# General Electric Advanced Technology Manual

## Chapter 4.4

## ECCS Gas Voiding

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## 4.4 ECCS GAS VOIDING

**Learning Objectives:**

1. Recognize the potential consequences of voiding in Emergency Closed Cooling Systems (ECCS) piping.

2. Identify potential causes of voiding in ECCS piping.

3. Identify the industry strategies for detecting, eliminating and/or minimizing the consequences of voided ECCS piping.

4. Recognize the regulations that apply to ECCS piping voiding, including Technical Specification requirements.

### 4.4.1 Overview

Industry experience indicates that maintaining a reasonable assurance of ECCS operability is a concern due to gas accumulation in ECCS system piping. Typical consequences of gas binding include the following:

- Inadvertent actuation of relief valves,
- Damage to valves, pipe supports,
- Pump cavitation,
- ECCS pump failure, and
- Increased times from actuation of ECCS systems until system injection.

This problem is not easily solved, as it has been the topic of two generic letters and numerous information notices. From a practical aspect it is impossible to eliminate all gas from the ECCS systems. It is not, in fact, necessary to completely eliminate gas pockets as very small gas volumes do not significantly affect operation. A realistic objective of ECCS gas voiding control is to establish system and program controls that reasonably ensure gas buildup does not jeopardize the operability of ECCS systems.

### 4.4.2 Causes and Contributors to ECCS Voiding

Gas can accumulate in the ECCS systems from many sources. Some of the more common sources include:

- Leakage from accumulators into ECCS discharge pipes (PWR),
- Leakage from the reactor into ECCS discharge pipes,
- Out gassing in ECCS piping from water in the condensate storage tank (CST) or the suppression pool,
- Introduction of gas during system draining, filling, realignments, and maintenance,
- System leakage from drain or check valves, and
- System design leaving “dead” legs that cannot be vented.
- Failure of installed line fill (keep fill) systems.

There are numerous locations where gas can accumulate, including high points in pipe runs, elevation variations in nominally horizontal pipes, heat exchanger U-tubes or water boxes, pipe diameter transitions that introduce traps at the top of the larger pipe, and in tees where gas in flowing water accumulates in a stagnant pipe.

### 4.4.3 BWR Industry Experience

At Monticello, on April 15, 1997, reported that the net positive suction head (NPSH) for its core spray pumps may not meet the required NPSH under all accident conditions. The licensee discovered this during a review of ECCS pump NPSH requirements, when a higher head loss for the ECCS suction strainers was calculated. It was determined that for a recirculation line break with a single failure of the low pressure coolant injection (LPCI) loop select logic, and with credit for containment overpressure, the core spray pumps would have an NPSH deficit and the LPCI pumps would have only 0.15 m (0.5 feet) of margin in NPSH. On May 9, 1997, Monticello performed a voluntary shutdown of the plant because of this issue.

At Dresden Units 2 and 3, on November 26, 1997, engineering became aware of a technical issue regarding vortexing at the high pressure coolant injection (HPCI) suction nozzle in the CST. An operability determination found that significant amounts of air could be entrained into the HPCI suction piping before the CST low-low level would be reached and automatic transfer of the HPCI suction from the CST to the torus initiated. The Unit 2 and 3 HPCI systems were declared inoperable.

At Dresden Unit 3, on July 5, 2001, experienced a reactor scram that was accompanied by a water hammer due to HPCI system voids resulting from inadequate pipe venting. The licensee discovered a damaged pipe support that rendered the HPCI system inoperable on July 19, 2001. On September 28, 2001, NRC discovered discrepancies in another HPCI hanger that may have been caused by the water hammer. The licensee repaired the hangers on September 30, 2001, and vented the system. An NRC inspector identified a high point that had not been vented and air was removed when the licensee vented that location. The HPCI system was inoperable from July 5, 2001, to September 30, 2001.

At Quad Cities, on June 4, 2003, operators were performing a vent of the 1B core spray discharge piping. The operator opened the vent valve and vented gas for 12 minutes before water flowed. The venting was continued for two minutes to ensure the piping was full of water and then the system was declared operable. The analysis estimated that one half of the piping was empty. This volume of gas would apply large water hammer loads on the core spray system, making the core spray “B” loop unavailable in a loss of cooling accident (LOCA).

