NEI 09-10 [Rev 1]

Guidelines for Effective Prevention and Management of System Gas Accumulation

December 2010

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Nuclear Energy Institute

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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
- Develop 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 process 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

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ACRONYMS

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
INPO	Institute of Nuclear Power Operation
NRC	Nuclear Regulatory Commission
OE	Operating Experience
PWR	Pressurized Water Reactor
RCP	Reactor Coolant Pump
RCS	Reactor Coolant System
RHR	Residual Heat Removal
SER	Significant Event Report

SIP	Safety Injection Pump
SOER	Significant Operating Experience Report
UT	Ultrasonic Testing
VCT	Volume Control Tank
LOCA	Loss of Coolant Accident
NEI	Nuclear Engergy Institute
HPCI	High Pressure Coolant Injection
HPCS	High Pressure Core Spray
BEP	Best Efficienct Point
SDC	Shutdown Cooling

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 published 20 Information Notices, two Generic Letters, and a NUREG related to this issue and has interacted with the nuclear industry many times in relation to these publications and in response to gas accumulation events. 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.

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 down stream 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 iys function and possibly damaging the pump.

Although gas may not air bind the pump, the pump or associated system can be rendered inoperable/non-functiuonal 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.

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
- 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.

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.

Plants are encouraged to 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.

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, Throtle, 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. For these 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.

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 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:

- Probability of gas intrusion due to known gas generation rates at that location (such as those identified in 12.1).
- Probability 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 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 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 limit for potential gas void locations, the criteria are included in the monitoring procedure, and the as found gas volume is below the design limit.

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 limit 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 Technical Specifications and the station corrective action process as long as appopraite operability evaluations are documented.,

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. **Design Limit** - As used in this document applies to acceptance criteria which has been fully evaluated in the stations design control program and incorporated into applicable station design documentation.

3. **Operating Limit** - As used in this document applies to an acceptance criteria used during the corrective action process for a gas void location(s) that exceed the documented design limit but can be considered operable but degraded.

4. **Dynamic Venting** – The use of high velocity fluid to flush the system of voids that remain following conventional fill and vent activities.

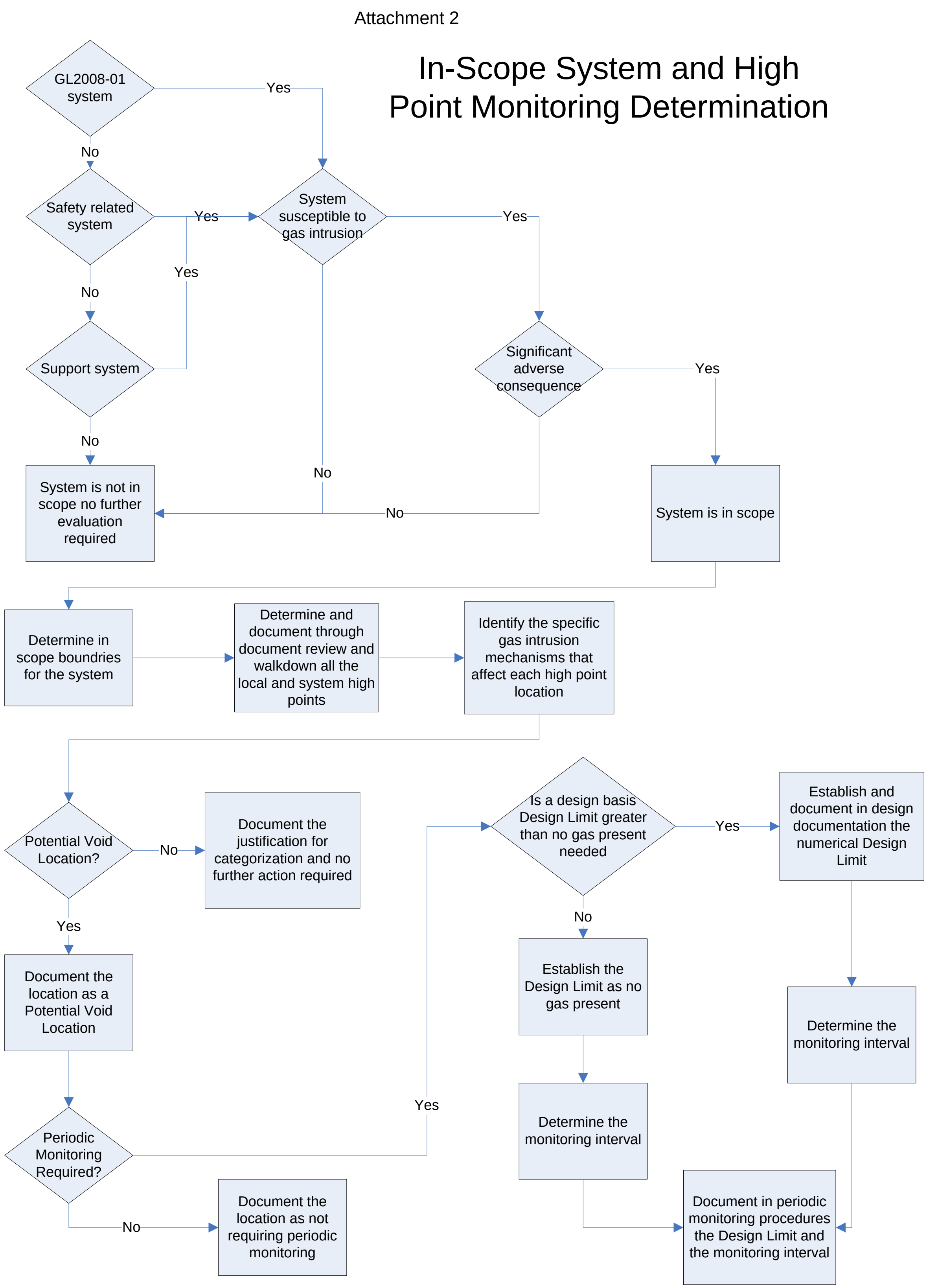
5. **Froude Number** – A dimensionless parameter which is the ratio of inertia force on a gas bubble to gravitational (buoyancy) force.

