

## Gas Accumulation: A Challenge to Successful Operability of Nuclear Plant Safety Injection Systems

By Phil Rush and Marwan Charrouf

**G**as accumulation in nuclear power plant piping systems is a recurring issue that can challenge the operability of systems critical to plant safety. Gas voids have been identified in emergency core cooling, containment spray and residual heat removal systems at many U.S. nuclear plants. Both pressurized water reactor (PWR) and boiling water reactor (BWR) plants are susceptible.

In the 1990s, the nuclear power industry set out to address the adverse effects on operations resulting from problems with gas voids. Voids in piping systems can affect the operation of critical plant systems by degrading the ability of pumps to generate differential pressure, or with excessive amounts of air, causing binding of pumps. In addition, voids in pump discharge piping can impose high dynamic loads on the piping and supports when pumps start up. Figure 1 shows a typical system configuration and identifies regions where voids can accumulate.

In 1997, the Institute for Nuclear Power Operations (INPO) requested

that all U.S. PWRs review the design of charging and high pressure injection systems to determine if level instrumentation on tanks could fail and lead to gas binding of pumps. From the mid-1980s to the late 1990s, the U.S. Nuclear Regulatory Commission (NRC) issued many generic communications related to gas intrusion events.

More than 60 gas accumulation events have been reported since 1997. As a result, the NRC issued Generic Letter 2008-01, "Managing Gas Accumulation in Emergency Core Cooling, Decay Heat Removal, and Containment Spray System."

The complexity of this problem requires a comprehensive solution that includes engineering analyses, changes to plant operating and maintenance procedures, and inspections of and modifications to plant piping systems. Analytically simulating the transport of gas voids through piping systems and quantifying the dynamic loads generated when voids are rapidly compressed from pumps starting are challenging technical problems that MPR has been solving

for years. More recently, MPR has been actively engaged in providing our clients with innovative, unique solutions that reduce operational problems with gas voids.

MPR addressed significant operational issues involving gas voids through research, development of unique programs, creation of software related tools, and devising new analytical techniques. Our research led to the development of an analytical tool that simulates gas void transport through piping systems. This air distribution program, known as AIRDST, was developed specifically to determine how voids move through Safety Injection piping. The program was benchmarked using data generated in a laboratory test; its accuracy was successfully validated for a range of gas void conditions and later validated in full-scale testing. MPR found the program particularly useful for calculating volumetric air ratios at the inlet to pumps when voids are

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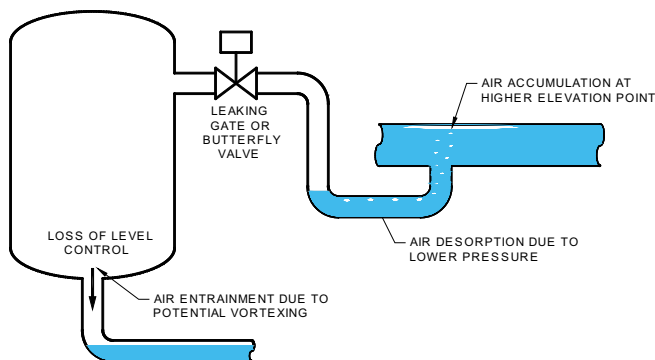


Figure 1 System Configuration with Gas Voids

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# MPR-Developed Iontophoresis Device May Revolutionize Treatment of Inner Ear Disorders

By David Mandel

**R**esearch and development in the medical field is continuing to spur advances in new technology and the creation of medical devices that treat common disorders. MPR recently completed the development of such a device to treat the inner ear during a procedure known as a myringotomy.

As illustrated in Figure 1, the human ear's Eustachian tube links the middle ear to the pharynx, the part of the throat immediately behind the mouth and nasal cavity. As atmospheric pressure changes, the small pocket of air trapped between the Eustachian tube, which is normally closed, and the tympanic membrane (eardrum), expands or contracts.

