NEI 09-10 [Rev 1a-A]

Guidelines for Effective Prevention and Management of System Gas Accumulation

April 2013

PREFACE

This document includes the NRC endorsed version of NEI 09-10 Revision 1a-A, *Guidelines for Effective Prevention and Management of System Gas Accumulation*, a copy of the NRC Safety Evaluation (SE) that approved it, and copies of the responses to the associated RAIs. The SE and its cover letter make up the first part of this document, NEI 09-10 Revision 1a-A follows the SE, and the RAI responses are included at the end.

The SE endorses NEI 09-10 without condition but contains conditions and limitations on a number of the documents referenced by NEI 09-10 that describe testing performed in support of the gas accumulation issue, specifically:

1. FAI/08-70, Rev.1, “Gas-Voids Pressure Pulsations Program,” Fauske & Associates, LLC, for the PWR Owners’ Group, September 2008.
2. FAI/08-78, Rev.0, “Methodology for Evaluating Waterhammer in the Containment Spray Header and Hot Leg Switchover Piping,” Fauske & Associates, LLC, for the PWR Owners’ Group, August 2008.
3. BWROG-TP-08-017, 0000-0086-7825-R0, “Potential Effects of Gas Accumulation on ECCS Analysis as Part of GL 2008-01 Resolution (TA 354),” GE Hitachi Nuclear, for the BWR Owners’ Group, August 2008.
4. BWROG-TP-08-020, 0000-0088-8669-R0, “Effects of Voiding on ECCS Drywell Injection Piping (TA 354),” GE Hitachi Nuclear, for the BWR Owners’ Group, September 2008.
5. LTR-LIS-08-543, Rev. 0, “PWROG Position Paper on Non-condensable Gas Voids in ECCS Piping; Qualitative Engineering Judgment of Potential Effects on Reactor Coolant System Transients Including Chapter 15 Events, Task 3 of PA-SEE-450,” Westinghouse Electric Company LLC, August 19, 2008.
6. FAI/09-130-P, Rev. 0, "Technical Basis for Gas Transport to the Pump Suction," Fauske & Associates LLC, December, 2010.
7. WCAP-17271-P, Rev. 1, “Air Water Transport in Large Diameter Piping Systems: Analysis and Evaluation of Large Diameter Testing Performed at Purdue University – Volume 1,” Westinghouse Electric Company LLC, October 2010.
8. WCAP-17271-P, Rev. 0, “Air Water Transport in Large Diameter Piping Systems: Analysis and Evaluation of Large Diameter Testing Performed at Purdue University – Volumes 2-3,” Westinghouse Electric Company LLC, August 2010.

Wherever the above references are cited in the text of NEI 09-10, the following note is included: “Note the conditions and limitations in the NRC SE regarding use of these references”.

March 19, 2013

Jim Riley
Nuclear Energy Institute 1201 F
Street, NW, Suite 1100
Washington, DC 20004-1217

SUBJECT: FINAL SAFETY EVALUATION OF NUCLEAR ENERGY INSTITUTE TOPICAL REPORT NEI 09-10, REVISION 1a, "GUIDELINES FOR EFFECTIVE PREVENTION AND MANAGEMENT OF SYSTEM GAS ACCUMULATION" (TAC NO. ME5291)

Dear Mr. Riley:

By letter dated December 21, 2010 (Agencywide Documents Access and Management System Accession No. ML110240120), the Nuclear Energy Institute (NEI) submitted for U.S. Nuclear Regulatory Commission (NRC) staff review and approval Topical Report (TR) NEI 09-10, Revision 1a, "Guidelines for Effective Prevention and Management of System Gas Accumulation." This letter transmits the NRC staff's final safety evaluation (SE) of the TR.

The NRC staff has found that TR NEI 09-10, Revision 1a, is acceptable for referencing in licensing applications to the extent specified and under the limitations and conditions delineated in the TR and in the enclosed final SE. The final SE defines the basis for acceptance of the TR.

Our acceptance applies only to material provided in the subject TR. We do not intend to repeat our review of the acceptable material described in the TR. When the TR appears as a reference in license applications, our review will ensure that the material presented applies to the specific plant involved. License amendment requests that deviate from this TR will be subject to a plant-specific review in accordance with applicable review standards.

In accordance with the guidance provided on the NRC website, we request that NEI publish accepted proprietary and non-proprietary versions of this TR within three months of receipt of this letter. The accepted versions shall incorporate this letter and the enclosed final SE after the title page. Also, they must contain historical review information, including NRC requests for additional information and your responses. The accepted versions shall include a "-A" (designating accepted) following the TR identification symbol.

If future changes to the NRC's regulatory requirements affect the acceptability of this TR, NEI and/or licensees referencing it will be expected to revise the TR appropriately, or justify its continued applicability for subsequent referencing.

Sincerely,

/RAJ

Sher Bahadur, Deputy Director
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

Project No. 689

Enclosure:
Final SE

If future changes to the NRC's regulatory requirements affect the acceptability of this TR, NEI and/or licensees referencing it will be expected to revise the TR appropriately, or justify its continued applicability for subsequent referencing.

Sincerely,

/RAJ

Sher Bahadur, Deputy Director
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

Project No. 689

Enclosure:
Final SE

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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

January, 2013

Principal Contributor: Warren C. Lyon

SUMMARY

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, NRC provided a final Request for Additional Information (RAI) 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 safety evaluations.

The NRC staff therefore endorses the Reference 31 NEI 09-10a 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 and Beaver Valley Power Station 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 Boiling Water Reactor 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	Agency-Wide 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

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

SER	Significant Event Report (INPO)
SIC	Spelling Incorrect
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 Topical Report (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 U.S. Nuclear Regulatory Commission (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 safety evaluation (SE). The NRC staff has evaluated this TR against the criteria of Title 10 of *Code of Federal Regulations* Part 50 (10 CFR 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 (INs), two Generic Letters (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 Generic Letter (GL) 2008-01 (Reference 2).

GL 2008-01 requested that each addressee evaluate its emergency core cooling system (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 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,

[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 safety evaluations.

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 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.

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

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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.

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 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.

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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 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.

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 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

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

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.

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."

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

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 CAP or elsewhere in addition to instances where found gas exceeded acceptance criteria and entry was made into the CAP.

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:

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

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 Φ ≤ 0.20[9].
0.31 < N_{FR} ≤ 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

[9] The Φ ≤ 0.20 criterion reasonably ensures there is sufficient flow area for liquid transport.

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 $\leq 10^2$ 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.

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;

- 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;

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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.

- 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 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 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 PIRT (Phenomena Identification and Ranking Table) 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,

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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.

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
- 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 causes (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 loss of feedwater 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.

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.

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

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 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 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.

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Guidelines for Effective Prevention and Management of System Gas Accumulation

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EXECUTIVE SUMMARY

The Nuclear Power Industry has experienced instances of gas intrusion and accumulation in fluid systems for many years. The Nuclear Regulatory Commission in January 2008 issued NRC Generic Letter 2008-01 "Managing Gas Accumulation in Emergency Core Cooling, Decay Heat Removal, and Containment Spray Systems." INPO also issued in January 2008 SER 2-05 Rev.1 "Gas Intrusion in Safety Systems." This document provides recommendations and guidance to nuclear generating stations for the effective implementation of programs and processes to prevent and manage gas intrusion and accumulation in plant systems. The document provides a structured approach to develop procedures and processes that will internalize principles and practices for effective station identification, management, monitoring and prevention of gas accumulation that would challenge system operation.

Topics discussed include:

- Identification of management sponsorship and single point ownership of the program
- Methods to prevent gas intrusion
- Adjustment to existing station programs
- Guidelines for determining which station systems should be in-scope
- Methods for evaluation of in-scope systems to determine locations where gas could accumulate
- Guidelines for limiting the locations that are required to be periodically monitored
- Development of acceptance criteria that are to be included in the design documentation for systems
- System filling and venting practices
- Implication of at power maintenance activities
- Guidelines for establishing periodic and additional monitoring frequencies
- Methods of gas quantification and trending practices
- Development of operability / functionality guidance when gas is detected
- Guidance for developing acceptance criteria to be used in operability determinations / functionality assessments
- Development of training material to raise awareness of all station personnel

FORWARD

The purpose of this document is to provide recommendations and guidance to nuclear generating stations for the effective implementation of programs and processes to manage gas accumulation and intrusion into plant systems. This document will outline principles and practices designed to effectively identify, manage, monitor and prevent accumulation of gas that would challenge the operability / functionality of the subject systems. Revision 1 incorporates the results of industry efforts associated with testing and evaluation of gas transport

TABLE OF CONTENTS

ACRONYMS

BEP	Best Efficiency Point
BWR	Boiling Water Reactor
CCP	Centrifugal Charging Pump
CS	Containment Spray
DHR	Decay Heat Removal
ECCS	Emergency Core Cooling System
GAT	Gas Accumulation Management Team
GL	Generic Letter
HPCI	High Pressure Coolant Injection
HPCS	High Pressure Core Spray
HPI	High Pressure Injection
INPO	Institute of Nuclear Power Operation
LOCA	Loss of Coolant Accident
NEI	Nuclear Energy Institute
NRC	Nuclear Regulatory Commission
OE	Operating Experience

PWR	Pressurized Water Reactor
RCP	Reactor Coolant Pump
RCS	Reactor Coolant System
RHR	Residual Heat Removal
SDC	Shutdown Cooling
SER	Significant Event Report
SIP	Safety Injection Pump
SOER	Significant Operating Experience Report
SSC	System, Structure or Component
UT	Ultrasonic Testing
VCT	Volume Control Tank

GUIDELINES FOR EFFECTIVE PREVENTION AND MANAGEMENT OF SYSTEM GAS ACCUMULATION

1 BACKGROUND

Instances of gas accumulation in nuclear power plant fluid systems have occurred since the beginning of commercial nuclear power plant operation. The NRC has interacted with the nuclear industry many times in response to gas accumulation events, including the publication of 20 Information Notices, two Generic Letters, and a NUREG. Several gas intrusion mechanisms can result in gas accumulation in system piping. For example, 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.

The objective of gas control measures is to limit the volume of gas accumulation 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 the accumulated gas, and the effects of the 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 impact system operation.

1.1 GL 2008-01

NRC Generic Letter 2008-01 "requests that each licensee evaluate its ECCS, 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." (Reference 1)

1.2 INPO SER 2-05 REV 1

INPO Significant Event Report (SER) 2-05, Rev 1 was "issued due to continuing problems with gas intrusion events in the industry. The reporting of approximately 30 events since the issuance of SER 2-05 in March 2005 indicates continuing problems, which reflect inadequate actions by some plants and the need for continuing industry attention to gas intrusion that affects safety systems. The introduction of gases in safety systems may result in unanalyzed conditions that could adversely affect the ability of systems to perform their intended functions."

1.3 TECHNICAL DESCRIPTION OF THE PROBLEM

1.3.1 Causes of Gas

The causes of this 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.

1.3.2 Effects of Gas

The introduction of gas into a pump can cause the pump to become air bound with little or no flow, rendering the pump incapable of performing its function and possibly damaging the pump.

Although gas may not air bind the pump, the pump or associated system can be rendered inoperable/non-functional because pump discharge pressure and flow capacity can be reduced to the point that the pump cannot perform its design function. Loss of developed head and resulting loss of flow based on the system response curve and downstream back pressure may make the pump incapable of delivering the flow assumed in accident analyses.

Gas accumulation can result in a system pressure transient, particularly in pump discharge piping following a pump start, which can cause piping and component damage or failure. Pressure pulses may lift relief valves in the system that then may fail to reseat.

Gas accumulation can result in pumping non-condensable gas into the reactor vessel that may affect core-cooling flow.

The time needed to fill voided discharge piping can delay delivery of water beyond the timeframe assumed in the accident analysis.

2 PURPOSE AND SCOPE

This document provides insights and attributes to implement an acceptable approach to effectively prevent and manage gas intrusion and accumulation in plant systems. This document 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 approach identified in this document is intended 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.

Systems considered within the scope of this program are those fluid systems that are necessary to reasonably ensure continued core cooling and prevention of significant release of radioactive material. This list of systems will include affected safety related systems and should consider non-safety related systems as appropriate. Where applicable, systems should also be addressed with respect to both typical single failure assumptions and for operation without failures including all applicable modes, and mode transitions. The scope of affected systems within this program may differ based on the degree of susceptibility for gas intrusion and its consequence.

The approach identified in this document is intended to satisfy 10 CFR 50 Appendix B Quality Assurance requirements. 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, 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. To satisfy the test requirements, the results should comport with Appendix B Criteria XVI (Corrective Actions) and XVII (Quality Assurance Records).

3 GAS ACCUMULATION MANAGEMENT OWNERSHIP

3.1 SITE OWNERSHIP

Sponsorship and commitment by senior level management at each station supports effective implementation of a process or program to prevent and manage gas intrusion and accumulation. Portions of the effort may be owned and performed by various departments as appropriate within the utility's organizational structure at each station, but single point management sponsorship and support is essential.

Additionally, each utility should designate an owner to effectively implement and manage the approach to minimize and control system gas accumulation. The designated owner should have appropriate training and experience to determine which systems are impacted and which areas are susceptible to gas accumulation. This responsibility should not be left to each System Engineer which likely would result in various interpretations and an overall inconsistency in the effective management of this issue.

3.2 CONSIDERATION OF SITE-WIDE CONCERNS

Utilities should realize that prevention and management of gas intrusion and accumulation is a site-wide issue and impacts many functions. Representatives from all appropriate departments should participate with the owner in establishing required parameters, programmatic direction, identifying procedures and potential void monitoring needs, and other process activities. Operations, Maintenance, Engineering, Licensing and Training are key stakeholders.

4 IDENTIFY GAS INTRUSION MECHANISMS

Each utility should create a list of site specific sources that could result in gas intrusion and/or accumulation in a fluid piping system. These may include, but are not limited to:

- Ineffective fill and vent
- Leakage from accumulators
- Leakage from the RCS
- Outgassing of dissolved gas when gas saturated liquid passes from piping at high pressure into piping at lower pressure.
- Outgassing of dissolved gas when gas saturated liquid is heated from low temperature to higher temperature
- Draining, system realignments, deficient maintenance procedures, and failure to follow procedures
- Failure of level instruments to indicate correct level
- Leakage through valves, including leakage through a series of closed valves
- Leakage through faulty vent system components when local internal pressure is less than external pressure
- Temperatures at or above saturation temperature at the lowest system pressure that will be experienced when the system is used
- Leakage or heat transfer through isolation valves in system configurations where temperatures on one side of an isolation valve or other interface are greater than the saturation temperature on the other side
- Vortexing in suction sources or gas introduced from suction sources
- Design deficiencies that may contribute to gas intrusion during accident conditions
- Keep-full system malfunctions
- Leakage of bladder material installed in positive displacement pump hydraulic pulsation dampener accumulators
- Cooling of an isolated section of piping.

5 GAS INTRUSION AND ACCUMULATION PREVENTION

5.1 PRACTICES TO MINIMIZE GAS

5.1.1 Examples of Practices to Avoid

- Filling from a tank source with a water level lower than the high point of the system to be filled
- System venting that reduces the system pressure at any point in the system below saturation pressure
- Operation or maintenance evolutions that reduce system pressure below saturation pressure

5.1.2 Examples of Practices to Prevent or Minimize Gas Intrusion

- Use a pressurized source with sufficiently higher pressure than the required static head needed to fill and vent the system
- Vent slowly and deliberately while using a adequate pressure source to maintain system pressure
- Form a loop seal with water in the vent hose to prevent gas ingestion
- Repeat venting after allowing time for any remaining gas to accumulate at a high point

5.2 DESIGN PROCESS IMPACT REVIEWS

The station design change process should include provision for impact review of those design changes that could affect in-scope systems and the potential for gas intrusion and or accumulation at the high points identified in those systems. Additionally, impact review should be performed for design changes that could introduce new high point locations or gas intrusion mechanisms.

The design change process should provide for identification of gas intrusion/accumulation as a design input for those design changes that involve piping and/or piping components in in-scope systems.

5.3 IDENTIFICATION OF REPEAT LOCATIONS

Specific locations where gas is repeatedly identified should have a detailed cause evaluation including action plans to prevent or mitigate continued gas accumulation. These locations where gas continues to accumulate should be evaluated for possible remedies which could prevent or minimize future gas intrusion. This could be through plant modification or operating procedure and practice changes. An important aspect of correcting such conditions is to have a clear understanding of the gas intrusion mechanism. If changes cannot be made to remedy these locations then enhanced monitoring should be considered to identify early onset of gas accumulation. See Section 12 for additional information regarding gas monitoring and Section 13 for addressing gas that is in excess of the design limit.

5.4 Design Solutions (additional vents, piping modifications…)

Utilities should consider installation of additional vents in locations that are evaluated to be potential gas accumulation points where the gas cannot be removed by other methods and/or where gas volumes may accumulate that would affect the ability of the system to perform a required function. It may be beneficial to have a generic plant modification package prepared for installation of vents when new locations are identified that put the station at risk.