At Perry Unit 1, on September 11, 2003, it was determined that the feedwater leakage control system (FWLCS) piping and the low pressure core spray to the residual heat removal (RHR) system contained air. The amount of air that had accumulated in the FWLCS line was such that it would have prevented both the FWLCS and RHR from performing their suppression pool cooling mode. This condition was believed to have existed since the initial plant operation. It was estimated that it would take 31 days

following a refueling outage to reach the amount of gas needed to impact system operability.

At Limerick Units 1 and 2, on April 20, 2004, air was found in the pump suction lines of Unit 1 and Unit 2 reactor core isolation cooling (RCIC) and HPCI systems. The air was present due to a combination of design and procedural deficiencies. The RCIC pump suction piping from the abandoned RHR steam-condensing mode did not include a vent valve. Procedures for filling and venting the HPCI pump suction lines following maintenance activities did not include venting the suppression pool suction check valve and the pump. These issues could have made both HPCI and RCIC unavailable during accident conditions.

At Duane Arnold Energy Center, on September 2005, discovered a void in the HPCI pump discharge piping resulting from “turbulent penetration” that caused hot water from the feedwater pipe to penetrate downward into the HPCI discharge pipe. This heated the HPCI pipe on the low pressure side of a closed valve to greater than the saturation temperature and caused steam to be generated in the low pressure pipe as fast as it was vented. The condition had existed since plant startup. The NRC determined the condition to be adverse to quality since it was not identified by the licensee, was uncorrected, and was a violation of Criterion XVI to Appendix B of 10 CFR Part 50. The issue was found to be of very low safety significance and entered into the corrective action program. The violation was treated as a Non-Cited Violation.

At Browns Ferry Unit 1, on May 20, 2011, Operations personnel were preparing to vent the HPCI system discharge piping. When the normally closed HPCI Injection Valve was opened, the HPCI System discharge and suction piping rapidly pressurized to near reactor pressure. Components in the lower design pressure suction piping leaked, some equipment in the HPCI Room was sprayed with water, and flood level alarms in the Main Control Room were received. Approximately one minute later, Operations personnel closed the HPCI Injection Valve and HPCI System pressure decreased. Seat leakage past the HPCI System Testable Check Valve, a primary containment isolation valve (PCIV), caused the increase in piping pressure. The cause of the valve seat leakage was misalignment of valve and operator parts. The steam pressurization of system piping created steam voiding in the HPCI discharge and suction piping.

### 4.4.4 Industry Strategies

Multiple methods are used to control and assess ECCS gas. These methods include, but are not limited to the following:

- Keep (line) Fill systems,
- Refill and venting post maintenance or operation and on a periodic basis,
- Ultrasonic testing (UT) on a periodic basis, and
- Analyses of acceptable gas volumes in a system.

SOER 97-01 was issued outlining multiple events at pressurized water reactors. These events detailed damage to pumps, and piping as a direct result of gas voiding. Recommendations were for PWRs only and included the following:

- Install or reconfigure tank level instrumentation to ensure that low tank level does not introduce gas into system suctions.
- Identify other gas intrusion sources into safety systems.
- Verify station operating, test and maintenance procedures include steps to remove gas buildup as needed.
- Provide training to plant personnel on this SOER, the sources of gas intrusion into systems, and the impact of gas binding.
- Although this SOER dealt with only PWR events, the lessons learned for mitigation of gas binding applied to the BWR fleet.

SER 02-05 covers similar events to SOER 97-01, but included multiple events associated with BWRs. The SER provided the following recommendations:

