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FINAL REPLY:

Mario V. Bonaca, ACRS

TO:

Chairman Diaz

FOR SIGNATURE OF : ** GRN ** CRC NO: 04-0659

Reyes, EDO

DESC:

Safety Evaluation of the Industry Guidelines Related to Pressurized Water Reactor Sump Performance

ROUTING:

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, D.C. 20555-0001

October 18, 2004

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

SUBJECT: SAFETY EVALUATION OF THE INDUSTRY GUIDELINES RELATED TO PRESSURIZED WATER REACTOR SUMP PERFORMANCE

Dear Chairman Diaz:

During the 516th meeting of the Advisory Committee on Reactor Safeguards, October 7-9, 2004 we met with representatives of the NRC staff, its contractors, and the industry to review the staff's draft safety evaluation (SE) related to Nuclear Energy Institute (NEI) Guidance Report (proposed document no. NEI 04-07), "Pressurized Water Reactor Sump Performance Evaluation Methodology" (Ref. 1 and 2). The guidance report and the associated SE are intended to describe a methodology that is acceptable to the staff for use by licensees in responding to Generic Letter (GL) 2004-02 (Ref. 3). Our Subcommittee on Thermal-Hydraulic Phenomena reviewed this matter during a meeting on September 22-23, 2004. We also had the benefit of the documents referenced.

**Recommendations**

1. The SE should not be issued in its present form. Both it and the NEI guidance contain too many technical faults and limitations to provide the basis for a defensible and robust long-term solution to Generic Safety Issue (GSI) 191, "Assessment of Debris Accumulation on Pressurized Water Reactor (PWR) Sump Performance."

2. The faults and limitations in the present technical knowledge base need to be addressed so that acceptable guidance can be developed. The staff should develop sufficient understanding to determine either the uncertainty or the degree of margin resulting from the application of the methodology.

3. If licensees are to be responsible for filling gaps in the analytical and experimental data base, the staff should clearly state the agency's expectations for the necessary quality and acceptability requirements.

4. The risk-informed approach should be extended to treat the entire sequence of phenomena that lead from the break to the end effects on the pump net positive suction pressure (NPSH) and thus the effectiveness of recirculation cooling. This would provide a technical basis for application of the Regulatory Guide (RG) 1.174 process. It will require a quantitative assessment of model uncertainties related to the physical phenomena.

**Discussion**

GSI-191 is concerned with long-term cooling of the reactor core following a loss-of-coolant accident (LOCA). In the later stages of the accident scenario, water is drawn from the sump and recirculated through the core. The pumps that recirculate this water are protected by screens. There is concern that debris generated by the accident might accumulate on the screens sufficiently to compromise the NPSH of the pumps.

The staff has taken several steps in its efforts to resolve GSI-191.

In Bulletin 2003-01(Ref. 4), which was issued on June 9, 2003, the staff requested that licensees "confirm their compliance with 10 CFR 50.46(b)(5) and other existing applicable regulatory requirements."

Regulatory Guide 1.82, Revision 3, "Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident," was issued in November 2003. As we pointed out in our letter of September 30, 2003 the RG presented many requirements for analyzing the phenomena affecting sump performance, but provided little guidance on how to do the analysis.

In GL 2004-02, dated September 13, 2004, the staff requested licensees "to perform an evaluation of the ECCS and CSS recirculation functions in light of the information provided in this letter and, if appropriate, take additional actions to ensure system function."

The response of licensees to this GL depends on their ability to assess the constituent phenomena and their effect on the pump NPSH. Guidance on how to make these assessments is the subject of the NEI submittal and the staff's SE.

The staff has made an effort, both in its research programs and in its review process, to develop sufficient knowledge and judgment to evaluate the adequacy of these assessments. The staff believes that the NEI methodology, as modified by the staff in the draft SE, provides a conservative basis for evaluating PWR sump blockage. It is our judgment that too many gaps remain for a technically defensible resolution at this time. The variety of technical challenges is large and there are unknowns and gaps in the knowledge base. For example, some basic methods include equations that contain incorrect physical descriptions of the phenomena. There are also questions about the extent of the supporting test data and the data's interpretation, and the guidance on implementing the proposed methods is vague and contains inconsistencies.

