November 26, 2004

Mario V. Bonaca, Chairman
Advisory Committee on Reactor Safeguards
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

SUBJECT: RESPONSE TO ADVISORY COMMITTEE ON REACTOR SAFEGUARDS ON SAFETY EVALUATION OF THE INDUSTRY GUIDELINES RELATED TO PRESSURIZED WATER REACTOR SUMP PERFORMANCE

Dear Chairman Bonaca:

Thank you for your letter dated October 18, 2004, providing the Advisory Committee on Reactor Safeguards' (ACRS) views on the Nuclear Regulatory Commission (NRC) staff's draft safety evaluation (SE) of the Nuclear Energy Institute (NEI) guidance report (GR), "Pressurized Water Reactor Sump Performance Evaluation Methodology." The draft SE is part of the Office of Nuclear Reactor Regulation (NRR) Action Plan for resolving Generic Safety Issue (GSI) 191, "Assessment of Debris Accumulation on PWR Sump Performance." The SE needs to be issued so that licensees can perform an evaluation requested by Generic Letter (GL) 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors."

The NRC staff met with the ACRS full committee on October 7, 2004, to present the draft SE. In response to comments and questions of the ACRS at the meeting and in your letter, the staff has made improvements to the SE and has conducted several activities to confirm aspects of the SE methodology. Specific responses to your recommendations and comments are provided in the enclosure. The staff will continue with its efforts to confirm that the methodology is conservative and will continue to encourage industry to perform testing as needed if they wish to relax conservatisms. As was the case with the Boiling Water Reactor (BWR) resolution, PWR licensees have primary responsibility for addressing this issue, including conducting additional testing if needed to support the evaluation results or planned corrective measures.

The ACRS' primary recommendation was that the SE not be issued in its present form due to concerns about technical errors and limitations in the knowledge base. Staff recognizes that despite substantial experience and knowledge gained by the NRC and industry over the years through addressing sump blockage issues for BWRs, performance of the volunteer plant analyses, NRC and industry experience with coatings, and research test results, knowledge limitations continue to exist. However, the staff does not agree that these limitations should preclude issuance of the SE. The SE addresses an important safety issue and resolution of GSI-191 will result in real safety improvement (i.e., resolution will reduce the large-break loss-of-coolant accident core damage frequency by at least an order of magnitude).

The knowledge limitations and the conditions for methodology application are understood by the staff and are clearly identified and addressed in the SE. Uncertainties in data are addressed by conservative assumptions to ensure a robust defensible solution. Consequently, the staff concludes that the SE provides an acceptable methodology and can be issued to resolve GSI-191.

The ACRS' letter also raised an issue regarding confusing or incomplete guidance. We have improved the guidance in a number of areas to respond to this concern; e.g., treatment of coatings. Also, since our meeting with the ACRS, the staff has met with several vendors with contracts to address GSI-191. The vendors indicated that the guidance is being successfully used to scope the extent of the problem and provide a basis for necessary improvements.

With regard to establishing staff expectations for quality requirements for data and analyses, the staff has provided in the SE its expectations with respect to those specific areas where additional information and/or data may be needed. Existing licensee Quality Assurance requirements are adequate for performance of tests or analyses necessary to address GSI-191. Additionally, the staff will audit the resolution activities of several plants. The audits will encompass a range of plants and approaches.

With regard to risk-informing the entire sequence from pipe break to the potential loss of recirculation cooling, the staff believes that the effort required would be significant and would still be subject to the existing limitations in knowledge. The GR, as approved by the SE, provides for an alternative resolution approach, which uses realistic and risk-informed methods for calculating emergency core cooling system pump net positive suction head for postulated loss-of-coolant accident break sizes larger than the "debris generation" break size and for assessing new sump design modifications. The industry did not attempt to risk-inform the other aspects of the analysis methodology regarding debris generation, debris transport, debris accumulation, and head loss across the sump screen. To do so would require more testing and technical basis development beyond the current industry approach and cannot be completed on the current GSI-191 resolution schedule. Given the limitations, the only practical path forward is the application of traditional, deterministic approaches using conservatisms to offset uncertainties.