Some utilities have made piping modifications that route or capture gas voids in a location that prevents the void from having an adverse effect on the system. Such modifications may be considered for locations that present difficulties removing gas by other means.

5.5 Include Gas Intrusion Precursors in Procedures

Operating, testing and maintenance procedures should include warnings about potential gas intrusion and or accumulation for those evolutions that have been identified during the evaluations of the plant systems. For precursor conditions that are monitored, criteria for when action is required to evaluate gas intrusion should be included in procedures. Section 12.1 of this document provides guidance for identification of these gas intrusion precursors.

6 REVIEW AND INCORPORATE OPERATING EXPERIENCE (OE)

When evaluating OE associated with gas intrusion and/or accumulation it is important that the mechanism be understood. It is possible that the station may not have that specific problem on the OE specific system but may identify a new gas intrusion mechanism that is applicable to a very different system. It is often important to seek more detailed information after an initial screen to be able to completely determine the impact on station systems or programs.

It is the intent of this guideline that plants should document OE related to gas intrusion events and lessons learned during gas evolutions. Items to consider for issuance of an OE include:

- Gas intrusion mechanism not identified in Section 4
- Events that result in system inoperability or non-functionality
- Gas intrusion events during lower modes of operation
- Identified Gas intrusion event occurring on different systems
- Events that require increased monitoring frequency

It is recommended that all plant and industry OE applicable to gas intrusion or gas accumulation be reviewed by the gas intrusion program owner.

7 PLANT SYSTEM SELECTION

Due to variation in station design and operation there is not a prescribed list of systems that should be included within the scope of processes and programs to prevent and manage gas intrusion and accumulation. Each utility should evaluate their plant systems to determine which are to be in the scope of gas accumulation management. The evaluations should identify which systems may accumulate gas, the potential for gas to remain after the systems are filled and vented, and the potential degassing and intrusion paths. The following criteria should be used in determining the in-scope systems.

- Systems that were specifically listed in NRC Generic Letter 2008-01 "Managing gas accumulation in emergency core cooling, decay heat removal and containment spray systems."
- 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.
- Support systems to those identified in the first two bullets above.

Plants may want to consider expanding the scope to include other systems that are important to plant operation and plant availability.

The result of this evaluation should be documented in station documents or procedures to clearly delineate the in-scope systems. Additionally when the station corrective action process identifies an event that may include an element of gas intrusion or accumulation in a system that was not previously included in the scope then an evaluation should be performed to determine if that system should be added to the scope.

The scope may be narrowed to portions of a system where gas accumulation can affect the ability to perform a specific function. These scope limitations should be evaluated and documented.

One method to perform this evaluation would be to identify from the list of potential gas intrusion mechanisms those that would be applicable to a specific system. If no method of gas intrusion can be identified then the system needs no further review. Careful consideration should be made here as all systems could be subject to gas intrusion due to an ineffective fill and vent.

For those systems that have identified potential gas intrusion mechanisms, evaluation of the impact of that gas on the performance of the system function should be performed. This evaluation must consider void volume, void transport to pumps, and pump void acceptance criteria. The void transport analysis must be performed to acceptable engineering standards. The evaluation should document the rationale that supports a determination that gas intrusion into the system would not adversely affect the ability of the system to perform its function. If such an evaluation can be performed then the system can be considered to not be an in-scope system and no further evaluation is required. Due to the complexity and variability of gas evaluation calculation methods, the method used should either have been approved by the NRC or be well understood and applied by experts who are well versed in such applications. Similarly, if vortexing is determined to be a possible mechanism, no generic method for determining the possibility or effect of vortexing has been developed as part of this guidance. Therefore, vortexing must be addressed on a plant-specific basis.

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. Trivial volumes of gas, such as occasional bubbles in a horizontal pipe that cannot be reasonably removed, do not require documentation.

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.

Attachment 2 provides a flowchart that should be used to identify in-scope systems.

8 SYSTEM GAS ACCUMULATION LOCATIONS

8.1 DEVELOP EVALUATION METHOD

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. Key elements of the evaluation method are described in the following subsections. These findings will be used to develop acceptance criteria, evaluate potential void locations, exclude locations from further evaluation, and identify additional desired vent valve locations, key monitoring points, etc.

8.2 IDENTIFY BOUNDARIES OF SUBJECT SYSTEMS

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.

8.3 IDENTIFY POTENTIAL GAS VOID LOCATIONS IN SUBJECT SYSTEMS

Perform a review of system design information, including piping and instrumentation drawings, isometric drawings, plan and elevation drawings, and calculations to identify potential gas void locations. Perform walkdowns of the subject systems to validate potential void locations and identify new locations. The walkdowns should confirm the location and orientation of important components that can become sources of gas or could otherwise cause gas to be trapped or difficult to remove during system maintenance or restoration.

- Inverted "U" piping
- Heat exchangers
- Valves (check, throttle, isolation…)
- Vent locations
- Branch lines
- Orifices
- Relief valves
- Reducers
- Interfaces with other systems

The walkdown should also verify that installed high point vents are actually at the system high points, including field verification to ensure pipe geometry changes (such as reducers) and construction tolerances have not inadvertently created additional high points. Long pipe runs with even slight elevation deviations have the potential to create void locations of significant volume.

Document the location and reference elevation of all local and system high points in the affected fluid systems on the appropriate drawings (for example, simplified elevation one-line drawings) for further evaluation. Identify the locations as either vented or unvented high points.

8.4 EVALUATE GAS ACCUMULATION LOCATIONS

8.4.1 Evaluate Locations for Gas Accumulation

The station should develop a process to evaluate all identified local high points, system high points and other potential void locations to determine if gas accumulation could occur. This evaluation process may group locations together or treat each location separately as long as criteria are developed to support the determination to group the locations. The evaluation process may document a specific void size at potential void locations below which further evaluation is not required. The justification for this conclusion shall be documented and include a discussion of the cumulative effect of multiple locations along the same line.

The potential sources of gas intrusion developed as a result of Section 4 of this document should be evaluated for applicability to identified high point locations. Understanding all sources of gas that could affect the high point location is the basis for the conclusion. These local or system high point locations are then determined to be potential void locations.

8.4.2 Evaluate Potential Void Locations for Monitoring Requirements

Potential void locations require further evaluation to determine what level of monitoring is required.

Monitoring may not be required for those potential void locations (vented or unvented) where the maximum potential accumulated gas void volume has been evaluated and determined to not challenge system operation, based on the maximum acceptable void volume, location, Froude number, or other technical basis.

Void locations along the same system flow path which are subject to the same gas intrusion mechanism may be grouped together and may require only a representative sub-set of locations to be monitored. The evaluation is based upon maximum self limiting size, location, Froude number or other technical basis. Such locations should consider the possibility of void interaction and transport over time or with changing conditions. The evaluation must be documented and the total potential gas volume from such a location reduces the overall system operating limit for that pipe segment. Subsequently, if gas is found during monitoring then the remainder of the locations would be monitored in order to determine the total volume of gas.

Monitoring may not be practical for locations that are inaccessible due to radiological, 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. (Note that a determination that a location is inaccessible may result in additional regulatory scrutiny.) For inaccessible locations alternative methods should be developed to monitor the potential void location. Methods may include but are not limited to; operating system parameters, remote monitoring equipment or design modifications. If alternate operating system parameters are used then an increased frequency may be required to provide adequate assurance that gas is not present. Regardless of accessibility considerations, surveillance is required for all locations of concern unless it is acceptably determined that the surveillance is not necessary to reasonably ensure operability. Alternately, a remote monitoring capability should be established.

The remaining potential void locations will have a monitoring frequency determined and are subject to additional monitoring as described in Section 12.2 and 12.3 of this document.

9 DESIGN LIMIT

This section addresses design limit. Operating limits are addressed in Section 13.

In general 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.

There may be potential gas void locations where it is desirable to determine a design limit that would insure that the system is sufficiently full to perform its design function. 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. In these cases where a non-zero gas volume design limit is desired, design change documentation shall be processed to support associated procedure changes to incorporate the potential gas void monitoring design limit. This is required by 10 CFR 50, Appendix B, Criterion III and Criterion V. Considerations for permanently acceptable conditions should include:

- Documenting in design output documents (e.g. design calculation)
- Updating system design criteria and descriptions
- Updating system monitoring procedures to include the criteria

Acceptance criteria should ensure, as a minimum:

- Pumps do not become air bound or degraded to a performance level that impacts design basis flow requirements or accident analysis assumptions
- Gas that can be swept into the reactor coolant system will not adversely impact flow through the core during operation, shutdown or accident conditions
- Gas that has accumulated in piping downstream of pumps will not cause an unacceptable pressure surge in the piping when the pump starts in a recirculation lineup or during accident conditions. The pressure surge must be limited to a value that does not damage piping, pipe supports, or other system components, or result in lifting of relief valves where system pressure exceeds reseat pressure.

10 FILL AND VENT PROCESSES

10.1 General Fill and Vent Requirements

Fill and vent activities are performed to restore a system, portion of a system or instrumentation to service following maintenance, modification, or for any reason the system may have been drained or gas may have accumulated.

10.2 Procedure Requirements

Fill and vent procedures should contain guidance on filling and venting methods to restore the systems as full based on the system configuration. Venting methods may include static venting through a valve, dynamic (flow induced) venting, and vacuum venting. Special situations such as inverted U-tubes may require additional actions to ensure that the system or piping segment meets its design limit. Verification that the system piping meets design limit following fill and vent is recommended.

Fill and vent procedures should:

- Specify vent locations to support operating and maintenance activities, the venting method, and the criteria to determine when adequately filled.
- Specify adequate steps that ensure the subject systems are free of accumulated gas and will perform their intended functions.
- Be revised as necessary to incorporate operating experience and to control gas voids that may be introduced by maintenance and/or operational activities.
- Be specific for the condition and alignment of the system at the time of the activity and any limitations on available vents from isolation boundaries.
- Include the following:
  - Use the appropriate fill source and fill location
  - Provide the proper sequencing of valve operations to maximize gas void removal. Vent sequencing from lower high points to the higher elevation high points is recommended.
  - Provide specific acceptance criteria for venting based on potential void locations and the duration of flow required to transfer the void to a vent location.
  - Include filling or backfilling instrumentation lines when applicable
  - Provide instructions (e.g., system alignment, minimum required flow rate) to perform dynamic venting if necessary
  - Perform verification after fill and venting, and re-verification if additional venting is required that the piping is sufficiently full
  - Document void identification and quantification information, including no void present.
  - Use the corrective action program if verification identifies weaknesses in prior fill and vent activities

10.3 Dynamic Venting

Use of dynamic venting has been found to be an effective means to remove gas from local high points and traps in piping. It involves pumping water through the system to force accumulated gas to a location that can be vented or removed. When static fill and vent efforts are not effective in removing all trapped gas during system restoration, procedures should provide for use of dynamic venting when it is allowed by the system configuration. Dynamic venting should be performed in accordance with written procedures. Procedures should consider the following:

- Acceptability of the location to which the gas will be transported
- Effect of transporting voids through pumps
- Required flow rate (Froude Number) to sweep the gas from the high point
- Time that flow should be maintained to ensure sweeping the gas

Determination of required venting time should be based on the dynamic flow rate, void volume, Froude number, and the system water volume.

10.4 Vacuum Fill

Vacuum filling may be an effective method for removal of trapped gas. Provisions for use of vacuum fill, as an option, should be included in applicable procedures. 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.

10.5 Verification

Fill and vent procedures should include requirements for verification of effectiveness (including quantification of any remaining gas found, e.g., UT (ultrasonic test) examinations for voids). If the fill and vent is performed for system restoration following maintenance on an isolated portion of the system, verification should include quantitative inspection to find gas accumulation that may be transported outside the isolation boundary once the system is restored (e.g., at system or local high point vents above the boundary valves).

10.6 Corrective Action

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.

11 SYSTEM MAINTENANCE

Any system maintenance activity that will result in a reduction in fluid inventory of a fluid system in the scope of gas accumulation management should be evaluated to determine the required fill, vent and verification inspection. The work processes should include provision for engineering review and evaluation of such evolutions. If the specific evolution has been previously evaluated and the fill, vent and verification requirement identified then engineering review if required could be limited to verifying applicability.

11.1 DOCUMENTED FILL AND VENT RESTORATION PLAN

For each specific activity a fill and vent plan should be documented either in procedures or in the work document.

11.2 ENGINEERING REVIEW OF WORK ORDER AND PLAN

Engineering should be included in the review process of any procedure or work document that breaches an applicable system. Consideration should also be given to the impact of changes to the work documents after the initial Engineering review.

11.3 ENGINEERING IDENTIFY REQUIRED CONFIRMATORY VERIFICATIONS

Engineering should either specify as part of their review or confirm the procedure that the selected verification locations will demonstrate that the system is sufficiently full to perform its functions. This includes the specification of appropriate verification locations and methods.

12 GAS MONITORING

12.1 LIST OF GAS INTRUSION PRECURSORS

Plant conditions that may result in generation of gas are called "precursors to gas intrusion." Each utility should evaluate and document a specific list of precursors based upon plant design and operation. These include but are not limited to:

- Unanticipated accumulator level decrease that is unaccounted for may be indicative of leakage of nitrogen saturated water into lower pressure systems where the dissolved gas will come out of solution.
- Unaccounted RCS leakage that may be indicative of system leakage into lower pressure systems. Such leakage may produce voids from gas coming out of solution or steam voids if the leaking fluid is above the saturation temperature for the lower pressure system.
- Degraded pump performance may be caused by gas intrusion causing decreased discharge pressure and/or flow, increased vibration and general poor performance.
- Unexpected low as-found pressures found in piping during testing and system walkdowns.
- Unexpected increase in system temperature or pressure.
- Rapid drop in VCT pressure.
- Increased RCP seal return flow.
- Taking a component out of service, draining it and refilling after work is complete may be a precursor to gas intrusion.
- Mid loop operation or unanticipated low level setpoint alarms on tanks acting as a pump suction source.

12.2 PERIODIC MONITORING

Utilities should determine the appropriate monitoring frequency for each monitored potential void location. 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. The monitoring frequency for each location determined in Section 8 to require periodic monitoring should be documented in station procedures. The monitoring frequency may be changed based on the system, location, function, and results of previous monitoring, and should be established considering:

- Likelihood of gas intrusion due to known gas generation rates at that location (such as those identified in 12.1).
- Likelihood of gas intrusion due to normal plant maneuvers and equipment manipulation.

- Ability to detect gas intrusion caused by equipment failure or degraded equipment conditions.
- Consequence of a gas intrusion event at that location (some locations may tolerate more gas than others).
- Long term system history of gas accumulation.
- Integration of monitoring frequencies into normal plant work schedules (e.g. 31 days, 90 days, 6 months, refueling).

12.3 Additional Monitoring Based Upon Potential or Actual Gas Intrusion

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.

Additional monitoring or increased monitoring frequencies should be established when potential problems are observed, until the root cause of gas accumulation can be identified and corrected. The monitoring frequency should be established based on evaluation or analysis that demonstrates operability/functionality of the system within the monitoring period.

A monitoring plan with specific locations, techniques, and frequency would then be employed to verify that any gas accumulation resulting from the active gas intrusion mechanism remains less than the volume that challenges the ability of the system to perform its design function(s).

The conditional monitoring plan may be pre-established based on the system evaluations and considering accumulation rates and void operating limit.

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.

12.4 UT Examination

UT (ultrasonic testing) is the preferred method to identify and quantify gas that has accumulated at a high point or other monitoring point.

12.5 Venting Requirements

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 Section 12.6 as to accuracy of the qualification method will apply.

12.6 Gas Volume Quantification

Gas identified should be quantified and compared to acceptance requirements for that specific location 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 water level in pipes and components can be accurately determined by using Ultrasonic Testing (UT) methods. Based on the UT measurement and system configuration drawings, engineering can calculate the volume of the gas. The recommended method would be to UT the pipe to determine is gas is present and quantify the volume, then to remove the gas by static or dynamic venting and finally to perform UT after venting to determine the as left condition.

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

12.7 Identification of the Gas Type

Identification of the gas type can be beneficial in determining the source of the gas intrusion. Gas chemistry is not always necessary to be determined by test. Engineering judgment and past experience can be used in the evaluation to reasonably conclude whether the gas is air, nitrogen, hydrogen, or other gas. However, when gas sources cannot be definitively determined, gas chemistry should be determined by sampling. Gas analysis provides evidence to verify that assumptions regarding the intrusion mechanism are correct and should be encouraged.

12.8 Trending of Gas

Methods should be developed to trend the location and volume of gas voids found in the subject systems and identify the source of the gas.

