INFORMATION NECESSARY FOR THE OFFICE OF NUCLEAR REACTOR REGULATION TO ASSESS LICENSEE RESPONSES TO GENERIC LETTER (GL) 2008-01

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NOMENCLATURE

BWR	boiling water reactor
CAP	corrective actions program
CLIIP	consolidated line item improvement process
CFR	Code of Federal Regulations
CS	containment spray
CVCS	chemical and volume control system
DHR	decay heat removal
ECC	emergency core cooling
ECCS	emergency core cooling system
GL	generic letter
HPCI	high pressure coolant injection
NRC	Nuclear Regulatory Commission
LPCI	low pressure coolant injection
PWR	pressurized water reactor
PWROG	pressurized water reactor owners group
RAI	request for additional information
RHR	residual heat removal
RV	reactor vessel
RWST	refueling water storage tank
SAT	spray additive tank
SDC	shutdown cooling
SI	safety injection
SR	surveillance requirement
TI	temporary instruction
TRM	technical requirements manual
TSs	technical specifications
TSTF	technical specifications task force
USAR	updated safety analysis report
UT	ultrasonic test
VCT	volume control tank

1.0 INTRODUCTION

GL 2008-01 (Reference 1) was issued to require "that each addressee evaluate its ECCS (emergency core cooling system), DHR system, and containment spray (CS) 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 objectives were to establish that these subject systems would be operable when necessary and were in compliance with the regulations, to address issues where confirmatory action is needed to assure operability and compliance, and to determine if additional regulatory action is required.

To assess the addressee evaluations and appropriate actions, the NRC requested "addressees to submit information to demonstrate that the subject systems are in compliance with the current licensing and design bases and applicable regulatory requirements, and that suitable design, operational, and testing control measures are in place for maintaining this compliance." The NRC further stated that it would "collect the requested information to determine if additional regulatory action is required" and it identified that activities "are being planned as a follow-up to this GL and for guidance in the Technical Specifications (TSs) Task Force program to develop improved TSs."

The NRC staff is reviewing the licensee responses to assess the addressee's:

- determination that there is reasonable assurance that the subject systems are operable under all conditions where they may be needed to mitigate events, and

- confirmatory and other actions to substantiate the above assurance.

The NRC staff has found that many responses are incomplete and additional information is needed to complete the reviews. The purpose of this document is to describe the information necessary to perform a complete review. This will give each licensee the opportunity to assess its nine month response to the GL and to provide any information that is missing, thus alleviating the need for requests for additional information (RAIs) and reducing the resources necessary to address the GL issues.

2.0 REGULATORY EVALUATION

In GL 2008-01, the NRC requested that each addressee evaluate its ECCS, DHR system, and CS 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 GL further requested that each addressee submit a written response in accordance with Title 10 of the Code of Federal Regulations (CFR) Part 50.54(f) within nine months of the date of the GL to provide the following information:

- A description of the results of evaluations that were performed pursuant to the above requested actions. This description should provide sufficient information to demonstrate that the addressee is or will be in compliance with the quality assurance criteria in Sections III, V, XI, XVI, and XVII of Appendix B to 10 CFR Part 50 and with the licensing basis and operating license as those requirements apply to the subject systems;

- A brief description of all corrective actions, including plant, programmatic, procedure, and licensing basis modifications that the addressee determined were necessary to assure compliance with these regulations; and,

- A statement regarding which corrective actions were completed, the schedule for completing the remaining corrective actions, and the basis for that schedule.

3.0 TECHNICAL EVALUATION

3.1 Subject Systems

Where voids are a potential concern, the subject systems should be identified in each licensee response. This would typically include the following pressurized water reactor (PWR) systems:

- Borated Refueling Water Storage System with respect to potential interactions with the ECCS

- Chemical and Volume Control System (CVCS) with respect to potential interactions with the ECCS

- CS System

- Residual Heat Removal (RHR), DHR, or Shutdown Cooling (SDC) System. Different licensees use different designations. Configurations typically include reactor vessel (RV) cold leg and hot leg injection, suction from the RCS, and containment emergency sump.

- Safety Injection (SI) System or ECCS. This typically includes charging pumps, high pressure coolant injection (HPCI) system, low pressure injection (LPI) system, and SI accumulators where different licensees use different nomenclature that is not listed in this report for the same function.

Typical boiling water reactor (BWR) systems include:

- Core Spray

- High Pressure Coolant Injection (HPCI)

- RHR. Functions typically include suppression pool cooling, shutdown cooling, containment spray, containment cooling, decay heat removal, alternate decay heat removal, drywell / wetwell spray, suppression pool spray, ECCS keepfill, torus spray, and low pressure core spray, depending upon the plant and the licensee’s designation of the system functions.

- Other components of the ECCS

Addressing potential void concerns in support systems, such as component cooling water and service water, and in other systems that are important to safety, such as the auxiliary cooling system, are outside the scope of this GL and reporting void-related activities related to these systems is not required. However, licensees are expected to have programs in place to address these systems.