Thank you for your views and recommendations on this matter. I will continue to keep the ACRS informed of the staff's activities as we move forward to resolve GSI-191.

Sincerely,

/RA Martin Virgilio Acting For/

Luis A. Reyes
Executive Director
for Operations

Enclosure: Responses to ACRS Recommendations and Comments in October 18, 2004 Letter

cc: Chairman Diaz
Commissioner McGaffigan
Commissioner Merrifield
SECY

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Responses to ACRS Recommendations and Comments in October 18, 2004, Letter

ACRS Recommendations

1. Recommendation

   The safety evaluation (SE) should not be issued in its present form. Both it and the Nuclear Energy Institute (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."

   Response

   One technical issue identified by the Advisory Committee on Reactor Safeguards (ACRS) was the incorrect physics associated with the head loss correlation proposed by NEI and accepted by the NRC staff to determine head loss across the containment sump screen for the emergency core cooling systems (ECCSs).

   With regard to physics, the correlation is empirically derived and has been shown by tests to provide realistically conservative results within the limited range in which it will be used resulting in an acceptable methodology for scoping. The correlation is published in NUREG/CR-6224, and has been accepted by the staff since 1994 for use in the Boiling Water Reactor (BWR) sump performance resolution and in the recently issued Regulatory Guide 1.82, Revision 3. Testing by industry for BWR sump resolution, separate from that performed for NUREG/CR-6224, yields similar results. Confirmatory work is ongoing for validation of the correlation for use in the specific range of parameters and conditions expected during a loss-of-coolant accident (LOCA). The staff in NRR and RES are working together to complete the confirmatory work. When the confirmatory work is completed, the staff will supplement the SE, if necessary, and will inform the ACRS of the results of this confirmatory work regarding the acceptability of this correlation for use in the evaluation of ECCS sump head loss in the event of a sump screen blockage.

2. Recommendation

   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.

   Response

   The staff agrees that there are limitations in the knowledge base and that the NEI guidance report (GR) would have benefited from additional testing. The staff ensured that the SE is conservative by a twofold approach of applying conservatism to bound the unknowns in those areas that would benefit from additional data and by clearly identifying the limitations

ENCLOSURE

and methodology conditions in the SE. For example, as discussed in the following pages, the staff requires that licensees determine a coatings zone-of-influence by plant specific analysis or use a volume of 10D instead of the volume recommended in the GR. Also, licensees are encouraged to perform additional testing as a basis for going beyond the technical limitations or to use more restrictive assumptions. The staff concludes that the assumptions in the SE are conservative and can be utilized today to resolve the issue.

3. Recommendation

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.

Response

The staff has provided specific expectations in the SE where additional information and/or data may be needed. For example, in the downstream effects evaluation, licensees are expected to develop their own source term for downstream effects. Similarly, if the correlation being used for calculating head loss across debris beds had not been validated for the type of insulation in the debris mix, licensees should validate it using head-loss data from tests performed for the particular type of insulation.

Licensees have quality assurance (QA) programs to meet 10 CFR Part 50, Appendix B. Those programs address requirements for testing and analyses. Testing performed in support of a plant will either be performed under the auspices of the licensee's QA program or the vendor's nuclear QA program. Additionally, the staff will audit the resolution activities of several plants. The staff's audit selection criteria will encompass a range of plants and approaches.

4. Recommendation

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 head (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.

Response

The NRC staff finds that the NEI GR and the staff SE provide an acceptable approach because traditional, deterministic methods are used to address uncertainties. GR Section 6 and SE Section 6 provide an alternative resolution approach, with both realistic and risk-informed elements. This alternative approach uses realistic and risk-informed methods for calculating ECCS pump NPSH for postulated LOCA break sizes larger than the "debris generation" break size and for assessing new sump design modifications. The staff assumes that this recommendation to expand the risk-informed approach includes probabilistic analyses and approaches associated with identifying the limiting break location, debris generation, debris transport, and debris accumulation and head loss at the sump screen.

