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Nuclear Grade Air Trap and Gas Void Management

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Abstract:

The Emergency Core Cooling System (ECCS) in nuclear power stations often sits idle until called into service by the safety-related Reactor Protection System instrumentation. In general, main components, such as pumps, remain idle until needed or are otherwise taken in or out of alignment for routine maintenance, during which a redundant component is likewise taken in or out of alignment as a "swing" component.

Since the advent of nuclear power, these systems have been plagued with a seemingly simple problem: Gas bubbles naturally come out of solution or are mechanically introduced and then gravitationally migrate and collect at each of the system's local high points. The nuclear industry calls them "Gas Voids". These gas voids are hidden from sight within the pipes and pose a significant danger to system operability. All types of nuclear power plants are susceptible.

Ultrasonic Testing (UT) has been the standard means of locating gas voids, but significant problems continue as a result of UT.

By eliminating the need for UT and by providing a constant visual indicator of "full of water", the "Nuclear Grade Air Trap" (NGAT) has emerged as a complete, yet elegantly simple solution to this vexing problem.

Introduction:

On January 11, 2008 the U.S. Nuclear Regulatory Commission (NRC) issued its third generic letter (GL) to address the issue of gas accumulation in the Emergency Core Cooling System (ECCS), Decay Heat Removal (DHR), and Containment Spray (CS) systems. The letter is commonly referred to as "GL-2008-01". [1]

In many cases, when a train of the ECCS is called into service, the pressure on the suction side of pump immediately drops, resulting in the expansion of an existing gas void. These voids are then transported through the pumps by the system flow-rate. The expansion and transport of these voids can cause erratic instrument readings, water hammer, cavitation, damage to pipes and pipe supports, relief valve actuation, impeller damage and pump failure.

The ECCS has a number of vulnerable subsystems that go by different names depending on the type of power plant: The Decay Heat Removal (DHR) system is also called the Shutdown Cooling (SDC) system and is sometimes called the Residual Heat Removal (RHR) system. These systems, as well as the Containment Spray (CS) Systems, were initially identified as being vulnerable to gas void issues.

After much discussion between utility owners and the US NRC, on February 21, 2013 additional surveillance requirements were added to other systems by TSTF-523[2]. In addition to surveillance requirements on DHR and CS systems, gas void surveillance requirements were added to their subsystems (hot shutdown, cold shutdown, high water level, lower water level and suppression pool cooling, as well as the Reactor Coolant System (RCS) Loops, Quench Spray (QS) systems, Recirculation Spray (RS) systems.)

Within each of these systems, the GL and TSTF-523 required that all operators:

1. Identify each of the local high points within the ECCS.
2. Have a system to periodically measure the volume of the gas void, if any.
3. Have a system to remove the gas void.
4. Have a system to show that the system is sufficiently full of coolant.

Periodically measure generally means every 30 days. Removing the gas void is generally performed by installing vent valves at each location. Show that the system is sufficiently full has been generally performed by tagging out nearby systems, building a scaffold and performing an ultrasonic test on the pipe.

Definitions:

Gas – Per NRC GL-2008-01 gas includes air, nitrogen, hydrogen, water vapor, or any other void that is not filled with liquid water.

Historical Methodology and Process:

The historical solution to gas void accumulation has not been trivial; neither has it been entirely successful. A great deal of effort has been expended on determining what “sufficiently full” means. Research on gas transport models, various pipe geometries, Froude numbers and the “Simplified Equation” have all been studied at great length. Research is ongoing.

Working with utility owner groups and the NRC, the Nuclear Energy Institute (NEI) issued NEI 09-10 [Rev 1a-A], "Guidelines for Effective Prevention and Management of System Gas Accumulation".[3] Even with this guidance, the industry continues to have significant problems with gas voids. The prevention and management techniques seem programmatically sound, but due to problems inherent to using UT in a dynamic, real-time environment, implementation of the program is proving to be error prone and frustrating to operators.

Continuing Problems

"Over the limit" gas void events that threaten operability continue to occur. On February 24, 2014, the NRC released a memo titled "Gas Management Action Plan Update" which indicates their continued collection of information.[4]

The intent of the gas transport equations are to determine that if a given gas void volume exists and if it is far enough away from the pump, and if the pipe's geometry is considered and if the Froude number is sufficiently small and if the flow rates and temperatures are within known limits then it is <u>not likely</u> that that gas void would affect system operability.

