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

ACRSR-2181

REVISED

April 10, 2006

The Honorable Nils J. Diaz
Chairman
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

SUBJECT: GENERIC SAFETY ISSUE 191 - ASSESSMENT OF DEBRIS ACCUMULATION ON PWR SUMP PERFORMANCE

Dear Chairman Diaz:

During the 530th meeting of the Advisory Committee on Reactor Safeguards, March 9-11, 2006, we considered several reports by the NRC staff regarding their efforts to resolve Generic Safety Issue 191(GSI-191), "Assessment of Debris Accumulation on PWR Sump Performance." The staff discussed licensee responses to Generic Letter 2004-02 (GL 2004-02), "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors," and presented the results of efforts by the Office of Nuclear Regulatory Research (RES) to understand several phenomenological issues that have arisen as part of the GSI-191 effort, including chemical effects, downstream effects, and head loss correlations through debris beds. The results were presented to our Thermal-Hydraulics Phenomena Subcommittee on February 14-16, 2006. We had the benefit of presentations by and discussion with representatives of the NRC staff and members of the public. We also had the benefit of the documents referenced.

CONCLUSIONS AND RECOMMENDATIONS

1. In response to GL 2004-02, many licensees plan to increase the size of their sump screens as quickly as feasible. Based on the current state of knowledge, we concur with this intent. However, it is not evident that this measure will be sufficient to resolve all long-term core cooling issues.

2. Results of prototypical experiments planned by industry to validate screen effectiveness will be difficult to extrapolate to plant conditions. Further work is required to provide the technical basis by which the staff can assess the adequacy of the planned modifications to the plants. Guidance should be developed to support the staff's review.

3. Recent research has revealed significant influences of particle/fiber mixtures and chemical reaction products on screen pressure drop for which improved predictive methods and guidance should be developed.

4. Increasing screen size to reduce the pressure drop may increase the amount of fine debris and chemical products that passes through the screen. Methods for predicting the quantity and properties of this bypassed debris should be developed. Potential adverse effects on downstream components, including pumps, valves, the core entrance regions, and the core itself, should be evaluated.

5. There has been some success at using adjustable parameters in an equilibrium chemistry model to match the chemical species that form in sumps. The methods should be validated further and guidance should be developed for their use.

6. The results of tests of coating debris formation and transport should be included in the assessment of core coolability as they become available. Future work should include the development of adequate predictive capability for the effects of coating debris on screen pressure drop and bypass.

OVERVIEW

At our meeting with the Commission on December 8, 2005, several Commissioners expressed the view that the sump screen issue should receive high priority. This was formally stated in the Commission's staff requirements memorandum of December 20, 2005: "... The ACRS shall make among its highest priorities its role in the resolution of GSI-191. ..." At the Commission meeting we indicated that we were waiting to hear status reports from the staff. We have now received several reports, some of them preliminary, and this has enabled us to form an opinion on progress towards resolving GSI-191.

We have written previous letters on the sump screen issue. In particular we raised the matter of chemical effects and questioned some aspects of the NEI guidance which the staff had endorsed.

The staff issued GL 2004-02 on September 13, 2004, and has received responses from all licensees. Though all licensees responded to the generic letter, the staff has concluded that none of the responses was complete. Gaps were evident in all important areas, particularly chemical and downstream effects. The staff has issued requests for additional information (RAIs) relating to several significant effects. Many licensees are finalizing plans to replace the screens before these RAIs are resolved.

While progress has been made in all areas of research, much remains to be done. These programs have produced significant results and are making important contributions to understanding the issues related to PWR sump performance. Many relevant physical and chemical phenomena are being explored. Assessments of other important effects may need to be added to the program.

This research has yet to lead to an ability to develop and validate predictive methods. Much of the work is exploratory in nature, in response to indications that existing analytical capabilities were incomplete and inadequate. The results from some programs are not yet available or are awaiting staff review.

The GL 2004-02 responses and recent research have raised new questions. Present plans by licensees to make hardware changes in their plants are driven by the need to reduce the potential for excessive head loss across sump screens during recirculation. Increasing the screen size will reduce this head loss, but the staff's ability to assess the adequacy of the reduction may be limited by uncertainties in the available knowledge base. In addition, downstream effects may be exacerbated by some screen designs and configurations. The staff needs effective means to evaluate these downstream effects and their influence on core coolability.