- All monitored points should be trended, even if no void is identified. This includes locations that have a greater than zero design limit and the amount of gas identified is less than the criteria such that entry into the corrective action process may not be required.
- When trending a known void at a specific location, the void size calculation should be based on a normalized pressure to ensure that system pressure fluctuations do not mask void growth. By establishing a normalized pressure, void volumes that are measured at different system pressures can be directly compared to establish a trend.
- As-found and as-left void volumes should be measured and documented to determine the effectiveness of periodic venting.
- Trending of gas accumulation data will help assess the performance of high/low pressure interface boundary isolations, help identify degraded component conditions, ineffective system fill and venting, and establish criteria for implementing corrective actions when necessary.
- Results of the trending data may be used to plan operating and maintenance activities to mitigate gas intrusion, and to adjust monitoring frequencies when needed.

13 OPERABILITY/FUNCTIONALITY REVIEW FOR FOUND GAS IN EXCESS OF DESIGN LIMIT

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.

13.1 CORRECTIVE ACTION PROCESS USED

Since the existence of gas accumulation in system piping exceeding the design limit is not an expected condition, 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.

13.2 OPERATING LIMITS IDENTIFIED

Utilities should develop either system generic or location specific 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. Attachment 4 provides guidance for determining the operating limit to be applied for operability determination/functionality assessment under the corrective action process.

13.3 CONSIDERATION OF COMPENSATORY MEASURES

When gas is found, the operability review or functionality assessment should include consideration of compensatory measures to enhance or maintain operability/functionality.

Potential compensatory measures can include:

- Additional monitoring as described in Section 12.3 of this document
- Increased monitoring of potential gas sources
- Temporary modifications
- Removal of gas from the system
- Increase system pressure to reduce gas being released from solution

13.4 Gas Removal

Gas that exceeds the design limit should be removed immediately using methods described in this document. Gas that cannot be removed immediately due to plant configuration or conditions 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.

13.5 Prepare a Model Prompt Operability Determination or Functionality Assessment for Gas Events

While each station's corrective action process describes the specific process for prompt operability determination and functionality assessment, it would be beneficial for the utility to develop a template or model to be used following the identification of gas voids. Such a template/ model would lead to consistent application of the gas intrusion and accumulation management at the station. Items to include in the template are:

- Identification and evaluation of the specific gas intrusion source
- Review of industry testing results and other technical documents
- Identification of previous identified gas voids at this location
- Results of the gas trending data for this location

14 TRAINING

The need for training on gas accumulation and gas intrusion issues has been recognized by the industry for some time. INPO SOER 97-1 called for providing initial and continuing training for station personnel who design, operate, or maintain systems and components that are susceptible to, or may cause, gas intrusion. Later, INPO SER 2-05 reiterated the requirement for training on safety systems susceptible to gas intrusion or systems and components that may cause gas intrusion in safety systems. More recently, however, Revision 1 of INPO SER 2-05 and Generic Letter 2008-01 indicate that instances of gas accumulation continue to occur throughout the industry and that the training that has been provided has not been effective in improving plant performance.

NEI and the Owners Groups in cooperation with INPO have undertaken an effort to develop a series of training modules that utilities can use to assist in training plant personnel on gas voids in piping systems. The modules are intended for use by Engineering, Operations, Maintenance, Management, and other technical staff who may need a background on preventing and managing gas accumulation.

The training modules are applicable to BWRs and PWRs. The modules provide a basis for licensees to develop plant-specific training that is in accordance with the Systematic Approach to Training process.

It is anticipated the training will be repeated after two to three years to fulfill the expectation for continuing training.

A module that is a basic overview of gas accumulation issues was developed. It is a broad discussion of the topic to demonstrate how various organizations are affected by gas accumulation.

Department-specific modules (Maintenance, Engineering, and Operations) were also developed that demonstrate how each organization contributes to the prevention and management of gas voids.

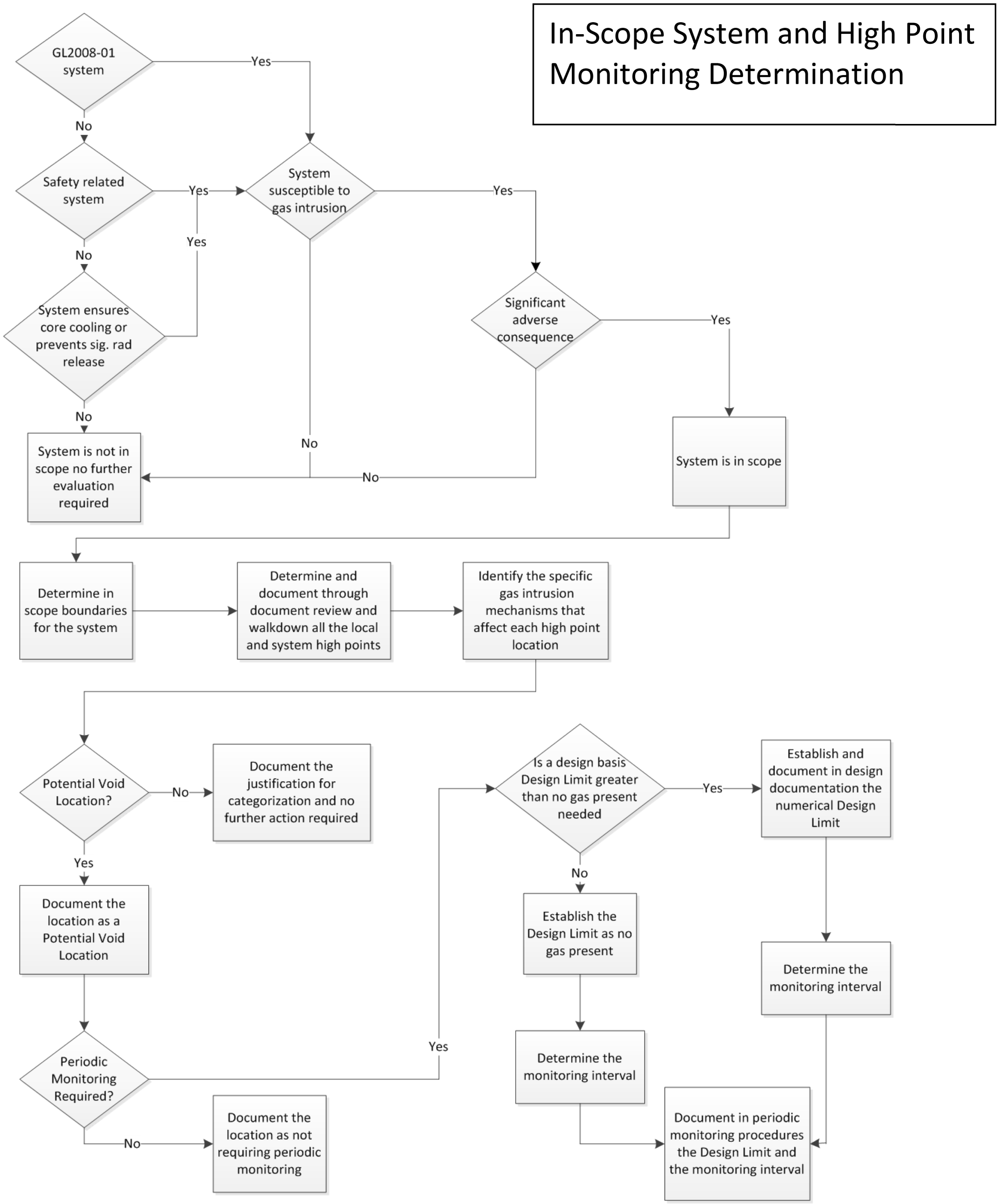
Each utility should use the generic modules created as described above as the basis for their station specific training on gas intrusion/accumulation prevention and management.

Attachment 1

Terms and Definitions

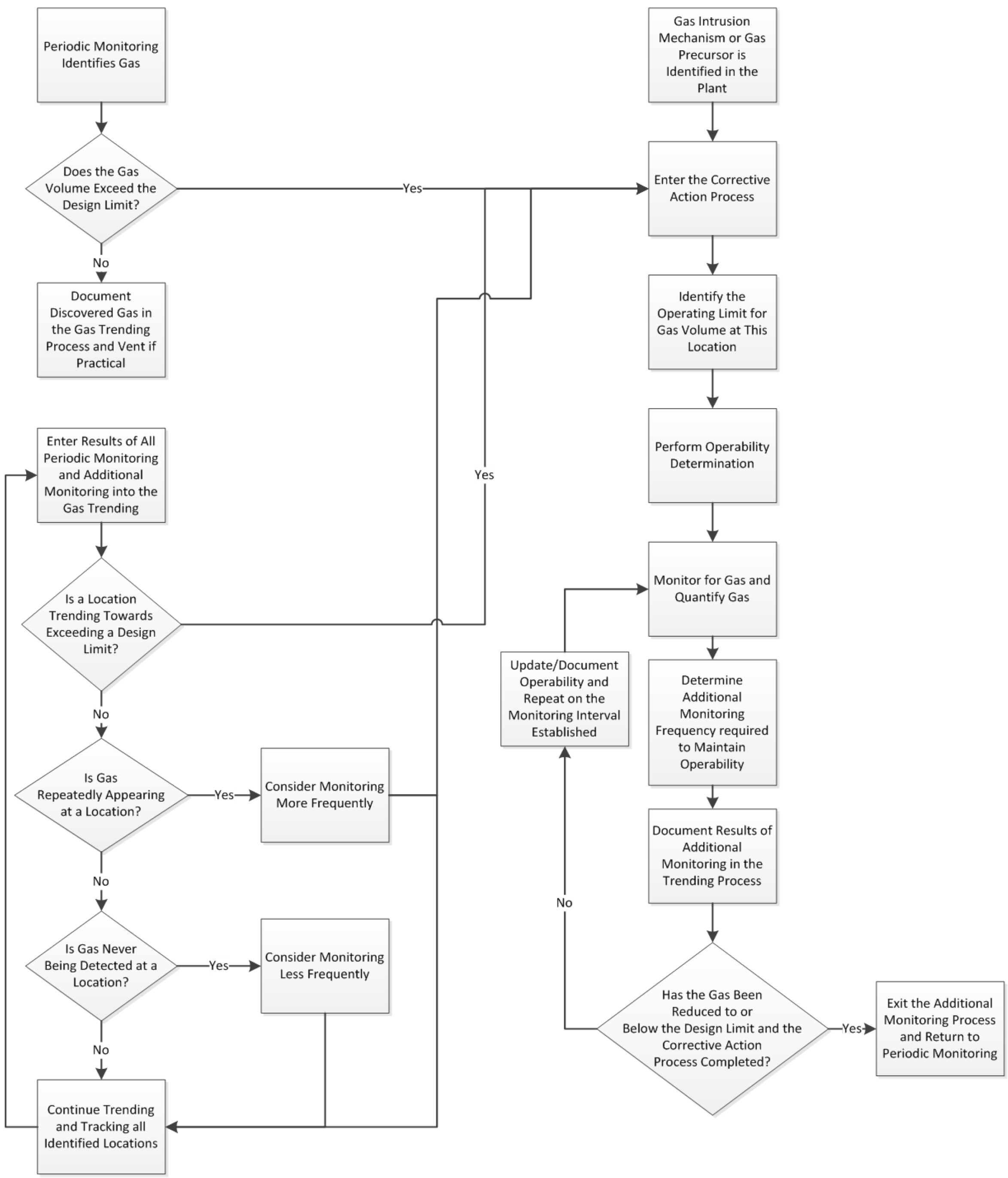
1. **Acceptance Criteria** – The maximum amount of gas at a location at any time which will allow the system to continue to perform its specified function.
2. **Bubbly Flow** - The bubbly flow pattern is characterized by a suspension of discrete bubbles in a continuous liquid.
3. **Design Limit** - As used in this document applies to acceptance criteria which have been fully evaluated in the stations design control program and incorporated into applicable station design documentation.
4. **Dynamic Venting** – The use of high velocity fluid to flush the system of voids.
5. **Froude Number** – A dimensionless parameter which is the ratio of inertia force to gravitational (buoyancy) force.
6. **Gas** – As used within the context of this document, the term includes air, nitrogen, hydrogen, or any other gas not including water vapor.
7. **Operating Limit** - As used in this document applies to acceptance criteria used during the corrective action process for gas void locations that exceed the documented design limit but can be considered operable but degraded.
8. **Ultrasonic Testing (UT)** – An acoustic technology where very short ultrasonic pulse-waves are launched into materials to detect internal flaws or to characterize materials. This technology can be used to detect level of the water-gas interface within a piping segment or component.
9. **Void** – As used within the context of this document, the term is essentially equivalent to “gas”.

Attachment 2



Attachment 3

Monitoring and Trending



Attachment 4

Acceptance Criteria

The guidance and tools described in this attachment are not intended to support permanent design bases changes or procedure changes that include acceptance criteria supporting the design basis.

The appropriate application of the guidance and tools in this attachment provide methods to support a reasonable expectation that a degraded or nonconforming SSC is operable or functional. Given situations where the guidance and tools do not provide sufficient, specific guidance, the NRC has also recognized the application of engineering judgment in the use of extending the available data. In all cases the licensee's Criterion XVI Corrective Action Program is expected to direct the timely resolution of degraded or non-conforming conditions.

REASONABLE EXPECTATION OF OPERABILITY

Operability/functionality of Systems, Structures, and Components (SSCs) has been the subject of many publications. While each plant defines operability in its plant specific Technical Specifications, and the system specific Limiting Conditions for Operation contained therein, and functionality is defined as a similar but separate concept in station-specific procedures, much of the available literature on operability/functionality is intended to guide the licensee and/or inspector.

When determining the operability/functionality of an SSC, it is important to ensure a "reasonable expectation" of operability/functionality. An absolute expectation is not required. Although the following excerpts from RIS2005-20 (Reference 3) are specifically addressing operability, the concepts and guidance applies to operability determinations as well as functionality assessments.

> "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 "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."

When detailed performance for the SSC under the conditions being evaluated is not readily available, or the data is not as complete or detailed as one would prefer, alternative approaches are still accepted by the NRC:

> "The scope of an operability determination must be sufficient to address the capability of SSCs to perform their specified safety functions. The operability decision may be based on analysis, a test or partial test, experience with operating events, engineering judgment, or a combination of these factors, considering SSC functional requirements."

Often, a first principles understanding of the functioning of the system under degraded conditions must be supplemented with additional tools:

> "When performing operability determinations, licensees sometimes use analytical methods or computer codes different from those originally used in the calculations supporting the plant design. This practice involves applying "engineering judgment" to determine if an SSC remains capable of performing its specified safety function during the corrective action period. …Although the use of alternative and normally more recent methods or computer codes may raise complex plant-specific issues, their use may be useful and acceptable in operability determinations."

These citations support and affirm the industry operability positions quite well, considering that limited data is available in some areas, and engineering judgment has been applied in others. However, consistent with the NRC guidance, a "reasonable expectation" of operability is assured by the appropriate application of these products.

With respect to correcting the degraded or non-conforming condition discovered in our systems, once operability has been established, and continued operability is expected, there are three generally recognized avenues for the resolution of the degraded or non-conforming condition. From RIS2005-20 (Reference 3):

> "A licensee's range of corrective action may involve (1) full restoration to the UFSAR described condition, (2) a change to the licensing basis to accept the as-found condition as is, or (3) some modification of the facility or CLB other than restoration to the condition as described in the UFSAR.
>
> If corrective action is taken to restore the degraded or nonconforming SSC to the UFSAR described condition, no 10 CFR 50.59 screening and/or evaluation is required. The 10 CFR 50.59 process applies when the final resolution of the degraded or nonconforming condition differs from the established UFSAR description or analysis. At this point, the licensee plans to make a change to the facility or procedures as described in the UFSAR. The proposed change is now subject to the review process established by 10 CFR 50.59. A change can be safe but still require NRC approval under the rule. The proposed final resolution may require NRC review and approval (via amendment) without affecting the continued operation of the plant because interim operation is governed by the processes for determining operability and taking corrective action (10 CFR Part 50, Appendix B).
>
> In two situations, the identification of a final resolution or final corrective action requires a 10 CFR 50.59 review, unless another regulation applies (e.g., 10 CFR 50.55a): (1) when a licensee decides the final corrective action is to change its facility or procedures to

> something other than full restoration to the UFSAR-described condition and (2) when a licensee decides to change its licensing basis, as described in the UFSAR, to accept the degraded or nonconforming condition as its revised licensing basis."

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".

DISCUSSION

In general, a void in the pump suction piping presents a more significant challenge to the SSC function than a void in the pump discharge piping. A gas void in the pump suction could result in the momentary degradation of pump performance (ability to provide the required flow at the required discharge pressure) or potentially gas binding of the pump if the void size is large enough and of sufficient duration. A gas void in the pump discharge typically would result in a pressure pulsation in the pipe and perhaps a short delay in the injection flow. Unbalanced forces potentially stress piping supports beyond their design, but rarely lead to severe damage that would challenge the successful fulfillment of the intended safety function. A pressure increase of sufficient duration may challenge a system relief valve, and the licensee should consider the potential impact due to an unexpected lift. Clearly, the consequence of gas binding a pump is more severe than momentary pump performance degradation.

Note that the above considerations differ from the acceptance criteria discussed in Section 9. Section 9 provides criteria that should be met so that a problem does not occur. In this section, the acceptance criteria have been potentially surpassed. This section discusses what attributes need to be evaluated to assess the potential impact of the event.

