Detecting and Mitigating Aging in Component Cooling Water Systems*

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ABSTRACT

The time-dependent effects of aging on component cooling water (CCW) systems in nuclear power plants has been studied and documented as part of a research program sponsored by the U.S. Nuclear Regulatory Commission. It was found that age related degradation leads to failures in the CCW system which can result in an increase in system unavailability, if not properly detected and mitigated. To identify effective methods of managing this degradation, information on inspection, monitoring, and maintenance practices currently available was obtained from various operating plants and reviewed. The findings were correlated with the most common aging mechanisms and failure modes, and a compilation of aging detection and mitigation practices was formulated. This paper discusses the results of this work.

INTRODUCTION

The component cooling water (CCW) system is one of many systems that is important for safe operation of nuclear power plants. In a research program sponsored by the U.S. Nuclear Regulatory Commission (NRC), the CCW system has been studied to determine how aging affects its performance and reliability. The study was performed in two phases and included extensive analyses of data obtained from national data bases, as well as data obtained from actual plant visits. This paper discusses how the results of those analyses can be used to help detect and mitigate the affects of aging in CCW systems.

The function of the CCW system is to remove heat from various loads throughout the plant and discard it to an open loop cooling system, such as the service water system. The loads serviced by the CCW system can be safety-related or non-safety-related, and include the reactor coolant pump seals, the shutdown heat exchangers, the residual heat removal heat exchangers, and the safety injection pumps. Due to the diversity of the loads dependent on it, the CCW system is continuously operating, and is required during normal, as well as off-normal plant operation. Therefore, the affects of aging must be properly managed to ensure safe plant operation in later years.

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PHASE I RESULTS

In phase I of the CCW system aging study¹ an analysis of past operating experience showed that the CCW components are susceptible to aging degradation, and that this degradation can lead to an increase in failure rate as the components age. Of the failures reviewed, over 70% were related to aging (Figure 1). The dominant cause of failure was found to be "normal service" (Figure 2), which includes exposure to all operating and environmental stresses the component is normally expected to see. As shown, the percentage of failures caused by normal service increases as the plants age. This can be partially attributed to aging and partially to a learning curve effect, which reduces the percentage of human error failures.

Figure 1 Fraction of failures related to aging

The dominant failure mechanism was "wear" (Figure 3), which is consistent with the high percentage of failures attributed to aging. Wear is an aging mechanism characterized by the physical wearing away of the component due to the relative motion between it and another component, such as valve packing being worn by the rotation of the valve shaft. Although wear accounted for over one-third of the failures, a number of other mechanisms were also found which can be related to aging. Each of these mechanisms can lead to component failures, if it is not properly monitored and controlled. In light of this, the need to have diverse monitoring methods to be able to detect all forms of aging mechanisms and mitigate degradation becomes apparent.

The data were also examined to identify the components having the largest number of failures. It was found that valves were the most commonly failed component, followed by pumps, instrumentation, and heat exchangers (Figure 4).

Figure 2 Causes of failures versus plant age

It should be noted that the data were not normalized to account for population effects, therefore, valves are the dominant components failing due to their large population. However, these findings show which components require the most resources in terms of monitoring and maintenance.

Using time-dependent failure rates calculated from the data, a simplified probabilistic risk assessment (PRA) analysis was done for a common CCW system design. For this analysis, the CCW valves, pumps and heat exchangers were given a failure rate that increases with time to simulate the effects of aging. The results showed that for component failure rates that increase by factors ranging from one (check valves) to nine (pumps) over a 40 year period, the unavailability of the system can increase by a factor of 40 (Figure 5). This is partially due to the combined aging of all components, and partially due to the degradation of multiple redundant components. Since the CCW system is important to safety, this could lead to an increase in plant risk. These findings clearly show that proper detection and mitigation of aging degradation should be an important part of daily plant operation.

PHASE II RESULTS

As indicated by the phase I results, aging degradation is present in CCW systems and must be controlled. This requires a two-step process involving detection and mitigation. It is important to be able to detect aging degradation before it results in failure, and it is equally important to mitigate the effects

Figure 3 Mechanisms of failure

of degradation once it is detected. In the second phase of this study² these two areas were addressed.

To determine the most effective methods of managing aging, inspection, surveillance, monitoring, and maintenance (ISM&M) practices were investigated. Information on ISM&M practices currently used at plants was obtained from a survey, along with actual plant visits and personnel interviews. In addition, various advanced practices were identified through literature searches and discussions with component manufacturers. The findings provided an excellent overview of what methods are available to properly control aging degradation.