3.2 Historical Background

Addressing this topic is not necessary for purposes of the NRC staff assessment since a principal objective is to address the post-GL status. However, the NRC staff will summarize such information if it is provided and it provides insight into plant conditions that may exist at other plants.

3.3 Licensing Basis

3.3.1 Licensing Basis Documents. Identified licensing basis documents include TSs, TS Bases, the updated safety analysis report (USAR), the Technical Requirements Manual (TRM), TRM Bases, responses to NRC generic communications, regulatory commitments, and operating license conditions. Additionally, Appendix B to Part 50, "Quality Assurance Criteria for Nuclear Power Plants," Criterion V, "Instructions, Procedures, and Drawings," states:

> Activities affecting quality shall be prescribed by documented instructions, procedures, or drawings, of a type appropriate to the circumstances and shall be accomplished in accordance with these instructions, procedures, or drawings. Instructions, procedures, or drawings shall include appropriate quantitative or qualitative acceptance criteria for determining that important activities have been satisfactorily accomplished.

Thus, any item that is credited in the assessment of whether the subject systems are reasonably ensured to be operable must be captured in the licensing basis. Therefore, such documents as instructions, procedures, drawings, analysis techniques, vendor documentation, and any other documents that provide information that affects operation, are part of the licensing documentation. Note also that appropriate quantitative or qualitative acceptance criteria are included. In general, the NRC staff will consider that such documents have been acceptably discussed if they, and acceptance criteria, are identified and discussed in the licensee responses consistent with the coverage described in the remainder of this NRR guidance document. It is not necessary that the identification and discussion be located in a specific part of the response.

3.3.2 TSs and TS Bases. Coverage of the subject systems provided by TSs and TS Bases, such as TS Surveillance Requirements (SRs) and clarification of the meaning of "full of water" should be summarized, and any changes in TSs or TS Bases accomplished after January 11, 2008, should be described and justified. Areas not adequately addressed by TSs and TS Bases, such as failure to provide SRs for ECCS suction piping and failure to accomplish a void assessment at high points that are not equipped with a vent, should be identified and the process of ensuring adequate coverage should be identified. For example, the NRC staff will accept use of the TRM, procedures, and similar documents to address areas that are not adequately covered in TSs provided that the acceptance criteria are acceptably described in the licensee's GL response. Further, the NRC staff will accept venting, ultrasonic tests (UTs), or other acceptably justified means of determining void volumes to supplement TS SRs, but substitution of a different method of assessing voids cannot be substituted for a TS SR that requires venting without a TS amendment.

The NRC has concluded that "when voids are discovered in piping, if the licensee can establish … that there is a reasonable expectation that the system in question will perform its specified safety function, the system piping can be considered filled with water such that the surveillance requirement is met" (Reference 2). This establishes that a TS SR that a system be "full of water" is consistent with the statement that voids are acceptable as long as the voids do not jeopardize operability, in contrast to a statement that a system be "water solid" which would preclude the presence of voids. Thus, reference to a process such as a procedure that requires acceptable surveillances to establish meeting acceptable void criteria will satisfy a TS SR until generic guidance is generated as discussed in Section 3.3.4.

With respect to void criteria, meeting the NRR criteria provided in the Attachment is acceptable without further justification. Deviations from the criteria must be acceptably justified. Use of the industry criteria provided in Reference 3 for pump damage is not acceptable because system operability can be lost without damaging pumps.

TS SRs often include a qualification that limits the SR to accessible locations and "accessible" is not defined. Licensees have often applied this to areas that are posted as radiation areas when there was no significant radiation or other hazard associated with conducting the surveillance. This is not acceptable. The NRC staff will generally accept that locations inside containment are not accessible during power operation. Other locations, such as selected pipe chases and posted high radiation areas, may be considered inaccessible when an acceptable justification, such as radiation level or a high temperature hazard, exists. In such cases, due consideration must be given to accessibility and conducting surveillances when the plant or system is shut down. Note, however, that inaccessibility cannot be used as a reason for not performing a surveillance if the surveillance is necessary to reasonably ensure operability. In such cases, a hardware change may be necessary.

There is typically no TS SR to verify that PWR CS piping inside containment be full of water since this piping does not need to be filled for the CS system to be operable. However, if there are potential water traps in the piping that could result in a water hammer concern, then this should be addressed as part of the void assessment process.

The NRC staff will also expect coverage of more frequent surveillances than required by TSs if necessary to ensure subject system operability. In the short term until generic TS guidance is prepared as identified in Section 3.3.4, it is acceptable to supplement such shortcomings or to supplement TS requirements by alternate means such as procedures that contain acceptance criteria when the total coverage is sufficient to reasonably ensure subject system operability.

3.3.3 The USAR. The licensee's review of the USAR should be summarized. Any changes should be identified in Section 3.6.2 and discussed in more detail here if such detail is needed to describe the actions. Planned changes should be entered into the corrective action plan (CAP) and identified in Section 3.6.3.