Gas voids and transport in the pump suction piping

A small amount of accumulated gas in pump suction piping could result in the momentary degradation of pump performance as the gas passes through the pump. In the event that a large accumulation of gas were to occur and if the flow rate is high enough to result in a high void fraction being transported to the pump suction piping, the pump may become gas bound, potentially leading to loss of function altogether. In order to address this potential, each licensee must assess the potential for gas accumulation to degrade important systems.

There are a number of factors affecting the transport of gas voids in the suction piping which can impact the final void fraction at the inlet to the pump. The simplest and most straightforward is the effect of static pressure as the elevation of the gas void changes. Also, larger bubbles resist transportation down vertical pipe runs due to buoyancy while the turbulence of the flow tends to strip smaller bubbles from the larger bubbles resulting in prolongation of the transport time. The actual flowrate in the suction piping is a dominant factor as well. At the low end of the spectrum the flow rate may be insufficient to transport gas, at high flow rates a bulk transport process is approached, and at intermediate flow rates the gas is transported in a distributed fashion due to the shearing nature of the entrainment process. In general, these effects act to reduce the average void fraction in the downstream process fluid. The Froude number is used to represent the balance between the inertial and gravitational forces:

$$NFR = v \left[D\, g\, (\rho l - \rho g) / \rho l \right]^{-1/2}$$

where:

- v = fluid velocity
- D = piping diameter
- g = acceleration due to gravity
- ρl = liquid density
- ρg = gas density

Note that in general, the fluid velocity and piping diameter in the above equation are based on the pipe cross-sectional area and the actual pipe diameter in industry documents (References 5 and 17 - Note the conditions and limitations in the NRC SE regarding use of reference 17). In addition, the density terms are neglected since the gas density is typically much smaller than the liquid density.

Recent NRC Inspection Guidance (Reference 19) states that "at low flow rates, gas may be assumed to not move in a horizontal pipe or downward in a vertical pipe if the Froude Number, N_{FR}, is ≤ 0.31 and the average void fraction in a plane perpendicular to the pipe centerline, Φ, is ≤ 0.20." 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.

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 those cases, the size of a gas void in the suction piping will decrease as the static pressure in the piping system increases nearing the pump suction. The transport of any voids is conservatively assumed to be bulk flow (bubbly, homogeneous mixture i.e. lack of slug flow), with little overall reduction in the average void fraction.

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 PWR Owners Group has conducted full-scale "ECCS Void Migration" tests on 4", 6", 8" and 12" test loops (Reference 17 - Note the conditions and limitations in the NRC SE regarding use of reference 17). These tests are designed to obtain empirical void fraction reduction correlations as gas bubbles travel to a pump. These test data show significant break-up of gas void pockets up to 20% into bubbly flow when transported at Froude numbers greater than 0.60. PWR owners can use these data to determine whether initial void fractions greater than the pump acceptance criteria can be reduced by the pump suction piping sufficient to be within those criteria by the time they reach the pump inlet. The application of this test data is beyond the scope of this document.

The above 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.

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 approach which can be used to perform this model is provided in Westinghouse report WCAP 17276-P (Reference 5). This approach utilizes the homogeneous flow assumption with corrections for system static pressure variations and is referred to as the Simplified Equation. The key feature of the homogeneous flow assumption is equality of gas and liquid transport velocities. The Simplified Equation enables the determination of allowable gas volumes at high point locations in pump suction piping based on specified allowable air volume fraction criteria at the pump inlet, system flows, and system pressures. Details as to how to apply the Simplified Equation are provided in WCAP 17276-P (Reference 5).

There are several limitations on the use of the Simplified Equation; these are described in Reference 5. In addition, there may be instances in which the Simplified Equation cannot be used, for example if a limitation cannot be satisfied, or if the results of the Simplified Equation are too conservative for use. Since the Simplified Equation may not apply to all suction piping configurations and pump inlet geometries. It is the user's responsibility to ensure the applicability of the Simplified Equation, as specified in WCAP 17276-P (Reference 5), to the specific piping configuration and to acceptably address all relevant gas transport phenomena.

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;

- Demonstrate that the flow regime at the pump inlet will be a dispersed, bubbly flow regime.

The following approaches for addressing specific configuration limitations are possible:

- Appropriately scaled tests could be used to demonstrate operability.
- Configurations that involve downward flow in a vertical pipe with an elbow to a horizontal pipe that has a small length to diameter ratio with a reducer immediately upstream of the pump entrance can be treated by:
  - Limiting the gas volume to an appropriate fraction of the horizontal pipe volume between elbow and reducer, or
  - Verifying that in all situations of interest the liquid flow rate is sufficient to maintain the gas in a dispersed flow regime.
- Configurations which include pump suction headers with off-takes / tees can be treated by basing the allowable gas volume in the header on the limiting gas volume allowed by each off-take.
- The case of a vertical upward intake residual heat removal pump where flow from a horizontal pipe passes through an elbow and short vertical pipe before entering the pump can be treated by ensuring the liquid flow rate is sufficient to maintain the gas in a dispersed flow regime.
- Lastly, for the case of HPI pumps which take suction direct from a vertical pipe, the factor of four criterion identified in FAI/09-130-P (Reference 16 - Note the conditions and limitations in the NRC SE regarding use of this reference) must be applied.

In these instances, a detailed system specific evaluation should be performed using a transient two-phase hydrodynamic model such as GOTHIC, RELAP5, TRACE, etc. Note 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.

<u>Gas void ingestion by pumps</u>

The Industry gas ingestion acceptance criteria supplied to their members reflect the various styles of pumps currently in service in the nuclear industry. These include single and multi-stage pumps, with flexible and stiff shafts. The available pump data in the available literature reviewed for this effort also reflects these various pump designs. As there is no need to provide overly conservative or bounding criteria to ensure a reasonable expectation of operability, it is appropriate to have the supplied criteria reflect the relative strengths and weakness of those designs.

In general, the available test data suggest that pumps with stiff shafts are less sensitive to gas ingestion and capable of accommodating a larger spectrum of loading considerations. On the other hand, flexible shaft pumps are more susceptible to damage and should have more limiting criteria applied. For a given load, a flexible shaft will have more deflection than a stiff shaft, and greater deflection results in a greater propensity for mechanical contact or eccentric loads resulting in damage to the pump. The PWR criteria recognize the differences between the pump types and use established industry guidance to support this classification.

The differences in allowable average void fractions between BWR and PWR typical pumps, or between single and multi-stage pumps, are not a difference in the application of this conservatism. Instead, they are a reflection of the different performance aspects of the various designs of pumps currently in service in the nuclear industry.

It is understood that flows containing slugs of gas could present serious concerns to pump operation, and that pump operation in this regime should be avoided or that additional measures should be taken to dissipate these slugs of gas prior to reaching the pump. Similarly, there is insufficient data to determine that an initially voided pump will be able to develop adequate head. Therefore, the pump criteria supplied by the Industry are only applicable to non-slug flow conditions and in pumps with an initial void fraction not exceeding 5%. Without further data, it is not a reasonable expectation that operability could be assured.

It is agreed that the use of a peak versus an average void fraction is more conservative. However, it is the concern of the respective PWR and BWR Owners Groups that the use of a peak value may result in overly conservative criteria. As stated above, large slugs of gas transmitted to a pump inlet could challenge the pump operation and therefore, this must be prevented. Large scale testing (References 17 and 18) and analyses (Reference 16) have demonstrated that stratified gas volumes that might be accumulated in a piping highpoint may transition to a bubbly flow pattern in the downcomer piping as the two phase mixture flows toward the pump suction. It is this transition that protects the pump inlet from large gas slugs and guidance is given in Reference 16 on what piping configurations/geometries would be sufficient to ensure this transition would occur. Note, however, for high velocity flow conditions such as those documented in Section 7.2.3 of Reference 17 and 18 (Froude numbers as large as 2.5), large gas volumes were observed to transport downwards from the piping high point. Utilities should consider the possibility of this phenomenon when considering flow conditions with similar or greater downcomer velocities than those tested when applying the factor of four criteria (downcomer volume to gas void volume) documented in Reference 16. (Note the conditions and limitations in the NRC SE regarding use of references 16, 17, and 18)

Nonetheless, the available information for the tolerances of pumps to gas voids (bubbly flows) are representative of steady-state conditions (minutes or tens of minutes of operation), and as such, are indicative of the sensitivity to the average void fraction. Therefore, with the added restriction of no slug flow transmitted to the pump, the concern of relatively short term peak void fractions is adequately addressed. 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. These configurations are discussed in more detail in the section on Pump Suction Gas Transport.

The criteria presented in the following tables are generic in nature and already include significant conservatism in the application of the available industry data on pump performance. Additionally, these data have taken into consideration the body of testing reported in NUREG/CR-2792 (Reference 8). Where data were not available for pump operation outside the range of normal operation, one-half the value of the criterion recommended for the applicable normal operating range was used as an additional conservatism. Table 1 presents criteria which provide reasonable expectation that pump mechanical damage will be prevented, while Table 2 presents conditions that provide a reasonable expectation that pump discharge head will not be significantly impacted. For those conditions where less than rated pump discharge head is assured, the licensee should ensure the impact of reduced system performance for the duration of the gas void passage has been considered relative to accident analyses assumptions.

Table 1 - Allowable Average Non-Condensable Gas Void Fractions (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

Guidance provided has been conservatively established based on engineering judgment to cover a broad spectrum of equipment and operation, and is not intended to displace more specific recommendations from NSSS vendors, pump vendors, or engineering evaluation which a licensee has determined is more applicable to their configuration.

As additional data and methods become available in the future, they may be used to change, simplify, or eliminate some of these criteria.

Table 2 - Allowable Average Non-Condensable Gas Void Fractions (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%

Note: Criteria in this table have been conservatively established based on engineering judgment to cover a broad spectrum of equipment and operation, and is not intended to displace more specific recommendations from NSSS vendors, pump vendors, or engineering evaluation which a licensee has determined is more applicable to their configuration. As additional data and methods become available in the future, they may be used to change, simplify, or eliminate some of these criteria.

<u>NPSHr for pumps</u>

The Net Positive Suction Head required (NPSHr) is an industry standard criterion used in the design and operation of pumps. The Hydraulic Institute defines NPSHr as the total suction head in feet absolute, determined at the suction nozzle and corrected to datum, less the vapor pressure of the liquid in feet absolute. Simply stated, it is an analysis of energy conditions on the suction side of a pump to determine if the liquid will vaporize at the lowest pressure point in the pump. The pump manufacturers' performance curves normally supply this data.

Cavitation is a term used to describe the phenomenon, which occurs in a pump when there is insufficient NPSH available. When the pressure of the liquid is reduced to a value equal to or below its vapor pressure the liquid begins to boil and small vapor bubbles or pockets begin to form. As these vapor bubbles move along the impeller vanes to a higher-pressure area above the vapor pressure, they rapidly collapse. The collapse of the bubbles may cause serious pitting damage to the impeller.

NPSHr testing methods vary based on test loop arrangements, but each method requires stabilized conditions to assess pump performance. NPSHr is typically identified by 3% degradation in pump head. This 3% head degradation is usually an immediate precursor for a dramatic change in head due to head breakdown. With the addition of entrained air, the nature of the head degradation changes. Non-Condensable gas does not collapse under increased pressure. Typically, some amount of head degradation is present and tends to become more pronounced as the suction pressure is reduced. With small amounts of air, the head breakdown can typically be discerned, but with increased amounts of air, this phenomenon becomes less readily apparent as head degradation leading to this point becomes more dominant.

Industry's interest in avoiding cavitation is to ensure the long-term mechanical health of the pump (i.e., ensuring that the pump will meet its design lifecycle). As such, its focus is on pump/system compatibility. Short-term failures due to pump cavitation typically manifest themselves in large vibration levels, noise, and lower than expected head rise, prior to pump failure. Longer-term failures due to cavitation may not initially manifest themselves in terms of decreased head rise, but typically vibration and/or noise provide some insight into the conditions at the pump. Whether short or long term failure modes are under consideration, the duration of pump operation necessary for such damage is substantially longer than the time necessary for the void to be transported through the pump.

The impact of cavitation from fluid vapor pockets forming and then collapsing as they condense is well documented in terms of erosion, wear, fatigue, etc. The temporal nature of these degradation mechanisms does not lend themselves to an immediate failure mode. Cavitation of the pump would need to be occurring for an extended period of time, much greater than the transient times under consideration above, in order for these failure modes to be realized. Even if a pump was subjected to these conditions multiple times, it is unlikely that any damage would occur. Detection and resolution of long-term degradation mechanisms such as these are the purposes of quarterly in-service testing performed for these safety-related pumps. Severe cavitation would be required in order to have prompt mechanical damage, which would have been already covered by the pump ingestion criteria discussed earlier.

The timeframe for a pump to experience a gas intrusion event usually occurs at the beginning of an event, when the pump is automatically started by the plant's ECCS actuation systems. This is usually also the time of maximum NPSH available as well, since suction sources are at their highest elevations, and the fluids are at their coldest temperatures. Note that there are times when meeting NPSHr can be a challenge. For example, switching from the refueling water storage tank (RWST) to the containment sump can occur when pressure is low and temperature is close to saturation.

In summary, NPSHr criteria can only be assessed at steady state conditions, since the vendor NPSHr criteria are determined by head degradation testing at stabilized conditions and are not applicable during transients. These criteria are developed by the industry in order to ensure pump/system steady state compatibility. In addition, damage due to cavitation is unlikely for a condition that lasts on the order of seconds unless the cavitation were to be so severe as to already be bounded by the pump ingestion criteria presented above. It is also expected that any gas voids present would be transported through the pump at a time when margin in NPSH available is quite large. Finally, transient NPSHr test data are not available nor is a procedure for collecting such data currently defined by the industry. 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 8).

Pump Discharge Pressure Pulsations and Downstream Effects

The Industry has provided additional guidance documents (References 11-15: Note the conditions and limitations in the NRC SE regarding use of these references) to assist in the evaluation of discovered voids on the discharge side of the pump. 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. References 11 and 12 (Note the conditions and limitations in the NRC SE regarding use of these references) provide a methodology for determining the impacts in discharge piping segments of PWR's, with the output being the pressure profile and the resulting increased forces associated with the transient event. Given the pressure profile, the potential for lifting of relief valves; and the increased forces, an assessment of the piping and support system must be performed to ensure that design loads are not exceeded. References 13 and 14 (Note the conditions and limitations in the NRC SE regarding use of these references) provide methodology for determining the impacts of gas in the discharge piping of BWR's. Reference 15 (Note the conditions and limitations in the NRC SE regarding use of this reference)provides a qualitative assessment of the impact of non-condensable gases entering the RCS on the core cooling functions of the RCS, concluding that with assumed quantities of 5 cu ft of gas in the low pressure injection system and 5 cu ft of gas in the high pressure injection system, core cooling is not compromised.

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.

CONCLUSIONS

This attachment has provided the criteria which can be applied to a gas void discovered condition in a piping system. These criteria have been conservatively determined from the best available open literature in the industry at this time, as well as recent test results. Further application of conservatism is not required, and engineering judgment in the application of these generic criteria to specific conditions within a plant is within NRC guidelines for determining a reasonable expectation of operability for the SSCs.

The final void fraction of gas voids transported through the system suction piping to the pump suction is subject to changes in the fluid pressure due to the static elevation head and the competing forces due to buoyancy of the bubbles and turbulence of the flow. Guidance has been provided in PWR Owners Group documents in order to determine the average void fraction at the pump inlet.

Open literature on the behavior of gas voids ingested by pumps has been reviewed by the respective Owners Groups for pump designs typically in use in their plants. The criteria presented for these pumps reflect the void fraction dependency on pump operating point (flowrate), as well as the expected duration of the pump event. These criteria address mechanical damage to the pump, as well as the potential for reduced discharge head. Application of steady-state criteria such as NPSHr to preclude long-term performance degradation is not required, and short-term mechanical failure has been adequately addressed by the average void fraction limitations provided in Table 1.

Finally, guidance has been provided by the respective Owners Groups on the downstream effects in the ECCS piping systems. Although not expected to significantly impact the intended safety function of the SSC, a complete evaluation of operability would include a discussion of these effects.

REFERENCES

Note the conditions and limitations in the NRC Safety Evaluation (SE) that documents endorsement of NEI 09-10 regarding references 11, 12, 13, 14, 15, 16, 17, and 18. The SE and associated Requests for Information are included at the front of this document. Users should ensure that any comments in the SE are considered when the references are used.

