



## ~\$10 Million Saved in Lost Generation Costs Canopy Seal Enclosure Modification for Crystal River Unit 3 Decay Heat Removal Valve DHV-3



In addition to the DHV-3 valve repair, during his 15 years at MPR, Patrick Butler has helped develop a variety of innovative design solutions for the nuclear power industry.

**L**eakage of system fluid past mechanical system boundaries occurs from time to time at power plants. Crystal River Unit 3 was experiencing leakage from a pressure seal bonnet of Decay Heat Valve 3 (DHV-3) which isolates the Decay Heat System from the Reactor Coolant System (RCS).

DHV-3 leakage levels were measured and trended between

1999 and 2001. Leakage was projected to remain below 3 GPM under steady operating conditions until the refueling outage scheduled for September 2001. This level of leakage was well below the Technical Specification Limit of 10 GPM, but presented undesirable conditions:

- Nearby equipment would eventually require costly and time-consuming decontamination.
- Periodic monitoring and volume additions to replace lost reactor coolant fluid were needed.
- Fluid collected in reactor building sump required processing as radioactive waste.
- A conventional repair was unattractive because a plant shutdown and complete removal of fuel from the reactor vessel were required to remove or disassemble this valve.

Several attempts were made to arrest leakage by injecting sealants into the leak path above the valve pressure boundary. Although initially successful, leakage recurred within a few weeks.

In parallel to sealant injection activities, permanent repair options were identified and evaluated. Valve replacement was identified as the highest success probability, and a new valve was ordered. However, a contingency

plan was also implemented due to the long lead-time associated with valve procurement.

The valve repair contingency plan focused on options that would preclude a core offload. Unlike valve replacement that would occur during a scheduled refueling outage, a valve repair requiring full core offload prior to the refueling outage would have a major impact on power production goals. The net impact is estimated at about two weeks or \$10M.

The selected repair design was a canopy seal enclosure concept, developed jointly by Florida Power Corporation and MPR Associates, with the detailed design performed by MPR. It consisted of a structural “canopy” element connecting the valve body to the bonnet neck, extending the pressure boundary of the valve beyond the seal ring, which would be completely enclosed within the canopy.

The canopy seal enclosure had to be designed to accommodate the as-built configuration of the valve. Specifically, the design had to address the as-cast condition of the valve body and bonnet and the assembly tolerances of the bonnet and pressure seal. And, since the Decay Heat System is the primary means of removing heat from the

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### Douglas M. Chapin Elected to the National Academy of Engineering

*Douglas M. Chapin, one of our Principal Officers for the past 17 years, has been elected to the National Academy of Engineering (NAE). The NAE recognized his contributions to the reliability and safety of nuclear reactors worldwide.*

*Election to the NAE is among the highest professional distinctions accorded an engineer. Academy membership honors those who have made “important contributions to engineering theory and practice, including significant contributions to the literature of engineering theory and practice,” and those who have demonstrated “unusual accomplishment in the pioneering of new and developing fields of technology.”*



# A Piece in the Nuclear Plant Success Picture

## Owner's and Users' Groups

**S**QUG, JOG, NHUG, CBOG—In this acronym-filled world, these particular ones don't look any more self-revealing, important or exciting than others. Nuclear power plants, however, are finding otherwise.

Several widely acknowledged trends led many to predict that the long-established role of Owners' and Users' Groups in nuclear power would diminish or disappear. Specifically, the improved performance of plants, the increased competition between generating companies, and the consolidation of plants among fewer owners was predicted to lead to an "island" mentality where several competitors independently developed (and fiercely guarded) their information on plant equipment and practices. Cooperative groups would become dinosaurs, only to die out from conditions in the new landscape. Although the trends are real, the prediction about cooperative groups was shortsighted and out-of-touch. Given the current role of nuclear power plants in the nation's energy mix (and in the strategies of the companies that operate them), Owners' and Users' Groups have not only kept, but in some cases expanded, their niches. Groups are in place covering everything from users of specific equipment to owners of types of plants. In our observations, these groups provide a useful (and demanded) service to their members because:

- They do not disrupt, threaten, or compromise the competitive balance between generating companies.
- They yield genuine benefits that improve the functioning of nuclear power plants as a fleet.
- They help the generating companies' interactions, as licensees, with their principal regulator (the NRC). The NRC has concluded that industry-led joint initiatives provide overall benefits

to the NRC's effectiveness in fulfilling its mission.