3.3.4 Technical Specifications Task Force (TSTF). The NRC staff expects commitments to monitor the industry resolution of the gas accumulation TS issues and, within no greater than one year following NRC approval of the TSTF or consolidated line item improvement process (CLIIP) Notice of Availability, to submit a TS amendment request, as appropriate, that is consistent with resolution of the generic changes process. This should be addressed in Section 3.6.3 and, optionally, additional information can be provided in this section.

3.4 Design Evaluation

3.4.1 Documentation.[1] The licensee should summarize its review of such design basis documents as calculations, engineering evaluations, vendor technical manuals, and other documents. The results of reviewing such documents as engineering procedures and other non-design basis documents should also be summarized. Deficiencies and follow-up actions to address the deficiencies should be described. The CAP that addresses incomplete actions should be identified and a corresponding completion schedule should be provided in Section 3.6.3.

3.4.2 Potential Gas Intrusion Mechanisms. Where applicable to the plant design, potential sources of gas and associated void monitoring and control actions which may include the following should be described:

- SI Accumulators. SI accumulator level and pressure monitoring, discharge piping pressure, suction piping pressure, and refueling water storage tank (RWST) level; and response action if a pre-determined change occurs.

- RCS. Monitoring as identified above for the SI accumulators.

- Dissolved gas coming out of solution due to pressure reduction through piping components. Monitoring and control processes such as surveillance procedures and venting should be summarized here or by reference to Section 3.5 where the topic is addressed.

- Containment Emergency Sump. Pipe slope from the sumps toward the ECCS pumps with respect to gas movement in the piping between the sump and isolation valves, the potential for gas to be trapped between valves, potential vortex formation and its effect, and potential steam and gas formation as water passes through the strainers and the potential transport into the pipes should be addressed.

- RWST. RWST level monitoring and operating procedures should be described with respect to controls to prevent air entrainment into the subject system piping.

- Level Instrumentation Error. Level instrumentation failure should be addressed with respect to prevention of gas intrusion from such sources as the RWST, volume control tank (VCT), spray additive tank (SAT), and the containment emergency sump supply water to the subject system pumps.

- Valve Leakage. Several potential concerns should be addressed, including (1) monitoring and control of gas due to leakage through isolation valves or through check valves that could potentially result in outgassing due to a pressure decrease and gas transport to other locations, (2) leakage through vent valves when the local system pressure is less than the nominal atmospheric pressure, and (3) leakage of pressurized air from the valves into the subject system piping if valve design permits a leakage path such as may be possible in some diaphragm valves.

- Operations. Gas concerns associated with system and plant shutdown, restart, and maintenance should be addressed.

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[1] Operating procedures, the CAP, and certain other documents are addressed in Sections 3.5 and 3.6.

3.4.3 Gas Volume Acceptance Criteria Versus Location. Typical potential gas accumulation locations that should be considered include:

- Highest locations as shown on applicable documentation.
- Local high points resulting from an erection tolerance of ± 1.0 inches of nominal.
- Traps between two valves in horizontal pipes that do not have an adequate vent between them, such as an isolation valve and a check valve in series.
- Normally closed valves, including check valves.
- Local high points such as in heat exchangers, valve bodies, and vertical piping to relief valves.
- Pipe diameter changes.
- Orifices.

Void acceptance criteria should be stated and justified for all potential gas accumulation locations. Criteria that are outside the Attachment bounds must be acceptably justified, such as by summarizing void movement analysis methodology with references to how the methodology has been verified. Note that the NRC staff will accept the Attachment criteria without justification. Note also that the Attachment criteria will be upgraded when justified by new information.

3.4.4 Pump Acceptance Criteria. Pump entrance void acceptance criteria should be stated. Justification should be provided if the criteria differ from the Attachment criteria. A commitment or a reference to a plant-specific document that describes the licensee's plan for addressing information that is obtained from the long-term industry tasks should be provided and addressed in Section 3.6.3.

3.4.5 Pipe and Instrumentation Drawing (P&ID) and Isometric Drawing Reviews. The as-built plant configuration should be compared to the P&ID and isometric drawings and any drawing errors should be entered into the CAP.

3.4.6 Walkdown Acceptance Criteria and Completed Walkdown Results.

Walkdowns conducted to address the following should be described, any discrepancies should be identified, and corrective actions should be identified to correct any discrepancies:

- Verify that each vent is installed and configured as shown on the design drawings.
- Verify the configuration of vent valves installed since GL 2008-01 was issued.
- Measure, or estimate in inaccessible areas, the distance on the pipe from the centerline of a nearby fitting (elbow, tee, etc.) to the centerline of the vent valve pipes using an acceptance criterion for identifying discrepancies from the design drawings of ± 1 inch.
- Perform a visual examination (no direct measurement) to determine if each vent is located at the top center of the pipe.