1. NRC Generic Letter 2008-01: "Managing Gas Accumulation in Emergency Core Cooling, Decay Heat Removal, and Containment Spray Systems".
2. NRC Generic Letter No. 91-18, Revision 1: "Information to Licensees Regarding NRC Inspection Manual Section on Resolution of Degraded and Nonconforming Conditions".
3. NRC Regulatory Issue Summary 2005-20, Rev. 1, Revision to NRC Inspection Manual Part 9900 Technical Guidance, "Operability Determinations & Functionality Assessments for Resolution of Degraded or Nonconforming Conditions Adverse to Quality or Safety".
4. NRC Inspection Manual Part 9900: "Technical Guidance, Operability Determinations & Functionality Assessments for Resolution of Degraded or Nonconforming Conditions Adverse to Quality or Safety."
5. WCAP-17276-P, Rev. 1, "Investigation of Simplified Equation for Gas Transport," Westinghouse Electric Company LLC, January 2011.
6. V-EC-1866, Rev. 0, "Pump Interim Gas Ingestion Tolerance Criteria: PA-SEE-450 Task 2," Westinghouse Electric Company, for the PWR Owners Group, October 2008.
7. BWROG-TP-08-014, 0000-0087-5676-R0, "ECCS Pumps Suction Void Fraction Study," GE Hitachi Nuclear, for the BWR Owners Group, August 2008.
8. NUREG/CR-2792, TM-825, "An Assessment of Residual Heat Removal and Containment Spray Pump Performance Under Air and Debris Ingesting Conditions," Creare Inc., September 1982.
9. "Centrifugal Pump Clinic, Second Edition, Revised and Expanded," Igor J. Karassik, copyright 1989.
10. "Centrifugal Pump Fundamentals," ITT Gould Pumps.
11. FAI/08-70, Rev.1, "Gas-Voids Pressure Pulsations Program," Fauske & Associates, LLC, for the PWR Owners' Group, September 2008. *
12. FAI/08-78, Rev.0, "Methodology for Evaluating Waterhammer in the Containment Spray Header and Hot Leg Switchover Piping," Fauske & Associates, LLC, for the PWR Owners' Group, August 2008. *
13. BWROG-TP-08-017, 0000-0086-7825-R0, "Potential Effects of Gas Accumulation on ECCS Analysis as Part of GL 2008-01 Resolution (TA 354)," GE Hitachi Nuclear, for the BWR Owners' Group, August 2008. *
14. BWROG-TP-08-020, 0000-0088-8669-R0, "Effects of Voiding on ECCS Drywell Injection Piping (TA 354)," GE Hitachi Nuclear, for the BWR Owners' Group, September 2008. *

15. LTR-LIS-08-543, Rev. 0, "PWROG Position Paper on Non-condensable Gas Voids in ECCS Piping; Qualitative Engineering Judgment of Potential Effects on Reactor Coolant System Transients Including Chapter 15 Events, Task 3 of PA-SEE-450," Westinghouse Electric Company LLC, August 19, 2008. *
16. FAI/09-130-P, Rev. 0, "Technical Basis for Gas Transport to the Pump Suction," Fauske & Associates LLC, December, 2010. *
17. WCAP-17271-P, Rev. 1, "Air Water Transport in Large Diameter Piping Systems: Analysis and Evaluation of Large Diameter Testing Performed at Purdue University – Volume 1," Westinghouse Electric Company LLC, October 2010. *
18. WCAP-17271-P, Rev. 0, "Air Water Transport in Large Diameter Piping Systems: Analysis and Evaluation of Large Diameter Testing Performed at Purdue University – Volumes 2-3," Westinghouse Electric Company LLC, August 2010. *
19. Temporary Instruction (TI) 2515/177, "Managing Gas Accumulation in Emergency Core Cooling, Decay Heat Removal, and Containment Spray Systems, (NRC Generic Letter 2008-01)," U. S. Nuclear Regulatory Commission, May 2011.

*- Note the conditions and limitations in the NRC Safety Evaluation regarding use of this reference.

Nuclear Energy Institute

Responses to NRC RAIs to NEI 09-10

NUCLEAR ENERGY INSTITUTE

James H. Riley
PRINCIPAL ENGINEER
NUCLEAR GENERATION DIVISION

October 28, 2011

Mr. Sheldon D. Stuchell
Licensing Processes Branch
Division of Policy and Rulemaking
U.S. Nuclear Regulatory Commission
Washington, DC 20005-0001

Subject: NEI Response to Request for Additional Information on Topical Report NEI 09-10, Revision 1: *Guidelines for Effective Prevention and Management of System Gas Accumulation*

Project Number: 689

Dear Mr. Stuchell:

On August 4, 2011 you sent a letter to NEI that contained two requests for additional information pertinent to the NRC's review of NEI 09-10, *Guidelines for Effective Prevention and Management of System Gas Accumulation.* Responses to these questions are attached. Your letter requested a response within 30 days, but our response has been delayed by the necessity of aligning industry strategies on its technical guidance for managing gas accumulation (NEI 09-10) with its technical specification change proposal associated with the same subject (TSTF-523). We appreciate the additional time you have allowed for us to formulate our strategy.

The industry fully supports the effort to achieve NRC endorsement of NEI 09-10. This document is the result of a significant amount of effort by the industry and NRC and reflects the best practices developed during the response to Generic Letter 2008-01. Failure to achieve an approach to managing gas accumulation that is acceptable to both the NRC and industry would reduce the value of the work done to date and possibly result in the publication of dual standards, a situation that would undoubtedly lead to confusion and continued disagreements between licensees and NRC.

At the same time, we would like to emphasize that the industry is proceeding under the premise that endorsement of NEI 09-10 must be independent of approval of TSTF-523. TSTF-523 is being developed as a self-contained, stand-alone document; it will not reference NEI 09-10. NEI 09-10 was never intended as a regulatory compliance document and revising it in a manner to achieve that end would substantially reduce its content and usefulness as a technical and operational guideline.

We look forward to continuing engagement with you in the resolution of any technical comments on NEI 09-10. If you have any questions on this letter, please contact me at 202-739-8137: jhr@nei.org.

Sincerely,

James H. Riley

Attachment

c: Mr. Anthony P. Ulses, NRR/DSS/SRXB , NRC
Mr. Warren C. Lyon, NRR/DSS/SRXB , NRC

Mr. Melvin L. Arey, Duke, PWROG
Mr. Ted Schiffley, Exelon, BWROG
Mr. Christopher C Brennan, Exelon
Ms. Jeff Brown, APS
Mr. Jack Stringfellow, SNC
Mr. Tony Browning, NextEra Energy

NRC Request for Additional Information: TOPICAL REPORT 09-10, REVISION 1, "GUIDELINES FOR EFFECTIVE PREVENTION AND MANAGEMENT OF SYSTEM GAS ACCUMULATION"

NRC RAI, Question 1

The first question in the NRC request for additional information is quoted below. Bold font has been added to emphasize the main question that the industry addresses in its response.

"The objective of the TR process is, in part, to add value by improving the efficiency of other licensing processes, for example, the process for reviewing license amendment requests (LARs) from commercial operating reactor licensees. The purpose of the U.S. Nuclear Regulatory Commission (NRC) TR program is to minimize industry and NRC time and effort by providing for a streamlined review and approval of a safety-related subject with subsequent referencing in licensing actions, rather than repeated reviews of the same subject.

A TR is a stand-alone report containing technical information about a nuclear power plant safety topic, which meets the criteria of a TR. A TR improves the efficiency of the licensing process by allowing the NRC staff to review a proposed methodology, design, operational requirements, or other safety-related subjects that will be used by multiple licensees, following approval, by referencing the approved TR. The TR provides the technical basis for a licensing action.

Request an explanation as to how TR NEI 09-10, Revision 1, will be used in licensing actions or improve efficiencies for the NRC and licensees."

NEI RESPONSE to RAI 1

TR NEI 09-10, revision 1 should improve the efficiency of a number of licensing activities including:

- Closure of GL 2008-001 – In their responses to GL 2008-001 a number of licensees committed to implement a gas management program. Needless to say, without guidance on what a gas management program should look like, the programs that may be adopted by licensees could vary considerably. In this case, the NRC would have to evaluate each on its merits. NEI 09-10 establishes expectations for a gas management program that, if endorsed by the NRC and used in lieu of a regulatory guide, could establish consistency in this matter.
- 10CFR50.59 evaluations for design modifications – The process for evaluating changes to facilities or procedures to determine if prior NRC review is required (10CFR50.59) includes a number of questions that could be affected by gas accumulation in fluid systems, for example:
  - (ii) "Result in a more than minimal increase in the likelihood of occurrence of a malfunction of a structure, system, or component (SSC) important to safety previously evaluated in the Final Safety Analysis Report."
  - (vi) "Create the possibility for a malfunction of a SSC important to safety with a different result than any previously evaluated in the Final Safety Analysis Report."

  A positive answer to these questions would require a license amendment request (LAR) to be submitted and reviewed. Changing a system or procedure in a manner that follows the guidance in an NRC endorsed version of NEI 09-10 should preclude the occurrence of gas accumulation and thereby avoid a positive answer to either of the above questions, the associated LAR, and the licensee and NRC effort required to process it.

- The NRC has stated that if NEI 09-10 is not endorsed, the Staff will prepare a regulatory guide on the subject. The preparation of a regulatory guide and the process of reviewing it and resolving public comments on its content requires a significant amount of time and licensee and NRC resources. A regulatory guide will not be necessary if NEI 09-10 is endorsed as one acceptable means of preventing gas accumulation in fluid systems.
    - Alternately, if the NRC does not endorse NEI 09-10 and writes a regulatory guide on the subject, and the industry proceeds with the publication of NEI 09-10, the result will be the existence of two standards on the same subject. This is an undesirable situation because of the confusion and additional interpretation effort caused by multiple standards.
- NEI 09-10 contains guidance on pump suction void acceptance criteria and the simplified equation that provide a means for licensees to assess the operability of systems with gas voids. Endorsement of NEI 09-10 will provide a consistent approach to these subjects and avoid misunderstanding between licensees and NRC inspectors when the guidance is applied to operability evaluations.

The generic technical specification change model (TSTF-523) that is being developed to address the gas management issue will not reference NEI 09-10. Instead the TSTF will be a stand-alone document with any information needed to explain the technical specification requirements captured in the Technical Specification Bases, consistent with 10 CFR 50.36(a). To our knowledge no licensee presently intends to reference NEI 09-10 in a license amendment request and the industry has no commitment from licensees to use NEI 09-10 in this manner in the future. Note that licensees may choose to reference NEI 09-10 in license amendment requests for their own purposes.

In summary, endorsement of NEI 09-10 will provide multiple opportunities for efficiency in the licensing process and also avoid wasting the effort expended to-date and that which would be required in the future to produce a new standard.

NRC RAI Question 2

The second question in the NRC request for additional information is quoted immediately below. Bold font has been added to emphasize the main question that the industry addresses in its response.

"It is stated in Section 2.0 of the TR, within paragraph 4, "The approach identified in this document is intended to satisfy 10 CFR [Title 10 of the *Code of Federal Regulations* Part] 50 Appendix B Quality Assurance requirements. 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, 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."

However, it is not apparent to the NRC staff specifically how Sections 3 through 14 apply to NRC regulations. Similar to an NRC Regulatory Guide, a TR should provide guidance to licensees on a way to meet regulatory requirements, therefore, **the NRC staff requests more detail as to how the TR satisfies regulatory compliance**."

Response to RAI 2

If endorsed by the NRC, NEI 09-10 will provide an acceptable method for managing fluid system gas accumulation and system operation so that applicable systems are operated in a manner consistent their design and licensing basis. Therefore, the regulations that help define the licensing basis for fluid systems are those pertinent to this document. These regulations include the Quality Assurance requirements listed in section 2.0 of NEI 09-10 and the General Design Criteria.

The General Design Criteria documented in Appendix A to 10CFR50 "…establish the necessary design, fabrication, construction, testing, and performance requirements for structures, systems, and components important to safety…" [10CFR50 App. A, Introduction]. As their name implies, these are general requirements. The General Design Criteria in Section IV (Fluid Systems) that are specifically applicable to the guidance in NEI 09-10 are:

- GDC 34: Residual Heat Removal
- GDC 35: Emergency Core Cooling
- GDC 37: Testing of Emergency Core Cooling System

During a reactor plant's licensing process, the NRC Staff determines if a specific design meets the General Design Criteria. The documentation developed during this process becomes the design and licensing basis for the plant. It is then up to the licensee to ensure that the plant continues to be operated and modified, if necessary, in accordance with its licensing and design basis. Accurate understanding of what is required to operate and maintain safety systems in a manner that preserves the licensing basis is essential. NEI 09-10 provides guidance that facilitates this understanding in the area of fluid system gas accumulation.

Sections 3 through 14 of NEI 09-10 provide guidance on principles and practices that will effectively prevent, identify, manage and monitor accumulation of gas that would otherwise challenge the capability of a system to satisfy its design functional requirements specified in GDC 34, 35, and 37 and Quality Assurance Criteria III, V, and XI. NEI 09-10 will be changed to make these references clear when it is revised to address all the comments received from the NRC.

In summary, the approach in NEI 09-10 is intended to ensure that fluid systems susceptible to gas accumulation are operated and maintained in a manner that meets the intent of:

- GDC 34, 35, and 37,
- Quality Assurance Criteria III, V, and XI, and
- The applicable system design and licensing basis

so that these systems and components remain ready to perform their intended design basis function when required.

James H. Riley
PRINCIPAL ENGINEER
NUCLEAR GENERATION DIVISION

September 26, 2012

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Subject: NEI Response to Request for Additional Information on Topical Report NEI 09-10, Revision 1: Guidelines for Effective Prevention and Management of System Gas Accumulation

Project Number: 689

On March 19, 2012 NEI received a request for additional information pertinent to the Staff's review of NEI 09-10, *Guidelines for Effective Prevention and Management of System Gas Accumulation.* Responses to these questions are attached. Your letter requested a response within 90 days, but our response has been delayed by the necessity of aligning responses from several different industry organizations and by the incorporation of the resulting information into NEI 09-10. We appreciate the additional time you have given us for the completion of this work.

Based on a preliminary review by the Staff, we believe that the attached information is fully responsive to the NRC information requests. We anticipate that the next steps in the endorsement process will be our review of the draft safety evaluation followed by receipt of the final safety evaluation and submittal of the endorsed version of NEI 09-10 to the NRC.

The industry fully supports the effort to achieve NRC endorsement of NEI 09-10. This document is the result of a significant amount of effort by the industry and NRC and reflects the best practices developed during the response to Generic Letter 2008-01. We look forward to the NRC's formal endorsement of the document.

If you have any questions on this letter, please contact me at 202-739-8137: jhr@nei.org.

Sincerely,

James H. Riley

Attachment

c: Mr. Jonathan G. Rowley, NRR/DPR/PLPB, NRC

Mr. Jack Stringfellow, SNC, PWROG
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NEI Response to Second Set of RAIs on NEI 09-19

NEI's response to the questions contained in the March 19, 2012 letter entitled: "REQUEST FOR RESPONSE TO SECOND SET OF ADDITIONAL INFORMATION QUESTIONS RE: TOPICAL REPORT 09-10, REVISION 1, "GUIDELINES FOR EFFECTIVE PREVENTION AND MANAGEMENT OF SYSTEM GAS ACCUMULATION (TAC NO. ME5291)" are provided below. The changes indicated in our responses will be included in revision 1A of NEI 09-10.

RAI 2-1

QUESTION

Is it the Nuclear Energy Institute's (NEI's) intent that the NEI 09-10 Rev 1 Topical Report explicitly indicate that operating experience be incorporated into the gas management program or that incorporation be only "encouraged" as stated in TR Section 6?

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. However, the TR does not explicitly indicate operating experience must be incorporated into the gas management program in the same fashion as the quality assurance program. The NRC staff requires that operating experience must be an integral part of a gas management program as opposed to the TR approach that "encourages" licensee documentation of operating experience.

RESPONSE

The first sentence in the second paragraph in section 6 was modified as shown below. The word "must" (as suggested above) was not used as it is not appropriate for use in a guideline.

"It is the intent of this guideline that plants should document OE related to gas intrusion events and lessons learned during gas evolutions."

RAI 2-2

QUESTION

Does NEI plan to expand the discussion of gas transport methodologies in TR Section 7 to identify the need for using a staff-approved or a well-supported gas transport analysis method?

The TR 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 NRC has found that such evaluations are often incorrect or inadequately supported by experimental data or theoretical understanding. Consequently, due to the complexity and variability of gas evaluation methods, the evaluation method should either have been approved by the staff or be well understood and applied by experts who are well versed in such applications. The TR should emphasize the need for an acceptable evaluation before concluding that a system is an out-of-scope system.

In regard to prediction methods and to the statement that "scope may be narrowed to portions of a system where gas accumulation can affect functionality," the NRC staff notes that gas volumes that are predicted to not affect functionality and that are excluded from further consideration must be documented. Trivial volumes, such as occasional bubbles in a horizontal pipe that cannot be reasonably removed, do not require documentation. Treatment of design limits and operating limits is discussed in NEI 09-10 Sections 9 and 12, respectively. The evaluation methods discussed in the above paragraph apply.

RESPONSE

In response to the first paragraph in the above question, the following text was added to the end of the third to the last paragraph in section 7.

> "Due to the complexity and variability of gas evaluation calculation methods, the method used should either have been approved by the staff or be well understood and applied by experts who are well versed in such applications."