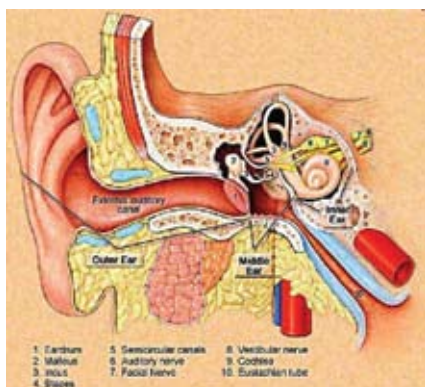


Figure 1 Inner Ear

Typically, the Eustachian tube opens to equalize this pressure; however, if infected due to bacterial build up, allergies or other reasons, the Eustachian tube can swell and become unable to equalize the pressure. If the ear is infected, fluid can build in the middle ear, further increasing pressure and causing pain. In the case of Eustachian tube blockage, pressure can be equalized by a procedure called a myringotomy. In this procedure, a small incision is made in a portion of the eardrum that is not critical for hearing, and a minuscule pressure equalization (PE) tube is inserted to create a pathway between the middle ear and the atmosphere. This procedure is performed on a considerable number of children each year.

Using a process known as iontophoresis, which is used for transdermal

drug delivery, MPR developed a new device to painlessly numb the tympanic membrane while the patient is conscious, allowing the physician to perform the myringotomy procedure without general anesthetic.

The advantage of using numbing by iontophoresis is that it is simpler, safer and less expensive than the use of general anesthesia. Avoidance of general anesthesia (and its potential complications) is a key benefit, particularly with children. Iontophoresis involves using a minute amount of precisely controlled electric current to drive an ionically charged substance transdermally into the patient. The repulsive electromotive force between the current and the ionically charged material – in this case the molecules of a positively charged numbing agent, lidocaine – drives the anesthetic deep into the tissue. The device can precisely control the anesthetic, as the amount of lidocaine delivered is directly proportional to the amount of charge delivered.



Figure 2 Handheld Iontophoresis Device

MPR designed and built a prototype iontophoresis device (as shown in Figure 2) that controls the delivery of current to a patient's inner ear and tracks the amount of charge the patient has received to ensure sufficient numbing for the myringotomy procedure. The key performance requirement was the ability of the device to accurately control output current. However, the "load" into which

this current is being delivered can vary greatly, thereby complicating the control scheme. A patient's electrical resistance is highly variable and unpredictable, not only between patients, but also for a single patient during the procedure.

To precisely control a current into a changing load, MPR designed a special operational amplifier (op-amp) circuit that automatically and instantaneously adjusts the output voltage to the patient; as the patient resistance changes, the voltage tracks the changes and holds the current constant. This simple design is the heart of the device and allows it to maintain a precision within a few percent, even as the load varies widely.

If the heart of the device is the current control unit, the brain is the microprocessor that controls the rest of the functionality (including providing the current set point value as an op-amp input). The microprocessor allows the device to independently control current delivery to each ear, detecting if the delivery electrode is seated properly, tracking how much charge has been delivered to each tympanic membrane, and ceasing the delivery of current when the appropriate amount of charge (and thus anesthetic) has been delivered.

The device is designed to be intrinsically safe to the patient. The microprocessor continuously monitors both the current being delivered to each ear and the total return current. If any value is outside the acceptable tolerance of the set point, the delivery of the current stops. This software safety feature is further backed by hardware protection methods. On the output line to each ear is a current limiting diode. Should the internal circuitry fail, these diodes will limit the current being delivered to the patient to a safe level. The diodes also prevent an electrode in one ear from acting as the return path for the other electrode, whereby current would be delivered transcranially.

The MPR-developed iontophoresis device is an innovative Class 3 device that has been cleared by the FDA and is currently in clinical trials. Because of the high frequency and current cost of the myringotomy procedure, the iontophoresis device has the potential to make an important impact on the field of otolaryngology.



# MPR Looks at Water-Saving Strategies for Electric Generating Stations

By Andrew Markle, P.E.

**T**oday, the availability of water is vital in the operation and siting of electric power generating facilities and is often the key factor when considering the expansion of existing facilities. MPR engineers are consulted in these situations and bring a deep understanding of new and conventional strategies, as well as equipment improvements for better plant operation and water conservation.

MPR's approach to developing a water conservation strategy starts with conducting a water audit focused on optimizing water consumption of existing equipment, identifying water conservation strategies, and replacing inefficient equipment with new technologies. During a water audit, MPR will determine which options are best suited to meet the client's goals.

