Appropriate Requirements for Validation of Software Used to Evaluate Gas Voids in Fluid Piping Systems

Background
Industry guidance on management of gas accumulation includes acceptance criteria for gas void fractions at the suction of pumps. In practice, applying these criteria involves an evaluation of a gas bubble at a location away from the pump and the mechanisms for gas transport as the bubble moves toward the pump. In simple cases, the industry has defined a "simplified equation" that is an acceptable, but conservative, means of performing this evaluation. In cases where the conservative approach results challenge the criteria or do not provide sufficient margin, or in situations that fall outside of the limitations established for the simplified equation, utilities perform more detailed analyses to determine if the criteria are met. Many of these analyses are performed using computer programs.

Questions have arisen regarding the degree of verification that must be completed prior to the use of software in these applications as part of an operability evaluation (OPERABILITY as defined in licensee Technical Specifications). The purpose of this paper is to document the industry's position on this question.

Industry Position
This paper documents the appropriate verification / validation requirements for software that is being used to evaluate the operability of pump when a gas bubble is discovered in its suction or discharge piping. In order to properly apply this position paper, it is essential to understand the difference in QA controls applied in operability evaluations as compared to design analyses. Specifically:

- Design analyses are governed by requirements in 10CFR50 Appendix B Criterion III, "Design Control", ANSI N45 2.11, NQA-1, etc. This involves extensive verification of design inputs and methods and multiple levels of approval.
- Operability analyses are not governed by specific regulations, but guidance on their performance is provided by documents such as RIS 2005-20 and NRC Inspection Manual Part 9900 Technical Guidance. In general, operability evaluations are less rigorous than design analyses and are "reasonable expectations" that can be based on engineering judgment, partial test data and less extensively qualified computer software.

The following provides a "gas bubble" example of the difference between when an operability evaluation and a design analyses should be performed:

- If a gas bubble is discovered in a fluid system and the utility takes action to remove the bubble in order to restore the system to its designed condition, an operability evaluation is required to determine if the presence of the gas bubble caused the affected pump to be inoperable. The operability evaluation would be available for review by NRC inspectors.
- If a gas bubble is discovered in a fluid system and the utility intends to leave the gas bubble in place, a design analysis is required to change the system design configuration. A 10CFR50.59 evaluation of the change would be necessary and NRC prior approval obtained if required.

The remainder of this section is focused on the expectations for operability evaluations.

The guidance in NRC Inspection Manual Part 9900, Appendix C, Section C.4 (Use of Alternative Analytical Methods in Operability Determinations) applies to the question addressed in the paper. The following quotations from the NRC Inspection Manual and the Industry's interpretation in the present context are offered below.

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- *"When performing operability determinations, licensees sometimes use analytical methods or computer codes different from those originally used in the calculations supporting the plant design. This practice involves applying "engineering judgment" to determine if an SSC remains capable of performing its specified safety function during the corrective action period. The use of alternative methods is not subject to 10 CFR 50.59 unless the methods are used in the final corrective action."*
  Industry interprets this statement to mean that the NRC does not need to approve computer codes used in operability evaluations.
- *"Utilizing a new method because it has been approved for use at a similar facility does not alone constitute adequate justification."*
  Industry interprets this to mean that a licensee must establish that they use of the software at their plant is appropriate.
- *"Acceptable alternative methods such as the use of "best estimate" codes, methods, and techniques. In these cases, the evaluation should ensure that the SSC's performance is not over-predicted by performing a benchmark comparison of the non-CLB analysis methods to the applicable CLB analysis methods."*
  Industry interprets this to mean that benchmarking to other analysis is acceptable and benchmarking to tests need not be necessary.
- *"The use of the software should be controlled in accordance with the licensee's quality assurance program, as applicable. This includes the availability of reviewers qualified to verify results."*
  Industry interprets this to mean that the software and those who use it must be qualified in accordance with the licensee's QA program. When utilities perform the analyses, the applicable program is the licensee's program. When vendors perform the analyses, licensees may invoke a vendor's quality assurance program and perform an oversight / owners acceptance review of the work.