In response to the second paragraph in the above question, the following additional paragraph was added at the end or section 7.

> "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. Trivial volumes of gas, such as occasional bubbles in a horizontal pipe that cannot be reasonably removed, do not require documentation."

RAI 2-3

QUESTION

Vortexing is identified in TR Section 4 as a gas intrusion mechanism. Does NEI plan to expand the discussion of vortexing in that section or in TR Section 7?

Vortexing prediction methods are not addressed in the TR. The TR must identify that vortexing is within the scope of Generic Letter 2008-01 gas issues and this must be addressed on a plant-specific basis until the NRC issues or endorses an acceptable approach. This must be identified in the revised TR. Further, due to the complexity and variability of vortex calculation methods, the need for using a staff-approved or a well-supported gas transport analysis method is to be emphasized in the TR.

RESPONSE
The following sentence was added to the end of the third to last paragraph in section 7.

"Similarly, if vortexing is determined to be a possible mechanism, no generic method for determining the possibility or effect of vortexing has been developed as part of this guidance. Therefore, vortexing must be addressed on a plant-specific basis."

RAI 2-4

QUESTION

TR Section 8 discusses monitoring and accessibility but accessibility is not defined. What are the criteria that determine whether a surveillance location is accessible?

The report states that "Monitoring may not be practical for locations that are inaccessible due to radiological, environmental conditions, the plant configuration or personnel safety," but it does not address accessibility. The NRC staff considers all locations accessible unless actual environmental conditions constitute a hazard to personnel or are such that conducting the surveillance in the specific locations will result in an unacceptable dose. Considerations of such aspects as high environmental temperatures or local high temperatures that constitute a burn hazard also apply to determination of non-accessibility. Regardless of accessibility considerations, surveillance is required for all locations of concern unless it is acceptably determined that the surveillance is not necessary to reasonably ensure operability.

An example that illustrates the need for increased guidance is classification of accessibility based on a posted high radiation area. Assume there are six locations within a posted high radiation area where surveillances are needed, five surveillances can be performed with negligible dose, and none of the surveillance locations entails personnel hazards such as high local temperatures. The NRC considers the five locations to be accessible whereas NRC inspectors have observed licensee facilities where the six locations were considered inaccessible.

<u>RESPONSE</u>
The following sentences were added to the fourth paragraph in section 8.4.2.

"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. (Note that a determination that a location is inaccessible may result in additional regulatory scrutiny.)"

"Regardless of accessibility considerations, surveillance is required for all locations of concern unless it is acceptably determined that the surveillance is not necessary to reasonably ensure operability. Alternately, a remote monitoring capability should be established."

<u>RAI 2-5</u>

<u>QUESTION</u>

Should the lists of precursors in Sections 4 and 12.1 include a condition where the system configuration may result in a temperature that is greater than saturation temperature?

Some system configurations may result in a temperature that is greater than the saturation temperature at the interface with system components that are expected to be at a lower temperature. For example, the NRC staff is aware of a condition where a high-pressure system operating at an elevated temperature caused steam to form on the low-pressure side of a closed valve where there should not have been a void. Attempts to eliminate the void were complicated by boiling due to the high temperature interface as steam was vented.

<u>RESPONSE</u>
The following additional bullet was added to the list in section 4.

• leakage or heat transfer through isolation valves in system configurations where temperatures on one side of an isolation valve or other interface are greater than the saturation temperature on the other side

<u>RAI 2-6</u>

<u>QUESTION</u>

Technical specifications (TSs) are mentioned in TR Section 13.4 and in Attachment 4 to the TR but there is no mention that many TSs are incomplete. Does NEI plan to revise the TR to address how licensees should address this condition?

Regardless of whether located in TSs, the Final Safety Analysis Report, procedures, or the corrective action plan, 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 as specified in TSs, without acceptable justification, do not meet this requirement. Many licensees have a 31-day TS surveillance requirement but conditions may exist where this is inadequate to reasonably ensure operability. Conversely, aspects of some systems may be consistent with less frequent surveillances but it is necessary to comply with the TS.

RESPONSE

The industry and NRC are in the process of developing and approving a technical specification change package that addresses gas accumulation issues. Until the package is complete and has been adopted by licensees as appropriate, existing technical specifications may not contain requirements that are consistent with recent guidance on the management of gas accumulation. Therefore the reference to technical specifications in the second sentence of section 13.4 was removed. The sentence now reads as follows:

Gas that cannot be removed immediately due to plant configuration or conditions should be removed at the next available opportunity, consistent with the station corrective action process as long as appropriate operability evaluations are documented.

RAI 2-7

QUESTION

TR Section 13 states that "Operability Determination or Functionality assessment processes are not required if the .... as found gas volume is below the design limit." Please clarify this statement with respect to a determination that the as-found gas volume may be below the design limit but the monitoring process must reasonably ensure that the design limit is not exceeded before the next scheduled monitoring.

TR Section 12.2 states, "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." The TR Section 13 quote is not consistent with the latter part of the Section 12.2 quote and is not acceptable as written. This must be corrected. 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." In light of the previous staff observation, it is not clear if the monitoring procedure design limit takes into account the predicted behavior until the next monitoring, although trending is identified in Section 12.8 that can provide information to support predicted behavior. The need to remain below the design limit throughout the next monitoring period should be clarified.

RESPONSE

The section 13 statement will be made consistent with the section 12.2 statement by adding the phrase underlined below at the end of the first sentence in section 13:

> "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, <u>and it can be reasonably assured that the system will remain capable of performing its design function throughout the next monitoring interval.</u>**"**

RAI 2-8

QUESTION

TR Section 9 addresses acceptance criteria and Attachment 4 covers situations where the acceptance criteria have been exceeded. This is not clear with the result that the discussion in the two sections appears to be inconsistent. What TR clarifications does NEI plan to make to eliminate the potential misunderstanding?

RESPONSE

In order to clarify this observation, the following sentence will be added as a separate paragraph at the end of the "Discussion" section in Attachment 4:

> "Note that the above considerations differ from the acceptance criteria discussed in Section 9. Section 9 provides criteria that should be met so that a problem does not occur. In this section, the acceptance criteria have been potentially surpassed. This section discusses what attributes need to be evaluated to determine what harm may have been done as result of the event."

RAI 2-9

QUESTION

The requirement that the instantaneous void fraction must be less than 1.7 times the TR Tables 1 and 2 allowable pump suction void fractions was concluded by mutual judgment of industry and NRC staff representatives following the June 2010, meeting at NEI's Washington, DC location (References 5, 6, and 7). The TR discussion identifies a factor of 1.7 but does not apply it to the Table 1 and 2 criteria. Rather, the TR provides a discussion of typical transient behavior that fits within the 1.7 factor and attempts to conclude that there will be no slug flow.

An alternate to using the 1.7 factor is to acceptably demonstrate that dispersed bubbly flow exists at the pump inlet throughout the transient and that the average void fraction meets the Table 1 and 2 criteria. Provide an in-depth justification for not requiring the 1.7 factor or discuss the alternate bubbly flow criterion as a means of meeting the no slug flow requirement. If the dispersed bubbly flow criterion is selected, provide a reference that defines bubbly flow and discuss how this approach reasonably ensures that no slug flow will occur at the pump.

RESPONSE

The 1.7 factor was based on correlations documented in Reference 1 (FAI/09-130). These correlations were obtained from published literature applicable to the impingement of a water jet into a pool of water. Specifically, Equation 12 of FAI/09-130 provides a correlation for the gas entrainment rate as a function of the liquid detached region (waterfall) length (yl). Equation 24 of FAI-09/30 is obtained by integrating Equation 12 from the initial liquid detached region length (y = yl) to the final liquid detached region length (y = 0). Therefore, the peak-to-average entrainment rate can be estimated as the ratio of the coefficients of Equation 12 and 24; that is, 0.049/0.029 = 1.7.

The correlations which form the basis for the 1.7 factor are not directly applicable to the formation of a kinematic shock in a piping system. Therefore, we plan to remove the 1.7 value from NEI-09-10 and replace it with the statement that the average values in the pump table are applicable as long as the flow is in the dispersed bubbly flow regime at the pump inlet.

Wallis, Reference 2, defines bubbly flow as follows:

> The bubbly flow pattern is characterized by a suspension of discrete bubbles in a continuous liquid. There are numerous regimes of bubbly flow. Void fractions range from the extreme cases of a single isolated bubble in a large container to the quasi-continuum flow of a foam, containing less than 1 percent of liquid by volume. Interactions between the forces that are due to surface tension, viscosity, inertia, and buoyancy produce a variety of effects which are quite often evidenced by different bubble shapes and trajectories. The regime in which bubbles are so large that they assume a cylindrical shape and almost fill the duct in which they are flowing is important enough to warrant a separate name, slug flow…

Relative to the transport of gas in pump suction piping, the key characteristic of bubbly flow is that the gas phase is distributed in a continuous liquid phase as opposed to the case where the gas phase is separated from the liquid phase. The flow upstream of the kinematic shock in a vertical downcomer corresponds to a separated gas region. Downstream of the kinematic shock the gas phase is dispersed in the liquid continuous phase. The work of FAI/09-130 demonstrates that the separated region of the kinematic shock remains within the vertical downcomer as long as the volume of the downcomer is sufficiently larger than the gas volume.

Reference 3 (WCAP-17167-NP) identified piping configurations which may result in a transition from the bubbly flow regime to either a stratified or slug flow regime. These include: vortexing at off-takes, phase separation at tees, flow stratification in horizontal pipes and pump entrance phenomena / piping entrance configuration effects.

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;
- Demonstrate that the flow regime at the pump inlet will be a dispersed, bubbly flow regime.

The following sentence on page 31 (paragraph under Figure 1) that discussed the 1.7 factor was removed:

"The analytical and experimental basis for this transition shows that the ratio of the peak to average void fraction in the bubbly mixture would be approximately 1.7, which is consistent with Figure 1."

In addition, the following sentence was added at the bottom of the first paragraph under Figure 1.

"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."

References:

1. FAI/09-130-P, Rev. 0, "Technical Basis for Gas Transport to the Pump Suction," Fauske & Associates LLC, December, 2010.
2. Wallis, G., "One Dimensional Two-phase Flow," McGraw Hill Book Co., 1969.
3. WCAP-17167-NP, Rev. 0, "Phenomena Identification and Ranking Table (PIRT) to Evaluate Void Fraction / Flow Regime at ECCS, RHR and CS Pump Suctions," Westinghouse Electric Company LLC, December, 2009.

RAI 2-10

QUESTION

The discussion of "Net Positive Suction Head Required (NPSHr) for Pumps" includes the following statements:

"The timeframe for a pump to experience a gas intrusion event is expected to be at the beginning of an event, when the pump is automatically started by the plant's ECCS [emergency core cooling system] actuation systems. This is the time of maximum NPSH available as well, since suction sources are at their highest elevations, and the fluids are at their coldest temperatures." "It is also expected that any gas voids present would be transported through the pump at a time when margin in NPSH available is quite large."

Switching from the refueling water storage tank (RWST) to the containment sump can occur when pressure is low and temperature is close to saturation where meeting NPSHr can be a challenge. Clarify the discussion with respect to this observation.

RESPONSE

The sixth paragraph under the section labeled "NPSHr for pumps" was revised to replace the words "expected to be" with "usually". In addition, the example cited by the NRC was added. The result is copied below.

> "The timeframe for a pump to experience a gas intrusion event usually occurs at the beginning of an event, when the pump is automatically started by the plant's ECCS actuation systems. This is usually also the time of maximum NPSH available as well, since suction sources are at their highest elevations, and the fluids are at their coldest temperatures. Note that there are times when meeting NPSHr can be a challenge. For example, switching from the refueling water storage tank (RWST) to the containment sump can occur when pressure is low and temperature is close to saturation."

The overall argument still indicates that no NPSH effects need to be accounted for during a transient void.

RAI 2-11

QUESTION

The NRC staff reviewed the newest versions of the TR references. Some of the TR references are to older versions of the documents that were not reviewed. The TR references should be updated to reflect the newest document versions.

The references are as follows:

- "Investigation of Simplified Equation for Gas Transport", Westinghouse Electric Company, for the PWR Owners Group, WCAP-17276-P, Rev. 0, September 2010. ---
  Not received. Reviewed Revision 1, ML110480381, January 2011.
- FAI/09-130, "Technical Basis for Gas Transport to the Pump Suction," Fauske &Associates, LLC for the PWROG, December, 2009.WCAP-17271-NP, Rev. 0, "Air Water Transport in Large Diameter Piping Systems: Analysis and Evaluation of Large Diameter Testing Performed at Purdue University – Volumes 1-3", Westinghouse Electric Company, for the

PWR Owners Group, No ML, September 2010. ---
Replaced by FAI/09-130-P, "Technical Basis for Gas Transport to the Pump Suction," Fauske &Associates, ML110480456, December, 2010.

- BWROG-TP-08-017, 0000-0086-7825-R0, "Potential Effects of Gas Accumulation on ECCS Analysis as Part of GL 2008-01 Resolution", GE Hitachi Nuclear, for the BWR Owners' Group, August 2008. Reviewed version is "Potential Effects of Gas Accumulation on ECCS Analysis as Part of GL 2008-01 Resolution," Proprietary ML
- BWROG-TP-08-020, 0000-0088-8669-R0, "Effects of Voiding on ECCS Drywell Injection Piping (TA 354)", GE Hitachi Nuclear, for the BWR Owners' Group, September 2008. Reviewed version is "Effects of Voiding on ECCS Drywell Injection Piping," ML091250178, April 30, 2009. Please provide a pdf version of this document. Note that ML091250178 is only a one page cover letter.
- LTR-LIS-08-543, "PWROG Position Paper on Non-condensable Gas Voids in ECCS Piping; Qualitative Engineering Judgment of Potential Effects on Reactor Coolant System Transients Including Chapter 15 Events, Task 3 of PA-SEE-450", Westinghouse Electric Company, for the PWR Owners Group, No ML, August 19, 2008. ---
Reviewed version is same title, ML090980303, dated April 2, 2009.

RESPONSE
The correct PWROG references are as follows:

- WCAP-17276-P, Rev. 1, "Investigation of Simplified Equation for Gas Transport," Westinghouse Electric Company LLC, January 2011.
- FAI/09-130-P, Rev. 0, "Technical Basis for Gas Transport to the Pump Suction," Fauske & Associates LLC, December, 2010.
- WCAP-17271-P, Rev. 1, "Air Water Transport in Large Diameter Piping Systems: Analysis and Evaluation of Large Diameter Testing Performed at Purdue University – Volume 1," Westinghouse Electric Company LLC, October 2010.
- WCAP-17271-P, Rev. 0, "Air Water Transport in Large Diameter Piping Systems: Analysis and Evaluation of Large Diameter Testing Performed at Purdue University – Volumes 2-3," Westinghouse Electric Company LLC, August 2010.
- LTR-LIS-08-543, Rev. 0, "PWROG Position Paper on Non-condensable Gas Voids in ECCS Piping; Qualitative Engineering Judgment of Potential Effects on Reactor Coolant System Transients Including Chapter 15 Events, Task 3 of PA-SEE-450," Westinghouse Electric Company LLC, August 19, 2008.

The TR will be updated to include the most current revision of these references.

The BWROG documents have not been revised since the versions listed in NEI 09-10, so these references remain accurate.

RAI 2-12

QUESTION

Sections 3.1.3 and 3.1.4 of Reference 1 summarize the status of available data. In general, data for large diameter (> ~ 3 inches) elbows is insufficient to support modeling of horizontal elbows, data obtained from the Purdue tests provides support for transient modeling of elbows in a horizontal to vertically downward orientation and limited support of vertically downward to horizontal configurations. Some vortexing and tee information is stated to exist but is not addressed in the reference, "the available models are not yet adequate in all situations," and "there is a significant knowledge gap in these areas." For example, some of the phenomena of potential concern were observed during the Arizona Public Service test program that is summarized in the reference's Section 3.2 and is the subject of RAI question 2-13, below.

The reference's Section 4 summarizes the conclusions of an expert panel that addressed the state of knowledge.1 Areas identified where an improved understanding of phenomena is necessary to perform a best estimate evaluation where a bounding approximation may be inadequate include:

- **a. "Kinematic shock at vertical plane elbows.**
- **b. Vortexing at off-takes.**
- **c. Phase separation at tees.**
- **d. Flow stratification in horizontal pipes.**
- **e. Pump entrance phenomena / piping entrance configuration."**

Phenomena that need to be well understood "to assure that re-accumulation of gas and subsequent formation of slug flow does not occur" are:

- **a. Flow stratification in horizontal pipes.**
- **b. Pump entrance phenomena (piping entrance configuration).**

Reference 1 concluded the discussion with "phenomena related to the pump and piping configuration directly upstream of the pump should be considered as part of ongoing pump gas intrusion tolerance investigations and any future pump testing efforts. Flow stratification in horizontal pipes can lead to an accumulation of gas, for instance in an off-take or tee geometry. Once gas is accumulated, a subsequent instability can lead to a large surge in gas downstream. Currently, no modeling approaches exist that can account for this type of behavior." And "flow stratification in horizontal pipes, leading to downstream surges in gas is the most significant knowledge gap identified by the PIRT (Phenomena Identification and Ranking Table) panel."