## Optimize Water Consumption by Existing Equipment

The first and least expensive step is to check that plant equipment consumes the correct amount of water. With a high-level water balance around the plant, each source and demand of water (see Table 1) is identified, quantified, summated, compared and analyzed.

Once the sources and demands of water are identified and quantified, they are totaled separately and compared to see if they balance. A thorough investigation can often yield sources and quantities of water that were previously unaccounted for.

## Water Conservation Strategies

In addition to the conventional water conservation strategies, such as boiler and cooling tower blowdown reuse, air-cooled condensers, offsite ion exchange regeneration and other well-tested methods, MPR also evaluates whether a client may benefit from employing any of the newer strategies. Some of the most promising are:

### Flue Gas Water Recovery (through cooling)

Flue gas water recovery through flue gas cooling uses a final stage heat exchanger to lower the flue gas temperature below its dew point to capture water vapor from flue gas. This has been successfully demonstrated and commercially implemented in Europe on steam generators that are equipped with flue gas desulphurization systems (FGD). For plants without FGD, the technology is still in the development stage.

### Rainwater Collection

Much like installing rain barrels at home for domestic water conservation, power plants can collect and use rainwater. The degree to which collection is possible varies by local regulations, land availability, and soil and climatic conditions. Some government jurisdictions require that streams, rivers and lakes are not disturbed by collection methods, and prohibit damming and formation of water reservoirs.

### Replacement with Water Efficient Equipment

MPR also evaluates the benefits of replacing existing equipment with more water-efficient technologies. These include:

### Hybrid Cooling Towers

Wet-dry and dry-wet hybrid cooling towers consume less water than wet cooling towers. A new type of low-cost hybrid cooling tower that recaptures the water evaporated by a traditional cooling tower recently came on the market. Using a segregated, PVC heat exchanger, it cools the plume and collects the condensing water on one side, and passes cooler ambient air that collects the reject heat on the other. The manufacturer estimates it can reclaim approximately 15% to 20% of the evaporation water flow.

The hybrid cooling tower technology has some drawbacks. It will not produce much water when the temperature of the cooling tower plume is close to the ambient air temperature. This is the case during the summer when water is needed the most. In addition, the technology has high operating costs due to the size of the equipment required and corresponding electrical load.

### Dry Bottom Ash Handling

For solid fuel plants, the bottom ash handling and cooling system demands a significant amount of water. Some water is typically lost in the disposed ash and through evaporation, but the amount of water introduced into the system for pump seals can be substantial. Since

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Source	Demand
Lake Water	Cooling Tower Evaporation
Well Water	Cooling Tower Drift
Rainfall	FGD Evaporation
Coal	Bottom Ash Moisture
	Calcium Sulfate Moisture
	Plant Washdown/Dust Suppression
	Pond Evaporation

Table 1. Typical Water Sources and Demands for a Coal Plant



# PET System for Novel Early-Detection Mammography Technique

By Ashley Wallin

“*If we find cancer early,  
90 percent survive.  
If we find cancer late,  
10 percent survive.*”

Thomas Goetz,  
*Wired Magazine, Issue 17.01*

Since 1975, the overall cancer mortality rate has fallen by only 8%. This is not a good statistic for nearly one-third of all Americans who will be diagnosed with cancer at some point in their lives. The key to improving this survival rate lies in early detection using diagnostic devices – an area in which MPR has been working with a number of our clients.

An example of the successful commercialization of one MPR-designed product is the Naviscan PEM Flex™ device. As illustrated in Figure 1, this is a high-resolution positron emission tomography (PET) scanner that allows physicians to visualize breast tumors as small as the width of a grain of rice. In its coverage of the annual meeting of the Radiological Society of North America in December 2008, *Medical Device Daily* reported the device was hailed as filling “a significant void in cases where traditional mammography and MRI fail to accurately diagnose cancer.”

MPR’s involvement in this project began in 1999 when Dr. Irving Weinberg, a world renowned NIH radiologist and founder of the venture-backed startup PEM Technologies, requested the engineering consulting firm’s help in developing a new application of PET for breast imaging. This imaging modality provides much better resolution of potential cancerous lesions than other methods, such as X-ray mammography or even MRI, in part due to the fact that it is a form of molecular imaging rather than being anatomically based. Up to 15% of breast cancers are not mammographically visible, including those tumors present in dense breast tissue (also a strong risk factor for

breast cancer). Positron emission mammography (PEM) is not affected by breast density and other factors, including hormonal cycles, which can cause false readings using traditional mammography approaches. In addition, PEM produces crisp and clear images, while traditional mammography films contain more artifacts and require a physician’s eye to spot the cancer.