6. **Gas** – As used within the context of this document, the term includes air, nitrogen, hydrogen, or any other void that is not filled with liquid water.

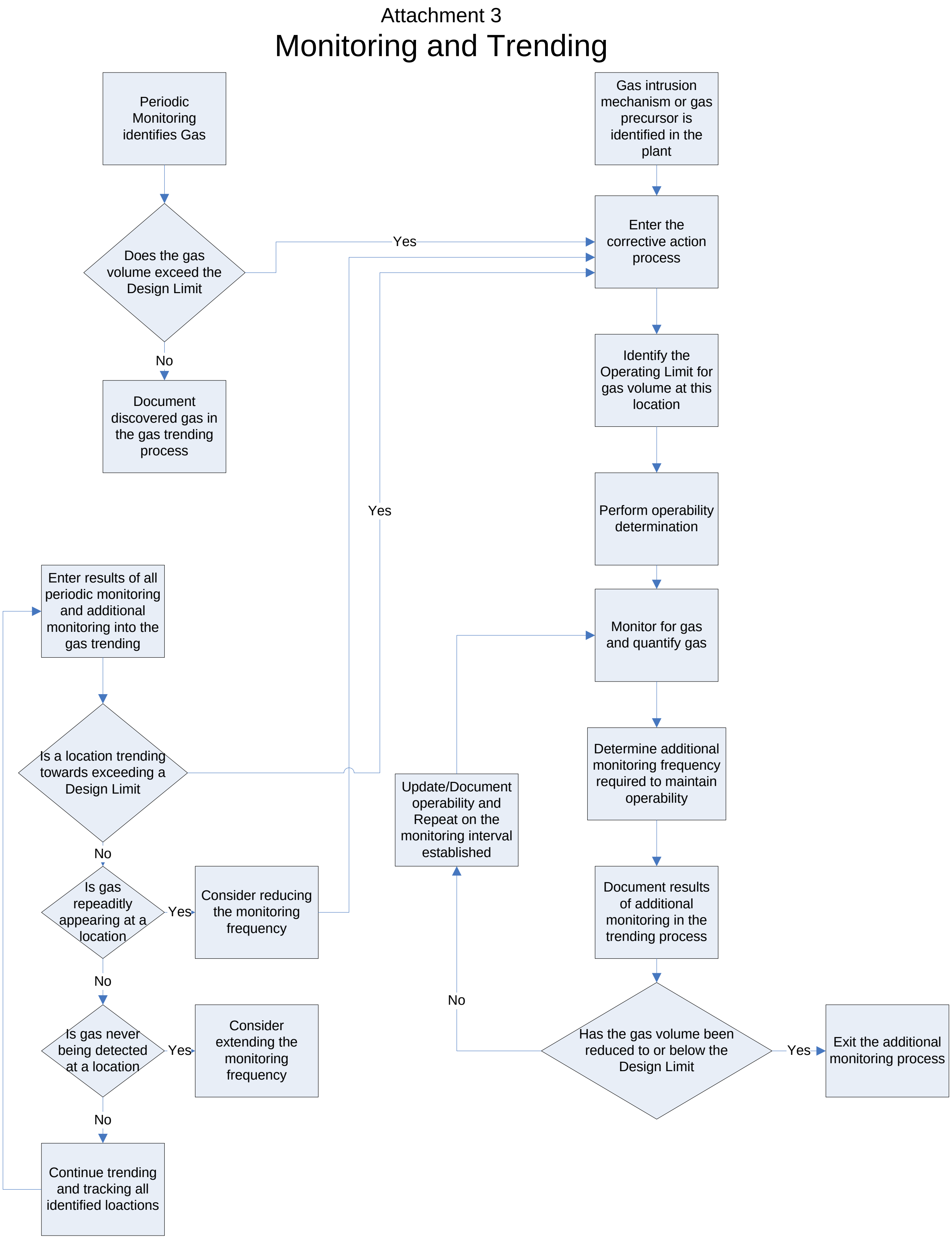
7. **Ultrasonic Testing (UT)** – An acoustic technology where very short ultrasonic pulse-waves are launched into materials to detect internal flaws or to characterize materials. This technology can be used to detect level of the water-gas interface within a piping segment or component.

