculations (FIVE-Rev1 and FDTs) to two-zone models (CFAST and MAGIC) to sophisticated detailed models (FDS). This study is the first systematic evaluation of the ability of fire models to predict experimental results and will be very useful to both the NRC and the industry.

The project team identified 13 parameters that are likely to be required in safety assessments involving fires. These parameters were selected by reviewing potentially risk-significant scenarios from a variety of sources and are limited to those that describe the environment created by a fire in a compartment, e.g., the height and temperature of the hot gas layer, the flame height, the smoke concentration, and the radiant heat flux. This set of parameters does not characterize other important fire phenomena that are out of the scope of the present work, such as fire propagation in cable trays.

The ability of the selected models to estimate numerical values for the chosen parameters was evaluated by comparing their results with experimental measurements. The measured heat release rates from the fires were used as input to the analyses. Twenty-six experiments were selected from five test series that were judged to be relevant to nuclear plant applications and for which sufficient information was available to allow quantitative evaluations. The experiments were performed using pool fires with a variety of hydrocarbon fuels and a wide range of heat release rates.

The model predictions for each experiment were compared with the experimental results. There are uncertainties associated with these comparisons because of uncertainty in model input (primarily the heat release rate) and uncertainty in the measurements themselves. The experimental *measurement uncertainty* and the experimental *model input uncertainty* are used to develop a range of possible values of the scenario parameter of interest. The accuracy of the model predictions is qualitatively characterized by a simple color code.

DISCUSSION OF THE USER'S GUIDE

The staff plans to develop a user's guide to complement NUREG-1824. A user will have to determine whether the results of the verification and validation study are applicable to the situation to be analyzed. This is done using "normalized parameters" (i.e., governing non-dimensional groups, not to be confused with the13 scenario parameters discussed above) that allow users to compare results from scenarios of different scales by normalizing physical characteristics of the scenario. These normalized parameters are traditionally used in fire modeling applications and are included in the NUREG report. The user's guide should provide estimates of the ranges of normalized parameters to be expected in nuclear plant applications. These estimates would allow a determination of whether risk-significant fires fall within or outside the parameter ranges covered by the verification and validation process.

The user's guide should also provide probability distributions for the model predictions due to the intrinsic model uncertainty, i.e., the uncertainty associated with the model's physical and mathematical assumptions. These distributions should not include the uncertainties in the heat release rate since the latter will be an input specified by the user. The color designations provide no quantitative estimate of the intrinsic uncertainty. This uncertainty is an important input in risk-informed applications. Even in non-risk-informed applications, a quantitative assessment of the tendency of a model to over- or under-predict would be valuable. The staff told us that such quantitative estimates will be provided in the user's guide. We look forward to reviewing this document.

CONCLUDING REMARKS

We commend the RES staff and EPRI for undertaking this project and providing the basis for the evaluation of fire models. The NUREG report and the user's guide will significantly improve the technical basis supporting the fire safety evaluations.

This commendable effort to validate models of compartment fires is an important first step in developing the fire models needed by the NRC to assess fire risks and licensee proposals. Validated models of the effects of fires on equipment and cables are needed. Also needed are models of smoke transport within plants and the effects of deposited smoke on equipment and structures. We look forward to interacting with the staff as this research progresses.

Sincerely,

/RA/

Graham B. Wallis
Chairman

References:

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2. *Verification and Validation of Selected Fire Models for Nuclear Power Plant Applications, Vol 2: Experimental Uncertainty,* U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research (RES), Rockville, MD, and Electric Power Research Institute (EPRI), Palo Alto, CA, NUREG-1824 and EPRI 1011999, August 2006.

3. *Verification and Validation of Selected Fire Models for Nuclear Power Plant Applications, Vol 3: Fire Dynamics Tools (FDT^s),* U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research (RES), Rockville, MD, and Electric Power Research Institute (EPRI), Palo Alto, CA, NUREG-1824 and EPRI 1011999, August 2006.

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8. NFPA 805, “Performance-Based Standard for Fire Protection for Light-Water Reactor Electric Generating Stations,” 2001 Edition, National Fire Protection Association, Quincy, MA.