The detection of aging degradation can be accomplished through the use of proper testing programs and monitoring practices. The objective in selecting the tests performed and the monitoring practices used should be to ensure that at least one measure is in place to detect each of the aging mechanisms most commonly encountered. Using the aging mechanisms identified previously, the objective of this phase II work was to identify what practices are available, and which aging mechanisms they can effectively detect.

Tables 1 and 2 are samples of the survey results, which address CCW pump and valve tests. As expected, these results reflect the ASME Section XI code requirements for in-service testing. It should be noted that not all units reported performing the Section XI requirements at the required frequency. This could be due to relief being granted by the NRC, misinterpretation of the survey question, or an error in responding. The results also show that, in addition to the code requirements, there are other actions which are performed by some of the

Figure 4 Components most frequently failed

units. Some examples include measuring pump motor voltage and current, and performing MOV signature analysis. These are typically performed based on past problems, or special plant operating or environmental conditions.

The tests performed provide an indication of how the component is functioning and can help identify aging related problems. Each parameter tested can be used to detect an aging mechanism. For example, if the measured pump developed head is lower than expected, this could be an indication that the wear rings have worn excessively and need to be replaced. If a valve stroke time is slower than expected, this could be an indication that the valve internals are corroded and need to be refurbished, among other things. By understanding what aging mechanisms a component is susceptible to and what the test results indicate, in-service testing can be used to detect aging degradation.

In addition to testing, parameter monitoring can be used to evaluate system performance and help detect aging degradation. As part of the survey each unit was asked which common parameters are monitored on a routine basis. The results show that pump discharge pressure, pump motor amperage, and heat exchanger flow are the most commonly monitored; however, only five units out of the 12 units responding reported that they monitor these parameters routinely (Figure 6). Surge tank level is an excellent indicator of system leakage, however, only three units reported monitoring this parameter routinely. None of the units reported monitoring heat exchanger pressure drop routinely, although several said they would if a problem were suspected. Each of these monitoring practices can be helpful in detecting aging degradation and should be considered as part of a monitoring program.

Figure 5 CCW system unavailability versus age

Table 1 CCW Pump Tests

Test Performed	Frequency (Months)		
	1	3	12
1. Measure Vibration Amplitude*	1 unit	10 units	3 units
2. Measure Pump Head*	3 units	10 units	
3. Measure Suction Pressure*	3 units	8 units	
4. Measure Flow Rate*	2 units	4 units	
5. Measure Bearing Temperature*		5 units	
6. Measure Lubricant Temperature*		2 units	2 units
7. Check Lubricant Level*		4 units	
8. Measure Motor Voltage/Current	1 unit	1 unit	

* Test required by ASME Section XI

Table 2 CCW Valve Tests

Test Performed	Frequency (Months)			
	3	12	18	24
1. Measure MOV Stroke Time*	10 units			
2. Check Valve Leakage*	5 units		4 units	
3. Check Valve Flow*	5 units			
4. Remote Position Indicator*			1 unit	2 units
5. Valve Seat Leakage*	1 unit			
6. MOV Insulation Resistance		1 unit		
7. MOV Current Measurement		1 unit		
8. MOV Signature Analysis			1 unit	

* Test required by ASME Section XI

PARAMETER

NOTE: BASED ON RESPONSES FROM 12 UNITS

Figure 6 Routine parameters monitored

The second part of an effective aging management program involves the mitigation of degradation. This typically is done through the use of preventive maintenance (PM) measures. As part of this study information on PM practices was obtained for the most commonly failed CCW components. Tables 3 and 4 are sample survey results which include the PM practices typically performed on CCW pumps and valves. As for the testing and monitoring practices discussed previously, each PM action can help mitigate one or more aging mechanisms. For example, lubrication of moving parts will help prevent wear and corrosion from occurring. Alignment of components will help prevent vibration, which can lead to weakening of materials. To ensure an effective PM program, all the aging mechanisms each component is susceptible to should be identified and a PM practice should be instituted to mitigate it.

As an aid in evaluating a plant's ISM&M programs, the various practices identified in this study were correlated with the aging mechanisms they can detect and/or mitigate, and the results were tabulated for the major components. Table 5 lists the basic practices which all units should perform along with the related aging mechanisms they can detect or mitigate. These include ASME Section XI requirements, as well as other commonly used practices already performed by some units. The frequency ranges are based on the ASME Section XI code requirements, which are recommended as a minimum, and the survey results. Tables 6 through 8 list the supplemental practices for pumps, valves, and heat exchangers which can be selected based on particular plant requirements. In using these tables the ISM&M programs should first be reviewed to identify any aging mechanisms that are not being addressed. Once this information is available, the tables can be used to identify an appropriate measure to be added to the maintenance or monitoring program.