Dimensions and determination of the configuration of insulated pipe should be evaluated by removing a portion of the insulation or otherwise obtaining sufficient insulation thickness measurements that the position of the pipe and components inside the insulation is acceptably established or, if these are not practical, by applying acceptable judgment that the pipe and component dimensional relationship to the outside of the insulation is known.

The following selection criteria are acceptable with respect to obtaining dimensional data for the subject systems:

- Any straight 10 feet or longer piping run.
- Any piping run that has a vent.
- Any horizontal run that has a reducer, reducing tee, valve, or line size change on the same elevation.
- Any 10 feet or longer run made up of segments connected by elbows or fittings.
- For any run with a tee, such that if the tee run segment lengths are added to the pipe length, the total is over 10 feet.
- Any pipe 4 inches or greater nominal pipe size of any length.
- The section of any vertical pipe 1 inch or greater nominal pipe size that is located below a valve that may be closed when in operation so that gas can be trapped below the valve.

Deviations from these criteria should be justified.

A number of methods are acceptable for obtaining dimension data, including use of transits, levels, scales, and laser metrology.

Parts of the subject systems that are not covered by walkdowns should be identified and omission of walkdown coverage should be justified.

3.4.7 Incomplete Walkdowns. Walkdowns that remain to be accomplished should be described. Section 3.6.3 should be used to identify plant documentation that ensures the walkdowns will be accomplished and to provide a completion schedule.

3.4.8 Hardware Modifications Accomplished. Hardware modifications accomplished in response to the GL should be identified in Section 3.6.2. It is not necessary to provide detail. Section 3.4.8 may optionally be used to provide more information.

3.4.9 Incomplete Items and Completion Schedule. Section 3.6.3 should be used to identify remaining modifications and the plant documentation that ensures the modifications will be accomplished, and to provide a completion schedule. It is not necessary to provide detail. Section 3.4.9 may optionally be used to provide more information.

3.5 Testing Evaluation

3.5.1 Overview of Procedures. A sufficiently detailed summary of procedures is expected for the NRC staff to assess coverage and to provide an NRR assessment report that the NRC inspectors can reference while conducting inspections under Temporary Instruction (TI) 2515/177.

Procedure verification should be described, such as review including actual plant walkdowns or by use of isometric drawings that have in turn been verified by walkdown results. Verification should consider the effect of pipe slopes in nominally horizontal pipes in addition to the items identified in Section 3.4.7. Completed procedure improvements and any new procedures that resulted from the review process should be listed in Section 3.6.2 and should be summarized here if the Section 3.6.2 listing does not identify the changes in general terms. Procedure changes that are planned should be listed in Section 3.6.3 and should be summarized here if the Section 3.6.3 listing does not identify the changes in general terms.

The NRC staff expects coverage of (1) surveillance procedures, (2) fill and vent procedures, and (3) operating procedures such as initiation and steady state system operation when there is a potential for gas to affect operation.

3.5.2 Surveillance Procedures.[2]

The preferred approach is to minimize or eliminate gas whenever identified. If this is impractical or clearly unnecessary, it is acceptable to implement actions to reasonably ensure gas will not jeopardize system operability until the next scheduled surveillance.

An acceptable summary of surveillance procedures would typically cover the following items:

- List applicable procedures, administrative controls if they add to coverage, and operating modes to which they apply.

- Describe surveillance coverage and frequency, identify piping locations that are not included in scheduled surveillances, and justify the excluded locations with respect to achieving a reasonable assurance of system operability. A broad identification of surveillance locations and methods is acceptable, such as all suction pipe high points vented via vents or that UTs are used where vents are not installed, etc.

- Where venting is accomplished, briefly describe how volumes are determined and provide estimated void volume determination uncertainty. In general, approximate methods of determining void volume are acceptable if the expected void volume is far removed from the acceptance limit. If a void volume is anticipated that may approach the acceptance limit because of such behavior as changing SI accumulator level or pressure or other anomalous behavior, then it may be necessary to provide a more accurate determination. Note that void pressure should be considered when assessing voids and acceptance criteria. If the pressure may decrease from the as-measured condition, such as during a pump start transient or during system operation, then the void volume will increase.

- Re-performance of UT / venting at locations where gas may accumulate during venting at other locations should be conducted to (1) verify gas was removed after venting and

[2] Surveillances required by TSs and other surveillances required during various operating conditions, including shutdown operation, are to be addressed in this section.

(2) to ensure gas was not transported into a high point that was previously found to be gas-free. If the procedure is designed to prevent such gas transport, this should be identified and the conclusion justified.

- Post-surveillance activities, such as gas volume trending and response to failure to meet void acceptance criteria, should be described.

- Instructions for sampling and chemical analysis of accumulated gas should be described.

