Nuclear Regulatory Commission
Division of Nuclear Reactor Regulation

FINAL SAFETY EVALUATION FOR

NUCLEAR ENERGY INSTITUTE TOPICAL REPORT

NEI 09-10, REVISION 1a

"GUIDELINES FOR EFFECTIVE PREVENTION AND MANAGEMENT OF SYSTEM GAS ACCUMULATION"

PROJECT NO. 689

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ENCLOSURE

SUMMARY

The Nuclear Energy Institute (NEI) submitted the subject Topical Report (TR) for Nuclear Regulatory Commission (NRC) review on December 21, 2010 (Reference 30). Following several exchanges of information, the NRC provided a final Request for Additional Information on March 19, 2012. NEI provided a response on September 26, 2012 (Reference 28) and provided the final version of the subject TR on November 1, 2012 (Reference 31). This final safety evaluation (SE) completes the NRC staff review of the subject TR and associated documentation.

The NRC staff finds that the subject TR:

- meets the objectives of a TR,
- conforms to and reinforces previously established NRC regulations,
- reinforces previously issued guidance such as contained in Generic Letter (GL) 2008-01 (Reference 2), various inspection guidance documents (References 23, 26, 27, and 33) and discussed in meetings (Reference 14),
- documents in one location practices that are in widespread use,
- provides insights and attributes to implement an acceptable approach to effectively prevent and manage gas intrusion and accumulation in plant systems,
- will aid in the identification of susceptible systems,
- outlines principles and practices designed to effectively prevent, identify, manage and monitor accumulation of gas that would challenge the capability of a system to perform its functions as designed,
- identifies training to ensure plant personnel can readily recognize and effectively respond to gas intrusion and accumulation in susceptible systems,
- provides guidance for addressing gas management issues,
- adds value to NRC and industry activities by detailing methods of resolving gas accumulation issues, and
- will improve the efficiency of licensing processes such as associated with license amendment requests since licensees can reference the TR in the same manner as they can reference previously approved NRC documents such as SEs.

The NRC staff therefore endorses NEI 09-10, Revision 1a (Reference 31), as an acceptable voluntary approach to effectively prevent and manage gas intrusion and accumulation in plant systems subject to the conditions identified in this SE.

Systems that are considered to be within scope of the TR are those fluid systems that are necessary to ensure continued core cooling and prevention of a significant release of

radioactive material. This includes safety-related systems and, where appropriate, non-safety related systems. Some aspects of gas behavior, such as application of computer codes to address gas movement and details associated with entrance of gas into systems due to vortexing, are outside of the TR's scope. These are to be addressed by licensees when covering gas-related issues.

The TR acceptably covers:

- causes of gas accumulation,
- personnel participation,
- currently recognized gas intrusion mechanisms,
- items to prevent gas intrusion,
- operating experience guidance,
- systems that should be included in a gas management program,
- potential gas accumulation locations,
- fill and vent processes,
- corrective actions,
- system maintenance discussion,
- gas monitoring,
- conditions where gas exceeds the current design limit,
- station-specific training,
- operability determination, and
- Net Positive Suction Head required (NPSHr),

The TR discusses a "Simplified Equation" to predict gas movement. The discussion covers conditions for using the equation and states that "It is the user's responsibility to ensure the applicability of the Simplified Equation … to the specific piping configuration and to acceptably address all relevant gas transport phenomena." The discussion is acceptable since it addresses application of the Simplified Equation to plant-specific conditions.

With respect to application of computer codes, the TR states "that any computer code used to develop a system specific model should be verified to be applicable to solve problems involving gas transport in piping systems via comparisons with laboratory test data or other appropriate methods. Further, a suitable safety factor should be added to predicted results to reasonably ensure the predictions encompass actual behavior." This is acceptable since it covers issues identified during inspections that followed guidance provided in Reference 24.

The TR references describe test data and methodologies to address gas movement and water hammer issues associated with gas accumulation that support the TR. The NRC staff assessment of the references is as follows:

- WCAP-17271-P (Reference 39), provides a valuable addition to data applicable to two-phase two-component transient pipe flow. Use of the data in verifying void transport methodologies is acceptable subject to the conditions identified in this SE.

- FAI/09-130-P (Reference 13) and WCAP-17276-P (Reference 40) develop a simplified equation for pressurized water reactor (PWR) licensee use in predicting gas movement in pump suction piping. The simplified equation is acceptable subject to the conditions identified in this SE. The principal condition is that the equation has not been acceptably established to address a horizontal pipe connection between a downcomer and a pump suction and this must be acceptably addressed by any licensee using the equation. Palo Verde Nuclear Generating Station (Palo Verde) and Beaver Valley Power Station (Beaver Valley) tests are summarized that provide additional insights into PWR suction pipe behavior.

- FAI/08-70 (Reference 11) covers almost 250 test runs and the data will be useful in assessing water hammer analysis methodologies. Application of the provided modeling methodology to plant configurations is not acceptably substantiated due to insufficient comparisons to test data.

- FAI/08-78 (Reference 12) concentrates on piping inside containment associated with containment spray and switchover to hot leg injection. The rationale used to conclude that phenomena associated with sonic phenomena will not occur is reasonable but, if applied, needs to be checked for applicability to the individual configuration. Treatment of phenomena associated with gas, addressed as flow transients, may not be generally applicable.

- BWROG-TP-08-017 (Reference 6) addresses the impact of gas accumulation that causes a delay and/or reduction in emergency core cooling system (ECCS) injection and causes gas to pass through the core of a boiling water reactor (BWR). The effect of delay of water injection is addressed by selecting a heat generation rate and determining the available time before the peak fuel cladding temperature would reach 2200 degrees Fahrenheit (°F). The selected heat generation rate is not consistent with calculation of peak clad temperature but licensees may use the BWR Owners Group (BWROG) process provided the correct heat generation rate is used. The approach to assessing a loss of feedwater event is acceptable on a plant-specific basis provided: (1) the licensee compares its estimate of the reduction in water depth due to its estimate of the delay in ECCS injection to its design basis minimum water depth above top of active fuel, and (2) the margin is approximately as large as discussed in the BWROG document. Meeting the anticipated transients without scram (ATWS) criteria will be acceptable if a licensee establishes that the plant-specific assumed ECCS injection delay time has an impact on plant parameters that is no greater than identified in the BWROG discussion. The BWROG hypothetical delay time for injection may be used for station blackout if the licensee demonstrates this to be bounding for its plant. The impact of delay on Appendix R fire safe shutdown requirements may be assessed similarly with addition of consideration of the low pressure system performance along with the automatic depressurization system/safety relief valve ability to maintain temperature below the Appendix R limit. Potential concerns with air injection include the effect on core heat transfer and waterhammer. The latter is not identified in the BWROG document and should be addressed via an approximate technique by licensees. The BWROG identifies that the BWR geometry allows air and steam to pass through the core and, since the volume of air would be small in comparison to the steam volume, that the air would not alter the heat transfer by any significant amount. Not mentioned is that water entering from above may condense steam but may be held up by air. This should be addressed by any licensee that applies the information provided in the BWROG document.

- BWROG-TP-08-020 (Reference 7) was intended to address waterhammer, core cooling, and injection delay due to gas in selected BWR piping. Each BWR licensee should establish the pressurization and waterhammer behavior due to potential gas in the subject systems.

- Review of LTR-LIS-08-543 (Reference 21) confirms that an initial gas void of 5 cubic feet (ft^3) in high pressure system piping at 400 pounds per square inch absolute (psia) and 68 °F or low pressure system piping at 100 psia and 68 °F is not of concern with respect to most aspects of injection into a PWR reactor coolant system (RCS). It is assumed that there is no delay or reduction in ECCS flow rate beyond the point assumed in the safety analyses of record. Licensees referencing the information provided in this report should establish that the assumptions are correct.

The TR states that "Users should ensure that any comments in the SE are considered when the references are used." Comment detail is provided in SE Section 3, below.

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ACRONYMS

ADAMS	Agencywide Documents Access and Management System
ALARA	As Low As Reasonably Achievable
ANS	American Nuclear Society
ANSI	American National Standards Institute
ATWS	Anticipated Transient Without Scram
BEP	Best Efficiency Point
BWR	Boiling Water Reactor
BWROG	Boiling Water Reactor Owners Group
BWST	Borated Water Storage Tank
CAP	Corrective Action Program
CDB	Current Design Basis
CFR	Code of Federal Regulations
DHR	Decay Heat Removal
ECCS	Emergency Core Cooling System
FAI	Fauske Associates, Inc.
FSAR	Final Safety Analysis Report
GDC	General Design Criterion or General Design Criteria
GI	Generic Issue
GL	Generic Letter
HPCI	High Pressure Coolant Injection
HPCS	High Pressure Core Spray
IN	Information Notice
INPO	Institute of Nuclear Power Operations
LOCA	Loss-of-Coolant Accident
LOFW	Loss of Feed Water
ML	ADAMS Reference or Accession number
NEI	Nuclear Energy Institute
N_{FR}	Froude number
NPSHr	Net Positive Suction Head required[1]
NRC	Nuclear Regulatory Commission
NSSS	Nuclear Steam Supply System
NUREG	NRC Technical Report Designation (Nuclear Regulatory Commission)
OE	Operating Experience
PIRT	Phenomena Identification and Ranking Table
PCT	Peak Clad Temperature
PWR	Pressurized Water Reactor
PWROG	Pressurized Water Reactor Owners Group
RCP	Reactor Coolant Pump
RCS	Reactor Coolant System
RG	Regulatory Guide
RHR	Residual Heat Removal
RWT	Refueling Water Tank
RWST	Refueling Water Storage Tank
SBO	Station Blackout
SER	Significant Event Report (INPO)

[1] "required" refers to the NPSH necessary for cavitation-free operation, not a regulatory requirement.

SR	Surveillance Requirement
SSC	Structures, Systems, or Components
TAF	Top of Active Fuel
TIA	Task Interface Agreement
TS	Technical Specification
TSTF	Technical Specification Task Force
US	United States
UT	Ultrasonic Test
VCT	Volume Control Tank

1.0 INTRODUCTION AND BACKGROUND

1.1 Introduction

An objective of the TR process is to add value by improving the efficiency of other licensing processes such as the process for reviewing license amendment requests (LARs). In addition, a TR may add value to both NRC and industry representatives by detailing a method of resolving a technical issue. The purpose of the NRC TR program is to minimize industry and NRC time and effort by providing a streamlined review and approval of a safety-related subject with subsequent referencing in licensing actions rather than repeated reviews of the same subject.

During the review, the NRC staff found that the subject TR (Reference 31) meets the objectives of a TR and reinforces previously established NRC regulations and guidelines as noted within this SE. The NRC staff has evaluated this TR against the criteria of Title 10 of *Code of Federal Regulations* (10 CFR) Part 50, and has determined that the NRC staff technical positions outlined in this SE are consistent with the regulations and established NRC staff positions while providing more detailed discussion concerning the methodology and data required for supporting the effective prevention and management of system gas accumulation programs. This SE endorses NRC staff positions previously established through licensing actions and interactions with industry and industry best practices.