Typical high-pressure injection (HPI) pump suction configurations include downward flow in a vertical pipe with an elbow to a horizontal pipe that has a small length to diameter ratio with a reducer immediately upstream of the pump entrance. This configuration may be inconsistent with pump vendor recommendations and is not replicated in the Purdue testing. Further, typical pump suction headers include offtakes / tees that are also not replicated in the testing. Consequently, modeling of such configurations must be done with care and a safety factor will likely be necessary to compensate for the lack of knowledge and supporting data. Further, in some circumstances, simply assuming all of the gas passes in one direction as a worst case may be inadequate to address the gas surge concerns, a potential condition that should be addressed as part of the overall modeling.

What are plans to address these areas?

Another configuration that may be of concern is a vertical residual heat removal pump where flow from a horizontal pipe passes through an elbow and short vertical pipe before entering the pump. Conversely, some HPI pumps take suction direct from a vertical pipe where the factor of four criterion identified in Section 6.0 (Page 41) of FAI/09-130-P (Reference 3) is applicable. Where information is insufficient to support application of a generic approach such as the simplified equation discussed in Reference 2, it may be necessary for individual licensees to address the issues on a plant-specific basis.

RESPONSE

The work of Reference 1 (FAI/09-130) demonstrates that the separated region of the kinematic shock remains within the vertical downcomer as long as the volume of the downcomer is sufficiently larger than the gas volume.

Reference 2 (WCAP-17167-NP) identified piping configurations which may result in a transition from the bubbly flow regime to either a stratified or slug flow regime. These include: vortexing at off-takes, phase separation at tees, flow stratification in horizontal pipes, and pump entrance phenomena / piping entrance configuration effects.

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;*
- *Demonstrate that the flow regime at the pump inlet will be a dispersed, bubbly flow regime.*

The following approaches for addressing the specific examples cited in RAI 2-12 are possible:

- For all of the specific examples cited in RAI 2-12 appropriately scaled tests could be used to demonstrate operability.
- Configurations that involve downward flow in a vertical pipe with an elbow to a horizontal pipe that has a small length to diameter ratio with a reducer immediately upstream of the pump entrance can be treated by:
    - Limiting the gas volume to an appropriate fraction of the horizontal pipe volume between elbow and reducer, or
    - Verifying that in all situations of interest the liquid flow rate is sufficient to maintain the gas in a dispersed flow regime.
- Configurations which include pump suction headers with offtakes / tees can be treated by basing the allowable gas volume in the header on the limiting gas volume allowed by each off-take.
- The case of a vertical upward intake residual heat removal pump where flow from a horizontal pipe passes through an elbow and short vertical pipe before entering the pump can be treated by ensuring the liquid flow rate is sufficient to maintain the gas in a dispersed flow regime.
- Lastly, for the case of HPI pumps which take suction direct from a vertical pipe, the factor of four criterion identified in FAI/09-130-P (Reference 1) must be applied.

In order to ensure that these limitations have been communicated to the users of NEI 09-10, the flowing text has been added to the section on Pump Suction Gas Transport in Appendix 4:

Since the Simplified Equation may not apply to all suction piping configurations and pump inlet geometries. It is the user's responsibility to ensure the applicability of the Simplified Equation, as specified in WCAP 17276-P (Reference 5), to the specific piping configuration and to acceptably address all relevant gas transport phenomena.

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;
- Demonstrate that the flow regime at the pump inlet will be a dispersed, bubbly flow regime.

In these instances, a detailed system specific evaluation should be performed using a transient two-phase hydrodynamic model such as GOTHIC, RELAP5, TRACE, etc. The following approaches for addressing the specific configuration limitations cited above are possible:

- For all of the examples cited above appropriately scaled tests could be used to demonstrate operability.
- Configurations that involve downward flow in a vertical pipe with an elbow to a horizontal pipe that has a small length to diameter ratio with a reducer immediately upstream of the pump entrance can be treated by:
  - Limiting the gas volume to an appropriate fraction of the horizontal pipe volume between elbow and reducer, or
  - Verifying that in all situations of interest the liquid flow rate is sufficient to maintain the gas in a dispersed flow regime.
- Configurations which include pump suction headers with off-takes / tees can be treated by basing the allowable gas volume in the header on the limiting gas volume allowed by each off-take.
- The case of a vertical upward intake residual heat removal pump where flow from a

References:

1. FAI/09-130-P, Rev. 0, "Technical Basis for Gas Transport to the Pump Suction," Fauske & Associates LLC, December, 2010.
2. WCAP-17167-NP, Rev. 0, "Phenomena Identification and Ranking Table (PIRT) to Evaluate Void Fraction / Flow Regime at ECCS, RHR and CS Pump Suctions," Westinghouse Electric Company LLC, December, 2009.

RAI 2-13

QUESTION

Reference 3 states that the measured void fraction is never one and that this demonstrates the most important observation from the tests "that, as a result of the kinematic shock, the two-phase flow regime is bubbly flow, not slug flow." (First paragraph of Section 5.1) This appears to be inconsistent with some of the Purdue test results where slug flow was observed at void fractions of less than one. Please explain.

This is discussed in Section 5.1 of Reference 3 where the rationale is that the vertically located differential pressure instrument used to determine void fraction never indicated zero and therefore a gas slug could not have existed. Test results are stated to provide maximum void fractions as high as 0.48, apparently due to the influence of buoyancy as downward velocity in the downcomer approaches bubble rise velocity. The length of pipe covered by the instrument is not identified nor is its transient response addressed. For example, the sketch in Figure B-2 indicates that the length is about 2/3 of the vertical pipe length whereas the sketch in Figure B-1 shows about 1/4 of the length - not surprising since sketches are not necessarily to scale. Further, the test configuration with a lower 4-inch horizontal pipe and a 3-inch vertical pipe would influence behavior in the region of concern. One may postulate that a 4 inch vertical pipe or a larger diameter pipe would have exhibited behavior similar to the Purdue test results or that a pipe larger than 4 inches would have reacted differently since countercurrent or co-current slug flow may occur in larger diameter pipes where it would not in smaller diameters. Finally, lower Froude numbers will not result in transit of a large upper void as a slug into lower piping. In any event, these observations appear to raise questions regarding the validity of the Reference 3 conclusions.

RESPONSE

It should be noted that paragraph two of TR RAI # 2-13 states that "test results are stated to provide maximum void fractions as high as 0.48" when referring to Reference 1. This statement is incorrect. Table B-1 of Reference 1 actually indicates that the maximum void fraction recorded by differential pressure transducers was as high as 0.61 for the PV229 experiment.

The Reference 1 statement "that, as a result of the kinematic shock, the two-phase flow regime is bubbly flow, not slug flow," (First paragraph of Section 5.1) is specifically referring to the regime transition observed in both References 1 and 2 from separated to dispersed. This comment addresses the question asked by the NRC staff which prompted the writing of Reference 1, which was in essence: what prevents the high point gas volume from being pulled down as a coherent gas volume (slug)? For the experiments discussed in Appendix B of Reference 1 (Palo Verde experiments), the air volume in the highpoint varied over the range of 0.19 ft3 to 0.25 ft3 (depending on the specific test conditions) after it had been compressed to the containment sump pressure. If these had been transmitted as coherent gas volumes into the 3" diameter downcomer, the gas would have occupied lengths of 3.9 ft to 5.1 ft. The measurements and videos of the downcomer lower (bottom) region confirm that this did not occur. The reason was the formation of a kinematic shock which was clearly observed in the upper regions of the downcomer. These observations of gas accumulated in the upper regions of the downcomer pipe and the formation of a kinematic shock are consistent with those documented for the larger scale Reference 2 (Purdue tests) sponsored by the PWROG. In addition, NEI guidance required that the downcomer have a volume of four times the highpoint gas volume used as the plant specific acceptance criterion. When considering the gas volume in the Palo Verde tests, the downcomer volume is approximately twice the highpoint gas volume, hence, they are a conservative demonstration that a kinematic shock would form in the downcomer when the ratio is four.

Since the differential pressure taps, used to determine void fraction in the Palo Verde experiments were placed 18 inches apart, only a slug with a body length greater than 18 inches would have resulted in a void fraction measurement of unity. In this respect, the statements referenced in TR RAI # 2-13 are correct. Therefore, the measurements confirm that the entire gas volume was not transported through the downcomer as a slug, which was originally considered to be the NRCs point of contention as described above, but it is difficult to demonstrate that smaller length slugs were not transported solely on the measured differential pressure.

For the Palo Verde experiments, the possibility of slug flow is questioned in TR RAI #2-13. TR RAI #2-13 specifically identifies unstable, co-current, downward moving slug flow conditions characterized by short length, short duration gas pockets that do not span the pipe diameter as identified in Section 7.2.3 of Reference 2 (Purdue tests). This type of slug is not consistent with classical slug flow behavior.

TR RAI # 2-13 correctly points out that the downcomer diameter used in the Palo Verde testing was 3", which is considered at or near the boundary of small diameter and large diameter behavior for water at standard conditions as documented in Reference 2. For small diameter piping, stable gas slugs occupying nearly the entire pipe cross section are possible, whereas only unstable slugs are possible in large diameter piping. Stable slug flow may be considered plausible for the Palo Verde tests; however, the instrumentation used in the Palo Verde tests was not designed to identify unstable short length slug behavior. It is noted that the formation of a kinematic shock in the top of the downcomer, the static head measurements in the bottom of the downcomer and the behavior in the lower pump header did not indicate any behavior consistent with co-current, downward slug flow.

The remainder of this response focuses on identifying the flow conditions that would result in both unstable co-current and unstable counter-current slug flow behavior in large diameter piping. This is based on the Purdue testing, which was heavily instrumented to observe this type of behavior, to clarify the conditions under which these short length, short lived slugs may form and evaluate under what conditions this type of behavior could impact pump operability. Discussion of stable slug behavior in large diameter piping is not relevant.

When a kinematic shock forms, which was shown through video evidence for all experiments documented in Reference 2, small bubbles are formed in the vicinity of the kinematic shock due to the entrainment of gas and bubble breakup in the high velocity shear flow in the transitional region downstream of the shock. (Note that the kinematic shock terminology is used here since the transition can be characterized as a discontinuity in the density mixture property as discussed in Reference 3.) These bubbles are transported downstream as a bubbly flow in the case that the liquid velocity is sufficient to transport them downstream at the same or greater rate of bubble generation. Reference 1 compares the flow of gas bubbles dispersed in water exiting the shock region and plunging liquid jets as depicted in Figure 8 of Reference 1. Comparisons may also have been drawn for very similar internal pipe flows observed in gas liquid contactors (References 4). In all cases, including plunging liquid jets, gas contactors and the kinematic shock flow transition as described in Reference 1, the flow exiting the shock region can be characterized as a bubbly flow.

For high velocity flow conditions such as those documented in Section 7.2.3 of Reference 2 (Froude numbers as large as 2.5), large gas volumes were observed to transport downwards from the piping high point. Note that these did not develop into a stable flow pattern and they disintegrated as they were transported through the downcomer. One severe example of this is documented in Reference 5 (Volume 2 of the Purdue test evaluation report) for the D8A20F250 run #2 experiment (Note that this experiment does not satisfy the factor of four criteria as discussed in the response to TR RAI # 2-16). During this experiment, when the gas volume upstream of the shock was eroded to the point that buoyancy was no longer sufficient to counteract drag imposed by the high velocity liquid flow around the bubble, break-off of the attached gas pocket upstream of the kinematic shock resulted in an unstable slug which was transported through the entire downcomer before it disintegrated. This behavior was clearly observed with the impedance based void fraction measurements. (Note that evaluation of this type of behavior with only differential pressure transducer readings would prove to be very difficult given the low state of knowledge for pressure drop across downward transported unstable gas pockets.) Therefore, individual utilities should consider the possibility of this phenomenon when considering flow conditions with similar or greater downcomer velocities than those tested when applying the factor of four criteria documented in Reference 1.

For intermediate velocity flows the rate of air entrainment out of the downcomer is greater than or equal to the rate of air entrained at the kinematic shock transition. In addition, the drag force on the trapped gas pocket upstream of the kinematic shock was not sufficient to overcome buoyancy and cause bubble break-off as opposed to the high flow rate cases in which this did occur. In this region, slug flow formation is not possible. This is evident by examining the test videos, calculated slip ratios and void fractions in the Reference 2 and 5 data in the intermediate flow ranges.

For low liquid velocity conditions gas may tend to hold up and re-circulate within the downcomer. This may occur locally and result in a churn flow as defined in Reference 6 or could be induced by downstream effects. In the churn flow regime coalescence and bubble breakup dominate with small bubbles continuously transported downward and larger bubbles, formed by coalescence, transported upwards, resulting in the churn behavior. In this regime, larger gas bubbles formed by coalescence are broken-up due to either, or both, of the following mechanisms, (1) the stagnation pressure of the flow exceeds the surface tension forces and/or (2) the velocity of the water flow accelerating around the gas volume is sufficient to cause entrainment (erosion) of the gas volume. The first is always tending to disrupt the larger gas volumes and the latter can be anticipated when the local void fraction becomes large with the actual value depending on the test conditions. This regime was observed in the Reference 2 experimental observations, but was not specifically called out in the final program summary report.

In some low flow rate conditions, such as when the downcomer is followed by an elbow or other geometry which can act to hold up gas, larger gas pockets can coalesce and move counter current to the flow such as those documented in Section 7.2.4 of Reference 2 in large diameter pipes. This flow regime may be characterized as counter-current slug. Again, these counter-current slugs are quickly broken up by the either, or both, of the mechanisms described above. In either low liquid flow rate case (churn or re-circulating slug), these effects act to reduce the downstream volumetric flux of gas.

In both cases described above, the downstream transport of gas is always liquid dispersed / liquid continuous. Chapter 9.1 of Reference 7 provides a generic definition for bubbly flow: "The bubbly flow pattern is characterized by a suspension of discrete bubbles in a continuous liquid." Within this framework the flow patterns described above, which result in only liquid continuous downstream transport, are characterized as bubbly, liquid continuous and not slug flow. This includes all conditions with the exception of the co-current slug condition as highlighted in Section 7.2.3 of Reference 2.

Regardless of the flow regime definition, what is most important is the rate at which gas is transported downstream. For conditions described above, with exception to co-current slug behavior, any recirculation or holdup of gas within the downcomer acts to lengthen the transport time and reduce the rate at which gas is transported to the pump. The longer the transport interval to the pump, the lower the volumetric gas flux is to the pump.

In order to capture the information in the above response the following two changes were made to NEI 09-10:

- Attachment 1, Definitions:

> **"Bubbly Flow** - The bubbly flow pattern is characterized by a suspension of discrete bubbles in a continuous liquid."

- First paragraph under Figure 1 in Attachment 4:

> "Note, however, for high velocity flow conditions such as those documented in Section 7.2.3 of Reference 17/18 (Froude numbers as large as 2.5), large gas volumes were observed to transport downwards from the piping high point. Utilities should consider the possibility of this phenomenon when considering flow conditions with similar or greater downcomer velocities than those tested when applying the factor of four criteria (downcomer volume to gas void volume) documented in Reference 16."

Note that the references cited above are those in NEI 09-10.

References:

1. FAI/09-130-P, Rev. 0, "Technical Basis for Gas Transport to the Pump Suction," Fauske & Associates LLC, December, 2010.

2. WCAP-17271-P, Rev. 1, "Air Water Transport in Large Diameter Piping Systems: Analysis and Evaluation of Large Diameter Testing Performed at Purdue University – Volume 1," Westinghouse Electric Company LLC, October 2010.
3. Brennan, C., "Fundamentals of Multiphase Flow," Cambridge University Press, 2005.
4. Atkinson, B. et al., "Bubble Breakup and Coalescence in a Plunging Liquid Jet Bubble Column," The Canadian Journal of Chemical Engineering, Volume 81, 2003.
5. WCAP-17271-P, Rev. 0, "Air Water Transport in Large Diameter Piping Systems: Analysis and Evaluation of Large Diameter Testing Performed at Purdue University – Volumes 2-3," Westinghouse Electric Company, August 2010.
6. Collier, J. and Thome, J., "Convective Boiling and Condensation," Third Edition, Oxford University Press, 1994.
7. Wallis, G., "One Dimensional Two-phase Flow," McGraw Hill Book Co., 1969.

<u>RAI 2-14</u>

<u>QUESTION</u>

Reference 2's Figure B-3 provides void fraction at the bottom of the downcomer as a function of time for Test PVA22. This starts at 0, maximizes at about 0.21, and the transient is over in about 30 seconds. Yet the void fraction remains at about 0.02 for the remainder of the plot that ends at 120 sec. Figure 9 provides the same information for Test PVA21 where the behavior is similar although the maximum void fraction is about 0.13, and void fraction is zero after about 30 seconds. Table B-1 does not identify any difference between the tests. The NRC staff does not understand the Figure B-3 non-zero behavior since the void source is finite unless for some reason the void is circulating in the bottom of the downcomer. Figure B-4 is stated to provide a comparison of gas transport to the pump compared to the initial gas inventory and may provide some insight, but the figure in the NRC staff's copies of the report is a solid black rectangle and provides no information.