Typical procedures may include the following actions:

- If gas is identified:

    - determine gas volume[3], and
    - notify the on-duty licensed Senior Reactor Operators, and
    - initiate a corrective action document and notify Engineering

- If gas volume is greater than the pre-determined acceptable volume for that location:

    - enter Condition / Required Action for inoperable system
    - vent gas and / or take other measures to re-establish operability and to comply with operability requirements
    - sample / analyze gas, and / or
    - determine source of gas, and / or
    - determine fix for source of gas[4], and / or
    - track and trend accumulated gas, and / or
    - determine any change of frequency of inspection – this should take into account the potential void increase until the next surveillance

3.5.3 Fill and Vent Procedures.

Many of the Section 3.5.2 items apply to fill and vent procedures as well. In addition, the following should be identified as appropriate:

- Venting or back-filling of instrument lines including controls or procedures that apply.

- Measures to guard against gas intrusion because of inadvertent draining, system realignments, incorrect maintenance procedures, or other evolutions.

- Use of clearance orders or other processes to establish boundaries to effectively isolate the portions of systems impacted by maintenance activities. Note the next high point location beyond a clearance order boundary should be checked to ensure piping that should have been unaffected by the maintenance activities is full.

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[3] A conservative approach is to vent or otherwise remove any accumulated gas.

[4] If the void accumulation rate requires an increased surveillance frequency with respect to the routine SR, a root cause analysis should be accomplished and a CAP established to correct the problem.

- The process for controlling / revising work packages due to change in maintenance work scope, including review and reauthorization of the package and any new temporary procedures.

- The post-maintenance recovery, review, and approval process should be summarized.

3.5.4 Operating Procedures. Procedures and administrative controls that were not discussed in Sections 3.5.2 and 3.5.3 should be discussed here. This may include, for example, monitoring of pump operation in all modes and specialized monitoring of appropriate plant parameters during shutdown operation, including reduced inventory and mid-loop operation for PWRs.

3.6 Corrective Actions

3.6.1 Interim Coverage of TS Inadequacies to Meet Appendix B Requirements. Supplementary actions, such as use of procedures and other processes to address control of voids in the subject systems that are not covered by TS requirements, should be identified. Reference to other sections in the report are sufficient.

3.6.2 Completed Corrective Actions.

Completed corrective actions, including such items as hardware modifications and procedures improvements, should be listed. The NRC staff suggests using a table that identifies the CAP and that includes a brief description. It is not necessary to provide detail.

3.6.3 Incomplete Items, Completion Schedule, and Commitments.

Remaining modifications and such items as completing walkdowns should be identified, the documentation that ensures the items will be accomplished should be identified, and a completion schedule should be provided. The NRC staff suggests using a table that identifies the CAP and includes a brief description. It is not necessary to provide detail.

3.7 Training

Training was not identified in the GL but is considered to be a necessary part of applying procedures and other activities when addressing the issues identified in the GL. Training should be briefly discussed and included in the Section 3.6 items.

4.0 CONCLUSIONS

This section should summarize why the above information is sufficient to support a conclusion that the subject systems are reasonably assured to be operable whenever needed.

5.0 REFERENCES

1 Case, Michael J. “NRC Generic Letter 2008-01: Managing Gas Accumulation in Emergency Core Cooling, Decay Heat Removal, and Containment Spray Systems,” Letter from Director, Division of Policy and Rulemaking, Office of Nuclear Regulation, NRC, ML072910759, January 11, 2008.

2 Wert, Leonard D., Jr., “Task Interface Agreement – Emergency Core Cooling System (ECCS) Voiding Relative to Compliance with Surveillance Requirements (SR) 3.5.1.1, 3.5.2.3, and 3.5.3.1 (TIA 2008-03),” NRC Memorandum from Director, Division of Reactor Projects, Region II, ML082560209, October 21, 2008.

3 Beaulieu, David P., “Summary of the September 4, 2008, Category 2 Public Meeting with the Nuclear Energy Institute to Discuss NRC Generic Letter 2008-01, ‘Managing Gas Accumulation In Emergency Core Cooling, Decay Heat Removal, And Containment Spray Systems,’” NRC Memorandum, ML082770088, October 6, 2008.

ATTACHMENT

REVISION 1 TO NRC STAFF CRITERIA FOR GAS MOVEMENT IN SUCTION LINES AND PUMP RESPONSE TO GAS

I INTRODUCTION

This document provides acceptance criteria that the NRC staff may apply to assessment of the subject topics in such documents as responses to GL 2008-01 and licensee functional and operability evaluations. This is not an all-inclusive document. Subjects not addressed below, such as gas in pump discharge piping, are important and should be addressed when they arise.

Revision 1 addresses information received since the original criteria were provided in References 1 and 2 and it includes editorial changes to better describe the subject. As discussed in the original version, the criteria are believed to be conservative and, if the items being investigated are bounded by the criteria, then the items may be accepted by NRC staff members without further justification. Less conservative criteria may also be used if acceptable justification is provided. Industry is continuing to investigate GL issues pertaining to gas movement and pump response and future revisions to these criteria are anticipated as new information is obtained.