1.2 Background

Instances of gas accumulation in nuclear power plant fluid systems have occurred since the beginning of commercial nuclear power plant operation. Several gas intrusion mechanisms can result in gas accumulation in system piping, and some gas may come out of solution due to changes in temperature and pressure during normal operation. However, the existence of gas in system piping is not a condition that was accounted for in the initial analyses of system performance during transients and accidents. Gas accumulation has been a continuing problem that potentially jeopardizes operability of systems that are important to safety.

The NRC published 20 Information Notices, two GLs, and a NUREG related to this issue. In addition, the NRC interacted with the nuclear industry numerous times in relation to these publications and in response to gas accumulation events. However, the problems continued because a comprehensive, in-depth resolution of the issues was not achieved. This situation changed as a result of the Institute of Nuclear Power Operations (INPO) issuing a Significant Event Report (SER) in March 2005 (Reference 16 is Revision 1 to the SER), and the NRC issuing GL 2008-01 (Reference 2).

GL 2008-01 requested that each addressee evaluate its ECCS, decay heat removal (DHR) system, and containment spray system licensing basis, design, testing, and corrective actions to ensure that gas accumulation is maintained less than the amount that challenges operability of these systems, and that appropriate action is taken when conditions adverse to quality are identified. The combination of the GL 2008-01 and SER 2-05, Revision 1, resulted in an in-depth industry effort to address the issues. This effort has resulted in a significant and continuing improvement in addressing gas management issues.

For most licensees, the current design basis (CDB) for the subject systems is a water-solid condition.[2] The desired objective during operation is to achieve this condition but, where this is not practical, an acceptable objective of gas control measures is to limit the gas accumulation volume to a quantity that does not jeopardize system operation. An acceptable volume depends on a variety of factors including, but not limited to, total volume, location, flow rate, type of pump, gas volume fraction at the pump impeller, pressure changes experienced by the system when it is activated, obstacles to flow downstream from accumulated gas, and effects of gas on core cooling. The amount and location of gas are both important in addressing the impact on system operation. An evaluation to develop and apply criteria is necessary to determine the amount of gas that could affect system operation.

The TR addresses issues identified in GL 2008-01 and SER 2-05, Revision 1, during industry evaluations of their operations, and in meetings and workshops. It provides recommendations and guidance to nuclear power plant licensees for development and implementation of programs and processes to prevent and manage gas intrusion and gas accumulation in plant systems.

1.3 Purpose

The NRC staff reviewed the TR and documents that were incorporated into the TR by reference to determine if it:

- meets the objectives of a TR,
- conforms to and reinforces previously established NRC regulations,
- reinforces previously issued guidance such as contained in GL 2008-01 (Reference 2), various inspection guidance documents (References 23, 26, 27, and 33) and discussed in meetings (Reference 14),
- documents in one location practices that are in widespread use,
- provides insights and attributes to implement an acceptable approach to effectively prevent and manage gas intrusion and accumulation in plant systems,
- will aid in the identification of susceptible systems,
- outlines principles and practices designed to effectively prevent, identify, manage and monitor accumulation of gas that would challenge the capability of a system to perform its functions as designed,
- identifies training to ensure plant personnel can readily recognize and effectively respond to gas intrusion and accumulation in susceptible systems,
- provides guidance for addressing gas management issues,

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[2] A condition where there is no void is described by such words as gas-free, free-of-gas, or water-solid. “Filled with water” is typically used to describe a condition where a system contains sufficient water to be operable. (See Reference 35)

- adds value to NRC and industry activities by detailing methods of resolving gas accumulation issues, and
- will improve the efficiency of licensing processes such as associated with license amendment requests since licensees can reference the TR in the same manner as they can reference previously approved NRC documents such as SEs.

The TR was found acceptable without conditions. Conditions regarding use of documents incorporated into the TR by reference are addressed in the SE.

The TR states that the primary objective of the submittal is to provide insights and attributes to implement an acceptable approach to effectively prevent and manage gas intrusion and accumulation in plant systems. The TR is intended to aid in the identification of susceptible systems, outline principles and practices designed to effectively prevent, identify, manage and monitor accumulation of gas that may challenge the capability of a system to satisfy its design functional requirement(s), and identify training to ensure plant personnel can readily recognize and effectively respond to gas intrusion and accumulation in susceptible systems. This SE provides conclusions, findings, and endorsement of the practices and requirements that can be referenced by a licensee to support the development and implementation of effective gas management programs in plant systems.

2.0 REGULATORY EVALUATION

The regulations in Appendix A to 10 CFR Part 50 or similar plant-specific principal design criteria[3] and in 10 CFR 50.46[4] provide design requirements. Appendix A requirements applicable to gas management include the following:

- General Design Criterion (GDC) 1 requires that systems be designed, fabricated, erected, and tested to quality standards.
- GDC 34 requires a residual heat removal (RHR) system[5] designed to maintain specified acceptable fuel design limits and to meet design conditions that are not exceeded if a single failure occurs simultaneous with failure of specified electrical power systems.
- GDCs 35, 36, and 37 require an ECCS design that meets performance, inspection, and testing requirements.
- GDCs 38, 39, and 40 require a containment heat removal system design that meets performance, inspection, and testing requirements.

The regulations in 10 CFR 50.46 provide specified ECCS performance criteria.

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[3]These apply to facilities with a construction permit issued before May 21, 1972, that are not licensed under Appendix A.
[4] 10 CFR 50.46(d) requires licensees to meet Criterion 35 of Appendix A.
[5] Various licensees use DHR, RHR, and shutdown cooling when referring to systems that are used to cool the reactor coolant system (RCS) during shutdown operation. These descriptors have the same meaning.

Quality assurance criteria provided in Appendix B that apply to gas management in the subject systems include the following:

- Criterion III requires measures to ensure that applicable regulatory requirements and the design basis, as defined in 10 CFR 50.2, “Definitions,” and as specified in the license application, are correctly translated into controlled specifications, drawings, procedures, and instructions.

- Criterion V requires important activities to be prescribed by documented instructions, procedures, or drawings, which must include appropriate quantitative or qualitative acceptance criteria for determining that important activities have been satisfactorily accomplished.

- Criterion XI requires a test program to ensure that the subject systems will perform satisfactorily in service. Test results shall be documented and evaluated to ensure that test requirements have been satisfied.

- Criterion XVI requires measures to ensure that conditions adverse to quality, such as failures, malfunctions, deficiencies, deviations, defective material and equipment, and non-conformances, are promptly identified and corrected, and that significant conditions adverse to quality are documented and reported to management.

- Criterion XVII requires maintenance of records of activities affecting quality.

Furthermore, as part of the licensing basis, licensees have committed to quality assurance provisions that are identified in both their technical specifications (TSs) and quality assurance programs. Licensees have committed to use the guidance of Regulatory Guide (RG) 1.33 (Reference 27) which endorses American National Standards Institute (ANSI) N18.7-1976/American Nuclear Society 3.2 (Reference 4) or equivalent licensee-specific guidance. Section 5.3.4.4, “Process Monitoring Procedures,” of ANSI N18.7 states that procedures for monitoring performance of plant systems shall be required to ensure that engineered safety features and emergency equipment are in a state of readiness to maintain the plant in a safe condition if needed. The limits (maximum and minimum) for significant process parameters shall be identified. Operating procedures shall address the nature and frequency of this monitoring, as appropriate.

In 10 CFR 50.36(c)(3), the NRC defines TS surveillance requirements (SRs) as “relating to test, calibration, or inspection to assure the necessary quality of systems and components is maintained, that facility operation will be within safety limits, and that the limiting conditions for operation will be met.” Typically, TS Sections 5 or 6 require that licensees establish, implement, and maintain written procedures covering the applicable procedures recommended in Appendix A to RG 1.33. Appendix A to RG 1.33 identifies instructions for filling and venting the ECCS and DHR system, as well as for draining and refilling heat exchangers. Standard TSs and most licensee TSs provide SRs to verify that at least some of the piping in systems that are important to safety is filled with water[6]. In response to the continuing issues with gas

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[6] If the licensee can conclude through an operability determination that there is a reasonable expectation that the system in question can perform its specified safety function, the system piping can be considered

management, the industry owners groups have initiated changes to the TSs through the Technical Specification Task Force (TSTF). The TSTF has proposed and is developing TSTF-523, "Generic Letter 2008-01, Managing Gas Accumulation" that is applicable to all plant types (Reference 34). The NRC found this proposal acceptable for review and requested additional information regarding TSTF-523 (Reference 15). The TSTF provided a response on August 30, 2012 (Reference 5).

Appendix B Criteria III, V, and XI are accurately described in TR Section 2. Criterion XVI is identified in TR Attachment 4 that addresses operability or functionality of degraded or nonconforming structures, systems, or components (SSCs). Criterion XVII is not specifically mentioned but the TR addresses applicable documentation in a number of locations.

Training was not identified in GL 2008-01 but is necessary to meet many of the above-identified regulatory requirements and the need for training is addressed in INPO documentation. TR Section 14 covers training.

The TR is consistent with regulatory requirements.

3.0 TECHNICAL EVALUATION

TR Section 2 states that the document provides insights and attributes to implement an acceptable approach to effectively prevent and manage gas intrusion and accumulation in plant systems. It is intended to aid in the identification of susceptible systems, outline principles and practices designed to effectively prevent, identify, manage, and monitor accumulation of gas that would challenge the capability of a system to satisfy its design functional requirement(s), and identify training to ensure plant personnel can readily recognize and effectively respond to gas intrusion and accumulation in susceptible systems.

The TR addresses many of the issues associated with gas accumulation management. Some aspects of gas behavior, such as application of computer codes to address gas movement[7] and details associated with entrance of gas into systems due to vortexing, are outside of the TR's scope. These are to be addressed by licensees when covering gas-related issues.

The stated approach is to “ensure that the fluid systems susceptible to gas accumulation are operated and maintained within their design bases and remain ready to perform their intended design basis function when required. It is expected that systems will be designed, operated, and maintained in a manner to prevent accumulation of gas. Where accumulated gas cannot be reasonably prevented, engineering technical evaluations must account for the presence of such gas and its impact on system performance.” This is an acceptable approach to providing guidance for addressing issues associated with gas management.

GL 2008-01 was limited to ECCS, DHR, and containment spray systems because the overall intent was to initiate needed improvements. The TR expands coverage to all systems of

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filled with water such that the surveillance requirement is met (Reference 35). A condition where there is no void is described by such words as gas-free, free-of-gas, or water-solid.

[7] SE Sections 3.15.2.4 and 3.16 identify some considerations applicable to computer codes that address gas movement.

concern, identifies both typical single failure assumptions and operation without failures for all applicable modes, and identifies that coverage of mode transitions should be addressed. The expansion of system coverage is both desirable and acceptable.