DISCUSSION

Industry Response to Generic Letter 2004-02

In general, licensees intend to address the sump screen issue by making a significant increase in the flow areas of the screens. Some designs may also have smaller openings and/or active debris removal mechanisms. Physical changes have already been made in some plants. Modifications to almost all plants are planned to be completed by the end of calendar year 2007. Some licensees have requested extensions until the spring outage of 2008. Each of the five vendors of the new sump screens plans to undertake integrated-effect “proof tests” with screens or segments of screens to demonstrate the ability of the screens to accommodate the anticipated loading of debris with an acceptable pressure drop.

The prediction of debris formation, transport, and impact on core coolability is a very complex technical problem. A number of phenomenological issues must be addressed, either by the development of a predictive capability or by the implementation of engineering solutions that circumvent the more difficult issues. The industry is focusing on engineering approaches that maximize screen area to the extent practical, control of materials that affect the quantity and character of debris generation, and the control of sump chemistry to minimize chemical effects.

Regulatory Approach

The staff intends to undertake eight to ten audits of plant modifications. The scope of the audits will be expanded if the staff encounters problems with the technical adequacy of the planned resolutions.

Because of the “proof test” nature of the planned industrial testing program, it is essential that the staff have a level of understanding and a modeling capability for the underlying phenomena adequate to support their technical review of the licensee results. It is doubtful that the current understanding of these phenomena will be adequate to support such a review. The results of recent research have served to call into question some previous guidelines and assumptions without replacing them with validated, improved methods.

Research Efforts

Research is being performed to address the following phenomena:

- Chemical effects – experiments (Los Alamos National Laboratory (LANL) and Argonne National Laboratory (ANL)) and model development for speciation (Center for Nuclear Waste Research Activities (CNWRA))

- Head loss from debris buildup on screens – experiments (Pacific Northwest National Laboratory (PNNL)) and model development (RES)

- Downstream effects – experiments (LANL)

- Coating debris formation and transport – experiments (Electric Power Research Institute (EPRI), Naval Surface Warfare Center (NSWC))

We have seen only the preliminary results from some of these research efforts. It is premature for us to perform a comprehensive evaluation until all the work is complete. However, several research projects have developed important new quantitative information which reveals the significance of certain phenomena. Understanding of those phenomena has not yet been established to the point where validated predictive tools are available. RES has set a target of the spring of 2006 to bring these activities to a conclusion. This schedule is unrealistic in view of the many unresolved issues.

Chemical effects

Exploratory integrated chemical effects tests (ICET) revealed that some species, particularly aluminum oxyhydroxide and calcium phosphate, can be produced under certain conditions. It was concluded that plant-specific evaluations would be required.

ANL is investigating the interaction between calcium silicate insulation (CalSil) and trisodiumphosphate (TSP), which forms calcium phosphate. A qualitative understanding of the chemical processes has been achieved. Studies of head loss on screens using debris quantities that duplicated earlier LANL tests with no chemical additives showed some variability. When calcium phosphate was produced by adding TSP to CalSil, or calcium chloride to TSP, the pressure drop increased substantially. For example, in one test (ICET3-9) the pressure drop through a fiberglass bed was 0.14 psi at a flow velocity of 0.1 ft/s. When calcium chloride was added in stages to the solution of TSP, the pressure drop eventually rose to 5.2 psi at a flow velocity below 0.02 ft/s. Since the flow regime was probably laminar, for which pressure loss is proportional to flow velocity, this corresponds to an increase in bed resistance by a factor of about 200, amounting essentially to blockage of the screen. Similar results were obtained in Tests 1 and 2.

The results of chemical speciation prediction by codes using chemical equilibrium models and measured corrosion rates are encouraging over the range of species that have been studied. CNWRA found that some ICET results could be matched by adjusting the speciation parameters.

Head Loss Tests

PNNL has been conducting head loss tests with mixtures of fiberglass and CalSil in amounts corresponding to those used in earlier LANL tests. The results in some cases differ significantly from the results obtained by LANL. No distinct pattern is evident though some trends might be inferred. In an extreme case, when the constituents were introduced in a particular way, the head loss was roughly 100 times more than the head loss with a well-mixed debris bed of the same overall composition. These results indicate that the structure of the debris bed and the way in which it is formed can have a huge influence on the head loss. Unless the assumption of a homogeneous bed can be justified, it will be necessary to develop an adequate model for these effects (for plants that intend to retain CalSil) or to find a way to scale them in the proof tests now planned by industry. The alternative of developing theoretical models for the way in which the bed builds up in different parts of the screen over time during a variety of accidents is probably unrealistic and may be beyond the capabilities of present state-of-the-art.