II CHANGES INCORPORATED INTO REVISION 1

1. Changed Item 1 in the Interim Gas Movement Criteria table from being applicable to a pipe diameter, D, from ≤ 3 inches to ≤ 8 inches on the basis of new understanding addressed in the Reference 3 tests. The remainder of the document is changed to be consistent.

2. Added qualifications to the tabulated criteria to address multi-dimensional flow configurations

3. Added qualifications to the tabulated criteria to exclude slug flow since available information indicates slug flow can cause immediate pump damage.

4. Corrected the transient times of void fractions of 100% and 50% in comparisons to the pressurized water reactor owners group (PWROG) acceptable average value of 20%.

5. Incorporated Reference 3 discussion of behavior as a function of Froude number (N_{FR}).

6. Included Flowserve information in discussion of pump response to gas.

III NRC STAFF CRITERIA FOR GAS MOVEMENT IN SUCTION LINES AND PUMP RESPONSE TO GAS

Criteria the NRC staff will accept without further justification for transport of gas into an emergency core cooling system (ECCS) pump are:

Table 1. Interim Gas Movement Criteria		N_{FR}
1.	Gas is not transported down a vertical pipe if Φ ≤ 20% at the top of the pipe and D ≤ 8 inches.	≤ 0.3

Table 1. Interim Gas Movement Criteria		N_{FR}
2.	Gas is not transported out of a nominally horizontal pipe under steady state conditions if the water is in the bottom of the pipe and $\Phi \leq 50\%$ at the pipe exit.	< 0.4

where: D = pipe diameter
Φ = average volumetric gas fraction measured in a plane perpendicular to the pipe centerline

$$N_{FR} = V \left[D\, g_c \left(\rho_L - \rho_g \right) / \rho_L \right]^{-1/2}$$

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

These criteria are not applicable to configurations where an equivalent diameter is applicable, such as in an annulus, because it may be necessary to consider both the liquid and the gas when calculating N_{FR}. Further, with the exception of pipes with a circular cross section and elbows that connect between horizontal and vertical pipes, the criteria do not be apply to geometries where the velocity is not single dimensional throughout the geometry because experimental data have not been provided to substantiate the criteria.

Criteria the NRC staff will accept without further justification for not jeopardizing operability of an emergency core cooling pump (ECCS) pump are:

Table 2. Pump Operation Interim Criteria		Allowable Φ
1.	Steady state (> 20 sec following initiation of gas ingestion) with $40\% \leq Q/Q_{BEP} \leq 120\%$	2%
2.	Steady state with $Q/Q_{BEP} < 40\%$ or $>120\%$	1%
3.	Maximum during 5 second transient with $70\% \leq Q/Q_{BEP} \leq 120\%$ and slug flow does not occur	10%
4.	Maximum during 5 second transient with $Q/Q_{BEP} < 70\%$ or $>120\%$ and slug flow does not occur	5%
5.	Head reduction is negligible if steady state and $80\% \leq Q/Q_{BEP} \leq 110\%$	2%

where: Q = water volumetric flow rate
BEP = best efficiency point.

The acceptance criteria are based on available information and include conservatisms in recognition that the available data are limited and, in some cases, non-existent. This is particularly true of transient conditions that often will present the most challenge to pump operation. In some cases, meeting the criteria will be straightforward. For example:

- One criterion addresses flow rates that are small enough that gas will not be swept downward in a pipe leading to the pump suction. Meeting this criterion when the pump is initially full of water[5] leads to the conclusion that there is no concern since no gas will be carried into the pump from the suction line. A pump flow rate corresponding to flow in the miniflow line will often satisfy this criterion. If pump flow rate then increases slowly, the gas at the pump inlet may consist of small bubbles and the rate of gas movement into the pump may be small enough for the suction line gas to be cleared without significantly affecting the pump.

- Another criterion applies to a pump that develops a flow rate sufficient to sweep gas into the pump when Φ exceeds acceptance criteria that were derived from pump damage considerations. In this case the pump must be assumed lost due to presumed physical damage unless the licensee can substantiate that the criterion is overly conservative for the existing conditions.

In other cases, the assessment will present more challenges. For example, consider an ECCS pump that is initially full of water that is injecting into the reactor coolant system (RCS) at a known pressure. An initial prediction of flow rate can be determined from a flow rate versus developed head curve[6] that applies to a $\Phi = 0$ condition by calculating discharge pressure at the pump as the sum of RCS pressure and downstream differential pressure where the latter is a function of flow rate. But if this predicted flow rate will cause gas to enter the pump from an upstream gas volume, the flow rate versus developed head curve will be affected and the developed head will be less than previously determined. Using the new developed head value will result in a reduction in predicted flow rate. An iterative process results to obtain convergence of Φ and flow rate. Simultaneously, pump net positive suction head (NPSH) criteria are affected by gas entering the pump and by gas in the suction line. NPSH criteria must continue to be met for the pump to be considered operable.