**Risk-Informed Approach**

In our report of September 30, 2003, we recommended that the staff investigate a risk-informed approach to sump screen blockage. Such an approach is presented in Section 6.0 of the NEI guidance report and is essentially endorsed in Section 6.0 of the SE.

Although we welcome the use of risk in this context, it is not clear that the NEI approach, as modified by the SE, will have a significant practical impact. Plants will still have to compute the consequences of a large-break LOCA with respect to debris generation, transport, and deposition. It appears that there will only be a significant difference in what licensees may be required to implement if the requirement for "mitigation" is somehow related to risk, as well as to the assumptions that surround the traditional 10 CFR 50.46 LOCA requirements. Thus, we are recommending that the risk-informed approach be extended.

Besides the complex technical issues that make resolution difficult, the present deterministic requirements of 10 CFR 50.46 make it difficult for licensees to demonstrate compliance. The process of risk analysis was specifically developed to handle complex situations where uncertainties exist. We are recommending that risk information be developed and that the model uncertainties be quantified in the representation of the phenomena described in RG 1.82, Rev. 3. This would provide a technical basis for application of the RG 1.174 process.

**Technical Errors**

We were surprised to find significant technical errors of a fundamental nature in the analytical knowledge base supporting the guidance.

For example, the zone-of-influence (ZOI) model is based on the ANSI/ANS 1988 standard. There are several inconsistencies and errors in the models described in the standard, as discussed in References 7 and 9. The "impingement pressure" is undefined. The assumed flow pattern does not correspond to observed and computed patterns for supersonic jets. The conditions in a free jet and in a jet impinging on a large target appear to be mixed up. The analysis of the area of an "asymptotic plane" is based on an unrealistic representation of the physics and inappropriate one-dimensional approximations which can be used to calculate a variety of results, spanning a factor of four. In addition, the density at this fictional "asymptotic plane" is evaluated as if the fluid were at rest, whereas in reality it is flowing at a high Mach number.

We also identified significant basic errors in the NUREG/CR-6224 correlation and its use for evaluating head loss. These are described in References 5, 6, and 8.

**Incomplete or Confusing Guidance**

A "thin bed" is invoked at several places in the NEI guidance report and in the SE. There is no clear definition of what it is, how to predict its occurrence or its effects for different combinations of particulates and fibers, or how to "substantiate no formation" of it.

This is an example of an area where we consider the guidance to be confusing and inadequate. Appendix VIII of the SE addresses the thin bed effect in the context of calcium silicate (CalSil). The definition given is:

> "The thin-bed effect refers to the debris bed condition in a fibrous/particulate bed of debris whereby a relatively high head loss can occur due to a relatively thin layer of debris, by itself or embedded as a stratified layer within other debris, because the bed porosity is dominated by the particulate and the bed porosity approaches that of the corresponding particulate sludge."

This definition is qualitative, but it clarifies some uncertainties in the SE. If this thin layer can occur anywhere in the bed, it might, for example, form on top of a thick (say four inch) layer of fiberglass. In contrast, the guidance described in Appendix V of the SE appears to apply only to uniform beds of debris.

The final phrase in the definition is conjecture since there appears to be no definitive evidence of the cause of the phenomenon. In Los Alamos National Laboratory (LANL) test 6H, which is discussed in Appendix V, there was an anomalous head loss that increased by an order of magnitude over the course of two hours while the flow rate was kept constant. Though the correlation could be made to fit this single data point by adjusting the specific surface area to the unusually high value of 800,000 $ft^2/ft^3$, this process provides no basis for extrapolation to other conditions.

Although this appendix provides some discussion of what might be the cause of the thin bed effect, it is speculative. Page 9 of Appendix VIII appears to discuss experiments performed in the recent past and not formally reported. It is clearly a work-in-progress and is not sufficiently mature to form the basis of guidance that could have a large impact on all plants containing CalSil insulation. It is also unclear if the effect could occur with certain latent debris or with the debris from destroyed coatings, as well as with CalSil.

Another example of confusing guidance occurs on page vi of the executive summary in the SE, where the staff imposes the following exception:

> "The [NEI guidance report] does not provide guidance for those plants that can substantiate no thin bed effect, which may impact head loss results and limiting break conditions."