What makes a "problem" or an "issue" a good candidate for Owners' Group cooperation? Some or all of the following usually play a role:

- Commonality of the problem or issue at the member plants
- Presence of a regulatory requirement
- Technical nature of the problem or issue. In other words, the problem is not fundamentally a business strategy or personnel management problem but rather a problem with effectively dealing with systems and equipment.
- Potential for a joint effort to yield a genuine benefit (i.e., effective solution at a lower cost) without bogging the process down.

At MPR, we have found that our skills and services are a good match to the efforts being carried out by cooperative nuclear industry groups. In other words, we are highly effective at helping them achieve the solutions they need. This effectiveness is facilitated by the fact that MPR is an engineering company that has:

- Worked at every nuclear power plant in the country
- Specialized in the technical aspects of nuclear power plant systems and equipment
- Had a unique permanence in a world filled with buyouts, acquisitions, and personnel migrations.

MPR has been the principal contractor for a number of completed and current projects sponsored by industry owners' groups. Among the more noteworthy:

- MPR developed innovative approaches, approved by the NRC, to seismically justify equipment installed in older plants, without performing costly, time-consuming qualification tests. The methods are based on

documented experience of equipment in earthquakes. The methods have now been extended to applications beyond the original older plants. [SQUG and SEQUAL]

- MPR developed fleet-wide solutions for problems in two types of emergency diesel generators (EDGs) used in nuclear power plants, and developed common troubleshooting guides and spare parts programs for these EDGs. [CBOG and AOG]
- MPR developed justified methods to predict the performance of motor-operated valves (MOVs), that most plants subsequently used in their MOV programs to satisfy NRC regulations. We have now adapted the methods to air-operated valves (AOVs), which are receiving increased attention at most plants. [PPP, EMPUG and BWROG]
- MPR developed generic qualifications for specific digital control equipment that allow them to be considered as replacements for outdated analog equipment.
- MPR developed new, innovative methods to test and verify the ice weight in ice condenser containments. [WOG]
- MPR is developing and justifying approaches for periodic verification of valves, using test data gathered from 98 of the 103 operating plants in the U.S. [JOG]



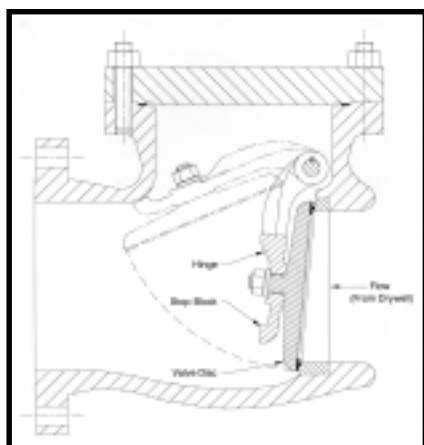
Paul Damerell, currently a Principal Officer at MPR and author of this article.



# Modification of BWR Relief Valve Discharge Line Vacuum Breakers to Prevent Damage Due to Cyclic Loading

by P. Knittle, W. McCurdy, C. Swanner, & S. Burns

In a typical BWR, electromechanical relief valves (ERVs) are mounted on the main steam line to help prevent overpressurization of the reactor coolant system (RCS). The ERVs are designed to open on high pressure, permitting steam to escape from the RCS to the suppression pool through discharge lines. Vacuum breakers (typically swing check valves like that shown in **Figure 1a**) are installed in the ERV discharge line and are designed to open quickly to



**Figure 1a.**  
Original ERV Vacuum Breaker Assembly

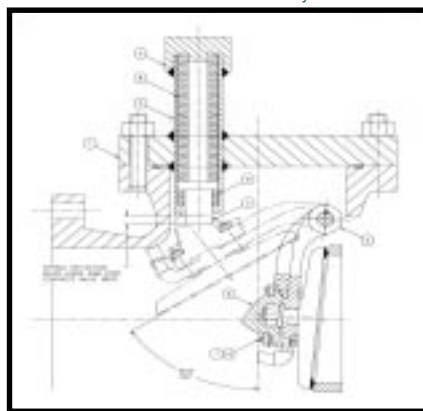
prevent rapid steam condensation from creating a vacuum in the discharge line after the ERV closes. Such a vacuum can draw water from the torus back up the discharge line where a subsequent ERV opening could then propel the reflow water down through the piping, resulting in significant and potentially damaging forces on the components and structural supports.