RES has begun development of a theoretical model to predict the head loss in a nonhomogeneous debris bed. Substantiation and validation of such a model would be a major undertaking.

Downstream Effects

Tests conducted by LANL revealed that fine debris, of a size characteristic of the debris expected during energetic loss-of-coolant accidents (LOCAs), would pass through a typical sump screen under some conditions. Unless a debris bed has been established, most particles of CalSil and fine fiberglass pass through the screen. Significant quantities of reflective metallic insulation were observed to pass through under some conditions. In the absence of a detailed model for the history of debris bed development on a screen and the arrival of various constituents as functions of location and time, there are considerable uncertainties about how to apply such results to an actual plant. An order of magnitude calculation, with 5000 ft^3 of debris produced, indicates that about 6% of the debris would fill the typical lower plenum of a reactor vessel, if it settled there and was not transported to the core or filtered by debris catchers below the fuel. The larger the screen, the more open area there is likely to be through which fine debris can pass. Chemical reaction products are also likely to pass through open areas of the screen.

In reply to our subcommittee's questions about the effects of such debris on core coolability, the staff and representatives of the Westinghouse Owners Group (WOG) stated that they thought the core would be adequately cooled in a number of scenarios. However, they presented no physical models or analytical predictions to show a validated, quantitative basis for such conclusions.

Tests by LANL of debris transported to throttle valves have revealed a significant effect on pressure drop. Adequate predictive methods are therefore needed for the amount of this debris which actually reaches these valves, and for the resulting consequences.

Coatings

EPRI is conducting experiments on the formation of debris from qualified and unqualified coatings. The results were not presented at our meetings.

NSWC is conducting some basic tests of terminal velocity and transport of paint chips of various shapes, sizes, and composition. Guidance for use of these data remains to be developed.

What Is Missing

We are not aware of research efforts in several important areas.

The most significant omission appears to be an adequate understanding of the effects of the various debris species which enter the reactor vessel and reach the core. These effects are likely to depend on the LOCA scenario, particularly the location and size of the break, and on the screen design. Although guidance developed by the WOG describes several of the phenomena to be modeled to represent these effects, the WOG apparently leaves the evaluation to engineering judgment and ad hoc model development. Unless these effects can somehow be avoided, there is a need for a comprehensive set of validated tools for representing them. Developing the tools would involve significant experimental and model development efforts.

The proof tests being developed by industry to evaluate new screen designs involve the phenomena described earlier in this letter, as well as others. Synthesizing these evaluations into a defensible method for scaling test results to the actual LOCA scenario is no trivial matter.

We have yet to see scaling laws, methods of extrapolation, or theoretical representations (e.g. computational codes) which can make a convincing case that the test results can be applied to the actual plant. For example, one issue is how to use tests on a single module to predict the performance of an array of modules. The Office of Nuclear Reactor Regulation (NRR) may need to draw on further research results in order to evaluate submissions based on these proof tests.

Formation and transport of coating debris are being studied. We have not seen results of work on the effects of this debris on screen head loss. In view of the difficulty of predicting head loss with the existing mix of ingredients, and the surprises that have been encountered, it is necessary to establish a knowledge base for the effects of coatings on head loss by means of an adequate set of experiments and predictive methods.

Research has already revealed that the structure of a debris bed influences head loss and the bypass of fine material. As screens become larger and perhaps have more complex geometry, the variability of bed structure over the surface of the screen is likely to increase. Some areas, such as the base of vertical screens or the outer layers of multiple screens, may be covered by a pile of coarse debris, other areas may support "thin beds" that are blocked by chemical products or fine debris, while some areas may be clear of debris, providing paths through which fine material can pass. There is a need to reduce uncertainty in predicting the performance of these screens under a wide variety of scenarios. Since modeling everything theoretically is impractical, the emphasis should be placed on designing for predictability, supported by data.

