ACRSR-2051

September 30, 2003

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

SUBJECT: DRAFT FINAL REVISION 3 TO REGULATORY GUIDE 1.82, "WATER SOURCES FOR LONG-TERM RECIRCULATION COOLING FOLLOWING A LOSS-OF-COOLANT ACCIDENT"

Dear Chairman Diaz:

During the 505th meeting of the Advisory Committee on Reactor Safeguards, September 10-13, 2003, we met with representatives of the NRC staff to discuss the draft final Revision 3 to Regulatory Guide 1.82, "Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident" (Ref. 1). Our Subcommittee on Thermal-Hydraulic Phenomena also reviewed this matter during its meeting on August 19, 2003. We previously provided a letter, dated February 20, 2003, concerning an earlier draft of this guidance. Regulatory Guide 1.82 (RG 1.82) is being revised to enhance the debris blockage evaluation guidance for pressurized water reactors. We also had the benefit of the documents referenced.

Recommendations

1. Draft final Revision 3 to RG 1.82 should be issued in order to facilitate licensee response and the resolution of technical issues. In addition, the staff should carefully review implementing guidance being developed by the Nuclear Energy Institute (NEI) because of the issues identified, the complex phenomena involved, and the need for more accurate plant-specific assessments.

2. The knowledge base report (Ref. 2) is a compendium of research results relevant to the problem, but it is confusing and it cannot be used directly as guidance for the analysis of sump blockage. Acceptable methods should be developed for use in satisfying the functional requirements described in RG 1.82.

3. An adequate technical basis should be developed to resolve the issues related to chemical reactions.

4. The staff should consider the possibility that the uncertainties associated with the calculational methodology may be so large, or that strainers may prove to be so susceptible to debris blockage, that alternative solutions may be required to ensure long-term cooling. This might involve, for example, changing the types of insulation used within containment or implementing diverse means of providing long-term cooling.

5. The staff should investigate a risk-informed approach to sump screen blockage.

Conclusions

- The technical basis for analyzing the phenomena described in RG 1.82 is not mature, the available information is inconsistent, and the knowledge base is evolving. Therefore, it is likely that the licensees' responses will be disparate and difficult to evaluate unless more consistent guidance is developed.

- The zone of influence (ZOI) models need revision and resolution of inconsistencies.

- Neither RG 1.82 nor the knowledge base report (Ref. 2) gives adequate consideration to chemical reactions.

Discussion

The sump screen blockage issue has a long history, dating back to the 1979 unresolved safety issue (USI) A-43. More stringent requirements have been developed as incidents or new knowledge revealed a need. These are reflected in various Bulletins, Generic Letters, and earlier revisions to RG 1.82. The case of boiling water reactors (BWRs) was revisited after the resolution of USI A-43 in 1985 because of several events, such as the one at the Swedish Barsebäck Nuclear Plant, Unit 2, in 1992, which demonstrated that larger quantities of fibrous debris could reach the strainers than had been predicted by models and analysis methods developed for the resolution of USI A-43 (Ref. 2). The BWR issue was resolved by installing large-capacity strainers in response to Bulletins 93-02 and 93-03. The strainers were designed on the basis of a BWR Owners Group report, NEDO-32686, "Utility Resolution Guidance for ECCS Suction Strainer Blockage," November 1996, which was approved by the staff.

The results of recent parametric study (Ref. 3) of 69 pressurized water reactors (PWRs) revealed that following a large-break LOCA, sump screen blockage was very likely in 53 of them. The same report stated that preliminary findings suggest that two-phase jets with a stagnation pressure of 1400 psia can inflict significant damage at distances much farther away than those measured in either USI A-43 studies or BWR air-jet impact tests program. Recent research has led to the discovery that very thin beds of fibrous insulation of the order of 1/8 inch thickness, in combination with particulates, can effectively block a sump screen. A risk study that supported the parametric study suggested an increase in the total core damage frequency (CDF) of an order of magnitude or more (Ref. 2). These studies were qualified with the caveat that many features of the problem are plant specific and, therefore, must be evaluated at that level. There appears to be sufficient evidence that new NRC guidance is necessary and appropriate action by PWR licensees may be needed.

Revision 3 to RG 1.82 describes the functional performance requirements for water sources that support long-term cooling. It also describes the main phenomena that are to be considered in the analysis of the performance of these sources, although it makes only general reference to chemical phenomena that may be important. Revision 3 to RG 1.82 should be issued in order to facilitate licensee response and the resolution of technical issues.

NEI is developing an implementing guidance document for licensees. Because of the many phenomena involved, and the significant plant-dependent nature of their manifestation, the staff will have to carefully review the NEI guidance and may need to perform confirmatory research.