To the casual observer, this seems like a lot of "ifs" while the mathematical basis remains prone to errors and is continually under regulatory review.[5] In defense of the industry effort, combining UT, void justification and venting were the only conceivable solutions at the time. Unfortunately, a system that justifies the existence of an invisible void of theoretical size is not a simple system to understand, maintain or regulate.

Those same invisible gas voids must then be located and quantified using ultrasonic testing and then vented once the theoretical limit has been reached. Based on these facts, other than delaying the venting operation, there appears to be no net gain from using gas transport equations while the complexity and uncertainty of UT surveillance frequency remains problematic.

Surveillance Frequency & Trending

Gas voids form in piping systems by various mechanisms. In the absence of continuous monitoring, it often becomes more difficult to determine exactly when or why a gas void occurs. Ideally, each local high point location would be monitored continuously. Practically, periodic Ultrasonic Testing (UT) is time consuming, error-prone, tedious, and dose-intensive.

Performing UT on 30 day surveillance intervals may not be sufficient to maintain operability since it is possible that the void may have been present for 29 of those 30 days. This is especially true after an outage when, as seen at Palo Verde, gas has been known to come out of solution at system high points and create voids in the system during the first 90 days following an outage. [6]

When a void is found, quantified and vented, the hunt for the source begins immediately. At times the source is obvious, but without knowing when the void formed, the hunt may require extensive UT testing and re-testing in multiple locations until confidence in system operability can be restored. The time and reason for the void formation is initially indeterminate and startup (Mode 4) may be significantly delayed due to UT retesting and troubleshooting as has been experienced by Exelon at a number of their plants. [7]

UT and Venting Should be Minimized

Ultrasonic testing activities need to be minimized because they are dose intensive and often require building scaffolds around sensitive instruments. As UT is minimized, so is dose, and ALARA (As Low As Reasonably Achievable) principles can be maximized.

Venting should be minimized because contaminated and/or borated water is typically the fluid that is being vented. When venting, the operator knows that the pipe is full when the operator sees liquid discharge from the vent. Contaminated discharge is reason enough to minimize the activity.

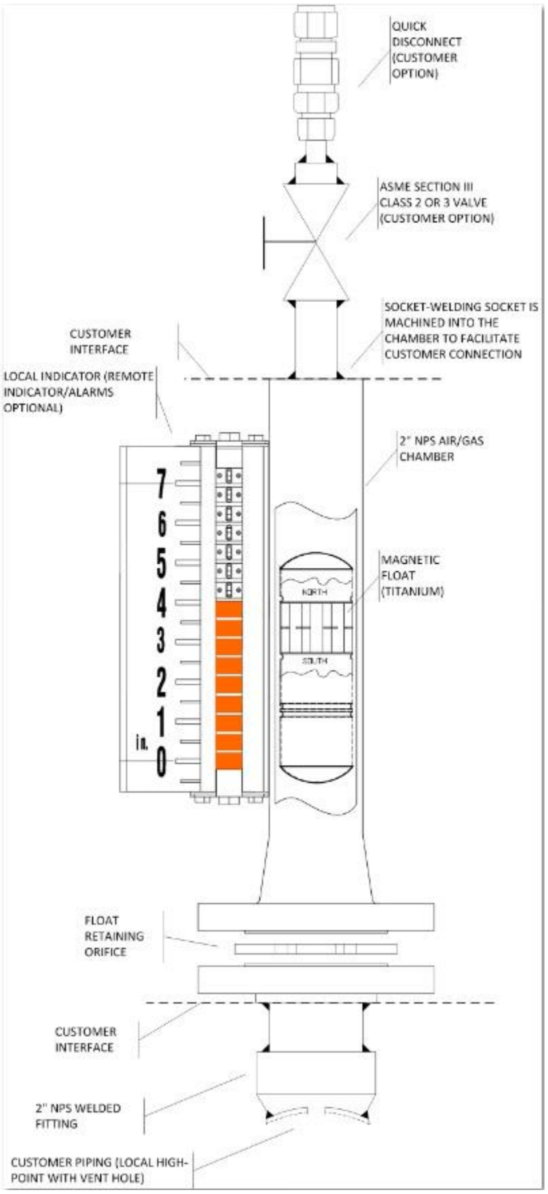
Unfortunately, the practical need to minimize (or at least optimize) UT and venting operations conflicts with the need for constant monitoring. As a result of trying to optimize operations, most gas voids are surprise discoveries that lead to condition reports, regulatory event reports, root cause analysis and possible declaration of an inoperable condition.