The TR references describe valuable test data and methodologies to address gas movement and water hammer issues associated with gas accumulation. The NRC staff finds the methodologies and correlations described in the references have not always been sufficiently compared to experimental data to establish that they are acceptable for determining operability under all conditions. Licensee use of the references must address the weaknesses that are addressed in this SE.

3.1 Overview of Concerns

The TR states that the causes of the issue include designs that allow gas introduction and accumulation, equipment issues that allow unanticipated transfer of gas-saturated fluids between systems, failure to properly fill and vent the system following drain-down or maintenance, improper controls on gas accumulation during operation, inappropriate programmatic controls, and unanticipated problems with keep-full systems. TR Section 1.3.2 continues by identifying effects of gas. This is an acceptable overview of the effects associated with gas accumulation.

3.2 TR Section 3, "Gas Accumulation Management Ownership"

The TR covers the need for senior level licensee management support and the designation of an owner to implement and manage the approach to minimize and control system gas accumulation. It states that representatives from all appropriate departments should be involved and emphasizes that the issues are site-wide and that they impact many functions. Coverage of management involvement is acceptable.

3.3 TR Section 4, "Identify Gas Intrusion Mechanisms"

The TR lists 16 gas intrusion mechanisms and notes the list is not necessarily complete. The NRC staff agrees with the list with the observation that the list is not necessarily complete since other mechanisms may be discovered.

3.4 TR Section 5, "Gas Intrusion and Accumulation Prevention"

The TR identifies practices to avoid and practices to prevent or minimize gas intrusion and it identifies responses to address gas accumulation concerns. It discusses that enhanced monitoring should be considered for locations where gas repeatedly accumulates to identify early onset of gas accumulation. TR Section 12 is identified for additional information regarding gas monitoring and TR Section 13 is identified for addressing gas that is in excess of the design limit. With respect to gas accumulation, TR Sections 12.2 and 12.3 provide monitoring guidance. TR Section 5 is acceptable.

3.5 TR Section 6, "Review and Incorporate Operating Experience (OE)"

The TR recommends that plants should document gas intrusion and lessons learned through operating experience. The importance of understanding gas intrusion and accumulation mechanisms and the possibility that a mechanism may apply to other systems is identified, as is the need for the gas intrusion program owner to review all plant and industry operating experience. The discussion of operating experience guidance is acceptable.

3.6 TR Section 7, "Plant System Selection"

The TR states that gas management programs should include systems listed in GL 2008-01, systems that affect safety that have susceptibility to gas intrusion or that would cause a significant adverse consequence if gas intrusion were to go undetected, and support systems. In addition it states that "Plants may want to consider expanding the scope to include other systems that are important to plant operation and plant availability." It provides guidance to identify and address systems that may be within scope and states that if an evaluation supports a determination that gas intrusion into a "system would not adversely affect the ability of the system to perform its function … then the system can be considered to not be an in-scope system and no further evaluation is required." The TR continues by stating that, due to the complexity and variability of gas evaluation methods, the evaluation method should either have been approved by the NRC staff "or be well understood and applied by experts who are well versed in such applications." This is consistent with NRC staff inspections where the staff has concluded that prediction of gas behavior is complicated and not fully understood and that evaluations are often incorrect or inadequately supported by experimental data or theoretical understanding.

In regard to prediction methods and to the statement that "scope may be narrowed to portions of a system where gas accumulation can affect the ability to perform a specific function," the NRC staff notes that this may be inconsistent with the CDB. Additionally, gas volumes that are predicted to not affect functionality and that are excluded from further consideration must be documented.[8] Further, the only presently approved methodologies and criteria to assess functionality are the methods approved within this SE. Each licensee must ensure the scope minimally meets the CDB.

TR Section 7 states, "In cases where the existence of voids is determined to be acceptable in the long term, a design change should be completed and evaluated in accordance with Section 9," and "If it is determined that the gas intrusion could impact the ability of the system to perform its function then the system is in-scope and further evaluation of locations where gas could accumulate in the system should be performed."

TR Attachment 2 provides a flowchart that summarizes identification of in-scope systems.

The TR Section 7 guidance is acceptable.

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[8] Treatment of design limits and operating limits is discussed in NEI 09-10 Sections 9 and 12, respectively.

3.7 TR Section 8, "System Gas Accumulation Locations"

Section 8 begins with a statement that "utilities should develop and maintain a method for determining and documenting all system high points, local high points and other potential gas void locations. Relevant dimensional information and similar data for use in evaluating all potential gas void locations should be included in the documentation." The section continues with "the system design information and functional requirements should be reviewed to determine the boundary of each affected fluid system. The boundaries and their basis for selection should be documented," system design information and calculations to identify potential gas void locations reviewed, and walkdowns should be conducted to confirm locations where gas may be a concern. Areas are identified that may be of concern.

The TR states that "Monitoring may not be practical for locations that are inaccessible due to radiological (conditions), environmental conditions, the plant configuration or personnel safety. The condition that causes inaccessibility must exist at the specific location where monitoring is required; for example, a location might be within a posted high radiation area, but the radiation level at the specific location to be monitored may not be a concern." The NRC staff notes that such aspects as high environmental temperatures or local high temperatures that constitute a burn hazard also apply to determination of non-accessibility.

The TR also addresses that "surveillance is required for all locations of concern unless it is acceptably determined that the surveillance is not necessary to reasonably ensure operability."

Monitoring frequency, including additional monitoring under certain conditions, is addressed in TR Sections 12.2 and 12.3 and reviewed in SE Sections 3.11.2 and 3.11.3, respectively.

TR Section 8 is acceptable.

3.8 TR Section 9, "Design Limit"

TR Section 9 addresses the design limit. Operating limits are addressed in TR Section 13 and gas in excess of operating limits is addressed in TR Attachment 4.

The TR states that "the design limit for gas accumulation in a fluid system may be documented in the design basis. If there is no specified design limit then the design limit is no gas present." It continues with "A greater than zero design limit may be derived from an engineering analysis of the impact of gas on system and component performance. This analysis must be performed in accordance with plant procedures and follow acceptable engineering standards... (and) design change documentation shall be processed to support associated procedure changes to incorporate the potential gas void monitoring design limit." Considerations for permanently acceptable conditions and the requirements for acceptance criteria are listed.

As stated in SE Section 3.6, due to the complexity and variability of gas evaluation methods, a NRC staff-approved or a well supported gas transport analysis method is necessary to support a design limit change. Further, the existing state of gas transport methodology requires that an acceptable safety factor be applied to the analysis method results.

TR Section 9 is acceptable.

3.9 TR Section 10, "Fill and Vent Processes"

3.9.1 Fill and Vent Procedures

The TR provides criteria that fill and vent procedures should meet including verification and "the corrective action program if verification identifies weaknesses in prior fill and vent activities."

3.9.2 Dynamic Venting

Dynamic venting "involves passing water through the system to force accumulated gas to a location that can be vented or removed. … Procedures should provide for use of dynamic venting when it is allowed by the system configuration." The TR identifies aspects that dynamic venting procedures should address. The NRC staff has concluded that use of dynamic venting is an effective means to remove gas from local high points and traps in piping when correctly "based on the dynamic flow rate, void volume, Froude number, and the system water volume."

3.9.3 Vacuum Fill

The TR states, "Vacuum fill should be done in accordance with written procedures. Appropriate evaluations of the effect of vacuum on the system should be performed and documented." The NRC staff agrees that "Vacuum filling may be an effective method for removal of trapped gas."

3.9.4 Verification

The TR states that the effectiveness of fill and vent procedures should be verified, including ultrasonic test (UT) quantification of any remaining gas, and that quantitative inspection for gas outside the isolation boundary should be performed following system restoration after draining.

3.9.5 Corrective Action

The TR states "the corrective action program should be used to resolve identified deficiencies in procedures. The final system condition should be verified to meet acceptance criteria or be resolved by appropriate corrective action. Any voids found following completion of fill and vent activities should be recorded, tracked, and trended for evaluation of gas intrusion management effectiveness." TR Section 13 that is reviewed in SE Section 3.12 contains the statement that "An immediate operability determination or functionality assessment is required if discovered gas volume is greater than the monitoring procedure design limit." Enhanced monitoring associated with corrective actions is addressed in SE Section 3.11.

TR Section 10 is acceptable.

3.10 TR Section 11, "System Maintenance"

The TR states that system maintenance activities that result in fluid inventory reduction in a subject system "should be evaluated to determine the required fill, vent and verification inspection" and each activity "should be documented in procedures or in the work document," "The work processes should include provision for engineering review and evaluation of such evolutions," and engineering should participate in the review process and should specify or confirm that the process “will demonstrate that the system is sufficiently full to perform its functions.” The NRC staff finds Section 11 guidance to be acceptable.

3.11 TR Section 12, “Gas Monitoring”

3.11.1 TR Section 12.1, "List of Gas Intrusion Precursors"

The TR lists nine precursors that may result in a gas accumulation problem and states that the precursors are not limited to those listed and utilities “should evaluate and document a specific list of precursors based upon plant design and operation.” This provides acceptable coverage of potential conditions.

3.11.2 TR Section 12.2, "Periodic Monitoring”

Periodic monitoring refers to the minimum monitoring frequency that is specified for routine operation. More frequent monitoring as a result of potential or actual gas intrusion is addressed in SE Section 3.11.3, below.

The TR states that "utilities should determine the appropriate monitoring frequency for each monitored potential void location” and “The monitoring plan must be developed to ensure the system meets the design limit and must reasonably ensure the system is capable of performing its design function throughout the next monitoring interval.” It discusses that the “monitoring frequency may be changed based on the system, location, function, and results of previous monitoring,” and lists considerations for addressing a monitoring frequency change.

The primary requirement is that monitoring must be sufficiently frequent to reasonably ensure continued operability of the subject systems. Licensees that use extended frequencies, such as 24 months without acceptable justification, do not meet this requirement. As identified in SE Section 2, this issue is being addressed via TSTF-523. (References 34 and 5)

The TR Section 12.2 is acceptable.

3.11.3 TR Section 12.3, "Additional Monitoring Based Upon Potential or Actual Gas Intrusion"

The TR initiates this topic by stating that “When an actual gas intrusion event has occurred or there exists an increased possibility that gas intrusion may occur in a given location or system, the condition should be documented in the corrective action program. The corrective actions should include additional monitoring” or increased monitoring frequencies “until the root cause of gas accumulation is identified and corrected. The monitoring frequency should” reasonably ensure that system functionality will be maintained. Further, “An extent of condition review should be performed to identify other locations that are potentially affected by the observed gas intrusion mechanism and inspections should be performed at the locations identified by the review.” The NRC staff finds this approach acceptable.