Examples of Other Software Applications

The expectations for verification of software that is used in gas void evaluations should not be any different than the expectations for software used for the same purpose in other applications. The following are examples of other software used in operability evaluation applications.

- The MAAP code is used to evaluate containment environmental conditions as input to gas entrainment
- Computer codes such as PROTO-HX are used to evaluate raw water heat exchanger performance in accordance with GL 89-13 (*Service Water System Problems Affecting Safety-Related Equipment*).
- Piping flow network codes are used to evaluate discovered system conditions that vary from normal to determine if flow requirements are met.

Guidance for Use of the Industry Position

Rather than require additional verification of software that has already been shown to be applicable to the analysis of voids in fluid systems, Industry proposes that conservatisms be applied when the software has not been demonstrated for a specific piping configuration. The following guidance should be used.

Computer software used for void transport analyses is qualified prior to use in safety-related engineering analyses and should be used within the bounds of the qualification analysis for each computer program. This is true whether the program is used for design or operability analyses.

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Software is typically qualified by either comparing program output to data obtained from testing or by verifying the equations and methodology through a line-by-line review of the software code. Gas void transport analysis software is typically qualified by comparison to test data due to the complexity of the piping systems, the potential interaction of hydraulic effects, and the empirical nature of the equations used to predict void transport.

A software qualification test program will include a step to identify the analysis critical variables (e.g., pipe geometries, flow rates) and establish the range of these variables appropriate for the intended application of the computer program. For example, pipe diameters used in testing may only range from 4 inches to 8 inches if this bounds the pipe diameters in systems that will be analyzed using the computer program. Qualification testing for void transport must also consider hydraulic phenomena that may occur, such has hydraulic jump, kinematic shock, and slug flow, if appropriate.

When a licensee identifies a condition that requires a detailed analysis of void transport to determine operability, ideally the computer code used for the analysis will have been benchmarked with test data where all critical variables of the actual system are bounded and potential flow phenomena were considered in testing. The uncertainty in the computer program output is known from benchmarking. Licensees that perform analyses using software when the all aspects of the actual situation are bounded by the qualification program use the gas void fraction acceptance criteria in NEI 09-10, Revision 1, to determine pump operability. Licensees may use more conservative acceptance limits to increase safety margin.

Qualification testing cannot always account for all geometries and conditions that require analysis. Using computer code for analyses where one or more critical variables exceeds the range of qualification introduces uncertainty into the results. Requalification of the computer program for each unique situation is typically not possible due to the time required to obtain additional test data and the time available to determine operability. Engineering judgment must be applied to determine if the computer program is the appropriate tool for the analysis and the uncertainties are acceptable. Uncertainties that cannot be quantified through alternate analytical methods or evaluated by engineering judgment may reduce the margin between the acceptance criterion and the analysis results. Void transport analyses that use software outside the range of qualification should establish acceptance criteria that are appropriate and conservative given the uncertainties in the analysis. Use of the NEI 09-10, Revision 1, acceptance criteria may be inappropriate without including additional margin to ensure the operability determination is conservative. For example, reducing the void fraction acceptance criteria by a factor of two can compensate for 50% uncertainty in the analysis results relative to analyses completed with a fully qualified and benchmarked computer code. Computer codes are not used when the uncertainties cannot be evaluated or the hydraulic conditions in the plant may differ significantly from those modeled in the computer software.

The above discussion can be summarized as follows:
- If the specific piping configuration being analyzed has been tested and the software benchmarked to it, or if the analysis fits within the limits of applicability documented for the software, the void fraction limits in NEI 09-10 can be used without modification.
  - In this case, a benchmark analysis has been completed to define the range of applicability and the application falls within that range
- If the configuration has not been tested and benchmarking is not available, use appropriate margins or conservative assumptions justified by engineering evaluation

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- o Note that using a 50% margin on the pump suction criteria (void size or transient duration) has been accepted in many situations, but may not be necessary or acceptable in all cases
- o Software should never be used outside of its valid areas of application

References

- NRC Inspection Manual Technical Guidance Part 9900
- NEI 09-10, Guidelines for Effective Prevention and Management of System Gas Accumulation