- A review of the piping configurations should be considered for safety systems (such as HPCI, RHR containment spray and low pressure coolant injection modes and the RCIC system).
- Enhance the effectiveness of venting to minimize voids within safety systems by the use of simplified, one-line isometric drawings that show system elevations and available vents.
- Develop a list of susceptible systems and appropriate periodicity for venting.
- Initiate plant design changes to add high-point vents if needed.
- Verify that installed high-point vents are actually at the system high points, including field verification to ensure pipe shapes (such as reducers) and construction tolerances (over long runs of pipe) have not inadvertently created additional high points.
- Implement operational, maintenance, or design improvements if a venting strategy is not practicable.
- Assess the impact of modifications on system venting capability.
- Give a high priority to the correction of known equipment deficiencies that contribute to gas intrusion in safety systems.
- Provide initial and continuing training on gas intrusion to personnel responsible for the design, performance monitoring, operation, and maintenance of safety systems.
- In station operating and test procedures, provide guidance regarding activities that could result in gas intrusion into safety systems and techniques for removing gas from a system after evolutions are completed.
- When an appropriate vent path does not exist to ensure that portions of piping can be purged during static filling and venting evolutions, implement alternate means of gas removal that include dynamic venting.
- When there is a potential for gases to come out of solution in portions of safety system piping, have administrative controls and venting capability in place to periodically vent the system to prevent unacceptable gas pockets from accumulating. Monitor and trend gas intrusion into systems that require periodic venting.

- Valves that serve as barriers against gas intrusion into safety systems receive periodic maintenance to ensure proper operation and leak-tightness.
- Guidance exists for disassembling and assembling level and flow transmitter fittings to ensure leak-tightness, along with procedures for filling and venting these indicators.

SER 02-05 deals with both PWR and BWR designs. This SER recommended a more comprehensive approach to controlling gas voiding that included analysis of all safety systems. Where indicated by the above analysis, design changes, periodic tests or maintenance are recommended to minimize gas voiding in safety systems.

### 4.4.5 NRC Notices and Regulations

Regulatory Guide 1.1 examines the issue of NPSH for the ECCS system. It points out that ECCS pumps will not function without the required NPSH which will degrade the usefulness of the ECCS system. The regulatory guide states that due to unpredictable accident situations, overpressure of the containment should not be included in calculations for NPSH.

Regulatory Guide 1.79 Rev. 1 describes the pre-operational test program acceptable to the staff for ECCS systems in PWRs. The guide directs the plants to test each individual ECCS system. High pressure safety injection systems should be tested in both the hot and cold configurations. The low pressure safety injection systems should be tested in the cold condition, but one test should be done for flow and a second for the recirculation lineup. Core flooding system should be tested in both cold and hot condition, along with testing the isolation valves for operation and leakage.

NUREG-0897 Rev. 1 examines information on post-LOCA recirculation from the containment sump, focusing on air ingestion and debris blockage on NPSH. For air ingestion, it was shown that if there is less than 2 percent air ingestion by volume, pump performance will only be slightly degraded. If air ingestion is between 2% and 15% pump performance will be variable based upon pump design and other operating conditions such as containment pressure and temperature. If the air ingestion percentage is greater than 15 percent, pump performance will be almost completely degraded. For multistage pumps, such as residual heat removal and core spray pumps, even small quantities of air can result in air binding and complete degradation of the pump.

Information Notice 86-63 provided information to the licensees of a potential problem with losing the safety injection (SI) capability as a result of common-mode failures of the SI pumps from the crystallization of boric acid. The events from this information notice were based upon the loss of emergency safety injection capability by either boric acid crystallization or gas binding. The source of gas was nitrogen cover gas dissolved in the boric acid solution.

Generic Letter 87-12 was written to request information assessing the safe operation of PWRs when the reactor coolant system (RCS) water level is below the top of the reactor vessel. It was realized that if RHR pumps are lost during the mid-loop process, there is a possibility of core damage. During the time this letter was written there was not a lot of information on vortexing and air ingestion from the RCS into the RHR suction line.

Information Notice 87-63 was provided to alert licensees of the potential for inadequate NPSH. It was identified in this report that excessive flow rates in the low pressure pimping could lead to lower than calculated suction line pressure, and in effect a lower NPSH. This could lead to vortexing or voiding in the suction line of the pumps causing damage to the low pressure pumps.

Information Notice 88-23 was provided to alert licensees that there was a potential problem resulting from hydrogen transport from the volume control tank (VCT) and accumulation in the emergency core cooling system piping. This information notice was brought about by an event at Farley 1. The licensee took a coolant sample from a vent downstream of the valves, before the sample could be obtained 50 $ft^3$ of gas was vented from the line. Had a small break LOCA occurred before this gas was vented, the gas would have been swept into the high pressure safety injection system and damaged the HPSI pumps. Water from the VCT is saturated with hydrogen. This trapped hydrogen can be released from the water in downstream piping if it has a lower pressure than the VCT.