3.11.4 TR Section 12.4, "UT Examination"

The TR states that UT is the preferred method to identify and quantify gas that has accumulated at a high point or other monitoring point. The NRC staff agrees with this position. Properly conducted UT methods often provide gas quantities accurate to two or three significant figures. Venting, in contrast, may only provide a qualitative indication.

3.11.5 TR Section 12.5, "Venting Requirements"

The TR states that "Venting through valves at high points in a system can be used as an alternate method to determine whether a gas void is present however, the precaution in (TR) Section 12.6 as to accuracy of the qualification method will apply." The NRC staff agrees, and notes the above TR Section 3.11.4 accuracy and preference comments.

3.11.6 TR Section 12.6, "Gas Volume Quantification"

The TR states that identified gas "should be quantified and compared to acceptance requirements to determine operability/functionality. The accuracy of the method used for quantification should be sufficient to verify operability/functionality during the next monitoring interval and to evaluate past operability/functionality. … The recommended method would be to UT the pipe to determine if gas is present and quantify the volume," remove the gas, and perform a UT after removal "to determine the as left condition." The NRC staff supports this approach.

The TR continues by stating, "Alternate methods for gas quantification (e.g., timing of gas from cracked open valves, gas volume measurement by water displacement, or rotometer) may be used, but care should be taken when using the results as the variability in the results could be significant. When these methods are used the degree of accuracy required at the given location should be evaluated and documented." This is acceptable.

3.11.7 TR Section 12.7, "Identification of the Gas Type"

The TR states, "Identification of the gas type can be beneficial in determining the source of the gas intrusion.…Gas analysis provides evidence to verify that assumptions regarding the intrusion mechanism are correct and should be encouraged." This is acceptable.

3.11.8 TR Section 12.8, "Trending of Gas"

The TR identifies that "All monitored points should be trended, even if no void is identified" and that "As-found and as-left void volumes should be measured and documented to determine the effectiveness of periodic venting." It states that trending "will help assess the performance of high/low pressure interface boundary isolations, help identify degraded component conditions, (identify) ineffective system fill and venting, and establish criteria for implementing corrective actions when necessary." It adds that trending results "may be used to plan operating and maintenance activities to mitigate gas intrusion, and to adjust monitoring frequencies when needed." The NRC staff finds that trending guidance is acceptable.

3.12 TR Section 13, "Operability/Functionality Review for Found Gas in Excess of Design Limit"

The TR introduces this topic by stating that "Operability determination or functionality assessment processes are not required if the 'Design Basis' establishes design limits for potential gas void locations, the criteria are included in the monitoring procedure, the as found gas volume is below the design limit, and it can be reasonably assured that the system will remain capable of performing its design function throughout the next monitoring interval." The TR also states that, "the discovery of all gas accumulation that exceeds the design limit should be entered into the station's corrective action program. An immediate operability determination or functionality assessment is required if discovered gas volume is greater than the monitoring procedure design limit."

The TR references TR Attachment 4 for guidance in determining operating limits and states that "Utilities should develop ... operating limits that can be used in the operability determination processes to show that the system although degraded will continue to perform its specified function." The NRC staff assesses Attachment 4 in SE Section 3.15, below.

The TR states, "When gas is found, the operability review or functionality assessment should include consideration of compensatory measures to enhance or maintain operability/functionality" and it lists potential compensatory measures. With respect to gas removal, the TR states, "Gas that exceeds the design limit should be removed immediately using methods described in this document. Gas that cannot be removed immediately ... should be removed at the next available opportunity, consistent with the station corrective action process as long as appropriate operability evaluations are documented and operability is reasonably assured."

Typical NRC review and inspections of licensee processes would include coverage of topics listed for inclusion where (1) no gas was found and (2) found gas was within acceptance criteria whether covered within the corrective action plan or elsewhere in addition to instances where found gas exceeded acceptance criteria and entry was made into the corrective action plan.

TR Section 13 is acceptable.

3.13 TR Section 14, "Training"

The TR discusses the need for training, a training frequency of two to three years, and the development of training modules by INPO for use in assisting training of plant personnel. It concludes with "Each utility should use the generic modules created as described above as the basis for their station specific training on gas intrusion/accumulation prevention and management." The NRC staff finds this acceptable.

3.14 TR 09-10 Attachments 1, 2, and 3

These attachments are acceptable.

3.15 Assessment of Attachment 4, "Acceptance Criteria"

TR Section 9 addressed design limits, TR Section 13 addressed gas in excess of design limits but within operating limits, and TR Attachment 4 covers operability determination when gas is in excess of limits. Attachment 4 is not intended to support design bases changes or procedure changes that include acceptance criteria supporting the design basis but the NRC staff notes that the information may nonetheless be useful in addressing plant-specific design basis changes.

The attachment states that the “application of the guidance and tools … provide methods to support a reasonable expectation that a degraded or nonconforming SSC is operable or functional,” and “In all cases the licensee’s Criterion XVI Corrective Action Program is expected to direct the timely resolution of degraded or non-conforming conditions.”

3.15.1 Reasonable Expectation of Operability

This TR section provides information consistent with Reference 26 issued as the attachment to Reference 33. NRC regulations and the plant-specific operating license, including TSs, establish requirements for SSCs to ensure that plant operation does not pose an undue risk to public health and safety. The TSs require that an SSC be operable given the plant condition (operational mode); thus there should be a reasonable expectation that the SSC in question is operable while an operability determination is being made, or an appropriate TS action requirement should be entered. In summary, the discovery of a degraded or nonconforming condition may call the operability of one or more SSCs into question. A subsequent determination of operability should be based on the licensee’s “reasonable expectation,” from the evidence collected, that the SSCs are operable and that the operability determination will support that expectation. Reasonable expectation does not mean absolute assurance that the SSCs are operable. The SSCs may be considered operable when there is evidence that the possibility of failure of an SSC has increased, but not to the point of eroding confidence in the reasonable expectation that the SSC remains operable. The supporting basis for the reasonable expectation of SSC operability should provide a high degree of confidence that the SSCs remain operable. It should be noted that the standard of a reasonable expectation is a high standard, and that there is no such thing as an indeterminate state of operability; an SSC is either operable or inoperable. Any licensees referencing or using this TR should develop guidance that will allow operability determinations to be made consistent with the Reference 26 Operability Determination Process. The NRC Staff expectation is that operability determinations should be documented in sufficient detail to allow an individual knowledgeable in the technical discipline associated with the condition to understand the basis for the determination.

The TR states that “As long as continued operability is expected, 'the licensee should establish a schedule for completing a corrective action…in a time frame commensurate with the safety significance of the condition.' This is intended to allow correction of the identified condition 'at the first available opportunity.'”

3.15.2 Gas Voids in the Pump Suction Piping

3.15.2.1 Introduction

The TR introduces this topic by stating that “each licensee must assess the potential for gas accumulation to degrade important systems.” It continues with a discussion of factors that influence gas transport and states that “it is the responsibility of the user to ensure that the proper mechanisms are considered and the dominant parameters are determined for the system.” Although it states that void fraction may be reduced as the void passes through piping, the NRC staff emphasizes that there are many conditions where the void fraction may not be reduced that are identified throughout the TR and in this SE.

The TR points out that, for “BWR piping systems drawing suction on the suppression pool, there are relatively short runs of piping with little elevation change, and fewer restrictions to the flow such as piping elbows or other fittings when compared to PWR suction piping. In other BWR cases, the piping is dominated by elevation drops, such as the normal lineup of the HPCI (High Pressure Coolant Injection) or HPCS (High Pressure Core Spray) systems to a condensate storage tank." In contrast, "Piping systems in PWRs generally are slightly more complex, with elevation changes combined with many pipe fittings such as elbows and eccentric reducers. Each of these tends to influence the average void fraction ultimately arriving at the suction of the pump." The Reference 39 test data are identified that showed large voids, a hydraulic jump, and stratified flow in the lower horizontal pipe near the downcomer that could affect a downstream pump. The NRC staff notes that application of these test data is beyond the scope of the TR, but, since the tests are referenced and the data are applicable to applying the TR information, the staff has elected to review the test reports as summarized in SE Section 3.16, below, as well as other references, to provide more comprehensive coverage of gas accumulation issues. Application of the Froude number is discussed in SE Section 3.15.2.2.

In reference to the BWR and PWR discussion, the TR states that the "BWR and PWR discussions are generalized considerations; it is the responsibility of the user to ensure that the proper mechanisms are considered and the dominant parameters are determined for the system." Any licensees referencing or using this TR must qualify the use of the references.

3.15.2.2 Use of Froude Number

Froude number is defined by:

$$N_{FR} = \frac{V}{\sqrt{\dfrac{Dg_c(\rho_L - \rho_g)}{\rho_L}}}$$

where:

D = pipe diameter
V = liquid velocity based on total pipe flow area
g_c = gravitational constant
ρ = density
subscript L indicates liquid
subscript g indicates gas

Froude number is introduced in TR Attachment 4 by identifying that $N_{FR} \leq 0.31$ with $\Phi \leq 0.2$ is a condition where gas will not move in a horizontal pipe or downward in a vertical pipe. "When evaluating the operation of a given pump across the spectrum of operating conditions, this criterion is useful in dismissing those low flow conditions, such as early operation on minimum flow, or a dead-headed pump, where the void will remain essentially stationary and not challenge pump operation."

Use of Froude number that is consistent with NRC acceptance criteria is summarized in the following table:

Froude number, N_{FR}	Effect
≤ 0.31	No gas movement in horizontal pipe if $\Phi \leq 0.20$[9].
$0.31 < N_{FR} \leq 0.65$	Some gas may be transported depending on pipe geometry
> 0.54	Gas will move toward the downstream end of a horizontal pipe that has no local high points. Some bubbles may move downward in a vertical pipe.
< 0.8	Dynamic venting not effective.
$0.8 < N_{FR} < 2.0$	Time to clear gas is a function of flow rate and piping geometry. Timing is not well characterized.
≥ 1	Gas will be removed from an inverted "U" tube heat exchanger for steady state flow lasting several minutes. Criterion not applicable at bottom of vertical pipe that connects to a horizontal pipe.
> 1.2	Horizontal pipe that is open at the downstream end will run full.
≥ 2.0	All gas will be removed from pipe but localized gas pockets may remain where full flow conditions may not exist such as in the vicinity of valves or orifices.

The table is consistent with the NRC staff's assessment to which the industry agreed as documented in References 14 and 24. This agreement also included that at $N_{FR} \leq 0.65$, some gas may be transported and if $N_{FR} \geq 2.0$, all gas will be carried out of a pipe with the flowing water. Time to clear gas from a pipe for $0.8 < N_{FR} < 2.0$ is a function of flow rate. Dynamic venting may not be assumed effective for $N_{FR} < 0.8$. Time to clear gas as a function of time has not been well documented.