During the development of this technology, it was also noted that the PET imaging process could be implemented using a scanning approach, allowing the use of a photonics detector array that is smaller and less costly than other imaging systems. Scanning, however, requires extraordinary accuracy in movement and positioning of the detectors. MPR’s challenge was to integrate the photonics array into a breast compression paddle geometry with the necessary motion control and positioning capability.

MPR developed this product in two phases. In the first phase, MPR engineers designed a portable breast compression device that could be used with other PET imaging systems. This device included automated motion control of the compression paddles with position sensing and compression-force feedback. The client desired to market this device as a stand-alone product so MPR developed a 510(k) submittal, and the device was quickly cleared by the FDA in 2001.

In the next phase, MPR tackled the more challenging PET scanner design. The scanners needed to accurately move the photonic array inside the compression paddles as the sensors scanned the field of view. Integrating the sensor array within a tight dimensional envelope required innovative engineering to combine mechanical functions of some of the structural elements. For example, the sides of the positioner were also designed to provide guides for the

sensor array. In addition, the lead screw drive mechanism was integrated within the positioner housing.

MPR successfully completed the design and built prototypes of the PET scanners in four months to support testing at UCLA Medical Center. Results proved that the new system provided resolution below 2 mm, twice that of other imaging systems. In 2005, PEM Technologies was acquired by Naviscan. After further product development, the first commercial sale occurred in 2006.

At the Radiological Society of North America meeting in December 2008, Dr. Kathy Schilling of Boca Raton, Fla., noted that the Naviscan PEM Flex™ device provides “great clarity and confidence in diagnosing cancer” and it is used for cancers that cannot be identified using other imaging modalities. Schilling also stated that “the sensitivity of PEM is equal to, or better than, breast MRI [with] fewer false-positive results.”

By maintaining focus on such diagnostic modalities as this PEM device, MPR continues to contribute to improving the lives of others diagnosed with various disease pathologies, including cancer, by assisting in the development and commercialization of additional first-of-a-kind devices that may be used in the early detection and treatment of cancer and other life-threatening illnesses. ▲



Figure 1 MPR Prototype Leading to Naviscan PEM Flex™ Scanner



## Gas Accumulation ...

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present in pump suction lines.

MPR also applied Computational Fluid Dynamics (CFD) techniques to resolve void transport problems through complex structures. These include gas transport through pump nozzles, around curved vanes, and complex geometry structures (see Figure 2). CFD methods are useful in assessing the potential for air entrainment by high shear jets, and identification of recirculation zones behind obstacles that are susceptible to gas void accumulation. The CFD solution can also serve to estimate the local magnitude of the Froude number, which is a good indicator of gas void transport through systems.

For years, MPR has used a thermal hydraulic analysis computer program (SYSFLO) to analyze two-phase flow and waterhammer problems in balance of plant systems. The program uses an implicit numerical technique to solve the integrated mass, energy, and momentum conservation equations over

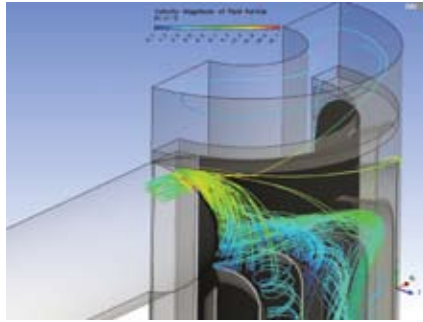


Figure 2 Flow Streamlines Released at the Suction Nozzle of a Low Head Safety Injection Pump with Swirl Limiting Vanes

a set of control volumes joined by fluid connectors. More recently, this program has been successfully applied to gas void compression problems in pump discharge piping.

One of the critical challenges in addressing the NRC's concerns in Generic Letter 2008-01 is determining acceptance criteria for downstream voids in piping systems. A hydraulic model of the piping system is developed

where voids are included in the model at appropriate locations. Then, a transient hydraulic analysis is run to determine the transient pressures in the system. Using these results, MPR engineers develop force-time histories for the piping system. The force-time histories are then input into a finite element model of the piping system and a dynamic structural analysis is completed to quantify piping stresses and pipe support loads. These results are then compared to the stresses and support load allowable limits.