While the revised RG 1.82 provides an extensive description of the phenomena of interest, it has little to say about the methods to be used for analyzing such phenomena. The major source of information on possible approaches has been the knowledge base report (Ref. 2) prepared recently by the Los Alamos National Laboratory. While this report comprises a compendium of research results obtained over several decades, these results are sometimes inconsistent and some have been superseded by recent work. The report does not clearly identify which results are valid, does not resolve apparent inconsistencies in the various studies, does not present a synthesis of validated methodologies that can be applied to actual plants, and provides little perspective to guide the user in the choice of appropriate quantitative methods.

For example, the production of debris is considered to occur in a ZOI. This is a useful concept, but for practical purposes, quantitative methods for describing the ZOI are necessary and Reference 2 provides several conflicting approaches. On page 3-25 it states that in a conical jet the centerline stagnation pressure is essentially constant at a distance of about 5-7 pipe diameters, at approximately 2 ± 1 bars. Figure 3-17 shows stagnation pressures between 3.5 and 5.5 bars in the same region. Both of these results originate from methods developed to resolve USI A-43, which were found to underestimate the Barsebäck damage. Results of recent studies show a pressure of about 11 bars in this same region. Page 3-6 states that the ZOI associated with prototypic two-phase (steam-water) jets is larger than the ZOI indicated by air jet simulated tests. Combining this with the statement on page 38 of NUREG/CR-6762, Volume I that single-phase air jets inflict significant damage to fibrous insulation types at a distance of 60 pipe diameters, one would conclude that the zone of influence is much greater than indicated in Figure 3.17. If licensees were to use such disparate information, we would anticipate the same variability in application of methods that was apparent in the BWR submittals.

During our meetings, the staff stated that the ZOI could comprise a large fraction of the entire containment. This does not seem consistent with the rather small ZOI shown in Figure 3-18 of the knowledge base report (Ref. 2). This figure is based on a set of spheres with the same volume as the zones shown in Figure 3-17, which is claimed to be a conical jet model originating from the work (Ref. 4) on jet loads reported by the Sandia National Laboratories (SNL) in NUREG/CR-2913, Rev. 4. The figure does not appear in the SNL report, but is actually Figure 3.25 of NUREG-0897, "Containment Emergency Sump Performance: Technical Findings Related to Unresolved Safety Issue A-43," 1985 (Ref.5). Use of this figure for estimating loads on containment structures appears to be a result of a misapplication of the SNL work, which considered the impact of a two-phase jet, issuing from a round break of diameter (D), on a large flat target perpendicular to the axis of the jet and a distance (L) away. The pressure distribution was computed on the target, as a function of radial distance, (R), from the axis. The stagnation pressure on the axis was lower than the original stagnation pressure of the jet because a shock wave occurred before impact on the target. This shock wave was the only mechanism of energy dissipation. Figure 3.17 in the technical basis report (Ref. 2) was constructed from contours of constant pressure on the target as (L) was varied.

This approach to computing a ZOI has two major errors. The first is the use of pressure distribution on a flat target to characterize the pressure felt by an object (such as a pipe) inserted into the same flow field when the target is there. The pressure falls away from the stagnation point on the target because of the large velocity of the fluid along the plate. However, if a pipe were placed on or near the plate at some radius, the fluid coming to rest at the stagnation point on this pipe would achieve a high pressure, comparable with the stagnation pressure at the axis of the target, as it was brought to rest. Moreover, the fluid that is diverted by the plate and disperses to the sides over a cylindrically-shaped area still has a very high velocity. For example, Figures 4.10 to 4.14 of the SNL report (Ref. 4) show that, in this example with L/D =2, at a radius of 5 diameters, the fluid flowing along the plate has a speed of about 2500 ft/sec while the fluid flowing along the plate from which the jet issued has a speed of about 3500 ft/sec. This latter fluid has not suffered a shock and has lost none of its energy. The result is a disc-shaped jet with an area that is 80 times the area of the original jet issuing radially into the surrounding space. Should the part of the jet that has not passed through a shock strike an object, the pressure load, according to the SNL model, would only be mitigated by whatever shock wave occurred in front of that object. Should the jet be focused by passing between suitable structures, it could conceivably recover most of its original stagnation pressure of 150 bars. The point is that even if there is a flat target in front of the jet the loads on other structures are not determined solely by the pressure distribution on that target.