Information Notice 88-23, Supplement 1 alerted licensees of three recent events on gas binding issues which had occurred at South Texas, Surry, and North Anna.

Information Notice 88-23, Supplement 2 alerted licensees to potential problems resulting from the transport of hydrogen in the VCT to the safety-related high pressure injection pumps during testing of the VCT outlet isolation valves at Trojan.

Information Notice 88-23, Supplement 3 informed licensees of a common-mode failure caused by hydrogen gas binding of the high head safety injection (HHSI) pumps during a LOCA. This information notice was brought about due to an incident at Sequoyah in August of 1990 where hydrogen gas was accumulating on the suction side of the HHSI pumps.

Information Notice 88-23 Supplement 4 alerted licensees to problems resulting from the transport of and accumulation of gases in ECCS piping. At Surry Unit 2 when the low head safety injection (LHSI) pumps were started, pressure spikes were observed. Investigation discovered gas voids in the recirculation mode transfer (RMT) piping. Approximately 50 $ft^3$ of gas was vented from the RMT piping. Another 32.5 $ft^3$ of gas was vented from the LSHI pump discharge to the cold leg piping. During the next week an additional 26 $ft^3$ of gas was vented from the LHSI pump discharge to the RCS cold leg piping. The vented gas contained varying quantities of oxygen, hydrogen, and nitrogen. The source of gas was reactor coolant that leaked past the cold leg check valves. The gases came out of solution as soon as it depressurized and cooled.

Generic Letter 88-17 was a follow up to the 87-12 generic letter, which focused on loss of decay heat removal (DHR) pumps during mid-loop operation. The current generic

letter was written because many licensees did not grasp the lessons being taught in the first letter. This was demonstrated by the number of events occurring between the two letters. 88-17 was written to rectify particular deficiencies in accident initiation prevention, accident mitigation before core damage occurs, and radioactive material control after a core damage accident. It was mentioned that small amounts of air may cause pump damage over a period of time, whereas a large amount of air may cause instant damage.

Information Notice 89-67 was to alert licensees of a potential problem resulting in the loss of residual heat removal (RHR) caused by the injection of nitrogen from accumulators into the RCS. Salem Unit 1 lost both their RHR pumps when nitrogen was injected in the RCS and migrated into the RHR system.

Information Notice 89-80 alerted licensees that there was a potential problem resulting from the failure of HPCI valves in a BWR. The failure of these valves could lead to leakage from the feedwater system into the HPCI system during power operation. At Dresden Unit 2 in 1989, the temperature in the HPCI room was higher than normal. This was caused by feedwater leaking through the un-insulated HPCI piping to the condensate storage tank. The leakage increased raising the temperature between the injection valve and the HPCI pump discharge valve so that it flashed to steam and displaced water in the piping system. The accessible portions of the HPCI were inspected and loose pipe supports were found, making the HPCI system inoperable.

Information Notice 91-50 alerted licensees of the NRC's evaluation of water hammer events between January 1986 and March 1990. There were about a dozen water hammer events that took place at Big Rock Point 1, Dresden 2 and 3, South Texas 1, Trojan, and Susquehanna 2. The causes for these water hammer events were due to either steam or non-condensable gases forming in the piping, followed with an opening of a valve in the line.

Generic Letter 92-04 discusses the effects of rapid depressurization on noncondensible gases dissolved in the reference leg of BWR water level instrumentation. The dissolved gases accumulate over time during normal operation. The gases can rapidly come out of solution during depressurization, displacing water from the instrument reference leg, producing a false high level indication.

Information Notice 94-36 alerted licensees of the possibility of gas accumulation in the RCS. This issue stemmed from an event at Sequoyah Unit 1 in March of 1993. During shutdown operations the plant was testing the containment integrity by pressurizing the containment. During the test, as containment pressure increased, pressurizer level decreased. It was discovered that the change in pressurizer level, as a function of containment pressure, was due to gas in the RCS. In order to remove the excess gas in the RCS, the reactor head had to be vented multiple times.

Information Notice 94-76 alerted licensees of a recent failure of charging/safety injection pump shafts at facilities designed by Westinghouse. Six different plants had issues with these pump shafts failing. There was no determination for the cause of these events however, the operating history of many of these failed pumps showed that they had

been operated with void formation, gas entrainment, or other abnormal conditions within a few years of failure.