8. **Void** – As used within the context of this document, the term is used essentially equivalent to “gas”.

Attachment 2



Attachment 3



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 are 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 staff 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.

Gas voids 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. In some cases, the flowrate may be so low as to be insufficient to transport the gas void; low enough that the gas void may be sheared by the flow, or high enough that the gas void may be transported more or less in a homogeneous, or bulk flow manner. All of these effects 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

Test data suggests that gas voids less than 20% will not be transported in piping with Froude numbers less than 0.31 (Reference 17). 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. Although test data is available for several pipe diameters up to and including 12 inches, the dimensionless Froude number can be used to scale these data to all pump suction piping sizes currently in use in the nuclear industry.

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 or HPCS 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 decrease 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). 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.

<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.

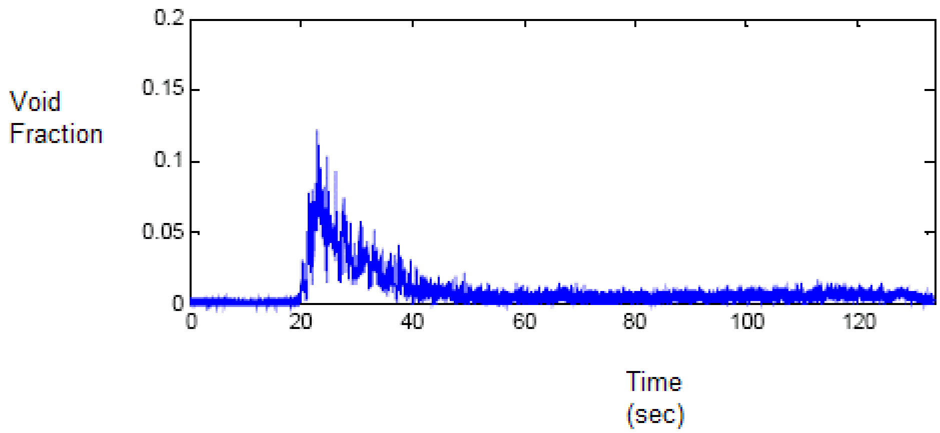
In general, the available test data suggest that pumps with stiff shafts are less sensitive to gas ingestion and capable of accommodating a larger spectrum of loading considerations. On the other hand, flexible shaft pumps are more susceptible to damage and should have more limiting criteria applied. 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.

Much of the testing discussed in open literature and documented in Industry documents was performed within the bubbly flow regime. As the information reviewed was an essential element in the development of the pump criteria, additional clarification in this regard is warranted. It is understood that flows containing large slugs of gas would 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.

The industry pump acceptance criteria have used averaged void fraction to establish the guidance. Based on gas transport testing, the temporal profile of void fraction indicates a peak followed by a rapid decay. This should not be misconstrued as a slug of gas. Rather, as the void is transported to the pump it is to be expected that the void fraction will vary with a tendency to decrease as the gas is forced through the pump. Figure 1 demonstrates this typical behavior.

Figure 1: An Illustration of Typical Void Fraction Transport Time Dependency



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 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 (Reference 17) and analyses (Reference 16) have demonstrated that stratified gas volumes that might be accumulated in a piping highpoint would 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. 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. 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 and further conservatism is not required beyond that already reflected in the pump gas void ingestion criteria discussed below.

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.

Further review by the respective Owners Groups may determine that criteria for pump operation below 70% BEP may not be required, as the conditions are bounded by the set of criteria for the 70%-120% BEP range. 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.

Pump Suction Gas Transport

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. There may be instances in which the Simplified Equation can not be used, for example if a limitation can not be satisfied, or if the results of the Simplified Equation are too conservative for use. 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.

NPSHr for pumps

The Net Positive Suction Head (NPSH) required 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 then 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 highly unlikely that any damage would occur. Detection and resolution of long-term degradation mechanisms such as these is the purpose 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 is expected to be at the beginning of an event, when the pump is automatically started by the plant's ECCS 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.

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 highly 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 is 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) 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 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 provide methodology for determining the impacts of gas in the discharge piping of BWR's. Reference 15 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 typical ECCS 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 are 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 a reduced 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

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