The second misuse of the SNL work is to interpret the contours of static pressure on the target plate as being representative of the stagnation pressure distribution in a jet when the plate is not there. The reduction in radial static pressure over the plate is determined by the radial velocity which is not the same as in a jet in the absence of a target. Moreover, the stagnation pressure distribution in the jet is what is needed to determine the maximum pressure on structures, not the static pressure, and it is uniform until the flow passes through a shock wave. In fact, with the assumptions of the original SNL model, the stagnation pressure is uniform everywhere, to any distance, until a shock wave is passed through by the fluid. To assess the pressure exerted on an object, one would have to compute the flow field for a free jet and evaluate the strength of the shock wave ahead of that object when placed in this field. In practice, in a real containment, there will be shock reflections from multiple objects, redirection of the flow, and possible refocusing of the energy.

Given these concerns, the NRC staff should reevaluate the basis for establishing a ZOI. That basis should be quantitatively related to actual damage observed in plants and in experiments designed to assess the actual damage observed in various flow fields. These events and experiments have been reported (Ref. 2) but have not been used to develop validated practical prediction methods.

Another concern is the lack of consideration given to chemical effects, in both RG 1.82 and the knowledge base report. A hot, acidic, borated, two-phase jet has the potential to react chemically with paints, coatings, insulation, and other materials, particularly those incorporating aluminum and zinc. When the hot, borated water drains to the pool, it is dosed with alkaline material to create a high pH in the pool. In the presence of zinc, this is known to lead to the production of zinc hydroxide with concomitant evolution of hydrogen. Results of some preliminary experiments performed by LANL indicate that several other precipitates may be formed, some of which have a gel-like or sticky consistency that could exacerbate the potential for screen blockage.

In addition, hydrogen evolution in the pool is likely to affect the settling of materials that are heavier than water. A zinc particle, for example, will sink in pure water; however, if a reaction produces hydrogen bubbles that stick to the surface of the zinc particle, the particle may become buoyant and rise to the surface, probably eventually sinking again as the bubbles are released, with the cycle repeating. Similarly, a sediment of fibrous debris could be rendered buoyant by gas bubbles released within it.

The chemical kinetics of the reactions of concern may be too slow to influence sump blockage. However, this needs to be shown by definitive analysis and testing. Moreover to the extent possible, such testing should be performed under the conditions expected in an actual plant.

RG 1.82 gives passing reference to chemistry in Sections 1.3.2.6 and 2.3.1.8, which state that debris created by the resulting containment environment (thermal and chemical) should be considered in the analysis. However, in response to a public comment, the staff acknowledged that there are no NRC-published references pertinent to consideration of these chemical reactions. While RG 1.82 discusses effects of buoyancy on debris transport, it does not mention buoyancy induced by the release of gas by chemical reactions.

The knowledge base report describes many experiments, most of which were conducted under laboratory conditions, designed to investigate the transport of debris. These are useful sources of information; however, the report presents many qualifications of these results, particularly in view of the variety of phenomena involved in an actual plant. For example, one area of concern is the potential for debris to block flow paths to the sump before reaching the pool; these paths are numerous and vary significantly from plant to plant.

Knowledge about the head loss to be expected on sump screens is evolving, with recognition that the combination of fibrous and particulate materials can produce unusual effects. Again, this knowledge base needs to be consolidated into a form that is less susceptible to misinterpretation by readers. For instance, page 7-6 of the knowledge based report (Ref. 2) states that the NUREG/CR-6224 correlation will need considerable modification, whereas page 7-29 appears to endorse the same correlation with the statement that its predictions were within ± 25% of the test data.

There is also a need to synthesize this information into practical methods of prediction. The forthcoming NEI guidance should help in this regard.

As we discussed in our letter dated February 20, 2003, there is a possibility that the assessment of the blockage of the sump strainer may be subject to such large uncertainties as to be intractable, and alternative solutions may be required to ensure long-term cooling. These might involve, for example, using active sump screen systems, changing the types of insulation used within containment, or implementing diverse means of providing long-term cooling, including using additional water sources to extend the injection phase. Section 1.1.4 of Revision 3 to RG 1.82 discusses the use of active sump screen systems, but these may be only one of several possible alternatives that should be considered to ensure long-term cooling.

PWR sump blockage is an issue for which the design-basis accident approach may lead to unnecessary conservatism. A risk-informed approach may be appropriate in which the design-basis requirement to maintain effective long-term recirculation cooling would be retained, but risk information would be used to establish an acceptable approach to comply with the requirements.

The quantification of the sump blockage issue is an excellent example of where risk information can be applied to design-basis accident issues to the benefit of the public and the licensees. The staff should explore the feasibility of a risk-informed approach to sump screen blockage.

Sincerely,

/RA/

Mario V. Bonaca
Chairman

References:

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