It appears that plants with any CalSil insulation could have the thin bed effect and therefore the methodology will predict clogging of their screens. Plants that do not have CalSil cannot use the guidance.

There is some discussion of the thin bed effect on page 69 of the main text of the SE. It is stated in the SE that the head loss model is valid for thicknesses larger than 0.125 inch.

> "Below this value, the bed does not have the required structure to bridge the strainer holes and filter the sludge particles."

This apparently indicates that one does not have to worry about beds with a thickness less than 0.125 inch thick. In other words, 0.125 inch is a criterion for a thick bed, as it defines a minimum thickness. On this basis, thin beds should be acceptable.

At the bottom of page 69, it is stated that calcium silicate can form a bed without supporting fibers, which contradicts the above statement.

On page 70 we find that "sufficient conservatism should be used in estimating the quantities of fibrous debris available to form a thin bed." Does this mean that one should assume that no fibers are required? Since all plants have fibers of some sort, even in latent debris, do they all exhibit the thin bed effect?

It is clear that the qualitative discussions in Appendix VIII of the SE need to be replaced by consistent and unequivocal guidance on how to deal with the possibility that a layer, or layers, in the deposit on a screen may result in a particularly high head loss. This needs to be supported by definitive experiments. Loose use of the term thin bed in the present version of the SE merely confuses an already uncertain situation.

Another example of inappropriate guidance is the staff's agreement with NEI that it is conservative to assume uniform debris accumulation on all types and orientations of screens. This appears to be a step of faith. It does not consider the possibility of a thin bed over part of the screen, or the layering of debris to form a thin bed as one of the strata in the accumulated layers. Anomalous and unexplained phenomena, which may increase the head loss by an order of magnitude, have been observed in tests with CalSil, and may be due to nonuniform effects of this sort.

If a stratified layer can form within a thick bed, such a layer could form somewhere in the strata on the screen and cause high enough head loss to challenge the NPSH in any plant with enough calcium silicate insulation to provide a layer comparable to the layer in LANL's test 6H, namely 0.018 inch. This amounts to about a gallon of CalSil on a 100-square-foot screen. Since the fine particles of calcium silicate are readily transportable to the screen, this would essentially mean that no plant could tolerate use of any amount of this insulation.

**Examples of Gaps in the Empirical Knowledge Base**

Coatings

The effect on coatings of a two-phase jet issuing from the break is not well understood. While NEI suggests a damage pressure of 1000 psi for qualified coatings, the staff adopts the default conservative requirement that the zone of influence (ZOI) for coatings be a sphere with radius equal to ten times the break diameter. The staff also requires that all unqualified coatings within the containment be assumed to be destroyed and entrained. These requirements appear to be arbitrary assumptions. They are said to be "conservative" but no rationale has been offered to support this claim. It appears that the requirements lead to the prediction of large amounts of particulate matter being generated and transported to the screens.

The nature and effects of coating debris are unknown. There is no guidance on how to compute head loss for coating debris, whether or not a thin bed effect will occur, or whether coatings are truly particulate, or actually flakes. If they are particulate, then supposedly a correlation such as NUREG/CR-6224 (if it were to be corrected) could be used. However, if the coatings are flakes, then a new model would have to be developed to account for their potential to behave like leaves on a street drain, overlapping and obstructing the flow paths in a way that is not described by the usual "specific surface area" models

Debris transport

There are many uncertainties in the modeling of debris transport. For example, one of the staff's assumptions, allowing only 15% of the debris to be held up in inactive pools, is based on model predictions for one specific plant and leads to the conclusion that much of the debris will reach the pool. This conclusion may not apply to other plants. A method to perform plant-specific calculations is sketched in very general terms but its implementation would be difficult.

Head Loss Correlations

While the NUREG/CR-6224 correlation, if it were to be modified to remove the technical errors, might be approved for use, the database does not contain enough data to determine the parameters to use in the correlation under realistic conditions. Licensees are required to develop their own results for latent debris and coatings. For other materials, licensees are required to "ensure that [the correlation] is applicable." Since the database for several materials, such as CalSil, does not cover all plant conditions, licensees may have to carry out new experiments to obtain definitive data. We are recommending that the staff clearly state the agency's expectations for the necessary quality and acceptability requirements for these experiments.