At one BWR, after experiencing a leaking ERV while at low power for several hours during a startup, one of the ERV vacuum breakers failed open. Inspections of the other vacuum breakers found nearly all with some internal damage to the hinge arms. Subsequent evaluation by MPR concluded that the damages were induced as part of an

opening transient and failure resulted from the continued cycling under the leaking ERV conditions.

Briefly, MPR's investigation into the event found that the rapid condensation and fast opening of the vacuum breakers results in high impact loads between the arm/disc assembly and its stop. Kinetic energy transmitted by the disc/arm assembly during this impact caused loads that exceeded the capability of the valve components for energy absorption. Plastic deformation and other damage to the components, particularly the disc/arm assembly, resulted from this impact. Also, review of industry experience has shown that failure of ERV discharge line vacuum breakers has occurred elsewhere (e.g., Generic Issue #85 in NUREG-0933

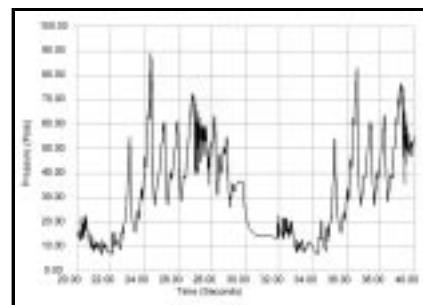
- |                         |   |
|-------------------------|---|
| 1. Bonnet cap, modified | 7. Socket head shoulder screw, modified |
| 2. Hinge, modified      | 8. Belleville spring upper              |
| 3. Spring tube          | 9. Belleville spring lower              |
| 4. End cap              | 10. Heavy hex nut                       |
| 5. Piston               |   |
| 6. Sticker              |   |



**Figure 1b.**  
Modified ERV Vacuum Breaker Assembly

which was evaluated in the early 1980's).

Although the failure did not prevent the valves from performing their design basis function, a modification to the valve was required to prevent damage to valve internal parts for all postulated ERV opening events, i.e. to improve reliability. Due to the significance of the valve, however, the modification needed to be



**Figure 2.**  
Steady Calculated Pressure Oscillations in ERV Piping Near Low ERV Flow Limit (Based on transient two-phase thermal hydraulic model)

ready for installation by the upcoming outage, which was less than 5 months away. Also, due to the limited time, the utility strongly desired that the modification not impact the significant work that was done under the BWR MARK I program during the early 1980's to ensure that the discharge piping and breakers were adequately sized.

A modification was developed by MPR Associates and the utility to prevent damage from occurring to the swing check vacuum breaker valve during rapid opening. The modification shown in **Figure 1b** involves the addition of an energy absorber to the valve to serve as a stop for the disc/arm during valve opening. The energy absorber is a series of Belleville springs that absorb the energy of the arm/disc assembly, thus limiting the stresses in the valve and preventing damage to valve components.

Development of the modification required MPR to employ special engineering analysis techniques. In particular, the source and magnitude of the cyclic loading was not understood and needed to be defined to update the valve requirements specification. Consequently, MPR developed a detailed transient two-phase thermal hydraulic model of the ERV discharge piping (including the specific sparger geometry) to confirm the potential for pressure

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## Risk-Based Maintenance Scheduling

by Phil Rush

Plant engineers are often faced with the problem of establishing the optimum interval between outages to complete inspections and repairs of critical plant equipment that cannot be maintained during operation. Following the advice of the OEM for maintenance scheduling will generally result in more frequent outages than necessary and higher costs. Extending the interval between maintenance outages could expose the plant to unanticipated component failures with significant economic consequences. A major petrochemical company had gradually extended the interval between “turn-arounds” from two to eight years. The rationale for this change was based largely on engineering judgement from senior engineers. A quantitative analysis tool was needed to decrease their reliance on experienced personnel and qualitative methods for outage scheduling. The tool would need to have the capability to weigh the benefits of longer operating runs against the risk of forced outages due to unexpected component failures.

MPR Associates was contracted to develop a method for establishing the optimum period between plant maintenance outages. The system bottleneck for maintenance planning was a turbine-driven compressor train, which was the focus of our effort. The objective was to calculate the frequency of component failures as a function of plant operating time. We applied our background in risk assessments and simulation methods to develop a computer program that could calculate the reliability of critical compressor train components using probabilistic methods (i.e. Monte Carlo). Critical components were defined as those whose failure would result in a forced

outage – either by automatic shutdown or catastrophic failure.