New Methodology and Process:

After NRC GL-2008-01 was issued, a plant engineer developed a passive device that uses classical physics to solve the problem. Archimedes' principle of buoyancy captures, indicates, measures and removes air from the system pipe in real time as a gas void forms. Bernoulli's principle keeps the gas void from returning to the system. It is a "smart vent" – an air trap that isolates the gas using the same principles that allowed the formation of the gas void to begin with.

As long as the always-visible air trap indicator shows that the air trap has at least some water in it, the underlying system pipe is always 100% full of water.

The simple device allows for constant and literal compliance with all NRC GL-2008-01 requirements. It is made to nuclear standards and called the Nuclear Grade Air Trap [8] (NGAT).



The NGAT consists of a vertically mounted stainless steel chamber into which a seismically qualified and specially designed titanium, magnetic and buoyant float is inserted. The float rises in the chamber when the chamber is full of water and it lowers with the water level as gas is trapped.

A magnetic indicator, external to the pressure boundary, is attached to the chamber. The indicator follows the magnetic field produced by the float, thereby providing constant indication of the air/water level interface. There are static components internal to the chamber which properly direct flow inside the chamber and serve as travel stops for the float. These also serve as datum points, which allow for NGAT calibration. During normal plant operations, when the actual level in the chamber is above the minimum allowed level, that portion of the subject system where the NGAT is installed is “full” by definition.

After venting, when the indicator shows that the NGAT is once again full of water, the valve is closed and little or no contaminated water needs to be released.

This simple device is installed between the system pipe and the new or existing vent. It virtually eliminates the need for UT.

Also, after an outage there is no mystery or risk when refilling. If air is released by any valve or for any reason, it will be found instantly by the NGAT.

Constant, Literal Compliance with GL-2008-01

The NGAT is always working – and constantly measures the gas void, removes the gas void and shows that the system pipe is full.

Enhancing Nuclear Safety Culture

The NGAT allows every operator in the plant to participate in the nuclear safety culture and practice situational awareness. With no training and with just one glance, any employee can see if the NGAT, and thus the piping system, is full of water. When gas is found, the time of the intrusion is much easier to pinpoint.

NEI "Top Industry Practice" (TIP) Award

After installation at the VC Summer station, the use of the NGAT was recognized by the NEI as a "Top Industry Practice". The TIP awards highlight the nuclear industry's most innovative techniques and ideas. They promote the sharing of innovative ideas and best practices, and consequently improve safety, work processes and the competitive position of the industry as a whole.

The NGAT was evaluated based on its contribution to safety, cost-savings Impact, productivity, efficiency, innovation and transferability.

Operating Experience:

Three (3) US nuclear stations are currently benefitting from the advantages of the NGAT, as they have installed twenty (20) NGATs and have scheduled more installations. The NGATs have already provided indication of trapped air on various separate occasions, and have been promptly vented to maintain the station's ECCS fully OPERABLE per station Technical Specifications, which ensures the highest level of nuclear safety.

NGAT installations have been reviewed by INPO and WANO observers and in all cases have been noted as a strength and an asset to the station.

Conclusions:

The advent and application of the Nuclear Grade Air Trap (NGAT) is making a tremendous impact in the commercial nuclear power industry by greatly enhancing nuclear safety, industrial safety and helping maintain worker radiation doses As Low As Reasonably Achievable. The proper application of the NGAT resolves concerns outlined in NRC GL-2008-01 and TSTF-523 Rev 2 by trapping, measuring and removing unwanted gas voids. Unwanted gas is kept out of the main ECCS piping, thus meeting the full, original intent of GL-2008-01. The NGAT provides uninterrupted indication of ECCS and other safety-related system's OPERABILITY and eliminates the need for Ultrasonic testing and gas transport equations.

AREVA works with NUCCORP to deliver the Nuclear Grade Air Trap (NGAT) to our customers. AREVA has developed the resources, infrastructure, test facilities and procedures to deliver the complete NGAT line.

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8. "Nuclear Grade Air Trap" and NGAT are trademarks of NUCCORP, Inc., USA. US Patent 8 505 568. Other US and WIPO patents pending. All Rights Reserved.