3.15.2.3 The Simplified Equation

The TR states that “Gas transport in suction piping must be modeled to determine what the void fraction will be at the suction of a pump for a given void volume present at a location in the suction piping.” One way of doing this is to use the “Simplified Equation” that is based on a homogeneous flow assumption that is discussed in Reference 40 and reviewed in SE Section 3.17, below. The TR states that “There are several limitations on the use of the Simplified Equation, these are described in” Reference 40. The NRC staff summarizes these as follows:

- Either $N_{FR} \leq 2.5$ or flow rate ≤ 10^2 gpm.
- Vertical downcomer volume must be greater than four times the gas volume.
- 4 inches ≤ pipe diameter ≤ 30 inches.
- Maximum transient time, Δt_{PUMP}, taken from Table 1 or Table 2, must be modified as discussed in the proprietary Reference 40 WCAP.
- Flow rate must be low enough that gas is not transported from its original location into the pump suction as a slug.
- Any downcomer off-take or other configuration change must be located below the elevation corresponding to a vertical downcomer volume that is four times the gas volume.

[9]The $\Phi \leq 0.20$ criterion reasonably ensures there is sufficient flow area for liquid transport.

The last item is necessary for homogeneous conditions to exist, a necessary condition for the simplified equation to apply.

The TR provides the following discussion that is applicable to the Simplified Equation:

> Note that there are piping configurations which may result in a transition from the bubbly flow regime to either a stratified or slug flow regime. These include:
>
> - Kinematic shock at vertical plane elbows.
> - Vortexing at off-takes.
> - Phase separation at tees.
> - Flow stratification in horizontal pipes.
> - Pump entrance phenomena / piping entrance configuration.
>
> In cases such as these, it is the responsibility of individual licensees to:
>
> - Verify sufficient volume exists in the vertical downcomer downstream of the gas accumulation location to ensure bubbly flow;
>
> - Identify if any configuration exists between the gas accumulation location and the pump which may result in a transition from a dispersed bubbly flow regime to a separated flow regime; and
>
> - Demonstrate that the flow regime at the pump inlet will be a dispersed, bubbly flow regime.

It is also important to note that when an off-take is downstream of the gas accumulation location, the worst case may not be when the liquid flow is maximized. The worst case may be when the liquid flow is low enough to allow gas to stratify at an off-take. In this case the Simplified Equation methodology is not applicable.

Approaches for addressing configuration limitations are identified. These include tests, elbows, off-takes, tees, and pump entrance configurations. It adds that "In these instances, a detailed system specific evaluation should be performed using a transient two-phase hydrodynamic model such as GOTHIC, RELAP5, TRACE, etc."

A weakness in verification of the simplified equation is the lack of experimental data directly applicable to characteristics at a pump inlet. The NEI response to RAI-2-17 (See Reference 28) summarized the status by stating that "Gas transport testing that forms the validation basis for the Simplified Equation did not assess the flow dynamics and gas transport characteristics at the inlet to the pump suction. Any additional limitations that are needed to deal with specific pump inlet concerns need to be addressed by the individual utilities for the specific gas intrusion circumstances since there are no plans to develop generic guidance for gas transport behavior at the pump suction inlet."

The TR covers this by stating that "It is the user's responsibility to ensure the applicability of the Simplified Equation … to the specific piping configuration and to acceptably address all relevant gas transport phenomena." It also states that "Plants should demonstrate that a dispersed bubbly flow exists at the pump entrance throughout transients and that the average void fraction meets the acceptance criteria. This demonstration should account for flow configurations which may exist between the accumulation location and the pump entrance which could allow the entrained gas to stratify."

The NRC staff finds coverage of the simplified equation to be acceptable.

3.15.2.4 Computer Codes and Related Topics

The TR states "that any computer code used to develop a system specific model should be verified to be applicable to solve problems involving gas transport in piping systems via comparisons with laboratory test data or other appropriate methods. Further, a suitable safety factor should be added to predicted results to reasonably ensure the predictions encompass actual behavior." Reference 39 provided a discussion that emphasized the need for benchmarking against data and illustrated the successful use of RELAP5/MOD3 (Reference 8) "because of the large amount of scale testing that has been done … (and) user control that accurately describe all of the known phenomena." It also emphasized that "An empirically based approach would most likely yield similar accuracy to a system computer code utilizing mass, momentum, and energy equation solutions." This is an acceptable overview of use of computer codes for determination of gas transport behavior.

At present, there is no acceptable generic methodology for assessing pipe void size and void transport behavior other than identified in this SE. Assessment of conditions not covered by the SE should be addressed on a plant-specific basis consistent with the above paragraph.

Vortexing prediction methods are not reviewed in this SE and are outside the scope of the TR. This must be addressed on a plant-specific basis that includes supporting detail until the NRC issues or endorses an acceptable generic method.

3.15.2.5 Conservative Gas Transport Assessment Method

An approved conservative method for determining upstream void volume that will not jeopardize current operability is to obtain the acceptable volume by multiplying the void fraction given in TR Attachment 4 Tables 1 and 2 times the total volumetric flow rate times 0.5 seconds. The method should be applied to the conditions expected to exist when the pump is started or is running, not to the void measurement conditions. For example, if the criterion results in a void volume of X and the void measurement will occur at a pressure of half that of the pump operating condition but at the same temperature, then the acceptable measured volume is 2X.

3.15.3 Gas Void Ingestion by Pumps

The TR provides the following tables that describe allowable void fractions at pump entrances:

Table 1 – Allowable Average Non-Condensable Gas Void Fractions, Φ (to preclude pump mechanical damage)

		% Q/Q(BEP)	BWR Typical Pumps	PWR Typical Pumps		
				Single Stage (WDF)	Multi-Stage Stiff Shaft (CA)	Multi-Stage Flexible Shaft (RLIJ, JHF)
A	Steady State Operation > 20 seconds	40%-120%	2%	2%	2%	2%
B	Steady State Operation > 20 seconds	<40% or >120%	1%	1%	1%	1%
C	Transient Operation	70%-120%	10% For ≤5 sec	5% For ≤20 sec	20% For ≤20 sec	10% For ≤5 sec
D	Transient Operation	<70% or >120%	5% For ≤5 sec	5% For ≤20 sec	5% For ≤20 sec	5% For ≤5 sec

where:

Q = water volumetric flow rate
BEP = best efficiency point
Transient Φ is averaged over the specified time span

Table 2 – Allowable Average Φ (to preclude significant reduction in discharge head)

	% Q/Q(BEP)	BWR Typical Pumps	PWR Typical Pumps		
			Single Stage (WDF)	Multi-Stage Stiff Shaft (CA)	Multi-Stage Flexible Shaft (RLIJ, JHF)
Steady State Operation	40%-120%	2%	2%	2%	2%
Steady State Operation	<40% or >120%	1%	1%	1%	1%

The transient operation criteria are based on the premise that bubbly flow exists at the pump entrance, that the initial void fraction in the pump does not exceed 0.05, that full head will be recovered after the gas has passed through the pump as substantiated by pump operation experience, and the judgment that the short times associated with the transients will not result in pump damage.

The most likely condition that would result in pump damage would be associated with an insufficient flow rate during the transient time, a condition that is not judged to occur during the listed transient times in conjunction with the requirement that bubbly flow exists if $\Phi > 0$. This is a change from the previous peak to average $\Phi < 1.7$ criterion that precluded momentary large void fractions and precluded slug flow with respect to applying the criteria.[10] One aspect for using the 1.7 criterion was lack of another approach to preclude slug flow. This has been clarified by a TR quote from Wallis (Reference 38) that characterized bubbly flow as a suspension of discrete bubbles in a continuous liquid and described various regimes of bubbly flow.

With respect to pump suctions, bubbly flow means that the gas phase is distributed in a continuous liquid phase as opposed to being separated from the liquid phase. For example, flow upstream of the kinematic shock in a vertical downcomer corresponds to a separated gas region. If the vertical downcomer volume is four times as large as the initial upstream gas volume, then, as shown in FAI/09-130 (Reference 13)[11], bubbly flow will exist at a downstream location corresponding to the bottom of the four times as large downcomer volume provided the flow is not perturbed by off-takes, tees, or effects downstream of the downcomer exit. For example, as shown by the Purdue tests (Reference 39), there may be a transition from bubbly flow to stratified or slug flow in the vicinity of the transition from a downcomer to a lower horizontal pipe and this must be addressed.

Consequently, it is the responsibility of individual licensees to:

- verify sufficient volume in the vertical downcomer downstream of the gas accumulation location to ensure bubbly flow at the downcomer exit if a vertical downcomer exists and;

- identify if any other configuration exists between the gas accumulation location and the pump which may result in a transition from a dispersed bubbly flow regime to a separated flow regime and;

- demonstrate that a dispersed bubbly flow exists at the pump entrance throughout transients and that the average void fraction meets the acceptance criteria.

The effect of the 1.7 criterion was to eliminate slug flow by, for example, not allowing a 100 percent void for four seconds with no void for 16 seconds. Replacing the 1.7 criterion with a bubbly flow criterion is acceptable on the basis that bubbly flow precludes slug flow since it precludes large bubbles that can no longer be characterized as “a suspension of discrete bubbles in a continuous liquid.” The NRC staff notes that stratified flow with a small void fraction over the time of void passage through a pump can also, with justification, be used to meet the Table 1 criteria.

The difficulty of determining if bubbly flow exists will vary depending upon flow rate and the geometry. For example:

- If Froude number is greater than 2.5, there is a potential that a void will be transported as a slug.

- If a vertical downcomer is connected directly to the top of a pump and the downcomer volume is at least four times as large as the original gas volume that existed above the

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[10] See ML101650201, ML102080675, and ML101590268. Information to support the change was provided in the NEI response to the NRC staff’s Question RAI 2-9 (Reference 28).
[11] FAI/09-130 is reviewed in SE Section 3.17, below.

downcomer, then bubbly flow will exist at the pump entrance provided Froude number is small enough to preclude slug flow as identified in the above bullet.

- If a horizontal pipe connects between the bottom of a downcomer and a pump entrance, a methodology should be applied that has a multi-dimensional two phase capability that has been verified by comparison to experimental data. Since phenomena in this region are not well understood, judgment may be a significant factor and a suitable safety factor should be added to predicted behavior to reasonably ensure the prediction encompasses actual behavior.

- Horizontal pipes may introduce other concerns. For example, flow stratification in horizontal pipes can lead to an accumulation of gas, such as in an off-take or tee geometry. Once gas is accumulated, a subsequent instability can lead to a large surge in gas downstream.

In all cases, it is the licensee's responsibility to reasonably and acceptably address the relevant gas transport phenomena. This includes any configurations that may result in a transition from bubbly flow to either stratified or slug flow including:

- Kinematic shock at vertical plane elbows.
- Vortexing at off-takes.
- Phase separation at tees.
- Flow stratification in horizontal pipes.
- Pump entrance phenomena / piping entrance configuration.