Information Notice 95-03 informed licensees of an incident which occurred at Wolf Creek where there was a loss of reactor coolant inventory during a shutdown condition. The RHR cross-over piping to RWST flow path was supposed to have been isolated. Because of a boration procedure, the cross-over piping to RWST valve was open. When the “A” RHR cross-over valve was stroked for testing, a flow path from the RCS to the RWST was created and water rushed out of the RCS. This flow path was realized and stopped. This incident could have lead to steam forming in the suction line of the RHR, resulting in RHR pump failure.

Information Notice 96-55 alerted licensees that the NPSH for ECCS and containment heat removal pumps may not be adequate under all design basis events. This was due to the use of an incorrect sump temperature, or not taking into consideration pump arrangements. If the NPSH is not adequate, voiding or cavitation can result, which will lead to pump failure.

Information Notice 96-65 alerted licensees of the possibility for nitrogen gas to leak into the RCS and accumulate in the reactor vessel head. Haddam Neck had nitrogen from the VCT find its way into the top of the reactor vessel head. This nitrogen was able to flow from the VCT, through several closed leaking valves in the chemical and volume control system and from there into the reactor vessel. The vent system in the reactor vessel was unable to remove all the nitrogen, which began to displace water. The nitrogen leakage into the RCS was discovered while trying to identify high nitrogen usage.

Information Notice 97-38 alerted licensees of a common cause failure at Oconee Unit 3. The letdown storage tank (LDST) level sensing system was inaccurate and lead to damaging two High Pressure Injection (HPI) pumps. The incorrect level displayed for the LDST, due to a drained reference leg, allowed the HPI pumps to take suction from an empty tank.

Information Notice 97-40 alerted licensees of nitrogen to accumulation in the interfacing systems resulting from back-leakage from safety injection tanks (SITs). At Waterford there were multiple instances where gas voids had been found in the system. Some of these voids led to water-hammer. It was discovered that the gas originated from the SITs leaking back through some the LPSI check valves. Similar events had also occurred at Sequoyah.

Generic Letter 97-04, Inspections, Licensee Notification, and Licensing Event Reports discovered that there may have been issues with NPSH for ECCS and decay heat removal pumps. These pumps may not have sufficient NPSH under all design-basis accident conditions. Certain plants lacked the necessary NPSH because of changes in plant configuration, operating procedures, environmental conditions, or other operating parameters that evolved over the life of the plant. Some NPSH calculations did not consider the appropriate bounding times for postulated events, or other non-conservatisms were incorporated into the analysis. Generic letter 97-04 was issued to request information on the available NPSH of ECCS or heat removal pumps taking suction from the containment sump or suppression pool. Also included were pumps

used in the “piggyback” operation that are necessary for recirculation cooling for reactor core and or containment.

Generic Letter 98-02 was issued to follow up on Information Notice 95-03, which examined the possibility of a loss of fluid from the RCS resulting in RHR pump damage. This generic letter requested information to address the susceptibility of RHR and emergency core cooling systems to a common mode failure resulting from reactor coolant system drain-down during shutdown conditions. It also requested information on potential pathways for inadvertent RCS drain-down, along with the suitability of surveillance, maintenance, modification, operating practices and procedures for configuration control during reactor shutdown cooling.

Information Notice 98-40 alerted licensees that incorrect level instrument setpoints or control deficiencies can lead to ECCS pumps being inoperable during design-basis accidents. These deficiencies, leading to incorrect measurements in the ECCS pump suction sources, can lead to a lack of required NPSH, or air ingestion into the pumps. It also discussed that modifications to plant procedures without re-calculating NPSH can lead to NPSH deficiencies.

GL 2008-01 identified events involving gas accumulation that have occurred since the beginning of commercial nuclear power plant operation. The NRC has published 20 information notices (INs), two GLs, and a NUREG related to this issue, along with interaction with the nuclear industry in relation to these publications. These events continued to occur even after these publications, leading to concerns that other unidentified design or procedural considerations will continue to create threats to ECCS system operability in accident conditions. The GL provided the following six examples to illustrate how inadequate gas control can have safety implications:

1. The introduction of gas into a pump can cause it to become air bound with little or no flow, rendering the pump inoperable. Air binding can render more than one pump inoperable when pumps share a common discharge or suction headers. These conditions greatly increase the risk significance of a gas accumulation failure. Such a common-mode failure could also result in the inability of the the DHR system to provide adequate core cooling and the inability of the containment spray system to maintain the containment pressure and temperature below design limits.