Appendix V of the SE provides additional guidance on the use of the NUREG/CR-6224 correlation. The formulae provided for computing specific surface area are based on the assumption that the debris bed is uniformly mixed, which may not be the case following a LOCA. There are several mechanisms that may create dense layers that contribute to higher head loss than would be computed using uniform mixing, as discussed in Appendix VIII. Table V-5 provides validation ranges of sources for fibrous insulation debris. No assessment is made of applicability to the LOCA context or of the very sparse data from some of the sources. For instance, an applicant who chooses to use the highest value of specific surface area for CalSil deduced in LA-UR-04-1227 (which can lead to an order of magnitude increase in head loss) will be basing all its predictions on a single, isolated, data point obtained at a single flow rate and temperature, with a single thickness, composition, and mode of formation of the bed, none of which may be representative of plant conditions.

Chemical and Downstream Effects

No definite guidance is provided for evaluating either chemical or downstream effects, both of which have may become of major importance as more knowledge is acquired.

The Committee will continue to work with the staff to develop solutions to the sump screen blockage issue.

Sincerely,

Mario V. Bonaca
Chairman

**Additional Comments from ACRS Members Graham B. Wallis and F. Peter Ford**

We agree with the recommendations of our colleagues. The SER and NEI guidance documents contain too many technical faults and limitations to provide the basis for a long-term defensible and robust evaluation of the PWR sump performance. However, in the short term, there may be some practical actions that can be explored. For instance, the staff should encourage licensees to pursue, at an early stage, corrective actions that will be as independent as possible of known model uncertainties. These actions may include, for example; removing material that is known to manifest anomalous or particularly detrimental sump blockage results in tests (and whose removal does not introduce secondary detrimental effects); use of "double-jacketing"; demonstrating that materials such as coatings are proven by testing to be sufficiently robust that conservatism in assessing their vulnerability can be reduced; testing alternative filtering devices, such as debris catchers and active screens to the point where their performance can be realistically characterized empirically, or can be conservatively bounded.

Such actions in this initial phase could be followed by a more complete evaluation of the technical analytical problem (as outlined in this ACRS letter) and the implementation of long-term risk-informed solutions.

**Additional comments by ACRS Member Graham B. Wallis.**

I agree that practical steps should be explored and long-term solutions developed. However, this responds only to part of the purpose of GL2004-02, which also requests that licensees perform an evaluation in the short term. In the absence of definitive guidance for making this evaluation, the staff needs to develop a success path that will avoid wasteful iterations while guidance is developed. One approach might be to break up the process into a set of phases, each of which is based on the best available methods, results that are clearly evident despite uncertainties, and decisions that can be implemented within a realistic schedule.

To justify actions which may have a major impact on operating plants, the staff needs to do a better job of explaining the rationale for regulatory decisions, particularly when the technical bases and assumptions are questionable.

**References**

1. U.S. Nuclear Regulatory Commission, Safety Evaluation by the Office of Nuclear Reactor Regulation Related to NRC Generic Letter 2004-02, Nuclear Energy Institute Guidance Report (Proposed Document Number NEI 04-07), "Pressurized Water Reactor Sump Performance Evaluation Methodology", September 2004

2. Nuclear Energy Institute, Guidance Report (Proposed Document Number NEI 04-07), "Pressurized Water Reactor Sump Performance Evaluation Methodology", May 2004

3. 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

4. U.S. Nuclear Regulatory Commission Bulletin 2003-01, "Potential Impact of Debris Blockage on Emergency Sump Recirculation at Pressurized-Water Reactors", June 9, 2003

5. Graham B. Wallis, "The NUREG/CR-6224 Head Loss Correlation", September 3, 2004

6. Graham B. Wallis, "Flow Through a Compressible Porous Mat: Analysis of the Data Presented in Series 6 Tests Reported by LANL in LA-UR-1227", September 2, 2004

7. Graham B, Wallis, "The ANSI/ANS Standard 58.2-1988: Two-Phase Jet Model", August 31, 2004

8. Sanjoy Bannerjee, "Review of Head Loss Prediction Across Sump Screens," October 5, 2004

9. Victor Ransom, "Comments on GSI-191 Models for Debris Generation", September 14, 2004