THE PATH FORWARD

In response to GL 2004-02, licensees have undertaken the task of showing that they satisfy the requirements of recirculation core cooling. In most cases, the response has been to plan the replacement of sump screens by those with significantly larger area. The hole size and other characteristics of these screens may also be changed.

These changes are in the right direction to alleviate the potential for excessive head loss. However, in view of uncertainties introduced by new research results, the incomplete response by industry to the generic letter, the difficulties of validating the "proof tests" planned by industrial consortia, and downstream effects, NRR will need to develop assurance that it has the capability to evaluate the effects of these changes. The staff anticipates that, if sufficient uncertainty is encountered, supplemental actions may be required. These may include the following measures:

- Removal from containment of constituents that are known to cause problems with head loss and lack of predictability.

- Development of screen designs that are insensitive to the plethora of uncertainties associated with many existing designs. These designs may include active screens or similar devices that can handle many forms of debris without the need for knowing the details of the debris characteristics.

- Design of screens for minimum bypass of fine debris. Emphasis is currently being placed on reducing head loss, but downstream effects should also be considered.

- Identification of other solutions to core cooling that get around the manifold uncertainties associated with the present range of screen designs and can more confidently demonstrate success in meeting specifications.

- Use of probabilistic analysis to show that the most undesirable debris bed configurations are highly unlikely. Evaluation would be based on realistic analysis rather than on a conservative approach.

We endorse the immediate plans to increase the size of sump screens because this will alleviate the potential for excessive head loss. This action by itself may not be sufficient to resolve all long-term core cooling issues.

We anticipate working further with the staff on these important matters.

Dr. William Shack did not participate in the Committee's deliberations regarding this matter.

Sincerely,

/RA/

Graham B. Wallis
Chairman

References:
1. U.S. Nuclear Regulatory Commission Generic Letter 2004-02: "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized Water Reactors", September 13, 2004.
2. U.S. Nuclear Regulatory Commission Bulletin 2003-01, "Potential Impact of Debris Blockage on Emergency Sump Recirculation at Pressurized-Water Reactors", June 9, 2003.
3. Letter from Mario V. Bonaca, Advisory Committee on Reactor Safeguards, "Proposed Draft Final Generic Letter on Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at PWRs," July 19, 2004.
4. "Draft NRC Staff Review Guidance for Evaluation of Downstream Effects of Debris Ingress into the PWR RCS On Long Term Core Cooling Following a LOCA", undated.
5. "Evaluation of Downstream Sump Debris Effects in Support of GSI-191," WCAP-16406-P, Westinghouse Owners Group, June 2005.
6. Information Notice 2005-26: "Results of Chemical Effects Head Loss Tests in a Simulated PWR Sump Pool Environment," September 16, 2005.
7. NRC Information Notice 2005-26, Supplement 1: "Additional Results of Chemical Effects Tests in a Simulated PWR Sump Pool Environment," January 20, 2006.
8. "Integrated Chemical Effects Test Project: Test #1 Data Report," LA-UR-05-124, June 2005.
9. "Integrated Chemical Effects Test Project: Test #2 Data Report," LA-UR-05-6146, September 2005.
10. "Integrated Chemical Effects Test Project: Test #3 Data Report," LA-UR-05-6996, October 2005.
11. "Integrated Chemical Effects Test Project: Test #4 Data Report," LA-UR-05-8735, November 2005.
12. "Integrated Chemical Effects Test Project: Test #5 Data Report," LA-UR-05-9177, January 2006.
13. Memorandum from Michele G. Evans to John N. Hannon, "Final Transmittal of Information Summarizing Integrated Chemical Effects Results and Implications", October 25, 2005.
14. "Corrosion Rate Measurements and Chemical Speciation of Corrosion Products Using Thermodynamic Modeling of Debris Components to Support GSI-191," NUREG/CR-6873, April 2005.
15. "Screen Penetration Test Report," NUREG/CR-6885, LA-UR-04-5416, October 2005.
16. Memorandum from Ralph Architzel to James Lyons, "Report on Results of Staff Pilot Plant Audit– Crystal River Analyses Required for the Response to Generic Letter 2004-02 and GSI-191 Resolution," June 29, 2005.
17. Memorandum from Ralph Architzel to Thomas Martin, "Report on Results of Staff Pilot Plant Audit– Fort Calhoun Station Analyses Required for the Response To Generic Letter 2004-02 and GSI-191 Resolution," January 26, 2006.

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