2. Gas introduced into a pump can render the pump inoperable, even if the gas does not cause air binding, because it reduces pump discharge pressure and flow capacity to below that needed for its design function.

3. Gas accumulation can result in water hammer or a system pressure transient, in pump discharge piping following a pump start. The pump starting rapidly fills the gas pocket with water, causing damage to piping or hangers. Gas can also cause pressure transients that have caused DHR system relief valves to open. If the relief valve reseating pressure is less than the existing RCS pressure, this can complicate recovery.

4. Unbalanced loads caused by entrained gas and the subsequent reduction in inlet pressure at a pump can cause pump cavitation resulting in additional stresses that lead to failure of pump components.

5. Gas accumulation can result in pumping noncondensible gas into the reactor vessel that may affect core cooling flow.

6. The time needed to fill voided discharge piping delays delivery of water beyond what was assumed in the accident analysis. The number of identified gas accumulation problems raises concerns over the potential for other unrecognized design, configuration, or operability problems at other facilities.

Given the above examples, from the review of the operating experience there are four principal concerns, which are the focus of this GL:

1. FSARs are the licensing basis for each plant. The FSARs at many facilities state that the safety systems are full of water. Technical specifications require periodic surveillances to confirm this condition. Some of these technical specifications may be inadequate or have incomplete surveillance requirements. The specifications may require verifying that ECCS discharge piping is full of water but may not include verification of the suction piping or containment spray piping despite operating experience that gas accumulation in suction piping may be more serious than gas accumulation in discharge piping. Since systems can be rendered inoperable or degraded by gas accumulation in any section of piping, the regulations require assessment of this gas accumulation to establish operability. Gas accumulation may not affect operability and where justified, some portions of these systems may be excluded from testing for gas accumulation.

2. Criterion III of Appendix B to 10 CFR Part 50 and the operating license identify regulatory requirements for the design of the safety systems. The failure to translate the design basis, for maintaining systems full of water, into drawings, specifications, procedures, and instructions is contrary to Criterion III of Appendix B to 10 CFR Part 50. System designs vary widely regarding both potential gas sources and the capability to control gas. Potential gas sources and symptoms of gas leakage from these sources should be identified and the potential gas accumulation locations should be known. The NRC staff has observed high-point vents that were not located at actual high points and non-existing vents where drawings showed vents. The NRC staff also noted that drawings and isometric diagrams often show piping as level whereas as-installed piping is sloped.

3. Criteria V and XI of Appendix B to 10 CFR Part 50 and the operating license require licensees to perform testing that incorporates the requirements and acceptance limits contained in applicable design and licensing documents. Testing of portions of piping and components in the subject systems where unacceptable gas accumulation may occur is necessary to confirm the acceptance limits and system

operability. Surveillance and testing that does not ensure operability prior to the next surveillance is not consistent with this testing requirement.

4. Some licensees have treated the accumulation of substantial gas quantities as an expected condition rather than a nonconforming condition. They have not entered these conditions into their corrective action programs, even when it involved a substantial volume of gas that clearly constituted a significant condition adverse to quality.

The enclosure to generic letter 2008-001, provides additional information for licensees to address during their response. The NRC staff will use this information during activities that are being planned as a follow-up to this GL and for guidance in the Technical Specifications Task Force program to develop improved TSs. The NRC requested that each addressee 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 system operability, and that appropriate action is taken when conditions adverse to quality are identified.

### 4.4.6 Summary

Four generic letters and 20 information notices to the industry have not resolved this issue. GL2008-001 provides guidance to the industry and on things to observe during inspections to raise questions associated with gas voiding. Some keys for the inspector can include the following:

- Do surveillances provide verification that all areas of ECCS and decay heat removal piping are verified to ensure no gas voiding?
- If some amount of gas voiding is allowed, is there a calculation to validate the amount of gas that is allowable?
- If there are issues associated with gas voiding, is the licensee looking for common cause failures?
- Is the licensee documenting gas voiding issues in their corrective action program?