Table 3 CCW pump preventive maintenance practices

PM Performed	Frequency (Months)			
	6 to 12	18 to 36	48 to 60	84 to 90
1. Lube oil system PM	4 units	2 units		
2. Bearing oil change	2 units			
3. Coupling lubrication	1 unit		1 unit	
4. Coupling alignment		1 unit		
5. Replace gaskets (EQ)				1 unit
6. Disassembly inspection			2 units	1 unit

CONCLUSIONS

The results of this study have shown that aging degradation leads to failures in the CCW system, which can result in an increase in system unavailability. In order to properly manage the effects of this degradation effective detection and mitigation methods are required. This study has identified various ISM&M practices which are currently used in the industry and

each practice has been reviewed to identify aging mechanisms it can potentially help to detect or mitigate.

From the study results it is seen that the currently used ISM&M practices fall into two categories; basic practices, which are typically required by codes or plant technical specifications, and supplemental practices, which are selected based on particular plant operating characteristics and environment. The basic practices alone are not comprehensive enough to control all types of aging degradation. An effective ISM&M program requires a combination of basic and supplemental practices to ensure that at least one method is in place to detect and mitigate each of the common aging mechanisms that may lead to component failure.

Table 4 CCW valve preventive maintenance practices

Preventive Maintenance	Frequency (Months)			
	3 to 12	18 to 36	40 to 43	48 to 60
1. MOV: Circuit breaker maint.	3 units			
2. MOV: Operator maintenance	2 units	3 units		
3. MOV: Operator EQ maintenance		2 units	2 units	
4. MOV: Packing replacement		1 unit		
5. MOV: Motor replacement				1 unit
6. MOV: Parts replacement			1 unit	
7. AOV: Lubrication	1 unit			
8. AOV: Packing replacement				1 unit
9. AOV: Diaphragm replacement				1 unit
10. AOV: Parts replacement			3 units	
11. MAN: Clean/lube stem	3 units			

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Table 5 Recommended Basic ISM&M Practices For The CCW System and Components

Component	ISM&M Practice	Frequency	Aging Mechanism Detected/Mitigated
Pumps	Monitor Vibration	1 to 3 Months	- Wear/degradation of bearings
	Measure Developed Head	1 to 3 Months	- Wear of impeller, wear rings
	Check Lube Oil Level	Daily to Weekly	- Deterioration of oil seals
	Check for Unusual Noise	Daily to Weekly	- Distortion of internals
	Check for Excessive Leakage	Daily to Weekly	- Degradation of shaft seals - Deterioration of gaskets
	Lubricate Grease Bearings/Couplings	6 to 18 Months	- Wear of bearings/couplings
	Perform Lube Oil Analysis	1 to 6 Months	- Wear of bearings - Deterioration of oil seals
	Inspect Casing/Shaft/Internals for Cracks, Warping, Erosion, Corrosion	12 to 60 Months	- Corrosion/erosion of parts - Distortion of internals
	Check for Casing Wall Thinning	5 to 10 Years	- Wear of casing wall material
Valves	Stroke the Valve	3 to 18 Months	- Corrosion of internals - Distortion of components
	Check for Excessive Leakage/Corrosion	Daily to Weekly	- Deterioration of gaskets - Wear of packing
	Adjust Torque/Limit Switches	12 to 24 Months	- Calibration drift
	Lubricate Moving Parts	6 to 18 Months	- Wear of components
	Check for Body Wall Thinning	5 to 10 Years	- Wear of valve body wall
Heat Exchanger	Monitor Flow	Daily to Weekly	- Corrosion/fouling of internals
	Monitor Outlet Temperature	Daily to Weekly	- Fouling of tubes
	Check for Excessive Leakage/Corrosion	Daily to Weekly	- Deterioration of gaskets - Cracking/corrosion of shell
	Clean Tubes	As Needed	- Fouling of tubes
	Check for Shell/Tube Thinning	5 to 10 Years	- Wear of shell/tube wall
System	Monitor Surge Tank Level/Makeup Flow	4 to 24 Hours	- Corrosion/cracking of welds/walls - Deterioration of seals/gaskets
	Monitor Temperature at Loads	4 to 24 Hours	- Fouling of heat exchangers
	Monitor Flow to Loads	4 to 24 Hours	- Degradation of pump performance
	Check for Pipe Wall Thinning	5 to 10 Years	- Wear of pipe wall material
	Hydrostatic Test	5 to 10 Years	- Degradation of welds/walls - Deterioration of seals/gaskets

Table 6 Pump ISM&M practices versus aging mechanisms

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Table 7 Valve ISM&M practices versus aging mechanisms

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Table 8 Heat Exchanger ISM&M practices versus aging mechanisms

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