With respect to the break selection phase of the analysis, 10 CFR 50.46 provides the requirements for the break locations to be considered. The regulation also requires that ECCS cooling performance be calculated in accordance with an acceptable evaluation model and be calculated for a number of postulated loss-of-coolant accidents of different sizes, locations, and other properties sufficient to provide assurance that the most severe postulated loss-of-coolant accidents are calculated. The staff is currently not considering a change to this requirement as part of the ongoing 10 CFR 50.46 risk-informed rulemaking effort. The staff position on GSI-191 resolution is to remain consistent with the 10 CFR 50.46 rulemaking activities. If this position changes, licensees may certainly reevaluate their GSI-191 analyses in accordance with a revised 10 CFR 50.46.

The industry did not attempt to risk-inform the analysis methodology for debris generation, debris transport, debris accumulation, and head loss across the sump screen. The alternative evaluation methodology relies on the GR/SE Section 3 and 4 methodology for these areas. The GR did not pursue these options because, "the current experimental and analytical basis for the generation, transport, and accumulation does not easily lend itself to the quantification of more realistic models....However, development of more realistic models is difficult due to the limited amount of experimental and analytical information available for any single aspect of the model. This development work has not been initiated due to the time constraints for completion of the Region II guidance." Therefore, the uncertainties of these aspects of the analysis are treated in a traditional, deterministic fashion.

To quantify the uncertainties of these aspects of the analysis would require significant effort. For each phase, the important phenomena and parameters must be identified and ranked. Further analysis and testing would be needed to develop probability distribution functions for each important parameter, and nominal values could be used for parameters that are not significant. This work would require even more testing and technical basis development than the current industry approach, and it cannot be completed on the current GSI-191 resolution schedule.

The NEI approach described in Section 6.0 of the GR, as modified by the staff SE, will have significant and practical impact on the resolution of GSI-191. This approach will allow licensees to design and install mitigative capability that is deemed to be appropriate, considering the potential uncertainties and risk of the sump clogging issue. Based on the generic information from a study by Los Alamos National Laboratory (LANL), the resolution of GSI-191 using the GR will reduce large-break LOCA core damage frequency (CDF) for PWRs by at least an order of magnitude.

The ACRS correctly states that licensees will still need to address the consequences of a large-break LOCA with respect to debris generation, transport, and accumulation. As the ACRS points out in its letter and as stated in the GR, there are gaps in the present technical knowledge and test data. The resolution path proposed by the industry, as modified by the staff SE, reflects a traditional, deterministic approach to addressing uncertainties by using conservative models, assumptions, and parameters. A risk-informed (i.e., more realistic) approach that explicitly modeled or quantified the uncertainties in the representation of the phenomena would suffer from the same limitations in knowledge and data and would not lead to a timely resolution. Given the limitations, the only practical path forward is the application of traditional, deterministic approaches using conservatisms to offset uncertainties.

ACRS Comments

Comment

The effect on coatings of a two-phase jet issuing from the break is not well understood.... The staff also requires that all unqualified coatings within the containment be assumed to be destroyed and entrained.... The nature and effects of coating debris are unknown.

Response

The staff agrees that the nature and effects of a two-phase LOCA jet on coatings are not well understood and that there is a lack of data on coatings. Therefore, the staff provided alternative guidance in the SE for coatings based on the precedents set by past applications approved by the staff and accepted by the ACRS or based on the staff approach of applying conservative assumptions to bound the unknowns associated with areas for which adequate data and justification are lacking.

Regarding the zone-of-influence (ZOI) requirements for coatings, as stated in the SE, the staff finds that (1) the volume of coatings assumed in the GR is not adequately justified, and (2) that because of the lack of data and knowledge in this area, licensees should "use a coatings ZOI spherical equivalent determined by plant-specific analysis, or 10D." The specified ZOI radius of 10D is based on the previous staff position used for BWR sump analysis. Any plant-specific analysis should incorporate, at a minimum, the temperature and pressure effects of the jet on plant coating systems in the ZOI. The analysis should be based on experimental data over the range of pressures and temperatures of concern using coating samples correlatable to plant materials. The analysis should also seek to accurately estimate the amount of coating on a plant-specific basis within the ZOI. If a realistically conservative approach is taken, the basis and justification for why the method is realistically conservative should be provided. The staff found the data in Appendix A of the GR to be an inadequate technical justification for the proposed ZOI of 1D because the data was not correlatable to plant conditions during a large-break LOCA and because no method was given for correlating the data to the plant conditions.