The simulation program was developed using the principles of reliability-centered maintenance and the ASME risk-based inspection guidelines. Statistical failure distributions were constructed

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## Canopy Seal Enclosure Modification

(Continued from page 1)

reactor core during shutdown, hardware and processes had to be developed to assure that the valve remained open during implementation of the modification. To maintain DHV-3 in the open position, a safety-related engineered clamp was designed, which, when torqued down against the valve stem, provided sufficient resistance to maintain the valve in the fully open position and restrain the packing.

To demonstrate the canopy design was adequate, MPR performed finite element analyses of the design using the ANSYS finite element analysis software.

To verify all aspects of the canopy seal enclosure could be successfully performed in the field, a surplus valve essentially identical to DHV-3 was purchased and used as a mockup. All



The canopy seal enclosure concept involves a stainless steel canopy that is welded to the valve body and bonnet to create a new pressure boundary around the existing pressure seal. The canopy is installed over the valve stem after the yoke and stem packing gland clamp are removed.

aspects of the modification including valve disassembly, installation of the clamp on the stem, valve machining, bonnet machining, canopy welding and weld examinations were performed several times at Welding Services Inc. (the welding and fabrication vendor). In addition, the mockup was shipped to Crystal River and one final mockup performed just prior to implementation.

In May 2001, CR3 was taken off line to repair a damaged check valve in the Main Feedwater System. As a result of the depressurization/repressurization cycle, leakage past the DHV-3 seal ring suddenly increased to ~6.3 GPM. Plant management made the decision to implement the canopy installation, which was performed during the final week of May.

The modification was implemented in 5 days with a total personnel exposure of ~10 man-Rem. The entire canopy seal enclosure modification project, from initial conceptual designs through mockup testing and installation, was completed over a period of 10 months.

The canopy was successfully installed, tested, and the valve returned to service with zero leakage.

“TOP INDUSTRY  
PRACTICE AWARD”  
RECEIVED

Florida Power Corporation  
received the 2002 “Top  
Industry Practice” Award  
from the Nuclear Energy  
Institute for the innovative  
solution implemented for  
this problem.

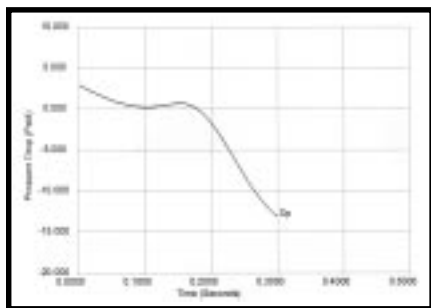


## Modification of BWR Relief Valve Discharge Line ...

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oscillations under the leaking ERV conditions, and to determine the magnitude of the pressure transients under various ERV discharge scenarios. **Figure 2** shows a trace of the pressure oscillations during the leaking ERV scenario.

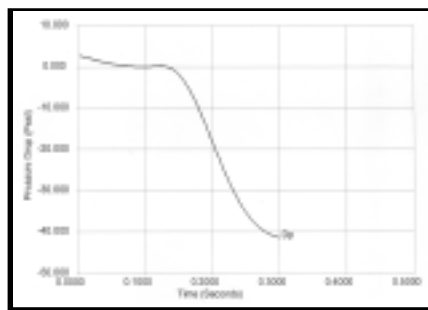
**Figures 3 and 4** show the rapid pressure differential transient from the steam condensation following ERV closure under normal operating conditions and under LOCA conditions, respectively.



**Figure 3.**  
Load Definition for ERV Vacuum Breaker - Full ERV Discharge During Normal Operation

Once the pressure transient load definitions were defined, the modified valve design was evaluated and shown to satisfy all the requirements of the valve specification without impacting the BWR MARK I program analyses. This included development of analysis tools to determine the hinge arm impact energy, sizing of the Belleville springs, ASME Code analysis of pressure boundary components, stress and fatigue evaluations of the non-code components within the load path, and a functional evaluation.

The modification was developed in under 5 months and successfully installed during the subsequent plant outage. Development included pre-fabrication of the spring pack assemblies, obtaining final measurements for as-built fit-up, and a final welding of the spring pack into the bonnet. The modification was performed on all 12 of the ERV piping



**Figure 4.**  
Load Definition for ERV Vacuum Breaker - Full ERV Discharge with LOCA Containment Conditions

vacuum breakers, without any significant problems and without impacting the outage schedule.

