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

February 28, 2008

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

SUBJECT: CABLE RESPONSE TO LIVE FIRE (CAROLFIRE) TESTING AND FIRE MODEL IMPROVEMENT PROGRAM

Dear Mr. Reyes:

During the 549th meeting of the Advisory Committee on Reactor Safeguards, (ACRS) February 7-9, 2008, we reviewed the draft final NUREG/CR-6931, "Cable Response to Live Fire (CAROLFIRE), Volume 1: Test Descriptions and Analysis of Circuit Response Data; Volume 2: Cable Fire Response Data for Fire Model Improvement; and Volume 3: Modeling," (Reference 1). Our Subcommittees on Thermal Hydraulic Phenomena and on Reliability and Probabilistic Risk Assessment reviewed this matter during a joint meeting on January 18, 2008. During these reviews, we had the benefit of discussions with representatives of the NRC, National Institute of Standards and Technology, and Sandia National Laboratories. We also had the benefit of the documents referenced.

## RECOMMENDATIONS

1. NUREG/CR-6931, "Cable Response to Live Fire (CAROLFIRE)," including the electronic data sets, should be published.

2. The staff should continue to analyze the CAROLFIRE test data and develop guidance regarding the use of the results.

## BACKGROUND

Since the 1975 Browns Ferry fire, where damage to power, control, and instrumentation cables occurred, there has been considerable interest in the response of cables to fire. It is often assumed that any system that depends on electrical cables that pass through a compartment exposed to fire is unusable for its intended safety function. In addition to preventing systems from performing their intended functions, fire can cause short circuits ("hot shorts"), which can result in spurious actuation of systems. The possibility of hot-shorts and spurious actuations must be taken into account in assessing the effects of fire (Reference 2).

In order to better understand the issue of hot shorts, a series of cable fire damage tests were conducted by the Nuclear Energy Institute and Electric Power Research Institute in 2001. Results of these tests, along with previous test data, were published in an NRC Regulatory Issue Summary (RIS 2004-03 Rev. 1) entitled, "Risk-Informed Approach for Post-Fire Safe Shutdown Circuit Inspections," (Reference 3). This RIS presented guidance to NRC inspectors and identified three categories, or bins, of circuit configurations. Those in Bin 1 were deemed the most likely to fail and were identified as the focus for inspection. Bin 3 configurations were deemed least likely to fail. The assessment of the likelihood of failure of Bin 2 configurations was deemed to require additional testing and research. These circuit configurations included

inter-cable shorting between thermoset cables, inter-cable shorting between thermoplastic and thermoset cables, configurations requiring failure of three or more cables, multiple spurious actuations in control circuits with control power transformers, and fire-induced hot-shorts that must last longer than 20 minutes to impair the ability of a plant to achieve hot shutdown.

The CAROLFIRE research project was undertaken to provide additional data on Bin 2 cable configurations to support further development of guidance and modeling capabilities. The project plan was peer-reviewed and modified before the experiments were initiated. The project information is presented in a three volume report that describes the tests, presents the cable fire response data, and provides a model to predict the thermal response of cables up to the time of failure.

**DISCUSSION**

CAROLFIRE consisted of 78 well controlled, small-scale, cable tests and 18 larger-scale open-burn integral tests. These tests were designed to complete and complement previous testing. The objectives of these tests were to provide data to:

- Elucidate the regulatory issues involved in the Bin-2 items noted in the RIS,
- Improve models for responses of cables exposed to fire.

The CAROLFIRE project has met these test objectives. It has provided an expanded database, including simultaneous measurements of hot-short failures and thermal responses for electrical cable fires (thermoset and thermoplastic). It has explored phenomena of interest over a reasonably wide range of conditions and provided significant data for both Bin 2 items and model development.

In addition to being useful in developing improved inspection guidance, many of the results from CAROLFIRE tests have important implications for plant safety assessments and fire PRAs. For example:

- Consistent with the observations in the RIS, Bin 1 events were observed in many cases; Bin 2 events occurred less often, but did occur; and Bin 3 events were not observed.
- Inter-cable shorts were observed between all types of cables tested, including thermoset to thermoset.
- Maximum duration of a sustained hot short was less than 8 minutes.
- Control power transformers did not significantly affect circuit response to fire-induced cable failures.
- Data do not support limiting the consideration of concurrent spurious actuations to only two cables; there is no basis for establishing an *a priori* limit to the number of spurious operations that may occur during a given fire.
- Damage follows quickly once a material-dependent threshold temperature is reached. Electric failures were often observed prior to cable ignition.

The extensive data from the CAROLFIRE tests will help analysts to identify various cable failure modes and their timing and inform analysts' judgment when they assess the likelihood of cable failure. Combined with additional modeling, they may also make it possible to better describe failures in instrument and protection systems and alternative fire configurations.

NUREG/CR-6931, Volume 3, presents a quantitative interpretation of the data using a one-dimensional transient conduction model (called "THIEF" – Thermally Induced Electrical Failure) with homogenized cable properties. Using measured conditions in the environment surrounding the cables to characterize the heat source, THIEF predicts cable thermal response up to the failure threshold temperature. Threshold temperatures for different cable types have been developed from the CAROLFIRE failure data. The model usually predicts failures close to the data or somewhat earlier than those observed because of effects such as shielding, e.g., by cable trays, which are not modeled.

THIEF must be coupled to a fire model that predicts the conditions surrounding the cables in order to predict cable response and failure times in postulated fire scenarios. The uncertainties in prediction of the surrounding conditions and the incident heat flux in the fire models are large compared to those in the THIEF predictions. The CAROLFIRE experiments and experiments being conducted in other venues, such as in France, provide data that may be used to improve such combined models and reduce uncertainties in the predictions. We encourage the staff to continue work in this direction.

The CAROLFIRE project has provided valuable data with regard to cable fires. It is an important step in the staff's efforts to develop modern fire assessment models. The staff should continue to analyze the test data and develop guidance for future use of these data. We would like to be kept informed of their progress. NUREG/CR-6931, including the associated electronic data sets should be published.

Sincerely,

***/RA/***

William J. Shack
Chairman

REFERENCES

1. NRC, NUREG/CR-6931 "Cable Response to Live Fire (CAROLFIRE) Volume 1: Test Descriptions and Analysis of Circuit Response Data; Volume 2: Cable Fire Response Data for Fire Model Improvement; and Volume 3: Modeling." (ML071300299)

2. 10 CFR 50, Appendix R, "Fire Protection Program for Nuclear Power Facilities Operating Prior to January 1, 1979."

3. NRC Regulatory Issue Summary 2004-03: Revision 1, "Risk-Informed Approach for Post-Fire Safe-Shutdown Circuit Inspections," December 29, 2004. (ML04244791)

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William J. Shack
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Executive Director for Operations

From: William J. Shack, Chairman
ACRS

Subject: CABLE RESPONSE TO LIVE FIRE (CAROLFIRE) TESTING AND FIRE MODEL IMPROVEMENT PROGRAM

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