Through development of tools such as AIRDST and SYSFLO, and the application of computational fluid dynamic techniques, MPR is able to provide assessments of complex gas void problems. MPR engineers have successfully applied these tools to efficiently resolve operability concerns and develop acceptance criteria for gas voids in piping systems. The technical solutions create smarter and safer operational conditions that ensure the operability of systems critical to maintaining plant safety while addressing issues raised in Generic Letter 2008-01. ▲

## MPR Looks at Water-Saving Strategies ...

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the water is in contact with the bottom ash it can be high in a number of heavy metals including selenium, mercury and lead. Dry bottom ash handling systems are one solution to eliminate the water demand and potential wastewater disposal problems.

The cost of retrofitting a boiler with a dry bottom ash handling system is high and rarely can be justified based on water savings alone. When coupled with other advantages, such as lower O&M costs, higher reliability and improved heat rate, dry bottom ash handling technology can be a competitive option.

### Costs

Table 2 presents a list of cost estimates on a \$/gpm basis to help determine the most cost-effective water

Option	NPV Cost (\$/gpm)
Optimize Existing Equipment	Variable on State of Plant
Flue Gas Water Recovery	35,000 to 75,000
Rainwater Collection	Variable on Climatic and Soil Conditions
Hybrid Cooling Towers	45,000
Dry Bottom Ash Handling	130,000

Table 2. Estimated NPV Cost on a \$/gpm Basis

conservation strategy. These costs are calculated on a net present value (NPV) in 2008 dollars and include capital and operating expenditures for a 20-year plant life. The NPV also assumes a 9% nominal weighted average cost of capital and 3% inflation. These NPV values are based on a nominal 900 MWe pulverized coal-steam electric plant. With the significant amount of water needed for electric power generation, water conservation at an electric generation facility makes sense, both economically and environmentally.

### MPR Experience

MPR's long history in assisting our clients in water conservation and minimizing the environmental impact of wastewater discharge dates back to the 1970s and 1980s when our engineers' efforts were instrumental in improving the operation of wastewater treatment facilities throughout the country, including a successful effort to clean up the Potomac River. Our recent experience includes:

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## MPR Looks at Water-Saving Strategies ...

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- Water audits for power plants investigating reduction of water consumption
- Analysis of power plants cooling system options to determine the best solution for the plant's needs
- Projects to optimize the design and performance of FGD and FGD wastewater systems
- Design oversight of complex water recovery and reuse systems in cogeneration plants
- Conceptual design analysis for algae dewatering to support algae-derived biodiesel production
- Water systems design for difficult-to-treat wastewater streams ▲

### From the Principal Officer's Desk *By Paul Damerell*

At the time I write this article, there are two dominant issues before the US Congress: greenhouse gases (climate change) and healthcare reform. Although we are not a company that lobbies or engages in the legislative process, it's meaningful that our efforts touch both of these national interests. Specifically, our work helping fossil-fired power plants run more efficiently, and our work on power generation technologies using low carbon technologies (from nuclear to a wide spectrum of renewables) have positive contributions to our customers' (and our country's) efforts to reduce carbon dioxide release to the atmosphere. Further, much of our work to help customers develop new or refined medical devices is prompted by the quest for delivering improved-effectiveness, and lower-cost alternatives – a critical need amidst current healthcare funding challenges. These activities are real-time examples of fulfilling our mission – to accomplish challenging tasks that bring benefit to society. ▲

### What's News @ MPR

*Doug Chapin presented two days of invited lectures at Xiamen, China in early October at the first large scale Nuclear Plant Digital Instrumentation and Control workshop to be held at Xiamen University.*

*Christian Haller to speak at AdvaMed 2009 MedTech conference on Crisis Prevention & Risk Mitigation 101: 5 Things Every Company Must Be Prepared For to be held in Washington DC.*

*Bob Coward has been appointed to fill the main interface role with Toshiba America Nuclear Energy, STP Nuclear Operating Company (STPNOC) and the owner's of South Texas Project Units 3&4. He will coordinate with an Owner Executive Steering Committee in regard to project decisions. He will report to the President and CEO of STPNOC.*



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