Based on the experience for this BWR modification, the potential for the vacuum breakers to be subjected to cyclic loading during conditions where the ERV is leaking or is discharging during low reactor pressure may not have been considered in the initial valve designs. This could therefore be a potential cause of failures reported within the industry. In addition, based on this experience, the potential for significantly high depressurization rates may not have been fully considered within the original valve specifications. Such rapid depressurizations are highly dependent upon the ERV piping and sparger geometry, but may contribute to any failures found after conducting routine testing involving actual ERV actuation.

Based on industry experience with failure of ERV discharge line vacuum breakers, the modification approach developed has potential benefits for implementation at other BWR plants to improve reliability.

## Risk-Based Maintenance Scheduling

(Continued from page 4)

for each critical component failure mode. The model was then used to estimate system reliability taking into account simple, compound, and hidden component failures. It accounted for scheduled inspections and replacement of maintainable components during operation. The Monte Carlo simulation program is a tool

to make calculated maintenance decisions.

The initial phase of the program included an evaluation of the compressor train design and its maintenance history. In this effort, we identified over 150 potential failure sequences and developed the statistical parameters necessary to model their occurrence. The second phase was building the reliability analysis program and compressor train model. The program is designed similar to finite-element analysis programs in that the user builds a model that is subsequently analyzed by the program. The output is then evaluated in a post-processor.

The results from the reliability assessment were used to identify plant components that are most likely to fail during extended operation. In addition, it pointed out several vulnerabilities that could be corrected by performing additional online maintenance. The information will be used to focus maintenance activities during the next scheduled turnaround.

MPR is currently involved in the final phase of this project, which includes expanding the capabilities of the reliability program to calculate risk. Risk is defined as the product of the failure frequency and the consequences of failure. The computer model will be updated to include data on failure event consequences. Using risk rather than failure frequency to direct maintenance decisions provides a direct link between the potential for economic losses and the ability to operate for longer periods of time. The long-term objective of this project is to develop the program into a product that can be easily used by the client. This will give them the capability to apply it to compressor trains in operation at their other processing facilities.

The computer simulation program was developed to evaluate the reliability of a system that included mechanical drive steam turbines, axial compressors, and their support systems. However, it was designed with sufficient flexibility to be used in other applications where the objective is to gain an understanding of the risks associated with increased system operating time.



## MPR's AOV Setpoint Control Software

by Tom Walker

MPR's AOV Setpoint Control Software (SCS) is a unique and powerful tool for performing AOV component level calculations, optimizing AOV design and setup, and controlling AOV setpoint. SCS uses a unique and innovative method to display allowable AOV setup parameters as an x-y plot of spring preload versus air pressure, called a Setup Box.

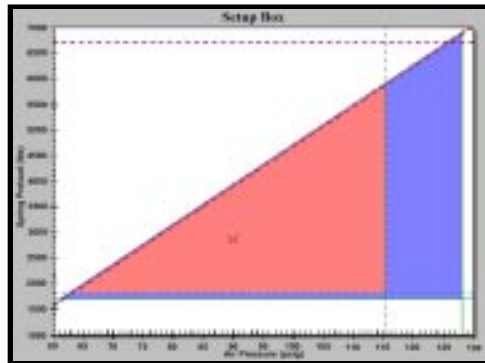
SCS evaluates the actuator capability equations for an AOV to determine: 1) margin for operation for the air stroke, 2) margin for operation for the spring stroke, 3) margin for overstressing the spring, and 4) the structural margin. Users can input uncertainties related to each margin, and margins are calculated both with and without the uncertainties applied.

SCS is an essential element of an effective AOV program. SCS can be used to:

- a. Ensure AOVs are set up with acceptable margin to ensure reliable valve operation.
- b. Quickly identify AOVs that require modification and choose a modification that achieves the desired AOV performance.
- c. Establish the interface between Engineering and Maintenance personnel.
- d. Perform actuator capability evaluations for design basis reviews
- e. Trend AOV setpoints and margins.
- f. Troubleshoot AOV operational problems.

SCS saves time and money in the following ways:

- a. Identifies AOVs that will require modification or may be difficult to set up.
- b. AOV setup time is minimized and unnecessary adjustments avoided since all acceptable combinations of spring preload and air pressure are shown.
- c. Design change effects (e.g., spring or actuator replacements) are easily and quickly evaluated to identify modifications to improve AOV performance.
- d. Costly retesting is minimized or eliminated since acceptable AOV setup can be positively verified.



Contact us for more information on our experience with the topics that appear in this issue of *MPR Profile*

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