Meeting the steady state criteria should (1) preclude pump damage provided pump miniflow requirements are met so that pump cooling is ensured and (2) reasonably ensure that operability requirements will be met if the pump head, H, satisfies the following:

$$(H_{\text{un-degraded}} - H_{\text{required to meet operability requirements}}) / H_{\text{un-degraded}} > 0.03$$

Head degradation due to gas should be addressed if this relationship is not satisfied.

The above criteria may be applied without additional conservatism but, as previously discussed, when using analysis methodologies, an acceptable safety factor is likely necessary when predicting the pump entrance void fraction.

The TR discussion of pump void criteria is acceptable.

3.15.4 Net Positive Suction Head Required (NPSHr) for Pumps

The TR describes NPSHr as the pump suction pressure required to prevent vaporization within the pump. Inadequate NPSHr may cause cavitation, the phenomenon where vapor bubbles form at a low pressure and then collapse as they move along impeller vanes to a higher pressure area. Cavitation may cause pitting damage to the impeller and, in the long term, pump damage. Cavitation damage is normally not of concern in the short term associated with transient passage of gas through pumps that is of concern here. Consequently, "Reasonable expectation of operability is assured without the application of NPSHr criteria for Transient gas intrusion events. It is possible that some gas intrusion events could be characterized as steady state (Example: closed loop cooling systems). In these events the treatment of NPSHr should be in accordance with NUREG/CR-2792" (Reference 19).

The TR discussion of NPSHr is acceptable.

3.15.5 Pump Discharge Pressure Pulsations and Downstream Effects

The TR introduces this subject by stating that "The expected system impacts can be pressure pulsations and/or non-condensable gas/water water hammers, which, despite having the potential for damage to piping supports and other piping attachments, are rarely severe enough to compromise the intended safety function of the SSC." It incorporates References 11, 12, 6, 7, and 21 by reference to provide guidance for addressing gas behavior downstream of pumps. The NRC staff evaluation of these references is summarized in SE Sections 3.18 - 3.22.

The TR concludes the discussion of downstream effects by stating, "The licensee must provide an evaluation of these effects specific to their plant configuration, and ensure that the evaluation is bounded by the methods provided, and conclusions drawn, in the respective Owners Group documents. These Owners Group's methods may be supplemented by the licensees own applicable plant operating experience, as well as analytical models and/or computer codes."

The TR conclusion acceptably addresses that issues identified in the NRC staff evaluation of the references will be addressed by licensees that use the references.

3.15.6 TR Attachment 4 Conclusions

The TR's Attachment 4 conclusions are:

- Further application of conservatism is not required when determining operability by applying the attachment criteria to a gas void discovered condition in a piping system.

- Guidance has been provided in PWR Owners Group (PWROG) documents in order to determine the average void fraction at the pump inlet.

- Guidance has been provided by the respective owners groups on the downstream effects in the ECCS piping systems. A complete evaluation of operability would include a discussion of these effects.

These conclusions are acceptable subject to the comments provided in this review. This is acceptably addressed by the TR References section statement that "Users should ensure that any comments in the SE are considered when the references are used."

3.16 Review of Purdue Test Report

Two-phase two-component transient fluid flow data in pipes larger than two inches in diameter were essentially non-existent before the Purdue test program that is described in WCAP-17271 (Reference 39). The two inch diameter is also important because, as stated in WCAP-17271, the transition to a diameter not having an effect on the drift flux distribution coefficient for slug/froth flow is about two inches. Yet much of the concern with determination of fluid transport in nuclear power plants is in pipe diameters larger than two inches.

The WCAP provided data for 4, 6, 8, and 12 inch diameter piping in testing at Purdue University that was funded by the Pressurized Water Reactors Owners Group (PWROG). The general configuration was an upper horizontal header that was connected to a vertical downward-oriented test section that was connected to a lower horizontal pump suction header. Lengths were typically about 31, 27, and 17 feet, respectively. The configuration applies to many PWR system suction pipe configurations and includes correlations for application of the data for evaluation of uncertainty. The tests covered 84 transient air/water test conditions with two to four repeat runs for each test condition. System flow rates approximated startup and running of an ECCS pump.

Most tests were run at about 21 degrees Celsius (°C) (70 °F). Some tests, termed "heated test section" tests, were conducted at 80 °C (128 °F) with 4 inch diameter pipes. In comparison to the low temperature tests, some heated test cases resulted in a large increase in gas volume at the top of the vertical test section and it sometimes resulted in doubling the time it took for complete gas entrainment to occur. Rapid condensation occurred in the vertical test section as pressure increased with decreasing elevation due to the head of water. The NRC staff has determined that assuming thermodynamic equilibrium for these cases is reasonable.

Test pressure was lower than generally occurs in plant ECCSs and an initial upper horizontal header pressure decrease was not typical of plant systems. The lower pressure caused voids to be a stronger function of elevation than in an ECCS. The initial pressure decrease introduced a transient that is not present in an ECCS. The NRC staff does not judge this to detract from the data usefulness because an analysis methodology that predicts the challenging test conditions should be applicable to similar configurations in plant applications.

The tests indicate data weaknesses exist downstream of the vertical downcomer for a range of gas volumes. For example, a hydraulic jump in the lower horizontal pipe potentially causes a significant increase in downstream gas flux in comparison to the test results.

A scaling analysis provided general correlations for the dominant phenomena observed in the testing, which included flow initialization via a vertical kinematic shock and vertical down-comer to horizontal elbow distribution. The resulting empirical correlations from the scaling analysis are acceptable for pipe diameters ranging from 4 inches to 30 inches.

WCAP Section 9.5 addressed differences between the 6 inch and other Purdue test results. Purdue and Westinghouse believe the 6 inch piping may have been tilted and the 5 percent initial void fraction cases were not used in the scaling analysis. In light of this observation, care must be taken in using the 6 inch test results since the effect was likely to have resulted in an initial void fraction that was less than believed.

Empirical correlation predictions are limited to estimating uncertainties. Further, scaling correlation uncertainties should be increased when applied due to the effect of the assumptions, the limited data, and the stochastic nature of the data.

WCAP Section 10.3.3 provides a proprietary correlation to address gas distribution behavior in an elbow connecting a vertical downcomer to a horizontal pipe. Although this is claimed to provide some benefit when evaluating pump suction void fraction, the WCAP states that other issues must still be addressed. This includes possible gas re-accumulation associated with a kinematic shock or flow stratification in a tee or off-take and subsequent instability that may lead to a large gas flux downstream. No test data covered horizontal elbows nor did the WCAP address changes in behavior as a function of elbow radius. The WCAP identifies that Reference 3 documented a detailed review of off-take geometry associated with the RHR connection to PWR hot legs, but the studies were performed with a low velocity in the header pipe, and are not applicable to a wide range of flow regimes.[12] The NRC staff concludes that the modeling of two phase, two component transient flow must be conducted with allowance for these data weaknesses.

A Phenomena Identification and Ranking Table (PIRT) process was discussed that concluded it is likely that additional testing efforts will be needed in areas such as horizontal flow stratification that can lead to a build-up and surge in downstream gas flux.[13] Furthermore, for conditions where large gas volumes exist, phenomena that were not investigated as part of the test program could occur. For instance, no information is available to determine what occurs when a kinematic shock reaches a downstream flow obstruction. Improved understanding was identified as needed regarding kinematic shock at vertical plane elbows, vortexing at off-takes, phase separation at tees, flow stratification in horizontal pipes, and pump entrance phenomena/piping entrance configuration.

The WCAP also discussed code modeling and use of Froude number. The code modeling discussion is generally consistent with the NRC staff position that codes or correlations must be validated through comparison of predictions and applicable test data or by other appropriate methods. There are minor differences between the Froude number discussion and NRC usage.

The NRC staff finds that the Purdue report provides a valuable addition to available information applicable to two-phase two-component transient pipe flow. Use of the data in acceptably verifying void transport methodologies is recommended subject to the conditions identified in this SE.

3.17 Review of Fauske reports "Technical Basis for Gas Transport to the Pump Suction" and “Investigation of Simplified Equation for Gas Transport”

FAI/09-130-P (Reference 13) developed an equation to address gas transport. WCAP-17276-P (Reference 40) proposed a modification that provided an experimental basis and referred to the modification as the “simplified equation.” The former should not be used to predict void behavior.

The following criteria were established for using the simplified equation:

- Froude number, $N_{FR,}$ ≤ 2.5 or flow rate in gpm ≤ $10^{2.5}$
- Vertical downcomer volume > than four times the initial gas volume
- 4 inches ≤ pipe diameter ≤ 30 inches
- Void transport time assessed using the proprietary WCAP Equation 23

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[12] Tests in this area have also been reported in References 9, 20, and 36.

[13] The work is addressed in Swartz, M., “Phenomena Identification and Ranking Table (PIRT) to Evaluate Void Fraction / Flow Regime at ECCS, RHR and CS Pump Suctions,” Westinghouse Electric company LLC, WCAP-17167-NP, Rev. 0, December, 2009. The report was not provided to the NRC although members of the NRC staff have read the report and judge it to provide excellent coverage of the state of knowledge. The WCAP Section 4 summary is sufficient for the review being reported here.

- If an off-take is located in the piping, potential stratification must be acceptably addressed.
- Void behavior in a horizontal pipe located between a downcomer and a pump must be acceptably shown not to jeopardize pump operation.

Aspects of these criteria are addressed below.

The stated purpose of the first Fauske report was “to develop a technical basis and a criterion for the conditions that are sufficient to prevent significant volumes that are formed in the piping high points from being transmitted to the pump suction location as gas slugs.” The approach was to establish conditions that reasonably ensured bubbly flow will exist at the pump suctions, a condition that precludes transport of gas slugs into the pumps. Fauske addressed this by establishing the conditions where gas in a horizontal pipe high point is transported to the top of a downward vertical pipe or downcomer where it initially accumulates. This accumulation causes a kinematic shock to form with a water column below the gas void. Water flowing from the upper horizontal pipe then falls through the void and impacts on the water column. This causes gas to be entrained in the water below the kinematic shock as the water plunges into the top of the water column. The TR then establishes that a downcomer volume that is four times as large as the initial gas volume will provide a sufficient downcomer length for homogeneous bubbly flow to be established at the bottom of the downcomer provided that downstream conditions have no effect. The Fauske report then postulated that the bubbly flow would continue to the pump suction, a condition that did not always exist in the Purdue tests. The approach also assumed a constant pipe diameter throughout the vertical and horizontal pipes.

Consideration of void transport behavior in the upper horizontal pipe and the upper downcomer, including development of an upper downcomer void and the resulting behavior in the transition region beneath the void due to waterfall effects, is acceptable for constant diameter pipes. Other configuration aspects of using the equation need to be addressed. A significant aspect is that the simplified equation has not been acceptably addressed with respect to void behavior in the region from the downcomer to the lower horizontal pipe and in the lower pipe where the data indicate void may accumulate and then move with the void fraction varying as a function of time and position. The situation is complicated by a lack of comprehensive data and variation in void behavior in otherwise identical tests. Other aspects regarding use of the simplified equation include meeting the acceptance criterion for bubbly flow to exist at the pump entrance and where a large Froude number may transport the gas to the pump as a slug.