The conservative default value of 10D represents a volume of debris approximately, three orders of magnitude larger than proposed by NEI, so that instead of an equivalent destruction pressure of 1000 psi, the default value provides an equivalent of less than 10 psi. The use of a value of less than 10 psi for the onset of damage to coatings systems is judged by the staff to be a conservative default value if the industry does not generate data to justify a more realistic value. This value is based on the radius for a conical ZOI geometry used in a Bechtel Report published in support of the BWR utility resolution guidance. This value was based on the predicted behavior of coatings by an expert in the coatings field. Note that the debris volume for any given radius does not require that the entire volume be assumed to be coated, only that the amount of coatings within that volume be assumed to fail.

Finally, the head loss section of the SE does provide guidance on debris types that are not specifically given in the GR, including coatings flakes or chips. Also, where both particles or flakes have been demonstrated in tests, the staff requires that the coatings sizes be assumed to be the most conservative size based on thin-bed susceptibility. In these cases, as throughout the SE, the staff has ensured that conservatism is used to bound the unknowns associated with areas for which data and justification are lacking, ensuring the conservatism of the overall methodology.

Comment

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.

Response

The staff agrees that the ANSI/ANS 1988 standard is not a model that represents two-phase water breaks with high fidelity. The staff's contractor has prepared a detailed evaluation of the model, which is included in Appendix I in the SE. The staff agrees with the ACRS's comment on the ANSI/ANS model and observes that additional model inaccuracies, such as unrealistically large isobars calculated for lower stagnation pressures, are noted in Appendix I. The staff will forward the ACRS's letter, references for the models described in ANSI/ANS 1988, and the SE, including the Appendix I evaluation of the model, to the American Nuclear Society for consideration by Working Group ANS 58.2 in the event of a future revision to this standard.

Notwithstanding these technical points, the staff considers the standard acceptable for use in determining the ZOI to be used for modeling debris generation during design basis accidents. This determination is based in large part on the method which is used to approximate the debris generation resulting from postulated breaks. To account for jet reflections, shadowing effects, directionally changing discharge from a whipping pipe, and the difficulty of assessing all potential orientations of breaks, the GR proposes using a spherical volume equivalent to a volume determined using the ANSI/ANS model using the demonstrated destruction pressure of debris sources. This volume translation conservatively ignores the energy that would be lost in multiple reflections and in the generation of debris.

Regarding the information to be gained by the development of a more accurate method to determine the characteristics of a freely expanding jet, the precision that would be gained is more than offset by using an equivalent volume spherical approach for determining ZOI. This is because in reality, damage does not occur throughout a volume but rather on a surface. Although reflection of jets will occur, energy will also be lost in generating debris and redirection of the jets. The staff's position is that the overall approach to determining ZOI is sufficiently conservative to allow use of the ANSI/ANS standard for determining ZOI.

An approach proposed by the ACRS in its July 9, 2004, letter, was to couple an existing computational fluid dynamic code, such as FLUENT, to the steam-water properties available as a subprogram which would make it possible to model the homogeneous supersonic jets issuing from various break geometries. As the staff noted in its October 1, 2004, letter to the ACRS, initiating any new research to confirm the technical basis in the guidance would not be timely for the resolution of GSI-191. The multiphase computational fluid dynamics (CFD) technology is not mature enough to accurately predict the conditions around steam/water high-speed jets. Any approach using CFD for this application would require significant code development and validation.

Therefore, the staff is not considering mandating the use of CFD at this time. However, as discussed in the SE and during presentations before the ACRS, the staff remains open to licensee use of alternatives which more accurately model two-phase jets. Such models could be used to significantly reduce the ZOI for low-damage pressure debris sources such as NUKON insulation.

Comment

We also identified significant basic errors in the NUREG/CR-6224 correlation and its use for evaluating head loss.