(a) Explain the differences, and
(b) provide a legible Figure B-4.

<u>RESPONSE</u>
As indicated in Reference 1 (FAI/09-130), this is the experimental data as measured and there are always subtle differences in the individual tests. These two tests, PVA-21 and PVA-22, were the first two tests performed with configuration "2A" for the Palo Verde test matrix. From the test data files, it shows that these tests were run approximately 13 minutes apart on November 4th, with test PVA-21 being the first followed by PVA-22.

Since these were similar tests, the results were also similar, i.e. essentially all the gas accumulation in the lower header was discharged down the HPSI suction line and caught in the gas separator. Figure 1, below, is taken from the test report and shows the measured gas accumulation in the separator with PVA-21 having a lower amount of gas then PVA-22. Hence, this information demonstrates that there was more gas transported in test PVA-22. How is this possible when the initial conditions were virtually the same? The answer lies in the fact that there were segments of the experiment that had to be pressurized to achieve the scaling needed for representation of the reactor system. One of these was the sump tank that is identified in Figures B-1 and B-2 in FAI/09-130. When the sump water is pressurized by a non-condensable gas, in this case nitrogen, the gas will begin to dissolve in the water mass and the fact that the water is circulated increases the rate of dissolution. The sump tank pressure used for both of these experiments was 15.8 psig and the repeated exposure to this pressure forced more gas into solution with some of the gas exiting solution as the flow transient progressed. The region for greatest potential to have gas exit solution is that region which experiences the most acceleration and this is likely as the flow passed through the check valve at the top of the downcomer. Gas coming out of solution will continue over a longer time and act to manifest itself as a greater gas accumulation in the gas separation volume which was mounted on the HPSI pump suction line. The digital video records of the tests show that, in the long term, only small individual gas bubbles are being transmitted from the upper horizontal header (likely generated in the check valve), downward through the downcomer and eventually to the gas separator. This is the interval when the static head void fraction measurement is small, but non-zero. Furthermore, there is no indication of any bubble agglomeration or recirculation of gas voids in the video records during this interval.

As illustrated in Figure 1, the long term slope of the accumulation in gas separator has a value of approximately 0.002 kg accumulated over 100 seconds, i.e. a rate of 2×10^{-5} kg/sec. The gas solubility tables given in the 40th Edition of the Handbook of Physics and Chemistry give a value of 18.68 cc of air dissolved in 1 liter of water at 20°C, with an overpressure of 760 mm Hg. Since the overpressure of the containment sump was 15.8 psig, this pressure above 1 atm characterizes the extent of additional gas that could be dissolved in the containment sump water. Given that the flow through the downcomer over the long term was approximately 60 gpm, the flow through the check valve and downcomer was 0.134 ft^3/sec (3.8 ℓ/sec). With the imposed overpressure, the additional gas dissolved would have the potential for approximately 35 cc/sec to exit solution (71 cc/sec at one atmosphere), and considering the density of air at two atmospheres to be 2.4 kg/m^3, would result in an accumulation rate of 8.4×10^{-5} kg/sec in the separator. Hence, the potential for gas to dissolve and exit solution in the check valve gives a larger accumulation rate than the measured value, suggesting that either the water in the sump tank was not yet saturated with nitrogen or not all of the additional gas exited solution. The fact that successive tests demonstrate increasing gas accumulations is also consistent with increasing dissolution and exiting from solution. Consequently, it is our conclusion that this gas exiting solution is the mechanism responsible for this longer term difference in the measured pressure response for the static head representation of the void fraction between the two experiments.

With respect to item (b) a legible copy of Figure B-4 is provided below (see Figure 2).

References:

1. FAI/09-130-P, Rev. 0, "Technical Basis for Gas Transport to the Pump Suction," Fauske & Associates LLC, December, 2010.

2. FAI/04-86, Rev. 0, "Test Report for Phase 2 of Experimental Investigation of Post-RAS Air Intrusion Into ECCS Suction Piping for Palo Verde Nuclear Generating Station," February, 2005.

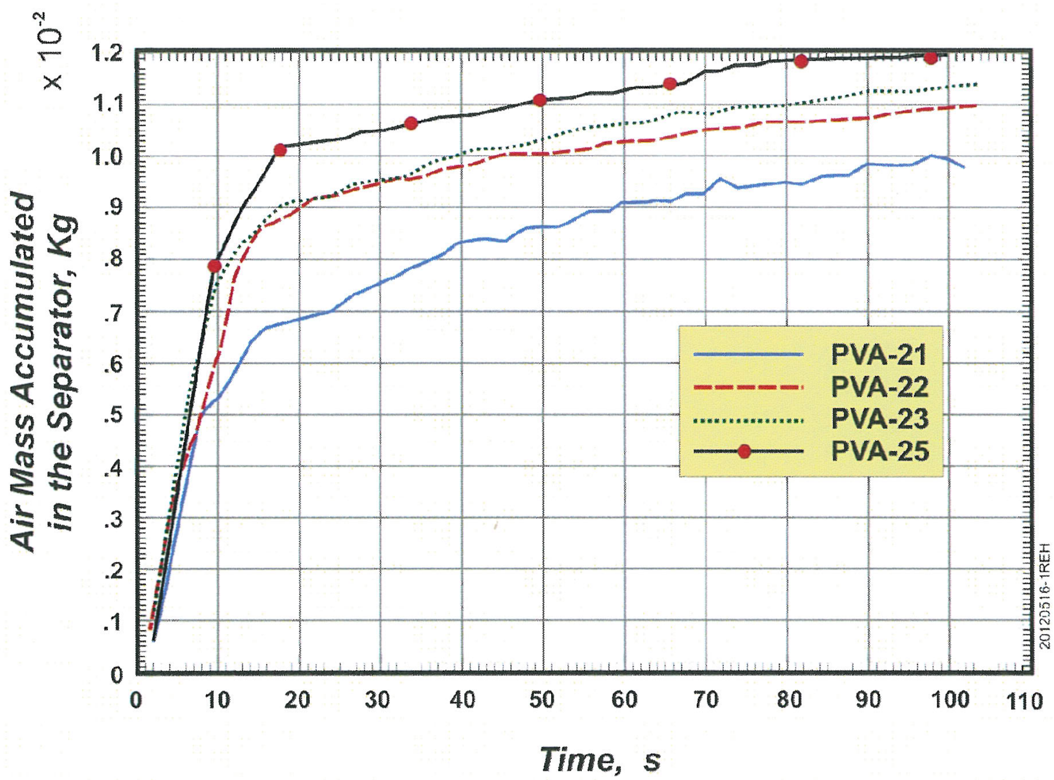

Figure 1 - Data Plot taken from Reference 2

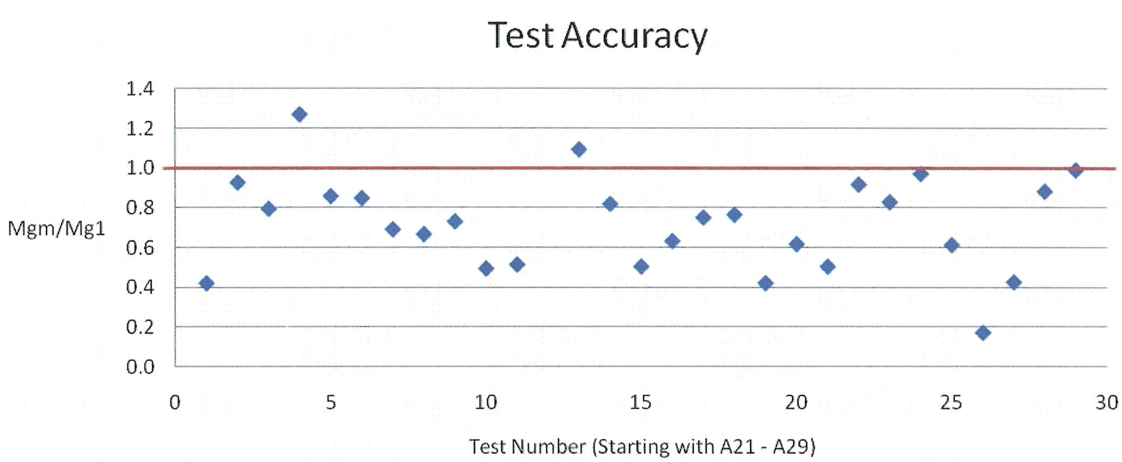

Figure 2 - Comparison of the Gas Transport toward the Pump Compared to the Initial Gas Inventory in the High Point

RAI 2-15

QUESTION

Reference 2 reported that the kinematic shock was about 1 ft below the bottom of the piping high point for Froude number, *NFR* , = 0.6 and the void fraction at that location was about 0.23. With a slip ratio of 0.72, "the void fraction of the flow being transported to the pump would be approximately 0.29." It continues with "Figure B-5 shows that this represents the upper limit of values observed for Froude numbers of 0.6 (velocity of 0.61 m/s) (2 ft/sec). As the Froude number decreases, the buoyancy influence increases and some large values of local void fraction can occur. Nonetheless, this method of assessing the void fraction at the bottom of the downcomer is demonstrated to be consistent with experiments and if anything conservatively biases to the maximum value." Figure 10 is identical to Figure B-5 except the line labeled "Calculated Peak Void Fraction @ 0.25" is at elevation 0.32 in Figure 10 and is at elevation 0.25 in Figure B-5. This appears to be an error in one or both figures. The NRC staff requests clarification.

RESPONSE

Figure 10 is the correct figure with Figure B-5 being from an earlier draft report. Nonetheless, this difference in the figures does not change any of the conclusions.

RAI 2-16

QUESTION

As discussed in References 2 and 3, a factor of four criteria has been established for determining that downcomer length is sufficient to reasonably ensure that fluid exiting a downcomer is characterized as bubbly flow. Reference 2 describes the Palo Verde and Purdue test facilities where the NRC staff determined that the factor of four criteria for downcomer length is met. However, at *NFR* = 2.5, in the 6 and 8 inch Purdue tests, co-current slugs moved down the vertical pipe and the Purdue report stated that "Trailing slugs were observed near the end of the transient and were characterized by complete flushing of the gas held up in the top horizontal header, elbow and kinematic shock region." Discuss this observation with respect to the validity of the factor of four criteria.

RESPONSE

Both the Purdue tests (References 1 and 2) and the FAI tests (Reference 3 Appendix B) demonstrated the formation of kinematic shocks. By definition, kinematic shock must have a step change in the density of the flowing stream and the only way that a kinematic shock can be formed is with bubbly flow being discharged from the kinematic shock. The factor of four criteria was primarily intended as a means to ensure the kinematic shock does not completely fill the vertical downcomer during the initial stage of the transient. This ensures the separated region of gas does not directly exit the downcomer. The co-current slug flow phenomenon is a separate phenomenon associated with a complete flushing of the last portion of gas comprising the kinematic shock during the final stage of the transient. Reference 1 notes that "Under all conditions, the trailing co-current slugs were unstable and tended to breakup quickly after traversing several diameters in the vertical downcomer."

While we concur that at high Froude numbers (Fr > 2.5) a co-current slug flow conditions can occur, the data and videos demonstrate the slug will break up within the vertical downcomer if the factor of four criterion is met, as demonstrated by the following data sets from Reference 2, Volume 2:

- Figures 3-723, 3-724, and 3-725 correspond to the 6-inch configuration with a Froude number of 2.60 and an initial void fraction of 20%. These figures show that the peak void fraction of the co-current slug decreased from 85% to 27% to 6% as the gas pocket passed void meters AIMP-2, AIMP-3, and AIMP-4, respectively. The videos also demonstrated that the gas slug broke up as it traversed the downcomer.
- Figure 3-1124 shows a case where the co-current slug did not break up at the bottom of the downcomer; the peak void fraction is 40% at AIMP-4. However, this case corresponds to the 8-inch configuration with a Froude number of 2.5 and an initial void fraction of 20%. It must be noted that after accounting for the expansion of the initial gas volume during the transient initiation, the gas volume for this case is greater than one-fourth of the downcomer volume specified by Reference 3. The videos confirm that the slug did not break up as it traversed the downcomer.
- Figure 3-953 shows a case where the co-current slug breaks up at the bottom of the downcomer; the peak void fraction is 18% at AIMP-4. This case corresponds to the 8-inch configuration with a Froude number of 2.60 and an initial void fraction of 10%. The gas volume for this case is slightly less than the one-fourth of the downcomer volume as specified by Reference 3 after accounting for the gas expansion during transient initiation.
- Therefore, for all the cases where the initial void volume was less than one-fourth of the downcomer volume the co-current slug broke up by the time it reached the bottom of the downcomer.

It is to be noted that the gas transport to the pump during these experiments is over a much longer time than is identified in the NEI acceptance criteria. Also, it needs to be restated that many of the experiments performed at FAI and Purdue used initial void fractions in the piping high point that are considerably larger than those that would meet the pump acceptance criteria provided in the NEI document. In short, these experiments are conservative representations of the gas that could be transported to the pump because of the extensive gas involved in the high point initial condition at the time that the kinematic shock is formed.

References:

1. WCAP-17271-P, Rev. 1, "Air Water Transport in Large Diameter Piping Systems: Analysis and Evaluation of Large Diameter Testing Performed at Purdue University – Volume 1", Westinghouse Electric Company LLC, October 2010.
2. WCAP-17271-P, Rev. 0, "Air Water Transport in Large Diameter Piping Systems: Analysis and Evaluation of Large Diameter Testing Performed at Purdue University – Volumes 2-3", Westinghouse Electric Company, for the PWR Owners Group, August 2010.
3. FAI/09-130-P, Rev. 0, "Technical Basis for Gas Transport to the Pump Suction," Fauske & Associates LLC, December, 2010.

RAI 2-17

QUESTION

A simplified equation has been developed for analysis of transient gas movement in pressurized water reactor (PWR) suction piping. A key aspect of configurations where the simplified equation can be applied is establishment of the kinematic shock and bubbly flow toward the bottom of a vertical downcomer, an aspect that is discussed in References 2 and 8 and is investigated in the referenced test programs. However, horizontal slug flow was observed in the lower horizontal pipe in both the 8- and 12-inch Purdue tests. In the 8 inch tests, it occurred at *NFR* = 1.65 and an initial void fraction of 20 percent. In the 12 inch tests, it occurred at *NFR* = 1.0 and an initial void fraction of 5 percent. Counter-current slug flow was observed after a large portion of the void had passed through the system for *NFR* < 1.0. Aspects of these observations are addressed in Section 3.4.2.3 of Reference 8, which stated:

> **"The gas transport testing conducted at Purdue University forms the validation basis for the Simplified Equation. This program addressed the transport of gas through piping systems. As such, the flow dynamics at the inlet to pumps was not within the scope of this program. Therefore, any additional limitations that are needed to deal with specific pump inlet concerns will have to be identified as part of a future PWROG project."**

The TR needs to be updated to clearly reflect that it is the user's responsibility to acceptably address phenomena issues associated with the lower horizontal pipe leading to the pump suction when using the simplified equation.

RESPONSE

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. Accordingly, an additional sentence has been added at the end of the second paragraph in the section labeled "Pump Suction Gas Transport" (page 33 of Attachment 4) to reflect additional limitations associated with the use of the Simplified Equation. The result is copied below.

> "Since the Simplified Equation may not apply to all suction piping configurations and pump inlet geometries, it is the user's responsibility to ensure the applicability of the Simplified Equation, as specified in WCAP 17276-P (Reference 5), to the specific piping configuration and to acceptably address all relevant gas transport phenomena."

RAI 2-18

QUESTION

Identify Reference 17 that is not included in the references listed in Reference 3 but is referenced in the report.

RESPONSE
This is a typographical error. Reference 17 (WCAP 17271) was inadvertently included with Reference 16 (FAI/09-130) in the list of references. The reference numbers have been corrected.

RAI 2-19

QUESTION

In Reference 4, Q, the pump flow rate at the fully run-up condition, is not provided. Provide this value.

RESPONSE
89 gpm

RAI 2-20

QUESTION

In Reference 4, the pump shutoff pressure is given on Page 28 as 27 psig and on Page 79 as 18 psig. What is the correct value?

RESPONSE

The pressure measurement in the piping highpoint measures the shutoff pressure at the end of each run. However, this is a high pressure pizeo-electric measurement that is somewhat difficult to read at lower pressure and in those cases with waterhammer, it is being read after the waterhammer. Nonetheless, we have examined the data that we have at the end of the test and a value of 27 psid is a good average for the experimental measurements of the pump discharge head. With a suction side pressure at the pump inlet of approximately 18.5 psia (14.5 psia plus 4.0 ft of water head), the average pump discharge pressure is 45.5 psia.