There are numerous approximations in the simplified equation methodology and Fauske provided comparisons with Palo Verde, Purdue, and Beaver Valley test data.

The Palo Verde prediction results were generally conservative although the NRC staff notes that downcomer diameter was smaller than the horizontal pipe diameters. Purdue data comparisons did not include the larger diameter tests, a weakness in the report since representative data for all Purdue tests needs to have been considered. The Beaver Valley tests did not meet the acceptance criteria for the simplified equation. Predicted void fractions were larger than the data for the upper downcomer, but smaller in the lower downcomer for Unit 1 with essentially a realistic fit for most cases involving Unit 2.

3.18 Review of FAI/08-70, "Gas-Voids Pressure Pulsations Program"

This report (Reference 11) described an experimental and analysis methodology program to assess water hammer. Almost 250 test runs were accomplished. However, no test results were compared to model pressure predictions. One comparison of calculated and measured axial force was provided with scattered results. At smaller initial void fractions the test results were under-predicted by the model by about 20 percent and over-predicted by about 400 percent. The model over-predicted the test data for higher initial void fractions. The NRC staff concludes that FAI/08-70 provides valid test data that provides insights into water hammer behavior and will be useful in assessing water hammer analysis methodologies. The prediction of pressure for different systems with similar configurations is likely to be relatively insensitive to minor perturbations in system design. However, axial force will be strongly affected by the system and its supports. Application of the modeling methodology provided in FAI/08-70 to plant configurations is not acceptably substantiated due to a lack of comparisons to test data.

FAI/08-70 summarized the report as follows:

> The results of this experimental program show that: (1) a Froude number in the piping highpoint of 0.54 is sufficient to sweepout an accumulated gas volume, (2) the gas void fraction for the initial stratified gas-water configuration is essentially preserved during the waterhammer event, (3) the peak waterhammer pressure is determined by the initial gas pressure and volume, the pump shutoff head and whether the system is flushed before the test conditions are established, (4) the peak force generated by the gas-water waterhammer event is determined by the peak pressure and the rate of rise of the waterhammer pressurization, (5) if the system piping includes a swinging check valve, the closure induced by the waterhammer event can cause subsequent forces, in both axial directions (upstream and downstream), that are larger than the waterhammer induced force and (6) the peak forces are a function of both the piping configuration and the initial gas volume.

With the exception of Item 1, the NRC staff agrees with the FAI/08-70 summary. Use of a Froude number of 0.54 may not be sufficient to remove gas from the vicinity of a transition from a horizontal pipe to a vertically downward pipe or in local high points where the full flow does not sweep through the high points.

The following conclusions may be drawn with respect to the test parameters:

- Peak waterhammer pressure is a function of such items as total gas volume, initial gas pressure, and the flow run-up transient. System structural properties affect waterhammer force calculations and require structural evaluation.

- Presence of a swing check valve or a miniflow line does not influence the initial peak waterhammer pressure. However, subsequent rapid check valve closure introduces a second waterhammer transient that has a faster rate of rise. This can increase the magnitude of the force imbalances. Presence of the miniflow line reduces the peak force imbalances.

- Peak pressure for equal initial gas volumes is not significantly influenced by the length of the high point.

- For equal initial gas volumes, peak pressure increased as initial pressure decreased. Peak pressure appeared to be highest when all of the gas was located at the high point and lower if some of the volume was elsewhere in the test system. This was not the case for waterhammer forces where the force can be significantly greater if gas existed in more than one location. This was apparently due to out-of-phase oscillations of the gas volumes. In one test, the difference was a factor of seven.

- Within the range of initial pressures from -20 to -5 inches Hg, the data exhibited an increase in waterhammer pressure followed by a decrease as initial gas volume was increased.

FAI/08-70 concluded that the test data indicate that relief valves can be lifted due to waterhammer pressures if there is gas in plant systems depending upon the initial conditions.

The NRC staff agrees and notes that this has occurred.

3.19 Review of "Methodology for Evaluating Waterhammer in the Containment Spray Header and Hot Leg Switchover Piping"

This report (Reference 12) concentrated on piping inside containment associated with containment spray and switchover to hot leg injection. It differentiated between waterhammer, which was treated as a condition involving sonic velocity, and loading associated with gas where sonic phenomena do not occur. This SE considers waterhammer to encompass any condition that results in a dynamic overpressure. The FAI/08-78 rationale used to conclude that phenomena associated with sonic phenomena will not occur is reasonable but, if applied, needs to be checked for applicability to the individual configuration. Treatment of phenomena associated with gas, addressed as flow transients in FAI/08-78, may not be generally applicable. For example:

- Treatment of switchover to the containment emergency sump is predicated on existence of a low RCS pressure.

- Dynamics associated with potential overpressure as flowing water velocity is reduced as water follows gas through a system is not adequately addressed.

- The conclusion that the designs considered "would encounter a flow transient as the header pressurizes to the steady state value" does not acceptably consider the dynamics.

- FAI/08-78 concludes that if the transient imbalance is comparable to or less that the dead weight of the spray pipe filled with water, then the forces are within the capabilities of the pipe hangers and the pipe stiffness to support the transient loads. The justification is the short loading time associated with a sonic event. A longer loading time associated with a pressure transient is discussed where the net force is about 12 percent of the dead weight and Fauske stated that the transient can be assumed to be well within the margin of the piping hangers. This does not consider the direction of the transient load and the resultant pipe hanger response to that direction.

3.20 Review of "Potential Effects of Gas Accumulation on ECCS Analysis as Part of GL 2008-01 Resolution"

This BWROG document (Reference 6) addresses the impact of gas accumulation in BWR systems that cause (1) a delay and/or a reduction in ECCS injection and (2) gas to pass through the core.

Gas in pump discharge piping may delay ECCS water injection because the gas may enter the RV before water, thus delaying water injection. Gas in piping may also be injected simultaneously with water thus reducing the water injection flow rate since some of the injected fluid is gas and not water. The BWROG addressed this behavior by collecting calculated post-LOCA peak cladding temperature (PCT) for the US BWR fleet and calculating heatup rate for each BWR type to obtain available time before 2200 °F would be reached. It selected a heatup rate that it believed would be bounding for all BWRs and established allowable injection time delays. However, the heat generation rate selected for the calculation is not consistent with calculation of PCT and the results are not acceptable although a licensee may use the BWROG process provided the correct heat generation rate is used

A loss of feedwater (LOFW) event can potentially lead to uncovery of the top of active fuel (TAF). The BWROG provided an estimate of the reduction in water depth due to a delay in effective ECCS injection due to gas and compared this to the general minimum water depth above active fuel determined from design basis calculations. This approach is acceptable on a plant-specific basis if a licensee estimates the reduction in water depth due to its estimate of the delay in ECCS injection and compares this to its design basis minimum water depth above TAF due to a LOFW event provided the margin is approximately as large as discussed in the BWROG document.

The BWROG stated that a specified delay in effective ECCS injection would have "no impact on meeting the ATWS (anticipated transients without scram) acceptance criteria." It is acceptable for a licensee to reach the same conclusion if it reasonably establishes that the plant-specific assumed ECCS injection delay time has an impact on plant parameters consistent with the BWROG discussion.

With respect to station blackout (SBO), the principal consideration is the impact on short term and long term figure of merit (PCT, RCS water level above TAF, suppression pool cooling) associated with initial startup of the system(s) that provide vessel inventory control since generally gas will be swept from the system(s) when initially operated. The short term concern involves consideration of the immediate effect of a delay in water injection. Propagation of the immediate effect during the remainder of the SBO time period is the long term concern. The BWROG hypothetical delay time for injection may be used if the licensee reasonably estimates this to be bounding for its plant.

The impact of delay on Appendix R fire safe shutdown requirements may be assessed similarly with addition of consideration of the low pressure system performance along with the automatic depressurization system/safety relief valve ability to maintain temperatures below the Appendix R limit.

The potential concerns with air injection relative to the reactor vessel and core include the effect on core heat transfer and waterhammer such as might be associated with flow through the jet pumps. The latter is not identified in the BWROG document. The BWROG identifies that the BWR geometry allows air and steam to pass through the core and, since the volume of air would be small in comparison to the steam volume, that the air "would not alter the heat transfer by any significant amount." Not mentioned is that water entering from above may condense steam but may be held up by air. These omissions should be addressed by any licensee that is using the information provided by this BWROG document.

3.21 Review of "Effects of Voiding on ECCS Drywell Injection Piping (TA 354)"

This report (Reference 7) was intended to address waterhammer, core cooling, and injection delay due to gas in BWR "piping downstream of the first normally closed motor operated valve in the discharge piping to the vessel, feedwater line, recirculation lines or containment spray headers" for the systems identified in GL 2008-01. Early in the report, it stated that "any voids for the sections of piping downstream of the first normally closed motor operated isolation valve will not create a waterhammer that could challenge the operability of those systems when required to mitigate any postulated events" and "any pressure transients occurring due to voids are accounted for in the original piping design margin." These statements are not supported by factual data and appear to be based on venting to preclude significant gas voids. The NRC staff notes that a dominant contributor to void problems in BWRs is failure to adequately vent after operations that may introduce voids into the subject systems. Further the report later recommended a specific evaluation of HPCI to address potential pressure and waterhammer occurrences.

For containment spray systems, the report stated that "no further actions in verifying the piping's actual configuration are necessary to address GL 2008-01 for the discharge piping downstream of the isolation valve" since the "systems are designed to be voided in standby." The NRC staff would agree if trapped gas entered the system before injected water, if the system was correctly vented following activities that could have left the system outside of its design condition,[14] and if the discharge piping cannot trap water in low points. However, with respect to trapped gas, some water may be injected before the gas and this would change the pressure dynamics. These aspects must be addressed for the report's statement to be acceptable.

"Due to the numerous waterhammer events and various plants' piping configurations, the recommendation is for each plant to perform a specific evaluation of HPCI to determine if further actions are warranted to address the concerns of GL 2008-01." The NRC staff agrees.

Section 3.2.1 states that "Rapid flow transients create pressure changes in piping systems.... If the pressure changes are large enough, the induced forces may impair the structural integrity of the piping. Additionally, the integrated effect of the transient pressure distribution along the piping causes a pipe reaction loading that may damage pipe supports." The NRC staff notes that pipe supports have been damaged and, in the case of an event at Perry as identified in GL 2008-01, an event occurred that could have resulted in a pipe rupture.

[14] See, for example, the Quad Cities core spray event due to inadequate venting that was discussed in GL 2008-01.

The remainder of the report adds detail to the discussion but does not provide additional information that changes an NRC staff conclusion that each BWR licensee should acceptably establish the pressurization and waterhammer behavior due to potential gas in the subject systems.