Response

Both the GR and the SE recommend the use of NUREG/CR-6224 correlation to calculate the head loss across a debris bed for the purpose of sump screen scoping. The correlation has been developed over more than a decade with test data generated directly by an NRC-funded research program and proprietary plant-specific test data for BWR strainer modifications. Although the NRC-sponsored research program has not produced an exhaustive set of data to cover every possible combination of debris type and bed formation history, the staff believes that the existing data base is sufficient for licensees to start resolving GSI-191. Additionally, the industry is required to fill in the data gap if the debris bed conditions are beyond the application ranges of the NUREG/CR-6224 correlation defined in Appendix V. Such testing by licensees would have to be conducted according to the quality assurance requirements of 10 CFR Part 50, Appendix B.

ACRS has pointed out that the application procedures for computing a specific surface area are based on the assumption that the debris bed is uniformly mixed, which may not be the case following a LOCA. The staff agrees that a uniform bed formation is an underlying assumption for using the NUREG/CR-6224 correlation. However, to date, staff has not seen any testing results or technical justification to show a stratified bed would appear during a LOCA scenario. Debris would be well mixed within the ZOI during a LOCA. The washdown process may play a role of changing the mass ratio for a certain species of debris, but it is still unlikely that the debris would be deposited on a screen in a stratified fashion. Even in a well-planned test, an intentionally formed stratified bed would be expected to experience the migration of particulate within the bed. The sharp discontinuity between the stratified layers may disappear as a result of this migration. Therefore, the staff believes that the uniform bed assumption is closer to reality than the stratified bed assumption. The staff recognizes that the NUREG/CR-6224 correlation is limited to a uniform debris bed condition; therefore, if licensees identify a nonhomogeneous bed formation, the NUREG/CR-6224 correlation is no longer valid and plant-specific test data will need to be submitted to support the head loss calculation.

In 2002, the staff decided to conduct additional head loss tests to further validate the NUREG/CR-6224 correlation against the pressure drop test data across a CalSil debris bed, since the CalSil thermal insulation material has been used in many PWR units. The test data have extended the knowledge base of the head loss correlation to CalSil/fiber mixture debris beds.

The staff recognizes that the test data only cover a limited range of CalSil/fiber mass ratios and variability has been observed in repeated test cases. Additional confirmatory tests have been planned to obtain head loss data across a CalSil debris bed with different CalSil/fiber mass ratios and to examine the repeatability of the filtration effect observed so far. When the confirmatory testing is complete, the staff will supplement the SE, if necessary.

Comment

There are many uncertainties in the modeling of debris transport.

Response

The staff agrees that there are uncertainties in modeling debris transport. The baseline guidance accounted for these uncertainties by using conservative values for transport fractions. After determining that such assumptions were not conservative, the staff imposed limitations on the baseline assumptions. The example quoted is a limitation to account for the non-conservative assumption in determining the fraction of debris moving into inactive pools.

The baseline guidance assumes that the debris transported to the inactive sumps is strictly based on the ratio of the volume of the inactive sumps to the total water volume in containment at the start of recirculation. The baseline guidance states that this assumption is conservative because the debris transport methodology ignored the preferential sweeping of the debris on the containment floor to the inactive sumps by the thin sheets of high-velocity water. This basis does not reflect realistic debris transport. Observations made during the integrated tank tests (NUREG/CR-6773) show debris being directionally driven by the sheeting-flow wave front. Such transport could drive debris across the tank bottom (either away from or to the sump) unless the debris became otherwise trapped along the transport path. With this type of sheeting-flow transport of fine debris, a sharp direction change, such as at an entrance into a hallway leading to the reactor cavity, could easily result in the debris being swept past the entrance because it was unable to go with the flow into the doorway. In addition, substantial debris blowdown deposited in the upper regions of the containment would arrive at the sump level well after the inactive pools filled, due to containment spray drainage. Because of the realities of pool formation and containment spray drainage debris transport, the baseline guidance assumption of debris homogeneity in the sump pool during inactive pool fill is nonconservative. The acceptance of this nonconservative assumption must be based on the simultaneous acceptance of other assumptions with known conservatisms. The comparison of the application of the baseline methodology to the volunteer plant with the detailed analyses of the plant (Appendix IV) provided a method to gauge the relative conservatism of the baseline methodology as a package.