There is significant scatter in information used to correlate gas transport and a number of different flow regimes can occur in suction piping depending upon Φ, pipe orientation, flow rate, and pipe size. Further, licensees typically determine gas volumes without considering measurement uncertainties. These volumes are then used in determining the influence of Φ and gas location on pump operability. In consideration of this background, the NRC staff has incorporated selected conservatisms in its acceptance criteria as discussed below.

The $N_{FR} \leq 0.3$ criterion in Table 1 is almost a factor of 3 less than the value sometimes used by licensees although it is close to the < 0.35 provided by Reference 3 for gas remaining trapped in the pipe at the first elbow leading to the vertical pipe. Further, at < 0.35, Reference 3 states that bubbles will remain suspended in the upper portion of the vertical pipe. The 0.3, rounded from 0.31, was taken from Simpson's publication in Chemical Engineering (June 17, 1968) that is referenced in numerous other publications as a value to reasonably ensure that significant quantities of gas will not be transported downward in a vertical pipe. The $D \leq 8$ inches criterion

[5] The NRC staff will consider that a pump is full of water if the gas volume within the pump is less than 5% before it is started. A pump that initially contains a larger gas volume will be considered to be inoperable.

[6] Pump characteristic curves may be based on conservative assumptions to bound 10 CFR 50.46 requirements. Such curves may not be applicable here. For example, a conservative curve may provide a smaller flow rate than actual which may, in turn, cause predicted Φ at the pump inlet to be too small. Conversely, use of a flow rate that is too great may cause the gas to move through the system more rapidly and may move the applicable acceptance criterion from the steady state to a transient condition where Φ may be found acceptable as opposed to a smaller allowable Φ in the steady state.

is based on potential non-applicability of N_{FR} to larger diameter pipes, a restriction that is not mentioned in industry guidance that was discussed with the NRC staff during the Nuclear Energy Institute's (NEI's) meeting on September 4, 2008 (ML082770088). However, industry is conducting testing in larger diameter pipes to obtain data and develop a better understanding of behavior and the N_{FR}, D, and Φ may change when the new information becomes available. The $\Phi \leq 20\%$ criterion is to ensure that water does not drop in a waterfall configuration into a vertical pipe where momentum might carry gas to the bottom of the vertical pipe. The $N_{FR} < 0.4$ criterion is roughly 25% smaller than typically used to assess horizontal flow to account for gas volume determination uncertainty and to provide conservatism. The NRC staff notes that Reference 3 states that $N_{FR} > 0.55$ will cause a pipe to run full if discharge is to an empty plenum and that $N_{FR} = 0.55$ may not be sufficient to purge all gas out of a local high point. The $\Phi \leq 50\%$ criterion at the pipe exit is to ensure that there is a layer of water in the bottom of a horizontal pipe where it meets a vertical pipe that includes consideration of a decrease in level as water flows along the horizontal pipe and to account for transient variation in flow along the pipe during startup or changing conditions. Additional data and analysis will be necessary to assess gas movement for $\Phi > 20\%$, D >8 inches, or larger N_{FR}, although the NRC staff believes larger Φ's in pipe diameters larger than a few inches may be reasonable if the vertical pipe is long enough to justify that local effects at the top of the pipe no longer affect the behavior.

The 2% steady state value in Item 1 of Table 2 is consistent with the PWROG and boiling water reactor owners group (BWROG) Reference 4 values with the exception that the NRC staff uses a restriction of $40\% \leq Q/Q_{BEP} \leq 120\%$ in recognition of the increasing impact of Φ when Q is not close to Q_{BEP}, examples of which are provided in NUREG/CR-2792 that in some cases result in greater than a factor of two reduction in developed head[7]. Other industry information states that $\Phi = 2\%$ is inappropriate for some conditions. The 1% in Item 2 is generally consistent with that information, although there is some information that identifies a concern that gas can accumulate in some pumps over time with $\Phi < 1\%$.

For transients, the PWROG assumes an average Φ can be used over a time that varies from 5 seconds to 20 seconds with average values of Φ that vary from 5% to 20% depending upon the pump. For the largest values, this would allow $\Phi = 100\%$ for 4 seconds or $\Phi = 50\%$ for 8 seconds if $\Phi = 0$ for 16 or 12 seconds, respectively. Large values of Φ would also be permitted for other times and other maximum allowed values of Φ. The BWROG criterion is $\Phi = 10\%$ for 5 seconds, which agrees with the PWROG criterion for flexible shaft multi-stage pumps although large short-term Φs are still permitted since an average Φ is used. There are also references to large gas slugs causing fatigue cracking or pump seizure, as discussed below. The NRC staff does not accept that large Φs are realistically acceptable unless substantiated by data and, therefore, the NRC staff will use maximum values of Φ, not averages, when applying the Table 2 Items 3 and 4 criteria.

The PWROG provides a criterion of $\Phi = 10\%$ for 5 seconds for a multi-stage flexible-shaft pump with the limit due to possible air binding of the first impeller that was identified by Flowserve. The PWROG limit is 20% for 20 seconds for a stiff shaft multi-stage pump. The NRC staff does not understand why the first criterion should not apply to the stiff-shaft pump as well although there may be reasons for this such as, for example, the number of impeller vanes and the vane configuration.