3.22 Review of PWROG Position Paper on Non-condensable Gas Voids

This report (Reference 21) establishes that an initial gas void of 5 ft^3 in high pressure system piping at 400 psia and 68 °F or low pressure system piping at 100 psia and 68 °F is not of concern with respect to most aspects of injection into a PWR RCS. It does not address any other aspects of gas voids such as gas in pump discharge or suction side piping. Further, it is assumed in the report that there is no delay or reduction in ECCS flow rate beyond the point assumed in the safety analyses of record. Licensees referencing the information provided in this report must consequently establish that these assumptions are correct.

With respect to LOCAs, the report states that "pumped ECCS flow during recirculation is not affected by potential voids in the ECCS piping, (and) the calculations that confirm the ability to flush the core and remove decay heat are not impacted." This is incorrect. There have been cases where voids in piping from the containment emergency sump and introduction of voids from the refueling water storage tank have potentially affected ECCS pump operation during switchover to drawing water from the sump. There have also been concerns with flashing in residual heat removal piping due to reducing pressure during plant transitions. Where applicable, these aspects of long term cooling must be addressed on a plant-specific basis. A similar conclusion applies to some of the non-LOCA events where the report fails to recognize the identified concerns.

The potential for gas causing problems with RCP seals is not addressed if gas in a non-active charging path is transported to RCP seals when the path becomes active such as due to swapping charging pumps.

4.0 CONCLUSIONS

The NRC staff has found that the TR meets the objectives of a TR and reinforces previously established NRC regulations and guidelines as noted within this final SE. The NRC staff has determined that the TR is an excellent step in providing guidance for addressing gas management issues and is acceptable for this purpose. It adds value to both NRC and industry activities by detailing methods of resolving gas accumulation issues. In addition, licensees and applicants may reference the TR and use the contained information to improve the efficiency of licensing processes such as license amendment requests.

Some aspects of gas behavior, such as application of computer codes to address gas movement and details associated with entrance of gas into systems due to vortexing, are outside of the TR's scope. These are to be addressed by licensees when covering gas-related issues.

Systems that the TR considers to be within scope are those fluid systems that are necessary to ensure continued core cooling and prevention of significant release of radioactive material. This is stated to include safety related systems and, where appropriate, non-safety related systems.

Topics covered by the TR and the NRC staff findings are as follows:

- The TR provides an acceptable overview of the effects associated with gas accumulation.

- The TR acceptably covers the need for senior level licensee management support, designation of an owner of the gas accumulation issue, and the need for representatives from all appropriate departments.

- The provided list of gas intrusion mechanisms, that is noted to not necessarily be complete, is an acceptable list of presently recognized mechanisms.

- Identified items to prevent gas intrusion and accumulation acceptably cover the issues.

- Operating experience guidance is acceptably covered.

- Determination of systems that should be included in a gas management program provides significant coverage beyond those systems identified in GL 2008-01 and is acceptable.

- Comprehensive coverage of potential gas accumulation locations is provided.

- The TR states that when no design limit is specified the design limit is no gas present. Guidance is provided for allowing gas as part of the design limit. However, the NRC staff notes that the goal should remain to have no gas in fluid systems. Further, due to the complexity and variability of gas evaluation methods, a NRC staff-approved or a well-supported gas transport analysis method in combination with an acceptable safety factor is necessary. The TR design limit coverage is acceptable.

- The discussion of fill and vent processes addresses procedures, dynamic venting, vacuum fill, quantitative verification that gases have been acceptably addressed, and corrective actions to resolve deficiencies. TR coverage is acceptable.

- The system maintenance discussion acceptably identifies procedures, verification, engineering review, and evolution to confirm that processes will demonstrate that systems will be sufficiently full to perform their functions.

- The gas monitoring discussion lists gas accumulation precursors and acceptably addresses periodic monitoring frequency, conditions when additional monitoring may be needed, ultrasonic testing, venting requirements, gas volume quantification, the usefulness of gas identification, and trending.

- The TR acceptably addresses conditions where gas is found that exceeds the design limit by requiring an immediate operability determination or functionality assessment if a discovered gas volume is greater than the monitoring procedure design limit in combination with follow-up measures.

- Station-specific training, training frequency, and the use of INPO training modules are acceptably covered.

- In the case of conditions that potentially jeopardize operability, the TR states that the licensee's Criterion XVI Corrective Action Program is expected to direct the timely resolution of degraded or non-conforming conditions. The TR continues by stating that as long as continued operability is expected, the licensee should establish a schedule for completing a corrective action in a time frame commensurate with the safety significance of the condition. This is stated to be intended to allow correction of the identified condition at the first available opportunity.

- With respect to operability determination, the TR provides the following:

  - Tables of allowable gas void fractions that may enter a pump.

  - Use of Froude number to determine gas movement.

  - Application of the "Simplified Equation" to predict gas movement. The discussion covers conditions for using the equation and states that "It is the user's responsibility to ensure the applicability of the Simplified Equation ... to the specific piping configuration and to acceptably address all relevant gas transport phenomena."

  - With respect to application of computer codes, the TR states "that any computer code used to develop a system specific model should be verified to be applicable to solve problems involving gas transport in piping systems via comparisons with laboratory test data or other appropriate methods. Further, a suitable safety factor should be added to predicted results to reasonably ensure the predictions encompass actual behavior."

  The TR acceptably addresses determination of operability limits.

- The TR states that reasonable expectation of operability is assured without the application of Net Positive Suction Head required (NPSHr) criteria for transient gas intrusion events. It recognizes that it is possible that some gas intrusion events could be characterized as steady state, such as closed loop cooling systems, and it states that in these events the treatment of NPSHr should be in accordance with NUREG/CR-2792 (Reference 19). Coverage of NPSHr is acceptable.

- The TR addresses pump discharge pressure pulsations and downstream effects by referencing several reports that are summarized below and by stating that the licensee must provide an evaluation of these effects specific to their plant configuration, and ensure that the evaluation is bounded by the methods provided, and conclusions drawn, in the respective owners group documents. These owners group's methods may be supplemented by the licensees own applicable plant operating experience, as well as analytical models and/or computer codes. Coverage is acceptable.

The TR references describe tests and methodologies to address gas movement and water hammer issues associated with gas accumulation. The TR states that users should ensure that any comments in the SE are considered when the references are used. The NRC staff assessment of the references is summarized as follows:

- The Purdue tests (Reference 39) provide a valuable addition to data applicable to two-phase two-component transient pipe flow. Use of the data in acceptably verifying void transport methodologies is acceptable subject to the conditions identified in this SE.

- The Fauske reports "Technical Basis for Gas Transport to the Pump Suction" (Reference 13) and “Investigation of Simplified Equation for Gas Transport” (Reference 40) develop a simplified equation for PWR licensee use in predicting gas movement in pump suction piping. Criteria that must be met to use the equation include flow rate, downcomer volume, pipe diameter, treatment of off-takes, and a proprietary determination of transit time. The simplified equation is acceptable subject to the conditions identified in this SE. The principal condition is that the equation has not been acceptably established to address a horizontal pipe connection between a downcomer and a pump suction and this must be acceptably addressed by any licensee using the equation. Palo Verde and Beaver Valley tests are summarized and provide additional insights into PWR suction pipe behavior.

- FAI/08-70, “Gas-Voids Pressure Pulsations Program” (Reference 11), covers almost 250 test runs and the data will be useful in assessing water hammer analysis methodologies. The prediction of pressure for different systems with similar configurations is likely to be insensitive to minor perturbations in system design. However, axial force will be strongly affected by the system and its supports. Application of the modeling methodology provided in FAI/08-70 is not acceptably substantiated due to a lack of comparisons to test data.

- FAI/08-78, “Methodology for Evaluating Waterhammer in the Containment Spray Header and Hot Leg Switchover Piping” (Reference 12), concentrates on piping inside containment associated with containment spray and switchover to hot leg injection. The rationale used to conclude that phenomena associated with sonic phenomena will not occur is reasonable but, if applied, needs to be checked for applicability to the individual configuration. Treatment of phenomena associated with gas, addressed as flow transients in FAI/08-78, may not be generally applicable.

- BWROG-TP-08-017, “Potential Effects of Gas Accumulation on ECCS Analysis as Part of GL 2008-01 Resolution” (Reference 6), addresses the impact of gas accumulation in BWR systems that causes a delay and/or a reduction in ECCS injection and causes gas to pass through the core. Cases considered and the NRC staff’s assessments are as follows:

  - The effect of delay of water injection is addressed by selecting a heat generation rate and determining the available time before 2200 °F would be reached. The selected heat generation rate is not consistent with calculation of peak clad temperature but BWR licensees may use the BWROG process provided the correct heat generation rate is used.

  - The approach to assessing a LOFW event is acceptable on a plant-specific basis provided (1) the licensee compares its estimate of the reduction in water depth due to its estimate of the delay in ECCS injection to its design basis minimum water depth above top of active fuel, and (2) the margin is approximately as large as discussed in the BWROG document.

- Meeting the ATWS criteria will be acceptable if a licensee reasonably establishes that the plant-specific assumed ECCS injection delay time has an impact on plant parameters that is no greater than identified in the BWROG discussion.

- The BWROG hypothetical delay time for injection may be used for station blackout if the licensee reasonably estimates this to be bounding for its plant.

- The impact of delay on Appendix R fire safe shutdown requirements may be assessed similarly with addition of consideration of the low pressure system performance along with the automatic depressurization system/safety relief valve ability to maintain temperature below the Appendix R limit.

- Potential concerns with air injection include the effect on core heat transfer and waterhammer. The latter is not identified in the BWROG document and should be addressed by licensees. The BWROG identifies that the BWR geometry allows air and steam to pass through the core and, since the volume of air would be small in comparison to the steam volume, that the air would not alter the heat transfer by any significant amount. Not mentioned is that water entering from above may condense steam but may be held up by air. This should be addressed by any licensee that applies the information provided in the BWROG document.

• BWROG-TP-08-020, "Effects of Voiding on ECCS Drywell Injection Piping" (Reference 7), was intended to address waterhammer, core cooling, and injection delay due to gas in BWR piping downstream of the first normally closed motor operated valve in the discharge piping to the vessel, feedwater line, recirculation lines or containment spray headers for the systems identified in GL 2008-01 (Reference 2). The NRC staff has concluded that each BWR licensee should acceptably establish the pressurization and waterhammer behavior due to potential gas in the subject systems independent of most of the discussion in this report.

• Review of the PWROG Position Paper on Non-condensable Gas Voids (Reference 21) confirms that an initial gas void of 5 ft^3 in high pressure system piping at 400 psia and 68 °F or low pressure system piping at 100 psia and 68 °F is not of concern with respect to most aspects of injection into a PWR RCS. It is assumed that there is no delay or reduction in ECCS flow rate beyond the point assumed in the safety analyses of record. Licensees referencing the information provided in this report should consequently establish that the assumptions are correct.

5.0 REFERENCES

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