If a plant baseline analysis estimates that a relatively large fraction of the debris is trapped in the inactive pools, as could be the case with a large reactor cavity volume and a shallow sump pool, then the inactive pool fraction should be more limited than the current baseline model. Note that the detailed analyses reported in Appendix IV of the SE predicted that only approximately 3 percent of the small fibrous debris generated would be trapped in inactive pools, compared with 14 percent predicted using the baseline model. Based on the acceptability of the baseline methodology as applied to the volunteer plant, the staff limits the fraction of debris assumed to be trapped in inactive pools to no more than approximately 15 percent, unless a higher fraction is adequately supported by analyses or experimental data. If a licensees analysis showed only a few percent of debris moving into inactive pools, the lower value would be used.

The staff agrees that performing plant-specific detailed calculations may be difficult. The staff provided additional guidance on performing plant-specific calculations for blowdown, washdown, and pool debris transport in Appendices III and VI.

Comment

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

Response

The staff does not agree that no definite guidance is given for evaluating downstream effects. In numerous passages in the SE, the staff advises licensees on specific areas of concern regarding blockage and wear of downstream components. The staff expanded its evaluation to address lessons learned from Davis-Besse. For example, licensees should consider system operating lineups, conditions of operation and mission times, fluid conditions (including fiber content), internal pump component materials, and various sizes of material particulate. The staff also advised licensees to consider a matting effect (an empirical finding), component rotor dynamics changes, system piping, containment spray nozzles, and instrumentation tubing. The staff further advised licensees to perform an overall ECCS or containment spray (CS) system evaluation integrating limiting or worst case pump, valve, piping, and heat exchanger conditions. The staff intentionally did not include guidance of the type that would typically be included in a licensee’s design control manual. The evaluation of the effects of the fluid properties on piping system components is considered to be a routine part of piping and component analysis.

NRC is continuing research to expand existing data with respect to the potential of high-pressure safety injection (HPSI) throttle valves to wear or clog. This information is expected to become available at the end of 2004. This time-frame will not affect the licensees’ ability to perform the downstream effects assessment.

In summary, the staff disagrees with the comment that no definite guidance is provided for the evaluation of downstream effects. The staff believes that the level of rigor is appropriate and will aid in assessing and closing GSI-191.

The staff agrees that limited guidance is given for evaluating chemical effects. An integrated chemical effects test program has been developed through a collaborative effort between the NRC and the nuclear industry. The SE notes that licensees will initially need to evaluate whether the chemical effects test parameters are sufficiently bounding for their plant-specific conditions and provide technical justification for using results from the chemical effects tests. In addition, the SE states that a licensee who chooses to modify its plant sump screens before completing the chemical effects testing and analyzing of the test results should consider potential chemical effects to ensure a second plant modification is not necessary if deleterious chemical effects are observed during testing. Initial test results from the integrated chemical effects program are expected to be available by the end of 2004. Definitive guidance will be developed after the final test results are available and evaluated. The staff plans to supplement the SE based on the chemical effects test results unless these effects are negligible. If the outcome of the testing yields information that would require reconsideration of the approach to address this issue, the overall schedule would have to be reassessed.

Comment

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.

Response

In response to ACRS thermal-hydraulic subcommittee comments, the NRC staff developed Appendix VIII to the SE to define and describe the thin bed effect and to describe the relevant operational experience. Following issuance of the October 18, 2004, ACRS letter, the staff has added guidelines to Appendix VIII on how to calculate the pressure drop across the thin bed and additional quantitative guidelines.

Three dominant factors contribute to the formation of a thin bed. First, fiber material is required for typical screen mesh sizes to filter the fine particulate from the flow and to structurally support the fiber/particulate debris bed. Second, substantial particulate must accumulate along with the fibers either in the interfiber space or on top of the fibrous debris in sufficient quantity that the bed porosity is dominated by the particulate. Third, because pressure-driven compression of the debris bed reduces porosity, the approaching velocity affects the formation of a thin-bed configuration. A thin bed is more likely to form at higher flow velocities than lower flow velocities.

In summary, the three factors of fiber mass content, particulate content, and the approaching velocity largely determine whether a thin bed can form and criteria are provided in the SE for a licensee to use to substantiate no-thin-bed effect for a given plant.