Flowserve, in Appendix F to Reference 3, addressed gas handling capacity of the Pacific Model JTCH high pressure safety injection (HPSI) pumps used at Indian Point 2. It stated that, for

[7] Developed head must be assessed separately as discussed later in this report.

bubble flow, performance degradation would begin at Φ = 2% and that the pump could handle up to 5% without distress. At Φ = 20%, it stated there was a good chance the pump would lose prime and run gas-bound. It did not recommend operation with Φ > 5%. It also stated that slug flow was more serious and, if the slug was large enough to gas-bind the pump, pump seizure would be almost immediate. Further, if the slug was small enough to be swept through the pump, it would cause hydraulic unbalance with possible contact between the wear rings. It was not aware of any data applicable to slug flow.

Arizona Public Power data indicate that substantial Φs can be tolerated for some time in their HPSI pumps provided the flow rate remains high and the gas is suitably distributed at the pump inlet. Flow rates substantially lower than the BEP were not investigated and the licensee assumed the pumps would not be operable if low flow rates were encountered while Φ was large.

Since the uncertainty of flow characteristics entering a pump has not been established, data are limited, and pump behavior is not sufficiently understood, the NRC staff has elected the conservative approach of using the owners group's minimum Φs[8] and times for 70% ≤ Q/Q_{BEP} ≤ 120%, and has reduced the allowable Φ to 5% for Q/Q_{BEP} < 40% or >120%.

The NRC staff has not differentiated between pumps in selecting the above criteria, in part because of the lack of data. The NRC staff notes that the PWROG provided Φ = 5% for 20 seconds for a single stage pump whereas the NRC staff stipulates that slug flow is not acceptable and uses 10% for 5 seconds or 5% for 5 seconds depending upon Q/Q_{BEP}. The NRC staff judges these selections are reasonable in light of the shortened times and the Flowserve information identified above.

The Table 2 criteria are based on a combination of potential pump damage and flow characteristics considerations, including such behavior as oscillatory flow rates at some values of Φ. However, other assessments are also necessary to establish pump operability. Head degradation and NPSH must be assessed to confirm that the Φ limits are acceptable because Φ > 0 may (1) reduce the developed head, (2) reduce the available NPSH, and (3) increase NPSH required by the pump. Either the smaller of the tabulated Φs or the value of Φ that does not reduce flow rate below an acceptable value is to be used for an acceptance determination.

The NPSH required for an air / water mixture can be calculated from the NUREG/CR-2792 equation that was selected by some in industry for this purpose:

$$NPSH_{Req} = NPSH_{Req\ for\ liquid}\ [\ 1 + 0.5\ \Phi\ ]$$

where $\Phi \le 2\%$. Although the correlation is based upon meager data, it includes a substantial conservatism.

As identified in Table 2, head reduction due to gas may be assumed negligible if steady state exists, Φ ≤ 2%, and 80% ≤ Q/Q_{BEP} ≤ 110%. If outside of these criteria, the head reduction must be assessed with respect to both Φ and the impact of operating outside the Q/Q_{BEP} range since such operation can result in a significant reduction in developed head.[9] Further, the actual

[8] The NRC staff will use maximum values of Φ, not averages, as previously discussed.
[9] The NRC staff has seen correlations that predict head reduction as a function of Φ and that do not consider the effect of Q/Q_{BEP}. These correlations are not acceptable when operation is outside of the stated range.

NPSH available at the pump suction should be calculated to take into account the inlet pressure reduction associated with gas in pipe sections upstream of the pump.

REFERENCES

1. Beaulieu, David P., “Forthcoming Meeting With The Nuclear Energy Institute (NEI) To Discuss NRC Generic Letter 2008-01, ‘Managing Gas Accumulation In Emergency Core Cooling, Decay Heat Removal, And Containment Spray Systems,’” NRC Memorandum, ML083250536, November 21, 2008.

2, Generic Letter (Gl) 2008-01: NRC Staff Criteria For Gas Movement In Suction Lines And Pump Response To Gas, Draft, November 18, 2008. (Provided as Enclosure 2 of Reference 1.)

3. Preliminary Assessment of “Testing And Evaluation of Gas Transport to the Suction of ECCS Pumps,” Westinghouse Electric Company LLC, WCAP-16631-NP, Revision 0, October 2006. (This document has not been provided to NRC on the docket. Referenced information is based on notes from reading the reference.)

4. Beaulieu, David P., “Summary of the September 4, 2008, Category 2 Public Meeting with the Nuclear Energy Institute to Discuss NRC Generic Letter 2008-01, ‘Managing Gas Accumulation In Emergency Core Cooling, Decay Heat Removal, And Containment Spray Systems,’” NRC Memorandum, ML082770088, October 6, 2008.